Costa Rican coffee and bananas: A social-ecological study of management practices and their effects on the environment

Angelina Sanderson Bellamy
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I dedicate this work to my children, James and Penelope. You are my light and I hope that in some small way this work may contribute to making the world a better place for you.
List of Papers

The list of papers in this thesis are referred to in the text by their roman numerals. The use of Paper I in this thesis is by permission from Springer Link.


As single author on Papers I and II, I planned and conducted the study, did all data analysis and wrote the papers. In Papers III and V, I planned the research, conducted the field work, and did the data processing with assistance from O. Svensson; I wrote the paper; RDA multivariate analysis was done by P. van den Brink; I did all other analyses. Paper IV was the result of an honors degree research project; I participated in the planning of the research and the field work together with O. Svensson, and supervised all aspects of the work; O. Svensson wrote the first draft and I did substantial work on rewriting the paper; I, O. Svensson, and P. van den Brink did different aspects of the data analysis.
Abstract

This thesis investigates the variability in management practices on coffee and banana farms in an attempt to identify practices that reduce the environmental impact of export crop production. Different banana production systems are studied to determine their level of environmental impact. Insect sampling and bird surveys are used to assess the level of ecological quality on banana farms and their surrounding environments. The first two studies are based on interview methods and focus more on the social aspects of the production system. Paper I identifies how farmers utilize labor and herbicides in weed control practices, and found that small-scale coffee farmers overuse herbicides when their relative use of herbicides to labor to control weed densities is compared to their large-scale counterparts and small-scale organic producers. Paper II attempts to identify variability in management practices for the production of export bananas, but instead finds that there is only one type of export banana production system. However, there are lessons to be learned from organic and banana-coffee intercropping systems of production.

Papers III-V use the information gathered in the interview studies of Paper II to give context to the results from analysis of ecological indicators collected from banana farms. Paper III is a comparison of insect community composition on high-input, low-input and organic banana farms. Paper IV is an analysis of aquatic macroinvertebrate in surface water sites upstream and downstream of banana farm canal entry points. Finally, Paper V is a comparison of ecological effects of management practices between Rainforest Alliance certified farms and non-Rainforest Alliance certified farms. Results showed that low-input banana production is not as good as organic production with regards to ecological impact, but it can still make a difference when compared to high-input banana production. Rainforest Alliance certified farms, however, are not low-input systems and the changes that they make in production practices are not enough to influence the quality of the ecological system. These results are encouraging for low-input production systems, but show that standards for Rainforest Alliance certification need to be tougher in order to make an impact on ecological indicators.

Keywords: Costa Rica, coffee, banana, production system, pesticides, organic, conventional, Rainforest Alliance certification
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<td>British Monitoring and Working Party</td>
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<td>Principle component analysis</td>
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<td>RA</td>
<td>Rainforest Alliance</td>
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<td>RDA</td>
<td>Redundancy analysis</td>
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<td>SAN</td>
<td>Sustainable Agriculture Network</td>
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Introduction

Since the advent of agriculture 10,000 years ago, human populations have come to depend on the cultivation of crops to meet dietary needs. Yet it has become more than just a means of meeting subsistence needs; the production of agricultural crops is, in many cases, a full-scale financial enterprise within a closely managed system. When population growth threatened to outstrip humanity’s ability to feed itself, Green Revolution technologies—a bundle of inputs consisting of high-yielding seed varieties, fertilizers, pesticides, and irrigation applied according to schedule—were introduced, leading in some cases to tripled crop yields (Evenson and Gollin, 2003). While the benefits of the Green Revolution technologies can not be disputed, they have also had many negative consequences, in particular on the ecological integrity of the world’s different ecosystems.

The use of pesticides and fertilizers often leads to a cycle of dependency on agrochemicals; heavier applications of fertilizers and pesticides become necessary over time in order to maintain productivity and control pests (Altieri, 1995; Conroy et al. 1996). The application of fertilizers and pesticides also can be problematic because by entering natural ecosystems, the substances may kill wild plants and animals, and disrupt the functions of the former agroecosystem (Matson et al., 1997; Pimentel et al., 1992). About 85–90% of pesticides never reach the target pest, and instead move into the air, soil, water and species other than the pest (Moses et al., 1993). There is also increasing documentation that shows that heavy use of pesticides negatively affects production by contaminating soils (Mäder et al., 2002; WRI et al., 2000), creating resistant pest populations (Pimentel et al., 1992; Power and Flecker, 1996; Naylor and Ehrlich, 1997), and inducing illnesses in farm laborers (FAO, 2000; Henao and Arbelaez 2002; Repetto and Baliga, 1996).

Agriculture’s dependence on fossil fuel-based resources and its degradation of natural ecosystems can not continue as it has. Arguably, one of the benefits of Green Revolution agriculture has been its intensive use of land; by managing to increase yields on agricultural land, Green Revolution technologies have ‘saved’ pristine natural areas from conversion to agricultural use (Waggoner, 1995). However, there is a need for a middle of the road solution; one which continues to ensure the production of food crops to meet the needs of a continuously growing population, but which does so in a way that
does not compromise the ecological integrity of the farm and its surrounding landscapes (Conway, 1997; National Resource Council, 1999; Tilman et al., 2001).

