Ecuador and Cacao: An Old Alliance
A Peace Corps Masters International Project

Submitted by:
Thomas Winkel

Colorado State University
Department of Horticulture and Landscape Architecture
College of Agricultural Sciences
Spring 2013
We hereby recommend that the thesis prepared under our supervision by Thomas Winkel entitled Cacao and Ecuador: An Old Alliance. A Peace Corps Masters International Project is accepted as fulfilling in part requirements for the degree of Masters of Agriculture.

Committee on Graduate Work

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Advisor

________________________________________________________________________

Department Head
Acknowledgements

I would like to dedicate this paper to my Ecuadorian hosts, the Seilema-Vaca family of Primavera, of the Naranjito-Guayas Province. During my stay in Ecuador, not only did they show civility with my many blunders, displaying patience with many cultural and communication differences, they also went out of their way to assist and familiarize me with Ecuadorian savoir-faire, the language, the local and national events, etc. They became an extended family to me in so doing.

The Seilema-Vaca’s also taught me quite a bit about how people in the coastal rural regions forge their living, like farming tilapia fish in back yard ponds, cultivating the sweetest pineapple profitably in the smallest of areas, in cultivating cassava, sugar cane, and most importantly cacao, to which most of this report discusses. To them I am indebted and very much appreciative.

In addition, I would like to recognize, and to thank in great appreciation the following people for their involvement in the process and completion of my educational endeavor:

To Dr. Tiffany Weir, my adviser, for her encouragement, advice and direction in my studies at Colorado State University and all throughout my assignment in Ecuador while in the Peace Corps Masters International Program. I am very appreciative in how she went far beyond what was expected in offering counsel, interest and support of the Biochar experiment that was initiated in Ecuador. Lastly for the many hours she set aside to preview this paper amidst her full and busy schedule.

To my committee members, Dr. Jessica Davis, Dr. Frank Stonaker who always made time to see me, and so often when I showed up at their offices without prior notice. Their helpful and wise advice was always given whenever needed, whether it was on soils, vegetable crops, scheduling classes, or just casual and informative conversations. I am also very appreciative to them for their counsel and direction given during my assignment in Ecuador while in the Peace Corps Masters International Program.
# Table of Contents

List of Figures .......................... 1

List of Tables .......................... 2

Chapter 1: Ecuador and Cacao ............... 3
  1.1 Geography and Climate of Ecuador .... 3
  1.2 Origins of Cacao .................. 5
  1.3 Cacao and Ecuadorian Climate ...... 6
  1.4 Cacao and Ecuadorian People: Brief History 6
  1.5 Cacao and Ecuador: The Present ...... 11

Chapter 2: Theobroma cacao L. ............... 15
  2.1 Cacao: Origin of the Name .......... 15
  2.2 Physiology of Theobroma cacao L. ... 18
     2.2.1 The Plant .................. 18
     2.2.2 Branching and Leaves ........ 19
     2.2.3 Florescence ................ 20
     2.2.4 Pollination ................. 21
     2.2.5 The Fruit .................. 22
     2.2.6 Other Factors ............... 24
  2.3 Theobroma cacao L. Varieties ......... 26
     2.3.1 Diversification of a Species ... 26
     2.3.2 Theobroma cacao L. subsp. cacao ‘Criollo’ ... 27
     2.3.3 Theobroma cacao L. subsp. sphaerocarpum ‘Forastero’ ... 27
     2.3.4 Theobroma cacao L: Varietal Group ‘Trinitario’ ... 28
  2.4 Cacao of Ecuador .................. 30
     2.4.1 Cacao Nacional .............. 30
     2.4.2 CCN-51 ..................... 33

Chapter 3: El Recinto Primavera ............... 38
  3.1 A Brief History of Primavera; the Seilemas ... 39
  3.2 Cacao in Primavera ................. 43
  3.3 Cacao Maintenance ................ 45
  3.4 Cacao Market for Primavera .......... 46
  3.5 The Exporters Warehouse ............ 51
# List of Figures

**Figure 1**: Map of South America, Map of Ecuador  
13

**Figure 2**: Climate-Zone Map of Ecuador  
13

**Figure 3**: Topographical Map of Ecuador  
13

**Figure 4**: Witches Broom (*Crinipellis perniciosa*) on Theobroma cacao L.  
14

**Figure 5**: The 24 Provinces of Ecuador  
14

**Figure 6**: Mayan glyphs for cacao  
34

**Figure 7**: Taxonomy of Theobroma cacao L.  
34

**Figure 8**: Theobroma cacao L.  
35

**Figure 9**: Jorquette growth pattern of a cacao tree  
35

**Figure 10**: Structure of cacao flower  
35

**Figure 11**: T. cacao flower  
35

**Figure 12**: *Forcipomyia midge*, pollinator of cacao  
36

**Figure 13**: T. cacao showing cherelle fruit stage  
36

**Figure 14**: Mature seed pods of the cacao tree  
36

**Figure 15**: Seeds from the T. cacao seed pod  
37

**Figure 16**: Monilia fungus (*Moniliophthora roreri*) on T. cacao seed pod  
37

**Figure 17**: One form of seed transport method to the market  
54

**Figure 18**: Cacao Association from Primavera, Ecuador  
54

**Figure 19**: Two methods of fermenting cacao seed  
54

**Figure 20**: Cacao seed drying  
55

**Figure 21**: Cacao seed being weighed for market  
56

**Figure 22**: Sampling of seeds for Quality Control  
56

**Figure 23**: Double Drum Kiln outline  
75

**Figure 24**: The Double Drum Kiln producing biochar and the product  
75

**Figure 25**: Pit Kiln outline  
75

**Figure 26**: The Pit Kiln display and in a burn  
76
Figure 27: The Single Drum in the Pit outline 76
Figure 28: The Single Drum Kiln producing biochar 76
Figure 29: Mound Method of producing biochar 77
Figure 30: Biochar being screened 77
Figure 31: Treatment of Biochar 78
Figure 32: Application of Biochar 78

List of Tables

Table 1: The Provinces of Ecuador, with number of Cantons of each 12
Table 2: Average Constituents of Pure, Shell-free Cacao Seeds 23
Table 3: General Description and Ecology of Theobroma cacao L. 24
Table 4: Principal Varietal Groups (3) of Theobroma cacao L. 28
Table 5: Traditional and Specialized Cacao Marketing Chains in Ecuador 47
Table 6: Production costs for 1 hectare of CCN-51(2008) 49
Table 7: Production costs for 1 hectare of Arriba/Cacao Nacional (2008) 49
Table 8: Example of Biochar Experimental Design BEJL-01 69
Table 9: Soil Classifications of the 7 Trials, pH and Dates Initiated 70
Chapter 1: Ecuador and Cacao

1.1 Geography and Climate of Ecuador

Ecuador is a relatively small country situated on the northwestern edge of the South American continent, where the equator transverses the northern half of the country (Figure 1). It borders the Pacific Ocean to the west, and is tucked between Colombia to the north and Peru to the east and south (CIA, 2012). Excluding the Galapagos Islands, Ecuador can be divided into three general regions. Each region is geographically and climatically distinct. The first region is the coastal plain (Costa), the second is the Inter-Andean Central Highlands (Sierra), and the third is the Eastern Lowlands, where the high level of precipitation directly contributes to the Amazon basin Region (Oriente) (South America, 2010).

La Costa

The western coastal region (Costa) is mostly undulating lands with periodic coastal mountains that reach up to 800 meters in height (Newson, 1995). It is hot and humid for most of the year, deviating only slightly depending on the warm or cool ocean currents (Hanratty, 1989). The average annual temperature ranges from 26°C in the northern region to 23°C in the south (Vera, 2006). Depending on the ocean currents, the northern coastal areas can receive yearly amounts of rainfall of up to 300 cm, whereas the southern region can receive minimum amounts as low as 30 cm (Vera, 2006). Much of the southern coastal areas reflect this low precipitation rate (Figure 2) by exhibiting somewhat arid landscapes (Newson, 1995).
starts at sea level along its western edge to its border with the Inter-Andean region which sits anywhere from 400 m to 1,800 m at the highest (Vera, 2006).

La Sierra

The central, Inter-Andean region (Sierras) differs from the coastal region not only in the contour of the land, but also in extreme differences in elevation. It is in the transition zone that the Andes Mountain range shoots straight up to great heights, with some mountain tops exceeding 6,000 m (Milivojevic, 2010). The Andes Mountains in this locale consist of two serpentine ranges that are more or less parallel to each other, running north-south through the center of the country. A number of large valleys sit between these two ranges (Knapp et al., 2012), extending from the northern border with Colombia and south to the Province of Loja, adjacent to Peru (Figure 3). It is here that Quito, Ecuador’s capital, is nestled in at an elevation of 2,800 m (South America, 2010). At these lofty altitudes, the ability to grow many tropical crops is limited because of extreme changes in the climate, i.e. low temperatures (Young, 1994).

The temperatures exhibited in this region of Ecuador are largely a function of altitude. That is to say, as the elevation increases every 200 m, the temperature decreases 1°C (Hanratty, 1989). Where the coastal and Inter-Andean regions meet one finds temperatures typical of the tropics due to lower elevations and an equatorial location, ranging from 20°C to 25°C (Vera, 2006). As the altitude increases, however, the tropical climate quickly slides into subtropical, ranging from 15°C to 20°C. In gaining elevation, a zone that mimics temperate-zone summer temperatures appears, having averages of 10°C to 15°C (CIA, 2012). Areas of extreme elevation defined as anything above 4,650 m, are referred to as the Frozen level (Vera, 2006). Here one can find mountain tops snowcapped year around, as is the case on Mount Chimborazo, the highest mountain in Ecuador, with an elevation of 6,268 m (Milivojevic, 2010).
El Oriente

The eastern region of Ecuador (Oriente) is a vast, predominantly flat area that gradually slopes eastwardly towards the Amazon basin (CIA, 2012). It can be divided into two sub-regions, the Andean piedmont and the Eastern lowlands. Starting from high up in the Andes, the piedmont drops from an altitude of over 3,000 m, leveling out at anywhere from 1150 to 300 m in the lowlands (Vera, 2006). The region is consistently hot and humid, even more so than the coastal plains region, as it exhibits a true equatorial climate (Hanratty, 1989). The terrain is covered by dense tropical rain forests.