Consequently, there is a need for a new model of crop production; a doubly green revolution (Conway, 1997). But unlike the Green Revolution package of inputs, this new model should not be a one-size fits all model because different crops and different countries have their own location-specific dynamics, requiring the application of different practices to meet the needs of local dynamics.

At the same time that Green Revolution technologies increased food production, the world became increasingly globalized, leading to the creation of international networks of traded crops that criss-cross the world. Crop exports have increased significantly over the last few decades (WTO, 2009), as the result of Green Revolution technologies, different trade policies and the opening up of new markets, and consequently, consumers in northern countries can enjoy exotic fruits and vegetables produced in warmer climates year-round.

Since colonial times, the Costa Rican economy has been based on primary exports (FitzGerald, 1991). Although the contributions of tourism and the electronics industry to GDP have grown significantly, the agricultural sector remains important, comprising 9% of GDP and employing 20% of the workforce (CIA, 2006). Coffee, banana, pineapple and sugar crops are grown largely for export to international markets. Costa Rica depends on the export earnings from primary goods in order to finance the import of processed (value-added) goods from industrialized countries and to pay off foreign debt. This was encouraged, and more often dictated, by external lending institutions (Hamilton and Thompson, 1994; Clark, 1995) and creditor countries (IADB, 1996), which subscribed to the neo-liberal policies embodied in Structural Adjustment Programs (SAP; Kroeger, 2000).

Export-led growth, however, is a double-edged sword; the same characteristics that can lead to economic development are the ones that can cause development to stagnate. The case of Costa Rican economic development illustrates this point well. Costa Rica successfully increased foreign exchange earnings through the expanded export of agricultural products, but the production of export crops relied on increasing quantities of imported inputs, which was calculated to cost some 25-30% of the value of the exports (Montanye et al., 2000). After deducting approximately 20% for debt repayments, only 45-50% of foreign exchange earnings was left to purchase other imports such as food, fuel, and manufactured goods; in many years, Costa Rica actually suffered a trade deficit (Figure 1).
Figure 1: Costa Rica’s imports, export and trade balance, 1970–1995 (IMF, 1999).

Farmers are also dependent on the desires of consumers in import countries. This is most clearly illustrated in the case of banana production. Consumers in industrialized markets demand banana products that are blemish-free, of uniform coloration and size, and meet certain taste expectations (U.S. Dept. of Justice, 1928; Soluri, 2002). In order to produce banana crops that meet these expectations, farmers apply large amounts of fungicides, insecticides, and nematicides to the crops, making it one of the most chemically-intensive crops grown in Central America. Despite these efforts, many bananas are still rejected because they do not meet export quality standards set by the large transnational banana companies (Soluri, 2002; pers. comm. R. Orhlich).

Agricultural exports comprise 33.9% of Costa Rica’s foreign exchange earnings (FAO, 2011), of which bananas and coffee are the first and third most valuable exports. In 2008, Costa Rica was the third largest exporter of bananas and twelfth largest exporter of coffee (FAOSTAT, 2011). Thus, Costa Rica plays a significant role in the global supply of these crops, the production of which plays an important role in the country’s economy, both with regards to their foreign exchange earnings and the jobs provided.

It is at the intersection of these two dynamics where this thesis lies. The objective of this thesis is to identify ways to reduce the environmental impact of export crop production given the constraints of producing crops profitably for the international market. The research presented here focuses on the pro-
duction of coffee and banana crops in Costa Rica. In this thesis, I use the term production system to refer to the collective set of practices that work together in a synergistic manner to form a highly productive crop system.
Background

An underlying theme throughout this thesis is that of diversity. Diversity is the condition of having or being composed of differing elements (Merriam-Webster, 2011). In ecology, diversity is often modified by the scale at which one is looking: for example, at the landscape scale, it can mean various ecosystems or habitat types; at the ecosystem level, it can refer to the different species present; at the species level it can refer to various genotypes. This thesis looks at the diversity of several aspects of the socio-ecological system. Papers I and II look at the diversity of management practices in both coffee and banana systems. Papers III and IV look at the diversity of insect communities on banana farms and in adjacent forests and surface waters. Papers III and V look at the diversity of management systems and how management practices affect the diversity of insect communities on these farms and their immediate surroundings.

In Papers III, IV, and V, diversity of insect communities sampled is used as a proxy for environmental quality. Insects were chosen in these studies because they comprise 90% of the organismal variability of all species; they dominate the structure of ecosystems (Pimentel et al., 1992); and they perform crucial functions to stabilize ecosystems (Wilson, 1987), all of which makes them a good measure for biodiversity evaluation (Duelli et al., 1999). Additionally, insect diversity underlies functional redundancy, which is also used in Papers III and IV as a measure of ecosystem resilience. Different species respond differently to stressors, so redundancy within functional roles acts as an insurance and increases the likelihood that net community function will be maintained after a disturbance or extreme event (Ives et al., 1999; Loreau et al., 2003; MEA, 2005; Yachi and Loreau, 1999). This enhanced ecosystem resilience is an important benefit provided by biodiversity. Loss of biodiversity undermines the resilience of the system, making it more susceptible to sudden environmental changes or management mistakes, and can translate into lower yields for producers, or even system collapse (Daily, 1997; Russell, 1989).

Finally, throughout this thesis, there is a diversity of management systems encountered, and more notably, a lack thereof in research presented in Paper II. Within coffee production systems, large-scale conventional producers, and small-scale conventional, semi-conventional and organic producers were
interviewed (**Paper I**). While there was a lack of different management systems within the export banana sector (**Paper II**), there were two other systems of banana production identified: organic and small-scale conventional banana-coffee intercrop. Even within the export banana production system, there still existed two different labeling schemes: conventional and Rainforest Alliance (RA) certified bananas.

Coffee and bananas are both crops whose production practices have received a lot of attention among the general public. The last ten years has seen remarkable growth in the marketplace of the sale of organic, fair trade and other sustainability labeled coffee (FAO, 2009; Raynolds et al., 2007). Similar trends are seen in the growth in the sale of organic bananas, and more noticeably, the sale of Rainforest Alliance certified bananas; RA claims that 15% of bananas exported and sold worldwide are RA certified (RA, 2011). An increasing awareness of the environmental impacts of pesticides among consumers in importing countries has helped to stimulate the demand for these products (FAO, 2009). While extensive research has been conducted on the ecological impacts of organically and conventionally produced coffee (Van der Vossen, 2005; Philpott et al., 2007; Haggar et al., 2011) and bananas (Damiani, 2001; Jimenez et al., 2007), to date, no research has been done comparing RA certified banana production with non-certified banana production.

**Thesis objectives**

The overall objective of this thesis, which has guided this work from the start to its completion, is to identify ways to reduce the environmental impact of agricultural practices. **Paper I** examines small-scale coffee farmers’ weed management practices and how they utilized herbicides versus manual labor to control on-farm weed problems. It was hypothesized that if small-scale farmers used more manual labor per hectare than large-scale farmers to control weed densities, then they would also use less herbicide per hectare overall compared to large-scale farmers. This research focused on weed control for several reasons. In the case of weed control there are well-known and widely used labor-intensive practices that substitute for herbicide application (IFAD, 2003). Additionally, small-scale farmers in developing countries spend up to 50% of their time managing weeds—a significant farm management activity (Labrada, 1997). Moreover, herbicides compose almost 50% of the pesticide market and are applied to more acreage than any other category of pesticide (NRC, 1989). The hypothesis for this research was driven by conflicting information in the literature about small-scale farmers use and misuse of herbicides, among other pesticides, in comparison to large-scale producers.
Similarly, **Paper II** focuses on farm management practices, but this paper focuses on banana production in Costa Rica, and broadens the focus to the entire production management system. Again, different banana farms’ management systems are compared, in an attempt to identify some structured variation among farms producing export bananas. The objective of this research was to identify farm management systems that are competitively producing export-quality bananas, but by managing the farm with qualitatively different practices that utilize fewer pesticides.

**Paper III** builds on the information collected on management practices in **Paper II**, and focuses on the ecological impact of high- and low-input and organic banana production. **Paper III** uses insect abundance and diversity as a measure of ecological impact of management practices. It was hypothesized that increased management intensity (in this case measured as pesticide use) leads to a higher dominance of some insects but lower overall biodiversity in terms of number of insect families (Greiler and Tscharntke, 1993; Paoletti et al., 1995). Other hypotheses tested in this study are: (1) banana farms with different management styles have different insect communities; and (2) banana farms have lower insect diversity compared to neighboring forests. The objective of this paper was to measure how decreased intensity of input use affects the on-farm ecology.

**Paper IV** follows from this research, and instead of looking at the on-farm ecology of banana production, the effect of banana production practices on aquatic macroinvertebrate community composition is studied. Banana production practices affect aquatic macroinvertebrates through runoff of pesticides, fertilizers and sediments from the farm into surface waters, which is facilitated through the construction of a network of canals built on the farm to efficiently move water away from the farm. Like in **Paper III**, it is hypothesize that surface waters downstream of banana farms would have a different benthic macrofauna community composition with less diversity compared to upstream sites. Among other indices, this research uses the British Monitoring Working Party (BMWP) score system in order to see if, together with the use of kick net sampling, the methods are sensitive to detect changes in samples taken up- and downstream of a single farm. If so, then it may be an ideal method to use to measure how different management practices implemented on the farm affect aquatic macroinvertebrates in surface waters adjacent to farms.

Finally, **Paper V**, like **Paper III**, measures the ecological impact of management practices, but this time on Rainforest Alliance (RA) certified farms compared to farms without RA certification. In addition to insect sampling, this paper includes results from habitat characterization and bird survey in
order to examine more broadly the effect of management practices such as maintaining hedgerows around the farm and conserving forests in adjacent lands. It was hypothesized that management practices resulting in RA certification lead to reduced environmental impact on and around these farms. While Chiquita began strongly marketing the RA certification seal in Europe in 2005, as an alternative ‘green’ label that promises reduced environmental impact on the farms receiving its certification (Corporate Social Responsibility, 2005), there is a lack of research to support these claims. Thus, the objective of this research is to fill the void of information regarding the ecological impact of various banana management systems.
Material and Methods

Study areas
The field work conducted for this study took place in various coffee and banana producing regions of Costa Rica.