The average temperatures here are 25°C along the western side of this region, increasing to an average of 28°C when nearing the eastern lowlands that border with Peru (Vera, 2006). Fluctuations in temperatures are minimal here. This region, as previously stated, receives large amounts of precipitation. This occurs especially in the piedmont area where the mean annual rainfall can exceed 500 cm (Hanratty, 1989). In contrast, the eastern lowlands average less than 250 cm of precipitation annually (Vera, 2006).

1.2 Origins of Cacao

It is in the lush tropical climate of the Oriente region that *Theobroma cacao* L. originated. The genus *Theobroma* in its wild state, has existed in the Amazonian and Orinoco River regions to the north and east of modern day Ecuador for millions of years (Young, 1994; Rosenblum, 2005). It was, however, in the eastern foot hills of the Ecuadorean Andes that the species *Theobroma cacao* appeared around 10-15 thousand years ago (Schmitz et al., 2012; Young, 1994). *T. cacao* is thought to have been the result of intentional hybridization of *T. pentagona* and *T. leioarpa* by indigenous peoples of the region (Young, 1994). Although neither the plant nor the seed of the cacao will tolerate cold temperatures (Schmitz et al., 2012), there is speculation that it traveled westward
through the lower, not-so-cold mountain passes of the Andes to the western coastal region via human or animal transport (Rosenblum, 2005). From there, the plant is hypothesized to have been taken north along the coast into the Mesoamerican region via trade routes (Schmitz et al., 2012).

1.3 Cacao and the Ecuadorian Climate

The fact that *T. cacao* originated in the northeastern Ecuadorian regions suggests that it could be successfully cultivated in most areas of that tropical region. There are constraints, though, that limit where this tree will grow, even in Ecuador. Cacao is a specialized plant that grows within a certain distance north and south from the equator. The exact distance is debatable as some investigations put it at 10° of either side of the equator (ICCO, 2012), others at a distance of 18° (Schmitz et al., 2012), and still others report that this limited banded growing area for cacao extends to 20° N and 20° S (Coe et al., 2007; Rosenblum, 2005).

Another characteristic of cacao is that it is limited by elevation, and grows best from sea level to 300 m (Duke, 1983). Again, there is some argument that puts the general limit for elevation at less than 1,000 m, with exception to certain ideal micro-climates found in Venezuela at altitudes of 4,000 m, or in Colombia with 3,000 m elevations that support cacao production (Young, 1994). Coe (2007) best defines it in stating that cacao will grow up to any elevation within 20° of the equator that does not fall below 16°C. Thus, with the exception of the Andean highlands, most of Ecuador is conducive to cacao cultivation.

1.4 Cacao and Ecuadorian Peoples: Brief History

As stated earlier, it is a known fact that although the genus *Theobroma* dates back millions of years, *T. cacao* is a relatively recent species, dating back only ten to fifteen thousand years (Rosenblum, 2005). One line of thought suggests that *T. cacao* arrived on the scene along with the
earliest human inhabitants of the Ecuadorian region (Young, 1994). Based on archeological findings, this area of Ecuador was home to an interesting succession of indigenous peoples and societies, starting with the Las Vegas culture, dating back 9000 to 6000 B.C. (Milivojevic, 2010). Later there came the Valdivia culture at 3000 to 2500 B.C. (Knapp et al., 2012), followed by the La Tolita around 300 A.D., the Manta at ~ 500 A.D., and the Cañar, Cara and Puruhá Kingdoms which lasted up into the 15th century A.D. (Milivojevic, 2010).

Very little archeological evidence, if any, shows that cacao had been specifically cultivated by these people (Young, 1994). The Ecuadorian civilizations were privy to T. cacao, and desired it not for the seeds themselves, but rather for its sweet and juicy mucinous pulp that surrounds the seeds. It is purported by some that the seeds were not desired due to the bitter alkaloids the seeds contain, resulting in an unpleasant taste when eaten (Young, 1994). There is, however, archeological evidence that T. cacao may have been used for medicinal purposes by these indigenous tribes (Orey, 2010).

Although most evidence asserts T. cacao was cultivated by Ecuadorians after the arrival of the Spanish incursion centuries later (Young, 1994), there is one exception. A small entry in the 1526 journals of Francisco Pizarro was made, where he noted seeing small cacao plantations along the northwest coastline of South America, of what is now thought to be northern Ecuador (Solorzano et al., 2012). It is most likely, though, that these “plantations” were nothing more than patches of densely populated, naturally growing cacao that had been purposely cleaned out by the locally indigenous people (Coe et al., 2007).

Interestingly, there is archeological evidence showing T. cacao had migrated from the Ecuadorian coast north into Mesoamerica through the years that predate 1500 B.C. (Young, 1994; Coe et al., 2007). Apparently, the first known cultivation of T. cacao for seed selection and for its
use in chocolate-type convections (Young, 1994) existed in the Olmec civilization for thousands of years in Mesoamerica (Rice, 2003), not Ecuador. This evidence shows that ~ 1000 B.C. the Olmecs had their first large agricultural period, which included vast maritime trade routes extending from Ecuador all the way to Mexico (Rosenblum, 2005). Furthermore, it shows that the Olmecs cultivated cacao on a large scale, dating from ~1500 to 400 B.C (Orey, 2010; Young, 1994; Rosenblum, 2005).

The cultivation of *T. cacao* continued with the Mayan empire which rose to prominence between the years 250 and 900 A.D. (Rosenblum, 2005). It was with the Mayans that the cacao seed increased in societal importance, in economic value, and began to appear in its religious mythology (Coe et al., 2007; ICCO, 2011). By the 12th century, cacao had then migrated into the beginnings of the Aztec civilization, where it maintained the same positions of societal and monetary value (Rosenblum, 2005). But with the Aztecs, it acquired more of a royal if not deified level of importance within the culture by the 14th century (Schmitz et al., 2012; Young, 1994; ICCO, 2011).

In Ecuador towards the end of the 15th century, an ever increasing threat by the Incan Empire, who commanded the lands to the south (Peru), began to shift their eyes northward. In the year 1471, the Incas aggressively moved into the Ecuadorian region with intent on conquering and ruling over its indigenous tribes (CIA, 2012). This conquest lasted until 1532, and had not yet fully coalesced (Young, 1994) when the Spanish conquistador Francisco Pizarro arrived. Within a few years Pizarro was able to overthrow the Incan Empire, making Spain the new sovereignty of Ecuador (Knapp et al., 2012).

By 1563 many Spanish colonialists had moved to this tropical terrain (Young, 1994) being spurred on by European mercantilism. This manifested itself in large “land claims” by wealthy
Spaniards, a movement which culminated by the late 17th century (ICCO, 2011). The ancient indigenous city of Quito was made the new seat of the Spanish Colonial government for the region (Milivojevic, 2010) and was given the name New Granada (CIA, 2012). Moreover, the beginnings of the Spanish migration into this region resulted in new industry for Ecuador; production of textiles, cattle ranching, cultivating trees for fine wood, and production of coffee and the first real effort at the large scale cultivation of cacao (Vera de Mayorga, 2011; South America, 2010).

Cacao’s introduction into Spain through the writings of Columbus (Coe et al., 2007; Young, 1994) and the cacao seeds taken to Spain by Hernando Cortez in 1528 resulted in an increased demand for chocolate by 1585 (Rosenblum, 2005). With the rising popularity of chocolate products in Europe and the favorable climate for cacao production in Ecuador (Young, 1994), the new Spanish arrivals set up large cacao plantations, becoming an important if not lucrative export crop for Ecuador by 1740 (Hanratty, 1989). Even the Spanish Capuchin Friars, who went there to evangelize the natives, grew cacao for extra income (ICCO, 2011). Its cultivation became the mainstay of New Grenada’s economy by 1780 (Butler, 2010), relying on it as a major source of its economic prosperity. By the 19th century, this Ecuadorian industry became the primary supplier for the demand of cacao worldwide (Foley, 1995).

Through the years, Ecuador has experienced turbulence in politics, in national defense and in economics (South America, 2010). Case in point was the rebel uprising against Spain in 1809 that, with the help of Simón Bolívar, helped Ecuador to achieve its independence by 1822 (Knapp et al., 2012). During this unsettled time, the production of cacao was important financially for the country, as cacao accounted for 40% to 60% of the total exports, and this in turn paid up to 68% of the state taxes (Guerrero, 2012).
Ecuador then formed an alliance (federation) with Venezuela, Colombia and Panama, only to secede from this union in 1830 (CIA, 2012; South America, 2010) in order to form a Republic (Milivojevic, 2010). The next hundred years of Ecuador’s history present a plethora of land disputes with neighboring countries (CIA, 2012), civil unrests, coup d’états, political polarization and strife, and economic woes often delineated as “unstable and malaise” (Knapp et al., 2012). Despite all this turmoil notwithstanding, cacao production nearly *tripled* from the last half of the 19th century on into the first quarter of the 20th century (Hanratty, 1989).

In the first two decades of the 20th century, the exporting of cacao continued as the bulwark of the economy, and the main source of foreign trade (Hanratty, 1989). But in the 1920’s two events happened to set the cacao industry on edge, nearly crippling it. The first was a devastating plight on cacao trees by the *Crinipellis perniciosa* fungus (USDA, 2012), commonly known as Witches Broom (Figure 4). With the incursion of this disease, cacao production was ravaged due to severely reduced yields of seed (Becker, 2007).

The second event that dealt a hard blow to the cacao industry in Ecuador was the collapse of the stock market (New York), ushering in the Great Depression (Butler, 2010). Before the stock market crash of 1929, the value of exported cacao from Ecuador stood at US $15 million. After the crash the revenues from cacao sales rapidly fell to US $7 million in 1931, and then to US $5 million by 1932 (Hanratty, 1989). The low prices caused further decrease in production by farmers. The cacao industry in Ecuador had “gone bust” due primarily to a fungus coupled with this price down turn (Foley, 1995). Plantations and large farms were either abandoned, or divided and diversified into growing other crops such as rice, sugar, corn and bananas (Butler, 2010).

Through the 1930’s and up to the mid-1940’s, banana production and exportation grew rapidly, replacing cacao as the main export by 1947 (Foley, 1995). At the same time World War II
came to an end, however, world prices for cacao rebounded and introduction of disease-resistant varieties set the industry back on track by the 1950’s (Butler, 2010). By 1958, Ecuador was the 6th leading exporter of cacao, even though bananas still led in the cultivation and exportation areas (Hanratty, 1989). By 1960, 33,000 metric tonnes of cacao were produced in Ecuador, where two decades later over 80,000 metric tonnes were produced on a total of 360,000 hectares (Guerrero, 2012).

1.5 Cacao and Ecuador: The Present

It is clear that for most of Ecuador’s written history agriculture has been the backbone of its existence. Currently agriculture is the second largest contributor to Ecuador’s economy, accounting for 40% of the country’s earnings (Milivojevic, 2010). Its major agricultural exports today are more diversified than previously, featuring crops such as bananas, cut flowers, coffee, sugar and cacao (Foley, 1995). Cash crops have greatly helped Ecuador to attain a level of modernization (South America, 2010). Since 2007, there has been an increase of 5% in the prices of cacao every year due to the 2011 political and civil unrest that occurred in Cote D ‘Ivoire, which currently produces the world’s largest supply of cacao (ICCO, 2011), and from the increased demand from China and India as well (Stern, 2011).

Ecuador is divided into 24 Provinces (states) which are broken down into 221 cantones, or counties (Table 1). There are between 2 to 25 cantones per province (Law, 2011). Five of these Provinces, located in the Coastal region, produce 85% of Ecuador’s cacao (Jano et al., 2007), and provide income to over 100,000 small cacao farmers (Guerrero, 2012). These five provinces are Los Ríos, Manabí, Guayas, Esmeraldas (Bayas, 2009) and El Oro (Guerrero, 2012). The Los Ríos province produces 24.1% of the cacao from Ecuador. The Province of Manabí is second at 21.6%,
Guayas third at 21.1%, Esmeraldas at 10.1% and El Oro at 7.6% (Figure 5). The remainder is found in various provinces on the eastern slopes of the Andes, or the Oriente region (Guerrero, 2012).

Table 1: The Provinces of Ecuador, the total area in km\(^2\), and the number of Cantones in each (Law, 2011).

<table>
<thead>
<tr>
<th>Name</th>
<th>Area km(^2)</th>
<th># of Cantones</th>
<th>Name</th>
<th>Area km(^2)</th>
<th># of Cantones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azuay</td>
<td>8,125</td>
<td>15</td>
<td>Los Rios</td>
<td>7,175</td>
<td>13</td>
</tr>
<tr>
<td>Bolivar</td>
<td>3,940</td>
<td>7</td>
<td>Manabi</td>
<td>18,879</td>
<td>22</td>
</tr>
<tr>
<td>Cañar</td>
<td>3,122</td>
<td>7</td>
<td>Morona-Santiago</td>
<td>25,690</td>
<td>12</td>
</tr>
<tr>
<td>Carchi</td>
<td>3,605</td>
<td>6</td>
<td>Napo</td>
<td>11,431</td>
<td>5</td>
</tr>
<tr>
<td>Chimborazo</td>
<td>6,569</td>
<td>10</td>
<td>Orellana</td>
<td>22,500</td>
<td>4</td>
</tr>
<tr>
<td>Cotopaxi</td>
<td>6,072</td>
<td>7</td>
<td>Pastaza</td>
<td>29,774</td>
<td>4</td>
</tr>
<tr>
<td>El Oro</td>
<td>5,850</td>
<td>14</td>
<td>Pichincha</td>
<td>9,110</td>
<td>8</td>
</tr>
<tr>
<td>Esmeralda</td>
<td>15,239</td>
<td>7</td>
<td>Santa Elena</td>
<td>3,763</td>
<td>3</td>
</tr>
<tr>
<td>Galapagos</td>
<td>8,010</td>
<td>3</td>
<td>Sta Domingo/Tsach</td>
<td>3,805</td>
<td>2</td>
</tr>
<tr>
<td>Guayas</td>
<td>16,740</td>
<td>25</td>
<td>Sucumbios</td>
<td>18,328</td>
<td>7</td>
</tr>
<tr>
<td>Imbaburra</td>
<td>4,559</td>
<td>6</td>
<td>Tungurahua</td>
<td>3,335</td>
<td>9</td>
</tr>
<tr>
<td>Loja</td>
<td>11,027</td>
<td>16</td>
<td>Zamora-Chinchipe</td>
<td>23,111</td>
<td>9</td>
</tr>
</tbody>
</table>

In 2009, Ecuador produced just over 4% of the world’s cacao (ICCO, 2012), and in 2010 US $402 million worth of cacao was exported, including semi-processed products in the form of cocoa powder, liquor, and cocoa butter (Stern, 2011). Ecuador’s world share of cacao production, however, decreased to 3.7% that year, possibly due to a large surge in cacao production in Ghana (ICCO, 2012). For 2011, with the goal of increasing production, Ecuador produced 130,000 metric tonnes from more than 400,000 hectares of cacao (Stern, 2011) and stood to provide more than 4% of the world’s cacao, according to the most current estimates (ICCO, 2011).
Figure 1: Map of South America (L) and of Ecuador (R).

Figure 2: Climatic Map of Ecuador and legend.

Figure 3: Topographical Map of Ecuador
Figure 4: Witches Broom (*Crinipellis perniciosa*) on Cacao Nacional

Witches Broom’s effects on the seed pods of cacao

Figure 5: The 24 Provinces of Ecuador
Chapter 2: Theobroma cacao L.

2.1 Cacao: Origin of the Name

The term *Cacao* is a derivative of a pre-classic, Mesoamerican word used to refer to the tree that predates even the Mayan civilization as a cultivated crop (Schmitz et al., 2012). Its earliest known usage is rooted in the ancient Mixe-Zoquean language group, of which the Olmec civilization was a part (Young, 1994; Coe et al., 2007). There is archeological evidence suggesting the name the Olmecs used for the cacao tree was a form of the word *kakawa* (Rosenblum, 2005). The Mixe-Zoquean word has been carefully deciphered by the epigrapher David Stuart from a Mayan hieroglyph, though apparently it is not clear exactly what the word meant originally outside of being the name of the plant/fruit (Coe et al., 2007) This fruit was important to them as a base ingredient in making an alcoholic drink (Young, 1994; Rosenblum, 2005), for medicinal purposes (Orey, 2010), and economic value in their culture (Moreno et al., 1968).

This word *kakawa* (Figure 6) transcended through the years and was used in various degrees of pronunciations from one civilization to the next (Coe et al., 2007; Rosenblum, 2005). The Mayan civilization, which came to major dominance after the Olmecs, used *kakawa* when generally referring to the tree, the plant, the seed, and/or the product from the seed. They were also part of the Mixe-Zoquean language group (Rosenblum, 2005). In the Mayan parchment Dresden Codex, a mythological story is told of two Mayan deities; the Opossum God carries the Rain God on his back while walking down a sacred road to the edge of town, and eating cacao for food (Coe et al., 2007). This fable might be considered a harbinger to what would be cacao’s official taxonomical name later in the 19th century, and to which it is currently known worldwide.

As the Mayan culture waned and the Aztecs soon ascended to rule over the region of Mesoamerica and north, the primary language spoken was Nahuatl. In the Nahuatl language the
cacao tree was referred to as *cacavaqualhitl*, the fruit (pod) was *cacvacentli*, the seeds as *cachoatl* which, when ground, made a cocoa beverage they termed *chocolatl*. Although the language spoken was different, *kakawa* was a phonetic crux for the names used by the Aztecs (Coe et al., 2007; Young, 1994). It was these terms used that Christopher Columbus and Hernandez Cortez had learned and relayed back to the Spanish court in Europe (Head, 1903).

It was not until 1582, in the botanical literature of Charles de L’Ecluse when the term *cacao* was first used (Braudea, 1975), giving semblance to the original Mesoamerican term. Cacao received its first binomial classification *Amygdalae pecuniae* (Rosenblum, 2005), which means “pecuniary almonds “, by the Italian theologian Peter Martyr Vermigli (Head, 1903). This nomenclature was given it due to the likeness the seeds had with almond seeds (*amygdalae*), and because of the well known fact that the seeds were used as currency (*pecuniariae*) by the Aztecs (Young, 1994; Moreno et al., 1968).

Soon after the novelty seed arrived in Europe, the Spanish court began endorsing the idea of cacao as a medicinal aperitif; a panacea for health ailments. It was recommended for consumption to the public by many a physician of that era (Cagindi et al., 2009). In the 17th century, the French physician Joseph Bachot also believed cacao products, like chocolate, had more medicinal qualities than just for palatable enjoyment. In his remedial writings he ironically referred to cacao as being “food for the gods” (Rosenblum, 2005; Grimes, 2009), just as the Mayans had centuries earlier. In 1735, the Swedish botanist Carl Linnaeus, being a devoted drinker of cacao based aperitifs himself, published his book, “Species Plantarum.” In doing so he renamed the *Amygdalae* genus to *Theobroma* (which is Greek for “Food of the Gods”) and *pecuniae* to *cacao* (Coe et al., 2007; Young, 1994).
Today, it can be said that “cacao” refers to the tree, and/or seeds up to the point of being processed (Grimes, 2009). “Cocoa” then would be a term used to define the processed products made from the fruit, i.e. the finely pulverized, defatted and roasted seeds for cocoa powder (Coe et al., 2007). Complicating the matter, the word “cocoa” is also a term used in British English to generally describe everything about the plant; from the tree to the powder, chocolate liquor or even cocoa butter (Grimes, 2009). And finally there is “chocolate”, referring to the product derived from the fat found in cacao seeds, expressed in liquid or solid form after being pressed and separated from the ground seeds (Aaron et al., 2008).

As is currently assigned, *Theobroma* sp. is a member of the Malvaceae family (Figure 7), under the subfamily of Byttnerioidea/Sterculiaceae (Sousa-Silva et al., 2003). (The family classification of Malvaceae has recently been changed, whereas before Sterculiaceae was recognized as the official family designation (Ogata, 2008).)

### 2.2 Physiology of *Theobroma cacao* L.

#### 2.2.1 The Plant

*Theobroma cacao* L. (Figure 8), though typically neotropical, is today distributed throughout the warm and humid rain forests of the equatorial regions of the world (Giacometti, 1998; Ogata, 2008). It is thought that this geographical serendipity of growing within 20° of the equator is why this genus survived the last ice age, protected (refuge theory) by its existence in the sultry pockets of equatorial micro climates (Solorzano et al., 2012; Young, 1994). Cacao responds best to maximum annual temperatures of 30-32°C and minimum averages of 18-21°C (ICCO, 2011). Tolerable rainfall amounts fall between 48-429 cm (Duke, 1983); however, optimum
precipitation levels are between 150 cm to 200 cm annually, distributed evenly throughout the year (Coe et al., 2007).