Coffee producing regions
All of the interviews conducted with coffee producers for Paper I took place in either the Central Valley, in small towns called Atenas and Naranjo (these locations from now on will be referred to as the Central Valley), just prior to the harvest period of autumn 1999, or in the southern region of Coto Brus, principally in the small communities surrounding the town San Vito (from now on referred to as Coto Brus) during autumn 2000. These two areas were chosen as representative of two main coffee-producing regions in Costa Rica (Figure 2). The farms and farming conditions sampled in the survey formed an eclectic mix, fairly representative of the coffee communities within these two regions. The altitude of the farms range from 750 to 1600 m in the Central Valley and 800–1200 m in Coto Brus. Farms in both regions have slopes ranging from 0 to 50%. According to the Fabio Baudrit Experimental Station in Alajuela, the average diurnal temperature for Alajuela Province is 29.42 ± 1.6°C. Average annual rainfall in this region ranges between 1639 and 2239 mm per year. Average rainfall in San Vito is 4200 mm, with an average temperature of 21.5°C and 88% relative humidity (Icafe, 1998).

Banana producing regions
The majority of export banana production in Costa Rica occurs in the Atlantic zone (98.2% of the total amount of bananas exported), in the districts of Matina (25.3%), Pococi (18.9%), Siquirres (18.2%), Sarapiquí (16.2%), Limón (7.5%), Guácimo (6.2%) and Talamanca (5.9%) (Corbana, 2005). According to Corbana (2005), at the end of 2004 there were 137 banana farms producing for export in Costa Rica, with the largest farm at 1367 hec-
tares and the smallest farm at only 12 hectares. More than 92% of the farms were larger than 100 hectares.

For **Paper II**, 39 banana producers were interviewed: 17 export banana producers; 7 organic producers; and 15 small-scale conventional producers. The geographic spread of the export banana producers, representing 61 farms (45% of all farms exporting bananas), covered each of the banana-producing districts (Figure 2). The organic producers all had their farms in Talamanca, and the small-scale conventional producers were located in the district of Perez Zeledon (Figure 2).

Banana farms that were sampled for field data in **Paper III** and **V** were a subset of those interviewed for **Paper II**, and were located in Puerto Viejo de Sarapiquí, Guacimo, Matina and Cahuita (Figure 2). Finally, sampling sites in surface waters for **Paper IV** were also located in the banana producing regions, in Cahuita, Matina, Siquierres, Guacimo and Puerto Viejo de Sarapiqui (Figure 2).

![Figure 2: Map of Costa Rica, showing all of the towns and areas where sampling was done for both coffee and banana production research (circles). Triangles indicate surface water sampling. The star indicates San Jose, the capital city.](image-url)
Methods Paper I

The principal methodological approaches used over the span of this research were structured and semi-structured interviews, observations of farmer training sessions, and shadowing extension workers during daily activities. The interview was chosen as the main means for data collection because it appeared to be the most reliable means of collecting farm-level detailed information about management activities in this context. Most of the interviews were retrospective, and collected information based on a recall of farm activities in which farmers engaged in 1999 (interviews were conducted in autumn 1999 and 2000). All interviews were tape recorded and later transcribed. Each interview was conducted in Spanish and lasted approximately 15–20 minutes.

The first interview consisted of a set of questions divided into seven sections: (1) descriptive data about farm production; (2) amount and division of labor for manually chopping weeds, pruning shade trees, and applying herbicides; (3) amount of herbicide used; (4) sources of information and assistance; (5) credit services; (6) future of the farm; and (7) sentiments on organic production. Overall, 215 farmers were interviewed during this phase of the research: 116 farmers in the Central Valley and 99 farmers in Coto Brus. Almost 25% (N = 52) of the farmers interviewed were large-scale producers with 20 ha or more in coffee. With regards to small-scale farmers, 85 small-scale conventional producers, 9 small-scale semi-conventional producers, and 14 small-scale organic producers were interviewed.

A second set of interviews conducted during the spring of 2001 consisted of structured but open-ended questions about the impacts of sources of information on coffee production. Interviews were conducted and collected in the same way as the first interviews; 18 interviews were conducted. Data analyses consisted of single regressions, ANOVA, and descriptive statistics. The data were divided in order to test the hypothesis using these criteria: (1) small farms (<5 ha), medium farms (5–20 ha) and large farms (>20 ha); and (2) small conventional farms, small semi-conventional farms and small organic farms.

Methods Paper II

The methodological approaches used for Paper II were similar to those used in Paper I: structured and semi-structured interviews and shadowing farm managers during daily activities on the farm. Since farm-specific data on management practices in banana production is not publicly available, interview methods were the only reliable means of obtaining information ne-
cessary to test the research hypothesis. Interviews were conducted in the autumn of 2005. Although some of the data was recalled from memory, the more detailed information was provided from computer and archive records kept in the main office at the banana farms. All interviews took place at the farm.

As in Paper I, the interviews were designed to collect quantitative data regarding management practices. The difference however for Paper II is that the interview focused on all aspects of production management, rather than just weed control practices. The interview for Paper II collected information on the following: 1) Farm characteristics; 2) information about production; 3) establishment/renovation of the plantation; 4) management of canals; 5) fertilization; 6) pest management; and qualitative data regarding 7) information services. Each interview was conducted face-to-face with either the farm owner or the farm manager and lasted between one and three hours.

Data analysis for variation in management practices between different farms was done using correspondence analysis (CA) and cluster analysis with the statistical freeware, Past (Hammer et al., 2009). Descriptive statistics were also used.

Methods Paper III

The focus of methods in Paper III turned from interviews, with a focus on the human element of crop production, to the sampling of insect abundances as an indicator of ecosystem health. Insect sampling was conducted using two different methods for trapping insects: yellow bowl and pitfall traps (Figure 3). Both trap types were set out at each sampling site in order to sample a wider variety of insect orders. In total, 16 banana farms were sampled: five organic farms; 9 high-input farms; and 2 low-input farms. Two to four sites were sampled per farm, depending on the size and neighboring habitat of each farm. The sites were placed along a transect running from: 1) the middle of the farm, referred to as the inside site; 2) 30 meters into the banana farm; 3) the edge of the banana farm; and 4) in the forest bordering the banana farm. There were five replicate yellow bowl traps and 5 replicate pitfall traps at each site. Each trap was placed at least five meters apart according to Sutherland (2006). Traps were left in place for 24 hours. Identification was conducted to family and then morphospecies, using a stereoscope.
The effect of management type and sampling location on insect species diversity was studied with multivariate statistics, using two ordination techniques: principle component analysis (PCA) and redundancy analysis (RDA). In addition to the visual representation of data provided by these ordination techniques, the statistical significance of hypothesized differences was obtained using Monte Carlo permutation testing according to Ter Braak and Šmilauer (2002).

PCA and RDA analyses generate ordination diagrams that allow one to compare how closely the different sites are related to each other in terms of species composition and how the species composition varies between treatments, i.e. management types. Sites that lie close together on the diagram share a more similar species composition than those sites that lie further apart (Ter Braak, 1995).

In ordination diagrams for samples, samples are represented by site points; site points with resembling species composition lie close together, while sites more dissimilar in species composition lie further apart. Additionally, species are represented by species points in ordination diagrams. Species points lying far away from the centre of the diagram are important for indicating sample differences; the further away, the larger the difference. The origin of a species ordination diagram represents the mean abundance of the

Figure 3: (a) Yellow bowl traps and (b) pitfall traps used in the insect sampling.
individual species in all samples. Consequently, only those species whose abundance shows variation from the mean are displayed in the diagram. Ordination diagrams that show both site points and species points are referred to as biplots.

Methods Paper IV

In Paper IV, another aspect of ecological impact of banana production was measured: the effects of runoff from banana farms into the adjacent surface waters. Kick-net sampling was used to collect aquatic invertebrate samples from 13 sites (one to three replicates; Figure 4) between March 8 and April 26, i.e. during the dry season, 2007. Sites were chosen in both watercourses receiving run-off from banana farms and sites assumed not to be affected by banana farming. Where possible, sites were chosen in pairs along the same watercourse, with one site situated upstream and the second downstream of banana farms (Figure 4). Identification was done to family level under stereoscope.

![Figure 4: Kick net sampling for aquatic macroinvertebrates in rivers.](image)

As in Paper III, PCA and RDA multivariate analyses were used to test the hypothesis. The Biological Monitoring Working Party score system (National Water Council, 1981) was used to measure water quality, in addition
to other indices such as Shannon-Wiener, individuals per taxon, and percent dominating taxon, to determine if differences between sites could be detected.

Methods Paper V

Paper V draws on interview data used in Paper II and and insect data collected for Paper III. In addition to this, Paper V uses data collected on habitat characterization and from a bird survey. Each bird survey consisted of two five minute point counts with audio recording according to Gibbons and Gregory (2006), with 6 recordings taken for each farm: two each from the inside, edge and forest sites. The audio recordings were later identified by an expert and a list was compiled of each bird species that was present at each site.

A habitat characterization was done for each site, in order to characterize the complexity of plant structure at each sampling site. This was done by employing 5x5m quadrants, according to Bullock (2006). Three quadrants were used for each sampling site and the inside, edge and forest sites were sampled on each farm. For each quadrant, the number of different plant species measuring over one meter tall were recorded.

Like in Papers III and IV, PCA and RDA multivariate analyses were used to test the hypotheses against the data.
Synthesis of results

Results from Papers I, II, and V all show that there is a deficiency of innovation in the production of export crops, as the result of the current type of support services offered, and a general lack of thinking outside the box with regards to experimentation with different production methods and systems of production.

While organic production systems show the least impact on ecological quality, results from Paper III show that even minor reductions in pesticide use make a difference. Results from Paper IV present methods that can help determine the environmental impact of changes in management practices on aquatic macroinvertebrates.

Paper I analyses small-scale coffee producers’ use of herbicides and concludes that small-scale producers overuse herbicides. When compared to large-scale producers, small-scale producers used significantly more labor, but similar amounts of herbicides, without receiving a competitive advantage in crop productivity (Table 1). Small-scale conventional farmers use similar amounts of labor to control weeds when compared to small-scale organic producers (Table 2). Small-scale semi-conventional producers, those who do not use herbicides, but do use other types of pesticides, also use similar amounts of labor when compared to small-scale conventional producers (Table 2). Thus, rather than using herbicides as a substitute for labor, small-scale conventional coffee producers continue to use as much labor as those producers who do not use herbicides, negating the need for their herbicide use. Analysis of productivity shows that they do not grow more coffee per hectare than their organic counterparts.