High humidity is not a problem with cacao, which prefers 70% at night and up to 100% in the day (ICCO, 2011; Moreno et al., 1968). *Theobroma cacao* is very drought sensitive, naturally favoring riparian zones in the wild (Brauduea, 1975). It is also sensitive to strong winds (FAO, 2007) as well as extreme temperature fluctuations (Augstburger et al., 2000).

The cacao tree is a small, semi-deciduous plant that grows typically to be 5 to 10 m in height, with a canopy of around 4 to 5 m wide (FAO, 2007). Rarely however, *T. cacao* has been found to grow to heights of up to 20 m in the wild (Duke, 1983), but under cultivation it is usually kept under 7 m for ease in management and harvest (Brauduea, 1975).

Having its roots in the tropical rainforests, *T. cacao* developed into an understory tree in its natural state, preferring shady surroundings (Figueira et al., 1994; Young, 1994). With that said, shade is recommended for the plant the first few years of growth under cultivation, whereas later on the plant will tolerate medium to full sunlight (FAO, 2007). This of course, depends on the climatic factors and to a large extent, the varietal characteristics (Rosenblum, 2005).

A dicot, diploid perennial species (2n=2x=20) (Brauduea, 1975), *T. cacao* has a small genome ranging from 411 to 494 Mb (megabase) comprising of 10 chromosome pairs (Solorzano et al., 2012). The majority of *T. cacao* varieties are self incompatible due to a gameto-sporophytic incompatibility system (Rieger, 2012). It has a C₃ photosynthetic pathway (FAO, 2007), and depending on the cultivar, the trees will start bearing fruit in 3 to 5 years (Ogata, 2008). They have been known to produce from 30 to 40 years, where some in the best of soils have produced up to 60 years before declining (FAO, 2007).
2.2.2 Branches and Leaves

_Theobroma cacao_ shows dimorphic branching. At about 18 months, the terminal bud from seedlings of an orthotropic main stem (or _chupon_) at a height between 1 to 1.5 m, will split into 3-5 plagiotropic meristems, or laterally upright shoots (Duke, 1983). This branching formation is called a “jorquette” (Figure 9). The primary branching is continued by successive whorls of normal spreading branches (Braudeau, 1975; Duke, 1983). Buds that are from these jorquettes continue exhibiting plagiotropicism. The dimorphic branching characteristic of _T. cacao_ is associated with changes in the phyllotaxis, or the leaf arrangements (FAO, 2007; Braudeau, 1975).

The leaves are large, coriaceous or chartaceous, alternate, and distichous on normal branching (FAO, 2007). They can be 12-60 cm in length, and 4-20 cm in width, and the size of the leaf can be directly dependent upon the amount of shade present, i.e. the leaves in full sun are small comparatively, whereas those in the shade are much larger (Braudeau, 1975). They are simple, entire and glabrous; elliptic to obovate-oblong in shape, being rounded and obtuse at the base, pointed at the apex (FAO, 2007).

Young leaves that appear in each growth flush are often a light pale green to a rose, or copper color before turning a dark green common in maturation (Braudeau, 1975). Leaf flush cycles are brought about by seasonal changes for the most part. They occur with decreased rainfall, or enhanced moisture stress, resulting in leaf abscission. This in turn breaks the dormancy of the new leaf buds due to a dormancy inhibitor found in the leaves that had dropped off. Soon after this drop, the new leaf flush cycle begins (Young, 1994). An interesting fact _ad rem_ the foliage of cacao is that it has an ability to move 90° from a vertical position on the stem to a horizontal position allowing maximum reception of light or to protect the younger leaves from sunburn (Braudeau, 1975).
2.2.3 Florescence

*Theobroma cacao* is cauliflorous, where the flowers form in clusters on the trunk and on the older branches of the tree (FAO, 2007). They are born in compressed dichasial cymes of a few to several individuals. Small in size, they measure 1 to 2 cm in diameter (Braudeau, 1975). The flower structure has a pentagonal configuration (Young, 1994) where the opened flower has 5 white or reddish, triangularly-shaped sepals joined at the base (FAO, 2007). There are 5 white (odorless) or pink petals alternating between the sepals, exhibiting an odd shape (Figures 10 and 11). The base of the petal is narrow, broadening to form a hollow sac-like pouch (Rieger, 2012; Braudeau, 1975).

There are ten male parts, or stamens, which are set in two groups, an outer row of five sterile staminoids pointing straight out of the middle of the flower (Braudeau, 1975) and an inner row of five stamens, where the filament carrying the anthers is doubled over so that they are carried inside the hollow sacs of the five petals (FAO, 2007; Young, 1994). The female segments contain an ovary with five carpels. Each carpel has six to ten ovules placed around the central axis of the ovary. Each carpel has a long style, all five joining at the base. It is the tops of the five separate stigmas that receive pollen (Braudeau, 1975). The flowers are morphologically and physiologically hermaphroditic, having both male and female reproductive parts (Young, 1994). Though many flowers arise in clusters of three to five at the sites of former leaf axils called *cushions*, relatively few of them actually become pollinated (Braudeau, 1975).

*Theobroma cacao* begins to flower at three to five years of age, and flowering tends to cycle with the wet and dry seasons. The apex of florescence occurs during the first rains right after the wet season is over (Young, 1994). Flowering is most abundant when diurnal temperatures increase to the point where the night time temperature does not fall below 27°C. However,
constant temperatures for both day and night at 31°C will severely impede florescence as will temperatures below 23°C. Although these are the optimal conditions for flowering, it can still occur throughout the year, enabling the plant to have flowers and fruit at the same time (Braudeau, 1975).

2.2.4 Pollination

The flowers begin to open in the afternoon, completing this process early in the morning of the following day (Young, 1994). The primary pollinator of T. cacao are midges (*Forcipomyia midge*), a very tiny insect in the Dipteran family that live in the leaf trash lying around the forest floor or the plantation, who are inclined to pollinate cacao flowers in the early morning hours (Rieger, 2012; Young, 1994) (Figure 12). Some believe that other insects are also involved in the pollination of *T. cacao*, such as the *Lasioshelea sp.* (Augstburger et al. 2000), *Dasyhelea* and *Stylobezzia spp.* (Rieger, 2012), *Euprojoannisia sp.* (Young, 1994) as well as thrips, ants and aphids (FAO, 2007).

It is common that only 1-5% of all the flowers actually become pollinated, developing into a mature fruit stage (Young, 1994). One reason that the majority of the flowers never get pollinated is that the flower will only be receptive for ~48 hours, after which it is aborted from the tree (Braudeau, 1975). Another reason that so few flowers get pollinated is because of its unique form of self-incompatibility, i.e. the flowers cannot pollinate themselves (Rieger, 2012), but require out-crossing (Young, 1994). This is true of almost all *T. cacao* except for a few, older domesticated varieties of Criollo, and the Forastero varieties of Amelonado and Cacao Nacionál, which are self compatible (Solorzano et al., 2012; Rieger, 2012).

The uniqueness of cacao’s self-incompatibility system is that the incompatibility does not occur at the location of the style and stigma, or by the inhibition of the pollen tube growth (Baker
et al., 1997). Rather, this self-incompatibility occurs at the point of fusion between the gametes in the ovary (Young, 1994). If there is no fusion between the sperm and the egg in the ovules, the flower is then aborted (Baker et al., 1997). Cultivars of T. cacao that arose from the Amazon area are all self-incompatible, inferring that there may have been strong selection in nature for out crossing in its original surroundings, before it became a cultivated crop (Young, 1994).

2.2.5 The Fruit

If, however, there is successful pollination of the flower, the sepals and petals drop away, and the stamens and pistil wither. A pod then forms (Figure 13), which at this point in development is called a “cherelle” (FAO, 2007). When the fruit reaches its final size (Figure 14), it is then commonly referred to as a pod, also known as “mazorcas” and “cabosse” (Braudeau, 1975), though it is actually a berry (FAO, 2007). The pod contains the fertilized seeds, taking 5-6 months from pollination to reach full maturation (ICCO, 2011; FAO, 2007). This time will vary, largely as a result of genetic variation (Braudeau, 1975). It has a pericarp of up to 20 mm thick (Augstburger et al., 2000), which is composed of 3 parts: the thick, fleshy epicarp whose outer epidermal layer may be pigmented; the thin, hard mesocarp; and the endocarp, which is also fleshy and relatively thick (Braudeau, 1975).

The pod will grow to be approximately 10-30 cm long and 8-10 cm wide, with a weight averaging around 300-400 g (Augstburger et al., 2000; Braudeau, 1975). Again, this will fluctuate depending on variety and climatic conditions. The pods can be green, or a subdued red-violet hue, or even a partially pigmented green with red-violet color. At maturity, green pods turn bright yellow, and the red-violet colored pods will turn an intense red-orange (Braudeau, 1975).

Pods generally contain approximately 20-30 seeds, greatly depending on variety and climatic conditions involved (Rosenblum, 2005; Young, 1994). For example, seed numbers have
been reported to be as low as 16 and as high as 60 per pod (Braudeau, 1994). These seeds are enveloped by a thin, white, bitter-sweet mucinous tissue (Augstburger et al., 2000; Young, 1994). The seeds are almond-shaped, 20-30 mm in length, 12-16 mm wide, and 7-12 mm thick. They will germinate easily if planted within five to seven days after extraction from the pod, and begin to lose viability quickly after one week (FAO, 2007). The cacao seed has a high percentage of fat, as well as other constituents (Table 2), all of which contribute to its market quality and value (Augstberger et al., 2000).

When reaching maturity, the pods are harvested and the shell of the pod is skillfully cut into two either by width or lengthwise, using a machete. The mucus coated seeds are removed and placed in a bucket or a sack (Figure 15). Under ideal conditions, a single tree can produce hundreds of pods per year (Young, 1994). A more realistic average, though, is usually 30 to 40 pods per tree per year, and 16-30 kg of freshly harvested pods will yield 1 kg of dried cacao beans (FAO, 2007). Another way to estimate yield is 10 pods will produce 1 pound of dried seeds (Young, 1997).

### Table 2: Average Constituents of Pure, Shell-free Cacao Seeds (Augstberger et al., 2000)

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>5-6%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>14%</td>
</tr>
<tr>
<td>Fat</td>
<td>53%</td>
</tr>
<tr>
<td>Starch</td>
<td>7-10%</td>
</tr>
<tr>
<td>Tanning Agents</td>
<td>5-6%</td>
</tr>
<tr>
<td>Organic Acids</td>
<td>2-3%</td>
</tr>
<tr>
<td>Pentosane (poly-sugar)</td>
<td>1.5%</td>
</tr>
<tr>
<td>Raw Fibers</td>
<td>4%</td>
</tr>
<tr>
<td>Ash (mineral substances)</td>
<td>3%</td>
</tr>
<tr>
<td>Phosphatide (fat-like substances)</td>
<td>1-2%</td>
</tr>
<tr>
<td>Caffeine</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

2.2.6 Other Factors

Soil quality is an important aspect in the cultivation of *T. cacao* (Table 3). The terrain should be level, slightly inclined or smoothly undulating. These terrains have soils that are
generally more fertile due to minimal erosion, and they facilitate maintenance and harvesting practices (Moreno et al., 1968).

It is recommended that the soil be deep, free of impermeable layers caused by compaction, clay layers, or excessive amounts of gravel and rocks. They should allow for easy penetration of the primary (tap) roots to a minimum depth of one meter in areas where conditions are optimal, or 1.5 meters if the soil is sandy and has excessive rocks or gravel, and where insufficient distribution of precipitation occurs (ICCO, 2011; Braudeau, 1975). An important point to mention here is that cacao is also very sensitive to water logging in areas of insufficient aeration (Braudeau, 1975). Consequently good drainage below 1.5 m, naturally or by drainage canals is necessary (ICCO, 2011).

Cacao is capable of adapting to various types of soil, but optimum soil texture can be a loam, loamy silt, loamy clay, or loamy sand (Moreno et al., 1968). It can thrive in poor soils also, including soils whose make-up may show low amounts of mineral elements (ICCO, 2011). Cacao has been known to survive in extreme soil conditions where pH levels are less than 5.0 or in soils with pH greater than 8.0 (Braudeau, 1975). Having given those extremes, however, the optimal soil pH for cacao cultivation is between 5.0 and 6.5 (FAO, 2007).

### Table 3. General Description and Ecology of Theobroma cacao L. (FAO, 2007).

<table>
<thead>
<tr>
<th>Life form:</th>
<th>Tree</th>
<th>Physiology</th>
<th>Optimal</th>
<th>Absolute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecology</td>
<td></td>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td>21°C</td>
<td>32°C</td>
</tr>
<tr>
<td>Requirements</td>
<td></td>
<td></td>
<td>10°C</td>
<td>38°C</td>
</tr>
<tr>
<td>Rainfall (Annual)</td>
<td></td>
<td></td>
<td>120 cm</td>
<td>300 cm</td>
</tr>
<tr>
<td>Latitude</td>
<td></td>
<td></td>
<td>100°</td>
<td>20°</td>
</tr>
<tr>
<td>Altitude</td>
<td></td>
<td></td>
<td>900 m</td>
<td></td>
</tr>
<tr>
<td>Soil pH</td>
<td></td>
<td></td>
<td>5.0</td>
<td>6.5</td>
</tr>
<tr>
<td>Soil Depth</td>
<td></td>
<td></td>
<td>Medium (50-150 cm)</td>
<td></td>
</tr>
<tr>
<td>Soil Texture</td>
<td></td>
<td></td>
<td>Heavy, Medium, Light</td>
<td></td>
</tr>
<tr>
<td>Soil Fertility</td>
<td></td>
<td></td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>Soil Salinity</td>
<td></td>
<td></td>
<td>Low (&lt; 4 dS/m)</td>
<td></td>
</tr>
<tr>
<td>Soil Drainage</td>
<td></td>
<td></td>
<td>Well (Dry Spells)</td>
<td></td>
</tr>
</tbody>
</table>
Organic material in the soil should be abundant in the A horizon, commonly referred to as “vegetable layer” by farmers (Moreno et al., 1968). Levels of 3.5-5.8% organic matter and sufficient nutrient levels (especially P, Ca, Mg, and K) are recommended for good growth and cacao production (Braudeau, 1975; Moreno et al., 1968). The symbiotic relationship cacao has with mycorrhizal fungi should be encouraged to increase access and uptake of soil nutrients (Young, 1994), especially that of phosphorous, from the upper levels of the soil strata (Young, 1994).

2.3 Theobroma cacao L. Varieties

2.3.1 Diversification of a Species

The Theobroma genus has 22 known species thus far (Grimes, 2009), of which only 12 are widely accepted. There is still continuing debate on the taxonomic status of the others (Hirst, 2011). Of these 22 species, nine are known to be native to the Amazonian region, making this the center of its genetic distribution (Giocometti, 1998; Young, 1994). *Theobroma cacao* is the only recognized species with major economic importance and which has been extensively cultivated for commercial purposes for centuries (Rosenblum, 2005; Figueira et al., 1994).

Based on morphological characteristics and geographical origin, there are two main Theobroma subspecies classified, *T. cacao* L. ssp. *cacao* ‘Criollo’ and *T. cacao* ssp. *sphaerocarpum* ‘Forastero’ (Hirst, 2011). It has been speculated that in pre-Colombian times, a type of naturally existing cacao, possibly a form of Forastero, once grew from the Guayana-Amazon region of South America up through the southern regions of Mexico (Hirst, 2011; Figueira et al., 1994). Due to geographic separation caused by the Panama isthmus, a divergence occurred within this species overtime, resulting into the two present day sub-species (Young, 1994).
Through domestication, the cacao north of the isthmus became Criollo (Ogata, 2008), while the type that flourished south of the isthmus, Forastero, was domesticated in the upper Amazon (Guerrero, 2012; Figueira et al., 1994) region and down into Brazil (Solorzano et al., 2012; Young, 1994). This latter subspecies became the more prevalent of the two, and includes many additional varieties (Solorzano et al., 2012) and wild types (Young, 1994), exhibiting a higher genetic diversity than Criollo (Giacometti, 1998).

2.3.2 Theobroma cacao L. ssp. cacao ‘Criollo’

The name ‘Criollo’ was given by the Spanish colonials and translates as “native” (Guerrero, 2012). It was developed through domestication in Mesoamerica by the various civilizations living there over 3500 years ago (Hirst, 2011). Today, Criollo trees are cultivated in Mesoamerica, Caribbean Islands, Indian Ocean zone, and Indonesia (Guerrero, 2012), and to a lesser degree in South America (Young, 1994).

The seed pods of Criollo exhibit elongate, fusiform, claviform or ovoid-oblong shapes that come to a tapered point. They exhibit anywhere from 5 to 10 deeply furrowed costate (ribbed) running lengthwise. At times the thin green skins of the fruit are verrucose (Ogata, 2008), but for the most part are smooth and slightly aromatic (Guerrero, 2012). They turn red or yellow when ripe (Figueira et al., 1994). The seeds have cream white to pale violet cotelydons (Ogata, 2008) which are also aromatic (Rosenblum, 2005). Even though Criollo is referred to as a “flavor bean”, exhibiting exceptional flavor and aroma, it does not at all favor well with cacao farmers (Guerrero, 2012; Aaron et al., 2008).

Though producing a high-quality cacao, this varietal group is also renowned for its high susceptibility to pests and diseases (Schmitz et al., 2012), coupled with a fragile plant structure and poor seed pod productivity (Guerrero, 2012). It has been said that this cultivar is “finicky”,
requiring highly specific conditions for productive growth. Criollo accounts for about one percent of the international chocolate market (Rosenblum, 2005).

2.3.3 Theobroma cacao L. ssp. sphaerocarpum ‘Forastero’

The more widely cultivated form of cacao is *T. cacao* ssp. *sphaerocarpum* ‘Forastero’, which translates to “foreigner” (Rosenblum, 2005). This varietal group is typically grown in South America (Young, 1994), as well as being the major subspecies of cacao grown in Africa (Guerrero, 2012). Forastero primarily exists in the Amazon region with various semi-wild types, as well as domesticated varieties like Amelonado, Común, and Cacao Nacionál (Figueira et al., 1994; Young, 1994), to name a few. It is a hardier plant, grows faster and is more resistant to diseases and pests (Ogata, 2008) and minor climatic differences than Criollo (Guerrero, 2012; Rosenblum, 2005). And though yields show to be much more per plant, the flavor characteristics are inferior to that of Criollo (Guerrero, 2012). The Amelonado variety of Forastero is the most widely grown cacao today (Young, 1994), and Forastero makes up approximately 90% of the world’s cacao production (Aaron et al., 2008).

Though seemingly the same, fruit characteristics are different between the subspecies. The fruit shape of ‘Forastero’ can be generally described as having an ellipsoid, rounded, rather smooth appearance (Ogata, 2008). The skins are thick, mostly non-pigmented, melon shaped with blunt ends (Figueira et al., 1994). The seeds have violet to purple colored cotyledons (Ogata, 2008), are more astringent (Young, 1994), and are also less aromatic than Criollo (Guerrero, 2012).

2.3.4 Theobroma cacao L: Varietal Group Trinitario

Trinitario is considered by some to be a hybrid variety of cacao (Table 4), exhibiting qualities of both Criollo and Forastero (Solorzano et al., 2012). There are two principle hypotheses
regarding the genetic origin of this varietal group. The first hypothesis suggests that Trinitario consists of a group of hybrids that display characteristics encompassing the total range of variation found in *T. cacao* (Figueira et al., 1994).

The second hypothesis suggests that it descended from a cross between Criollo and Forastero, being derived from *T. cacao* subsp. sphaerocarpum, but exhibiting the fine cocoa characteristics of *T. cacao* subsp. cacao (ICCO, 2011). This is the most likely scenario, as wild-types of the Trinitario variety have not been found anywhere to date (Young, 1994). Furthermore, the subspecies Criollo and Forastero are strongly heterogeneous. Trinitario as a prodigy from these two would show little if any distinct difference from the parental populations, hence making Trinitario “impossible to define” (Figueira et al., 1994).