A second round of field work and interviews revealed the disproportionate impact of chemical companies over other less-biased support services offered by the local coffee cooperatives and the local National Coffee Institute extension workers. It also revealed farmers’ lack of knowledge about alternative production systems, including organic production. This is remarkable, given that it was less than 20 years prior to this investigation that Green Revolution technologies were introduced to the region. In that short space of time producers had already forgotten how to farm effectively without the use of pesticides.
Table 1: Analysis of variation (ANOVA) between small farms and large farms. P-values refer to Bonferroni p-values. Since the degrees of freedom in each analysis were over 200, using a 5% level of significance, an R-value of .138 or greater with a P-value less than .05 was used as the criterion to conclude a significant difference between variables (* denotes significance).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Small farm mean (SD) N=109</th>
<th>Large farm mean (SD) N=52</th>
<th>P-value</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total # of labor days spent on all weed management activities/ha-year</td>
<td>76.7 (116.6)</td>
<td>37.1 (57.5)</td>
<td>0.013*</td>
<td>3.272</td>
</tr>
<tr>
<td>Total # of days spent chopping weeds/ha-year</td>
<td>55.0 (110)</td>
<td>18.6 (41.3)</td>
<td>0.012*</td>
<td>3.188</td>
</tr>
<tr>
<td>Total # of days spent fixing the shade/ha-year</td>
<td>13.3 (14.4)</td>
<td>8.9 (14.4)</td>
<td>0.087</td>
<td>1.557</td>
</tr>
<tr>
<td>Total amount of herbicides used/ha-year (L)</td>
<td>6.37 (8.87)</td>
<td>5.21 (6.15)</td>
<td>0.379</td>
<td>0.424</td>
</tr>
<tr>
<td>Total # of hours worked by hired labor/ha-year</td>
<td>50.8 (120.0)</td>
<td>134.9 (173.9)</td>
<td>0.001*</td>
<td>7.276</td>
</tr>
<tr>
<td>Total # of hours worked by family labor/ha-year</td>
<td>405.9 (702.6)</td>
<td>43.9 (85.7)</td>
<td>0.000*</td>
<td>9.386</td>
</tr>
<tr>
<td>Average plant density/ha</td>
<td>4844 (1252)</td>
<td>5414 (1404)</td>
<td>0.010*</td>
<td>3.453</td>
</tr>
<tr>
<td>Production (kg)/ha</td>
<td>1844.6 (920)</td>
<td>2120.6 (607.2)</td>
<td>0.041*</td>
<td>2.167</td>
</tr>
<tr>
<td>% of the farm shaded</td>
<td>79.2% (31.7%)</td>
<td>68.9% (41.1%)</td>
<td>0.093</td>
<td>2.073</td>
</tr>
</tbody>
</table>

Table 2: Analysis of variation (ANOVA) between small conventional, semi-conventional and organic farmers.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Conventional farm mean (SD) N= 83</th>
<th>Semi-conventional farm mean (SD) N= 9</th>
<th>Organic farm mean (SD) N= 14</th>
<th>P-value</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total # of days spent on all weed management activities/ha-year</td>
<td>63.6 (54.1)</td>
<td>25.9 (19.5)</td>
<td>42.4 (47.5)</td>
<td>.06</td>
<td>2.884</td>
</tr>
<tr>
<td>Total # of days chopping weeds/ha-year</td>
<td>39.8 (44.2)</td>
<td>19.5 (16.5)</td>
<td>27.3 (32.2)</td>
<td>.2575</td>
<td>1.375</td>
</tr>
</tbody>
</table>
Paper II was a similar analysis of crop production practices, but this time looking at all of the management practices in export banana production in order to identify variations in practices among export banana producers that may constitute a different type of production system. Yet what the results showed was that all export producers were using the same set of practices to produce export bananas (Figure 5); some producers may have used fewer applications of nematicides or fungicides, but none of them were using alternative practices for nematode or fungus control (Table 3). Even Earth University, which is a university with a focus on conducting research in improving banana production practices (they also have a 350-hectare commercial banana farm, part of which is designated for research), fails to take advantage of that opportunity to investigate alternative production systems. Although they do not produce export bananas, organic and coffee-banana intercrop systems are alternative production systems that rely on a very different mix of practices. Further research into these systems may identify to what extent the farms can be expanded before encountering pest problems or reduced financial returns.
Figure 5: Ordination plot generated from CA, with variables also plotted. Red dots are numbered according to farm site sampled and blue dots are the variables that were outliers from all other variables. All other variables were located at the center of the cluster of red dots representing most of the farms sampled; they were excluded for purposes of clarity. The three outlier variables, cost for organic fertilizer, the amount of organic and chicken fertilizer applied, and the number of other crops cultivated on the farm, were outliers due to farm 5 and 17’s much larger application amounts compared to the other farms.