The variety first became popular in Trinidad, and some believe that the actual cross between the two subspecies occurred there on the island (Rosenblum, 2005). Others believe that Trinitario is the result of a cross between Criollo seeds brought to Venezuela in the 17th century by Capuchin friars, and the Amelonado variety which already had been growing there (Motamayor et al., 2003; Young, 1994). This gave rise to a cacao tree with the morphological robustness of Forastero, but maintaining the delicate flavor for which Criollo is renowned (Guerrero, 2012).
In 1727, the “blast that devastated Trinidad” (Rosenblum, 2005), either an unusually strong hurricane or a severe plague of some sort (Coe et al., 2007), passed over the island destroying almost all of the Criollo cacao plantations (Motamayor et al., 2003). Soon afterward the Venezuelan hybrid was successfully growing on the island; the cultivar gained fame, was given the name *Trinitario*, and has remained the main cacao variety grown there since (Guerrero, 2012).

This cultivar is more resistant to disease as well as more productive than the Criollo or Amelonado varieties (Motamayor et al., 2003). In the international market it is placed in the same fine-quality category as Criollo. That is to say, it is regarded by the international market as a “flavor bean” (Young, 1995), and today reflects around 10% of the world’s cacao production (Rosenblum, 2005).

Since the emergence of the hybrid Trinitario centuries ago, many new hybrids have come into being worldwide. Most of them have been hybridized in efforts to; improve resistance to diseases, to increase yields, and enhance flavor and aroma. Some of these hybrids, for example, are the United Fruits (UF-29, UF-221, etc.) varieties, Scavina (SCA) varieties, Pound varieties, Estación Experimental Tropical (EET-96, EET-103, etc.) varieties and others (Figueira et al., 1994; Young, 1994).

2.4 The Cacao of Ecuador

2.4.1 Cacao Nacional

Although *T. cacao* had its origins in the area that is currently Ecuador (Rice, 2003; Young, 1994), it has been cultivated there for only ~500 years (Solorzano et al., 2012). In the 16th century, a new variety of cacao with unclear origins was found growing in Ecuador’s south central region (Young, 1994), an area where Spanish colonists had been deforesting the land (Solorzano et al., 2012). The specific areas of this find were in what are the modern day Provinces of Guayas, Los
Rios, and parts of Bolivar (Figure 5) (Stern, 2011). This variety is a type of Forastero, but exhibits qualities of fine-flavored cacao, similar to that found in Criollo varieties. It was described as a “Super Forastero,” being spicy in flavor and having a floral aroma (Solorzano et al., 2012; Rosenblum, 2005).

By 1592, the colonists were cultivating this variety on their newly established haciendas (Solorzano et al., 2012; Young, 1994). It may have been around this time when a chocolatier from Europe was en voyage along the Guayas river near Guayaquil looking for the “pepa de oro” (seed of gold) for his business. The story recounts that a boat loaded with freshly harvested cacao seeds came into dock near to where he was standing. Upon inquiring about the origin of this aromatic harvest of seeds, the boat man answered “…del rio arriba”, which translates up the river. Hence, the chocolatier took the word ‘Arriba’ for the name of this variety (Bray, 2012). Today it is referred to by a different name, yet the variety is still known by many worldwide as ‘Arriba’, signifying the fine quality cacao (Stern, 2011).

The ‘Arriba’ variety soon gained notoriety in Europe, which created a large demand for the seed it produced. This, in turn, eventually caused a mass planting of this variety throughout all areas of Ecuador that were climatically supportive of it (Solorzano et al., 2012). By the latter half of the 19th century, the largest expansion of ‘Arriba’ production took place (Young, 1994) to such an extent that in the 1890’s ‘Arriba’ was the only variety of cacao being cultivated in Ecuador (Solorzano et al., 2012).

The popularity of ‘Arriba’ continued into the first quarter of the 20th century when, as was discussed earlier, in the 1920’s Witches Broom (C. perniciosa) arrived in the area, decimating the majority of ‘Arriba’ farms (Bray, 2012). This disease causes the tree to send out a spray (clusters) of shoots stemming from flower cushions and branch tips that resemble a stick broom (Becker,
Witches Broom is the most prominent disease found in cultivated cacao in Ecuador to date (Augstburger et al., 2000).

New germplasm, which was introduced for the first time into Ecuador in the 1890’s (Solorzano et al., 2012) began to flow in from Venezuela (Criollo varieties) and Trinidad (Trinitario varieties). These varieties were chosen specifically because of exhibiting higher tolerance to Witches Broom as well as seed quality (Bray, 2012). Little by little the ‘Arriba’ variety was amalgamated with the new germplasm (cultivars) to the point where it began to lose its uniqueness; it’s fine aromatic qualities (Solorzano et al., 2012; Motamayor et al., 2003). The local farmers and cacao merchants, in a patriotic effort to keep their Ecuadorian variety separate and distinct from all the foreign varieties entering the country, renamed ‘Arriba’ as ‘Cacao Nacionál’ (Stern, 2011; Rosenblum, 2005).

In the first half of the 1940’s, another disease descended upon the cacao plantations (Butler, 2010; Bray, 2012). This time it was Monilla (Moniliophthora roreri), a fungus that attacks the pods, turning them solid white, then black (Figure 16), eventually rendering the seeds worthless by advancing the rotting process of the pod before ripening (Young, 1994). As a result, banana production began to replace cacao in Ecuador (Foley, 1995). However, within a few years, new resistant strains became available to the farmers which began to somewhat revitalize the cacao production once again in Ecuador (Butler, 2010).

An outcome of the epidemics coupled with the introduction of new germplasm is that today the original Cacao Nacionál (‘Arriba’) is rare to find. It has been reported that only 10% of the cultivated Cacao Nacionál existing today is the true variety (Braudeau, 1975), while the other 90% is actually a genetic mixture of Cacao Nacionál, native varieties and foreign germplasm.
(Solorzano et al., 2012). Still others claim that Trinitario varieties are slowly replacing the Nacionál varieties in Ecuador (Motamayor et al., 2003).

In 2006, the Instituto Ecuatoriano de la Propiedad Intelectual (IEPI), a government department responsible for establishing trademarks, approved the title ‘Arriba’ for all Cacao Nacionál varieties grown anywhere in Ecuador (Stern, 2011), even though much of this high quality had been lost. As a result, this variety, now officially classified for having “fine quality, aromatic” properties, has actually lost its significance and esteem in the world market in contrast with the reputation the original Nacionál cultivar held (Stern, 2011; Young, 1994).

2.4.2 CCN-51

In 1965, an Ecuadorian independent researcher named Homero Castro Zurita developed a strain of cacao (Bray, 2011) that had notably increased disease resistance, much higher yields, and the ability to grow in full sun (Bentley et al., 2004). It was named CCN-51, an acronym for Colección Castro Naranjal. Although many believe that 51 represents the number of seeds per pod, it is actually the cross number of the variety (Stern, 2011). This variety is recognized as a Forastero type (Bray, 2012), and is a cross of an F₁ of IMC-67 (Iquito Mixed Calabacilla hybrid cultivar from Peru) with ICS-95 (Imperial College Selections hybrid from Trinidad) by 0-1, where 0-1 was a cacao ascension found in the upper Amazonian region of Ecuador (Stern, 2011).

In 1997-98, yet another catastrophe occurred with the cacao production in Ecuador. Along with the fungal devastations, severe weather caused by El Niño damaged vast tracks of cacao trees. This resulted in extensive planting of CCN-51 throughout the coastal region (Stern, 2011). Although APROCAFA (Asociación de Productores de Cacao) in Ecuador has classified CCN-51 as a fine quality cacao (Stern, 2011), many consumers regard this variety as commodity or bulk cacao (Jano et al., 2007) which in and of itself may cause future complications for cacao farmers.
Today in many of the Ecuadorian research centers (INIAP), one can find almost every type of hybrid and variety of cacao in existence, but on the farm-level it is common to find a mix of Cacao Nacional (majority being Cacao Nacional hybrids from the EET series) and the CCN-51 variety. This is causing some significant issues as the two cultivars require different fermentation and drying processes (Bray, 2012; Young, 1994). Also, because the international market increasingly considers CCN-51 to be an inferior quality cacao, the mixing of the seeds at harvest results in a less desirable cacao product. That, in turn, reflects ultimately in the price the farmers receive for their yield (Stern, 2011).

In 2005, the International Cacao Organization (ICCO) downgraded Ecuador from being a 100% fine-aroma product to 75%. Yet even with this, CCN-51 continues to be popular with farmers. It is estimated [on paper] that more than 20% of cacao cultivated in Ecuador currently is CCN-51, and its cultivation is rapidly increasing (Stern, 2011). This is due to the fact that the market price for quintals (100 pound bags of fermented and dried seeds) of CCN-51 is exactly the same as that of Cacao Nacional, and CCN-51 produces up to 3 times more seed per hectare (Bentley et al., 2004).
Figure 6: Two different Mayan Glyphs for cacao (*Kakawa*)

Figure 7: Taxonomy of *Theobroma cacao*. List as per Integrated Taxonomic Information System (ITIS).

*These varieties were not stated in the ITIS list.

**The 6 sections are listed at; Sousa-Silva et al., 2004
Figure 8: Theobroma cacao L. The two samples shown are CCN-51 cultivar (L), and Trinitario (R).

Figure 9: The Jorquette of a cacao tree: Both figures are T. cacao L. ssp.sphaerocarpum

Figure 10: Structure of T. cacao flower.

Figure 11: T. cacao Flower.
**Figure 12:** *Forcipomyia* midge, pollinator of *T. cacao*.

**Figure 13:** Two samples of the *Cherelle* stage of fruit maturation on *T. cacao* L.

**Figure 14:** Mature ‘Mazorca’ (cacao seed pod) of a CCN-51 (L) and of Cacao Nacionál (R).
Figure 15: Two examples of seeds from the cacao seed pod.

Figure 16: Two samples of the fungus ‘Monilia’ (*Moniliophthora rorera*) on cacao mazorcas.
Chapter 3: El Recinto Primavera

To bring a lot of this information down to a point of clarity, in this chapter I will in short discuss a few aspects of how a marshy, densely overgrown coastal area of Ecuador grew into an established, flourishing farming village. I will then continue to describe how the farming community of this village came to be primarily cacao producers, aligning and assembling themselves into an alliance, thereby enabling them to maximize their earnings.

In 2011, while I was on Peace Corps Masters International assignment in Ecuador, I was sent to reside and work in the recinto (village) of Primavera, which is located in Zone 8 of the cantón Naranjito, situated on the eastern side of the coastal province of Guayas. It is 2.5 km south of the recinto of San Francisco that sits on the major Highway E-488, approximately 15 km east of the city of Naranjito, and about 25 km west of the town of Bucay (Sunmap, 2012), nestled in at the base of the Sierras.

Primavera sits at an elevation of approximately 85 m above sea level. The climate of this area is typically tropical; hot and humid year around with an average annual temperature of 26.3°C (Sanchez et al., 2009) and an average relative humidity level of 84% (Ramlachan et al., 2009). Having a flat terrain, the landscape primarily exhibits densely covered strips of land that fill in and frame endless farms of cacao, bananas, sugar cane, and other crops with an occasional proliferation of clustered, taller trees like balsa, teak, zapote, and palm trees. The rain falls January through April, and it is relatively dry from May through December, with an average rainfall of 120 to 200 cm annually (Ramlachan et al., 2009; Sanchez et al., 2009).
3.1 A Brief History of Primavera; the Seilemas

In the mid 19th century, the eastern half of what is today the province of Guayas was part of a huge hacienda named Naranjito, which covered over 200,000 ha in size (Vera de Mayorga, 2011; Law, 2011). It was owned by the salient Vicente Rocafuerte y Rodriguez de Bejarano, who happened to have been President of Ecuador from 1834 to 1839 (Milivojevic, 2010). Vicente Rocafuerte cultivated trees for fine wood (Vera de Mayorga, 2011), cacao, sugar cane, tobacco, cotton and raised cattle also (Sanchez et al., 2009). Many decades thereafter, the hacienda was divided, sold, handed down, and resold into smaller haciendas/plantations, although each one could still be considered quite large in size (Vera de Mayorga, 2011; Sanchez et al., 2009).

By the mid 20th century, the eastern region of the original hacienda Naranjito had been sectioned off to become a “smaller” one named Rocafuerte. Through the years large areas of this property had gone unattended and had become overgrown, underdeveloped and sparsely populated. The area of what was to become the Primavera community had a population of approximately 10 families scattered throughout a 2 km radius (Vaca Samaniego, 2011). For half of the year, much of this territory was a swamp due to high precipitation during the rainy seasons coupled with poor drainage in this lowland. It was also occasionally inundated throughout the year from sporadic flooding of the Chimbos River (Melo, 2008; Seilema Vaca, 2011).

Mosquitoes were always prevalent, causing dengue, yellow fever and malaria (Seilema Vaca, 2011). The nearest town at that time for purchasing supplies was Barraganetal, 5 km to the east. The Guayaquil-to-QUITO train line, constructed in the late 19th century, would stop at the station located in the center of town. For years this had been the easiest and fastest access to the market for those living in the area. The only other option was to traverse through the dense and
overgrown brush on roughly forged pathways by horseback or on foot (Sanchez et al., 2009; Seilema Vaca, 2011).

In 1957 an assiduous and determined farmer named Pedro Pablo Seilema Ramires, with his wife Maria Georgina Vaca Samaniego, migrated to this region from the Sierra city of Ambato to try their luck at farming this inflexible, rocky terrain. The hacienda Rocafuerte had recently parceled sections of their property into lots with intent to sell, whereby the Seilemas were able to purchase 15 hectares. In what was to be to their advantage later, this land also just happened to be located right on the train line (Vaca Samaniego, 2011).

Over the first couple years there, they planted crops like pineapple, rice, yuca (cassava), corn, plantains, bananas, and ultimately tried their hand at raising cattle (Seilema Vaca, 2011; Vaca Samaniego, 2011). The banana crops, however, did not take well and for one reason or another presented them with various problems, resulting in low fruit yields. To resolve this, they planted Cacao Nacional between the bananas, which were eventually removed.

They also planted sugarcane, and to increase their income, the Seilemas would mill their own cane using a horse powered “trapiche” (primitive mill), which greatly facilitated the making of panela (Vaca Samaniego, 2011). Panela is basically sugar cane juice that has been boiled, dried and formed into solid pieces of unrefined whole cane sugar. Few knew that a deal for exporting locally made panela to Uruguay had been under way by the government of Ecuador, making for an increase in market value. But the deal collapsed not too long after, creating an abundance of panela in Ecuador. This situation was compounded with the entrance of sugarcane factories to the area causing the demand, as well as the price for handmade panela, to fall sharply (Sanchez et al., 2009).
In 1978 the Seilemas contracted with Ingenio San Pedro, a sugarcane processing factory that had recently moved into the area, just southwest of Primavera’s locale. The factory supplied management, planting and harvesting labor, harvesting equipment, plus a set price per ton of canes harvested for all those farmers willing to contract. This freed-up the time that it usually took the Seilemas to harvest and process the sugarcane themselves, yet still generated a decent income (Seilema Vaca, 2011; Vaca Samaniego, 2011).

Even though the Seilemas’ land was situated on the rail line, it had not been to their benefit, as the train did not stop. Around 1960, and with the construction of a new depot, the train began to stop at the recinto of San Antonio 3 km to the west of the Seilemas property, making it easier to get materials both in and out of the area. At the same time, the Seilemas and those in the community began working on a local road that allowed easier access. At first it was for horses only, but by 1970 construction was under way for a road that serviced motorized vehicles (Vaca Samaniego, 2011).

Pedro Seilema, in taking advantage of being along side of the rail line, petitioned the Province of Guayas for the establishment of a station in that community. To achieve this, however, the community had to be registered as a village, and given a name. Seilema then petitioned to the province for the formation of a village, calling it San Pedro. Unfortunately this name had already been used elsewhere within the region. So he opted for the name ‘Primavera’, reflecting the many flowering plants that gave a spring like appearance to the area (Seilema Vaca, 2011; Vaca Samaniego, 2011).

Not long after the official establishment of Primavera was set, construction of a small station was granted, and the train began stopping. This greatly facilitated commodity transport for the local farmers, and aided in the ongoing development of Primavera (Vaca Samaniego, 2011).
The advantage to having the train stop there was short lived, though, as the line was shut down nationally in 1997 due to the effects of the El Niño Southern Oscillation (ENSO) that had caused major landslides and flooded sections of the line, as well as from general managerial neglect (Sanchez et al., 2009).

The ENSO weather patterns were such that during this time, over 18.9% of all area in Ecuadorian cacao production had been severely inundated. Over 40,000 hectares of cacao were lost. The areas not flooded were severely plagued with the seemingly ever present Witches Broom (*C. perniciosa*), Monilla (*M. roreri*) and Black Pod (*Phytophthora* sp.) fungi. This attack was a direct result of the high and prolonged levels of moisture and humidity, and then augmented by the shaded conditions in which Cacao Nacionál traditionally is grown. At the end of 1998, the national cacao harvest in Ecuador was 43% of what the previous year had been (Melo, 2008).

In the second half of the 1990’s, and amidst the most severe economic crisis of Ecuador’s history, the price for cacao in the international market had for the most part been steadily climbing (Sanchez et al., 2009). Even though in 1998 the market price dropped somewhat severely (Fairtrade, 2011), speculation by many a farmer that the prices would rebound expeditiously was strong (Seilema Vaca, 2011). This was an encouragement to many cacao farmers to continue on with cacao production.

On the other hand, and because the recent ENSO devastation had been so severe along with this downturn in the prices, many a cacao farmer, including a few of the Primavera residents, abandoned cacao altogether for other crops (Vaca Seilema, 2011). The majority of them, however, began planting entire fields with the increasingly popular CCN-51 variety.

All these circumstances led the Seilemas to renovate their existing Cacao Nacionál in 1999, saving the trees they could and taking out the dead, diseased or damaged ones. The cacao trees
that had been planted years before had been mostly ignored and passed over, as the other crops had priority. The types of cacao trees used for replacement were CCN-51 because this cultivar had many advantages over Cacao Nacional. It was also fairly easy to purchase in large numbers and was reasonably affordable (Seilema Vaca, 2011; Melo, 2008; ACDI/VOCA, 2011).

The fact was that CCN-51 had become popular all throughout the cacao growing regions of Ecuador due in part to its reliably higher yields (Ramlachan et al., 2009), coupled with the fact that the plantations cultivating CCN-51 had recovered from the ENSO malady the quickest (Melo, 2008). Hence, this variety became a very attractive cultivar to the Seilemas, as well as to other farmers of Primavera. Within 3 to 5 years, cacao production in the newly formed recinto was in full swing (Seilema Vaca, 2011).

Today the community of Primavera has grown to a population of approximately 350, and farming is still the primary livelihood. Although a few farmers with larger land ownership have remained diversified, the vast majority of small-holder farmers currently grow cacao as their main cash crop (aside from the intercropping of yuca, papaya and plantains for personal consumption). CCN-51 alone or intercropped with Cacao Nacional are still the primary varieties of cacao cultivated in Primavera (Seilema Buenaño, 2012).

3.2 Cacao in Primavera

As stated earlier, the benefits of growing CCN-51 for farmers in Primavera outweighed that of Cacao Nacional in that it was highly resistant to C. perniciosa fungus; it grew in full sun, allowing for ease in monocropping and produced greater yields sooner (Bentley et al., 2004). Even though CCN-51 was not of the same fine-aroma quality seed as Cacao Nacional, it out-produced Cacao Nacional by 2 to 4 times (Bray, 2012; Melo, 2008). Cacao Nacional had a higher market value, but
farmers could earn more from CCN-51 because of superior yields, making its cultivation a win-win situation.

A boon came to the cacao farmers everywhere in Ecuador growing the CCN-51 cultivar when the market price for a quintal of CCN-51 seeds increased and became the same price as a quintal of Cacao Nacionál (Bray, 2012; Bentley et al., 2004). This meant an even larger increase in returns for those farmers growing CCN-51 (Melo, 2008).

This boon, however, may have come at a price to the reputation of Ecuador’s fine quality cacao in general. The equivalent pricing of Cacao Nacional and CCN-51 seeds resulted in farmers continuing to inter-plant the two varieties as well as mix the seeds at harvest (Melo, 2008). As was stated in Chapter 2, the quality and processing requirements for seed differ between the two varieties, altering the quality of the final processed product (Bray, 2012; Stern, 2011).

The other drawback was that the internationally renowned Cacao Nacionál variety was losing ground. Its germplasm was being continually mixed, affecting its renowned quality, and former Cacao Nacionál fields were being replaced by CCN-51, the “bulk” seed (Solorzano et al., 2012; Bentley et al., 2004).