Table 3: Descriptive statistics of 2004 management practices for export banana producers.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm size (ha)</td>
<td>294</td>
<td>54</td>
<td>1050</td>
<td>230</td>
</tr>
<tr>
<td>Density (plants ha⁻¹)</td>
<td>1738</td>
<td>1625</td>
<td>1843</td>
<td>66</td>
</tr>
<tr>
<td>Productivity (boxes ha⁻¹)</td>
<td>2666</td>
<td>2200</td>
<td>3510</td>
<td>380.1</td>
</tr>
<tr>
<td># of fertilizer applications</td>
<td>14.3</td>
<td>10</td>
<td>26</td>
<td>4.7</td>
</tr>
<tr>
<td>Amount of fertilizer applied (kg ha-year⁻¹)</td>
<td>2775</td>
<td>2000</td>
<td>3560</td>
<td>511</td>
</tr>
<tr>
<td>Amount of organic fertilizer applied (kg ha-year⁻¹)</td>
<td>2221</td>
<td>0</td>
<td>21840</td>
<td>5448</td>
</tr>
<tr>
<td># of cycles of nematocide applications</td>
<td>2.7</td>
<td>0</td>
<td>4</td>
<td>.9</td>
</tr>
<tr>
<td># of cycles chopping weeds</td>
<td>2.7</td>
<td>0</td>
<td>12</td>
<td>3.7</td>
</tr>
<tr>
<td># of cycles applying herbicides</td>
<td>4.4</td>
<td>0</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td># of cycles applying fungicides</td>
<td>50.4</td>
<td>22</td>
<td>60</td>
<td>9.3</td>
</tr>
<tr>
<td>Cost to apply fungicides (USD)</td>
<td>1357</td>
<td>1126</td>
<td>1760</td>
<td>181</td>
</tr>
</tbody>
</table>

Paper III investigates the ecological effects of high-input, low-input and organic banana farming systems (Table 4). The results confirmed the hypothesis that increasing pesticide intensity leads to reduced and different insect community composition and decreased functional group diversity (Figure 6 and 7); and that insect community composition is smaller and less diverse on farms compared to neighboring forests (results not shown; see Paper III). While it was expected that organic banana farms would have a more diverse insect community composition, the results of this study showed that even smaller decreases in pesticides applications can have a positive effect on the ecological impact of production practices. This can be significant, when the
reduced and less diverse community composition resulting from high-input production systems leads to less functional diversity provided by insects (Figure 7). The reduced functional diversity can lead to a less resilient system, with less capability to respond to extreme events like pest infestation or flooding.

Table 4: Average values for the three farm management types studied: organic, high-input and low-input. N is the number of farms in the category. Mean size (ha) is the average size of the farms in hectares. The following three columns refer to the number of herbicide applications, nematicide applications and fungicide applications, respectively, per year. Insecticide-impregnated bags refers to whether or not farms used them (all conventional and Earth farms used them, while none of the organic farms did) to cover the banana bunch during the maturation phase. The final two columns refer to the average number of times manual weeding per year and the average number of other crops cultivated on the farm.

<table>
<thead>
<tr>
<th>Farm type</th>
<th>N</th>
<th>Mean size (ha)</th>
<th># herb. apps</th>
<th># nem. apps</th>
<th># fung apps</th>
<th>Insecticide-impregnated bags</th>
<th># times man weeding</th>
<th># other crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic</td>
<td>5</td>
<td>13.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>No</td>
<td>3.8</td>
<td>9.2</td>
</tr>
<tr>
<td>High input</td>
<td>9</td>
<td>226</td>
<td>7.3</td>
<td>3</td>
<td>54</td>
<td>Yes</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Low input</td>
<td>2</td>
<td>84</td>
<td>0</td>
<td>1.5</td>
<td>46</td>
<td>Yes</td>
<td>10</td>
<td>.5</td>
</tr>
</tbody>
</table>
Figure 6: Pitfall traps RDA biplot showing the differences in species composition between management styles using only the inside and 30m samples. Inside and 30m were introduced as covariables, which explained 1% of the variation in species composition. Management style explained 10% of which 67% is displayed on the horizontal axis and another 33% on the vertical axis. Triangles in the figure represent different families. Organic, low-input and high-input farms are all in different quadrants of the chart, indicating differences, and there is a decreasing number of species clustered near each management type as intensity of management practices increase.
Figure 7: Functional roles represented by insect families positively correlated with organic, low-input and high-input farms for both pit-fall and yellow bowl traps.

Results from Paper IV showed that sites sampled downstream of banana farms suffered from reduced benthic macroinvertebrate diversity and increased species dominance compared to sites sampled upstream of the banana farm. These sites are located close to each other, with only the banana farm located in between, leading to the conclusion that differences seen in the benthic macroinvertebrate community composition is the result of runoff from the banana production system.

It is also concluded that kick-net sampling, used together with BMWP score system, was sensitive enough to detect changes in aquatic macroinvertebrate community composition up- and downstream of the point source where banana farms drain into naturally-occurring surface waters (Figure 8). This combination of methods is relatively cheap to employ and moderately time consuming compared with other monitoring activities, and it is adapted to the tropical region.
Figure 8: PCA biplot showing the variation in species composition between samples taken up- and downstream paired sites 1 and 2, and 3 and 4. Of the variation in species composition, 50% is displayed on the horizontal axis and another 16% on the vertical axis. Triangles represent families/taxon. Sites 1 and 3 are upstream and sites 2 and 4 are downstream of banana farms. All four sites are located in different quadrants, indicating differences, and both sites 1 and 3 have more insects clustered in their quadrant, compared to their downstream counterparts, sites 2 and 4.

Finally, in the analysis comparing RA-certified farms with non-RA certified farms in Paper V, it was found that RA farms have fewer insect families compared to non-RA farms (Figure 9). The research also showed that the conservation of forest at farm edges does significantly impact on-farm insect community composition (p<.001; Figure 10). Additionally, Figure 11 shows that the largest diversity of birds is associated with the organic farms; the forest, edge and inside sites are all different from each other, and each associated with a few bird species; the inside sites are not as strongly associated with any particular bird species, evidenced by its placement close to the origin; there is a difference between RA certified farms and non-certified farms with regards the diversity of the bird species surveyed; and plant diversity is positively associated with forest, organic farms and a larger proportion of the bird species.
Figure 9: RDA biplot using pitfall trap data and management style (RA, non-RA and organic) as explanatory variables and sample position (inside and 30m) as covariables. Permutation tests showed that all management styles differed significantly (p<0.001) in species composition. Sample position explained 1% of the total variation in species composition, while management styles explained 11%. Of the latter 68% is displayed on the horizontal axis and the remaining 32% on the vertical axis. Triangles represent insect families/order. Organic, non-RA and RA certified farms are all located in different quadrants, indicating differences in species community composition. RA certified farms are only positively associated with one insect family, whereas non-RA certified farms are positively associated with more insect families, and organic certified farms positively associated with the most insect families.
Figure 10: RDA biplot using sites as explanatory variables and sample position (inside and 30m) as covariables. Only the RA and non-RA sites are included in the analyses. Sites highlighted in green are RA sites with forest, sites highlighted in blue are RA sites without forest, sites highlighted in red are non-RA sites with forests, and sites in black are non-RA farms without forest. Permutation tests showed that sites with forest differed significantly ($p<0.001$) in species composition from sites without forest. Sample position explained 1% of the total variation in species composition, while sites explained 37%. Of the latter 48% is displayed on the horizontal axis and 28% on the vertical axis. Triangles represent insect families/orders. All of the RA-certified farms lie to the top of the horizontal axis, whereas the non-RA certified farms all lie under the horizontal axis, along with all of the species.
Figure 11: RDA biplot of bird species data, using management, sample position and number of plants (square root transformed) as explanatory variables. The explanatory variables explained 22% (p=0.004) of the total variation in species composition, of which 41% is displayed on the horizontal axis and 20% on the vertical axis. RA-certified farms are positively associated with 2 bird species, the non-RA certified farms and the edge sites are positively associated with 5 bird species, whereas the organic certified farms are associated with approximately twice as many bird species compared to non-RA certified farms. Plant diversity is also positively correlated with organic and forest sampling sites.
Implications of major findings

The results of Papers I and II both show the need for restructuring support services for producers, including the type of research conducted for improving production management. In the case of coffee production, there needs to be more outreach and work together with small-scale coffee farmers. This means that there needs to be more resources, in the form of manpower, to meet one-on-one with individual farmers on their farms. Otherwise, the chemical companies will continue to dominate in the exchange of information with small-scale producers, and overuse of herbicides will continue. In the case of banana producers, there is a need for a radical change in research approaches compared to the current approach by the National Banana Corporation. Current research looks at only one aspect of production practices in a single experiment, whereas there is a need for a systems approach to improving the production system. It is at the level of the whole production system where synergies between practices occur, leading to better performance than measured by any individual practice taken on its own.

Paper III shows that low-input banana production is not as good as organic production with regards to reducing ecological impact, but it can still make a difference when compared to high-input banana production. Rainforest Alliance certified farms studied in Paper V, however, are not low-input systems and the changes that they make in production practices are not enough to influence the quality of the ecological system. The lack of a difference that we see in the research results in Paper V may be due to the fact that many of the practices implemented on RA-certified farms are also implemented on the non-certified farms. This is the case of forest conservation adjacent to banana farms: conservation of forest influences the insect community composition on the farm, but since both types of farms implement this practice, it does not distinguish them from each other with regards to insect community composition. These kinds of changes in management practices across farm types are a positive trend, but it leads one to question the value of the RA certification scheme. To be of value, RA should strive to set standards that achieve genuine improvements in the ecological impact of management practices, over those implemented on non-certified farms. Their cooperation with independent researchers to investigate the environmental impacts of their changes in management practices is a positive step towards achieving the goals of RA certification.
Finally, Paper IV provides a means for assessing the ecological impact of changes in management practices. For example, among their attempts to improve ecological quality, Chiquita RA-certified farms have experimented with the implementation of sediment traps on their farms, which are ditches dug in the canals that are used to capture sediment before it runs off of the farm. This can be effective by reducing the amount of organic pollution and sediment-adhered pesticides in runoff to surface waters. The methods set forth in Paper IV can serve as a means of testing the effectiveness of this and other methods in reducing negative impacts on aquatic macroinvertebrate community composition.
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