The cacao farmers in Primavera were no exception. The price equality led most of them to inter-plant CCN-51 with Cacao Nacional, and for lack of incentive and/or knowledge, they did not keep the seeds separate when harvesting. Although the majority of cacao harvested there is the CCN-51 variety, product quality was tainted due to mixing (Bray, 2012). This could play against them if changes in farming practices and management are not implemented. Though the market currently is tolerating if not overlooking this situation, efforts towards better control of farm management have increased in recent years (Stern, 2012; Jano et al., 2007).
3.3 Cacao Maintenance

Cacao is planted, maintained and pruned using the same techniques by most cacao farmers nationwide, and the upkeep of the CCN-51 variety is pretty much the same as that of Cacao Nacional. The Cacao Nacional variety, until recently, has traditionally been grown with one main stem branching at approximately 1.5 m in height (Braudeau, 1975). CCN-51 on the other hand, exhibits 3 to 5 branches coming off of the main trunk near or at ground level (ACDI/VOCA 2011). This reduces the amount of time and effort put into harvesting the pods as they are primarily developing at reachable, more accessible heights than on Cacao Nacional. It also facilitates more pod production per plant due to an increase in area of its primary (cauliflorous) branching surface (Seilema Buenaño, 2012; FAO, 2007).

Traditionally cacao was planted at distances of 3 m x 4 m. At this density, it gave approximately 900 plants per hectare, with 5 to 6 primary branches per tree allowed to grow out from the main trunk at 1.5 m in height (Duke, 1985). More recently, planting distances have been reduced to 3 m x 3 m, giving approximately 1,111 plants per hectare (Moreno et al., 1968). At this density, it is recommended to maintain 4 to 5 main branches per tree to limit competition. With intent to increase their yields, a few of the farmers in Primavera have planted their cacao fields at a density of 2.5 m x 2.5 m, giving them 1600 plants per hectare. At this plant density, cacao should have no more than 3 main branches per plant (Seilema Vaca 2011, Seilema Buenaño, 2012). The reasoning follows the idea that more plants produce more pods, which is more seed, hence more return.

Increasing density, however, does not necessarily increase yield. At the density of 3 m x 4 m, and maintaining the recommended 5 to 6 branches per tree, one achieves 5,400 branches per hectare. Plantings of 3 m x 3 m produce 5,555 branches/ha if at the recommended branching
practice. But planting at the density of 2.5 m x 2.5 m would yield only 4,800 branches /ha. The reasoning follows that by allowing any more branches to grow per plant at this density results in an overcrowding of the plants (competition), whereby pod production begins to decrease. The 2.5 m$^2$ density also creates difficulties in areas of maintenance as well as harvesting, i.e. labor (Seilema Buenaño, 2012).

For best yield, it is encouraged to maintain the trunk density of 3 m x 3 m with 4 to 5 branches per plant (Seilema Buenaño, 2012). Those farmers that have planted at a higher density than 3 m x 3 m tend to ignore warnings and resist these figures, probably for the reason that they have already planted large tracts of land in this way and are not about to pull trees up and replant them elsewhere (Seilema Vaca, 2011; Seilema Buenaño, 2012).

Other common crop maintenance practices by the farmers in Primavera are pruning for initial development, control of diseases (phytosanitary), regular maintenance in growth habit, and pruning for rejuvenation or recovery (ACDI/VOCA, 2011; Jano et al., 2007). The practices of fertilization, irrigation and replacement of non-productive/dead trees are also regular endeavors whenever they can be afforded and/or when labor is available (Braudeau, 1975).

### 3.4 Cacao Market for Primavera

The local markets for selling cacao have been set up in such a way that they cater to the infrastructure and demographics of those coming from the rural areas. In Ecuador, few people from rural settings have personal vehicles, let alone a truck for hauling a product to market. Therefore, the transport of cacao (as well as other products) out of the area is either by personal motorcycles, moto-taxis (three-wheeled motorcycles with a bed over the rear axle), buses, small trucks owned by community members (Figure 17), or by larger trucks specific for hauling heavy loads that are rented or hired (Vaca Samaniego, 2011; Seilema Vaca, 2011).
It is difficult for most of the farmers in Primavera to get their product out by themselves. Therefore, the farmers in Primavera, after harvesting, fermenting, drying, weighing and sacking their cacao, traditionally have had to sell to a middleman (broker) nearby (Fairtrade, 2011). Some of the farmers, when motivated, will find ways to get their cacao to an intermediary (broker) in the city to increase the returns on their crop (Table 5). Selling the cacao in the city could mean the difference of $6.00, $8.00, even $10.00 per quintal (Jano et al., 2007).

Table 5: Traditional and Specialized Cacao Marketing Chains in Ecuador. (Jano et al., 2007)

<table>
<thead>
<tr>
<th>Traditional Chain</th>
<th>Specialized Chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>International Clients (95%)</td>
<td>International Clients (95%)</td>
</tr>
<tr>
<td>National Consumption (5%)</td>
<td>Exporters</td>
</tr>
<tr>
<td>Wholesale Intermediaries</td>
<td>Producers</td>
</tr>
<tr>
<td>Small Intermediaries</td>
<td></td>
</tr>
</tbody>
</table>

In Ecuador, about 93% of the cacao production is commercialized by wholesale intermediaries. Focusing on attainable profits, they neglect important issues like quality of the seeds, pre and post harvest practices, and fair treatment of the farmers themselves (Nestlé, 2012).

Another option is to sell the cacao directly to exporters (Jano et al., 2007), i.e. Ristock Cacao, Nestlé, APROCAFA, etc. A minimum amount of seed weighed out in quintals, however, is usually required by the exporters to even begin negotiations. This might be, for example, 16 quintals of fermented and dried seeds, or seeds en baba (non-fermented, fresh seed) per weekly load (Seilema Buenaño, 2012). For the smallholder cacao farmers of Primavera to come up with those large volumes on a weekly or bi-monthly basis is impossible most of the year. But when
these same farmers join together, they are able to reach the minimum amount of cacao required, thereby enabling them to receive a better price for their yield.

To maximize their returns, a majority of the smallholder cacao farmers of Primavera did just that. They grouped together with the help of an American-based organization named ACDI/VOCA. This organization, through large support of USAID (USDA, 2012) and the World Cocoa Foundation, initiated a program entitled SUCCESS (SUstainable CoCoa Enterprise Solutions for Smallholder) Alliance (ACDI/VOCA, 2013). This program worked towards educating the smallholder cacao farmers throughout Ecuador in topics such as tree rehabilitation, fertilizer and pesticide applications, proper pruning and maintenance techniques, as well as the strengthening of farmer associations (ACDI/VOCA, 2011). They also provided access to technical assistance, offered training in improved farm management skills, post harvest handling, and market practices (ACDI/VOCA-News, 2013).

Over time, and with a number of meetings, long conversations and the encouragement of ACDI/VOCA, 32 farmers of the Primavera area joined together to form an association (Figure 18). They elected to call it the Asociación Agropecuaria Union Trabajo Primavera (AAUTP). For a number of years ACDI/VOCA had been aligned with, supported by, and worked closely alongside Nestlé. To a large degree, this strong alliance was a major reason the AAUTP ended up contracting with Nestlé in 2011 (Vaca Samaniego, 2011; Seilema Vaca, 2011).

The AAUTP-Nestlé contract mandates that farmers participate in educational lectures and informational meetings on topics such as how to budget for the farm, figuring costs, etc. (Tables 6 and 7). Each associate must also adhere to a number of agricultural *sine qua non* that Nestlé insists upon via their own program not unlike the SUCCESS Alliance. Nestlé’s program is called
Nestlé Cocoa Plan, and is pretty much a spin-off of the ACDI/VOCA’s SUCCESS Alliance program (Nestlé, 2012).

**Table 6: Production cost for 1 hectare of CCN-51 (~1000 plants/ha) with hose irrigation, weeding, pruning and application of fertilizer, for 2007 prices (Melo, 2008).**

<table>
<thead>
<tr>
<th>Input</th>
<th>Amount</th>
<th>Cost/Unit</th>
<th>Cost</th>
<th>Notes</th>
<th>Notes 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilization (Crew)</td>
<td>10 Wages</td>
<td>$7.00</td>
<td>$70.00</td>
<td>Once a year</td>
<td>Crew includes the farmer</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>50 Pounds</td>
<td>$0.80</td>
<td>$40.00</td>
<td>Once a year</td>
<td>Urea and Potassium</td>
</tr>
<tr>
<td>Irrigation</td>
<td>24 Wages</td>
<td>$7.00</td>
<td>$168.00</td>
<td>Two days every two weeks in dry season (24 weeks)</td>
<td>Using a hose</td>
</tr>
<tr>
<td>Pruning</td>
<td>7 Wages</td>
<td>$7.00</td>
<td>$49.00</td>
<td>Ten days every year</td>
<td>Crew included farmer; no power tools used</td>
</tr>
<tr>
<td>Weeding (Crew)</td>
<td>8 Wages</td>
<td>$10.00</td>
<td>$80.00</td>
<td>Two persons for two, twice/yr.</td>
<td>Crew includes the farmer manual pump</td>
</tr>
<tr>
<td>Herbicides</td>
<td>3 Liters</td>
<td>$4.00</td>
<td>$12.00</td>
<td>3 liters/ha</td>
<td>Herbicide: Glyphosate</td>
</tr>
<tr>
<td>Harvest</td>
<td>4 Wages</td>
<td>$7.00</td>
<td>$28.00</td>
<td>One day every two weeks, 4 months/yr</td>
<td>Wages</td>
</tr>
<tr>
<td>Post Harvest</td>
<td>16 Wages</td>
<td>$7.00</td>
<td>$112.00</td>
<td>Two days every two weeks, 4 months/yr</td>
<td>Wages (Sun-dried)</td>
</tr>
</tbody>
</table>

Total Production Costs $559.00

**Table 7: Production cost for 1 hectare of Arriba (~800 plants/ha) with gravity irrigation, weeding, pruning and application of free organic fertilizer (manure) in 2007 (Melo, 2008).**

<table>
<thead>
<tr>
<th>Input</th>
<th>Amount</th>
<th>Cost/Unit</th>
<th>Cost</th>
<th>Notes</th>
<th>Notes 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilization (Crew)</td>
<td>8 Wages</td>
<td>$7.00</td>
<td>$56.00</td>
<td>Four days, twice/yr</td>
<td>Farmer only</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>2 Pick-up</td>
<td>$10.00</td>
<td>$20.00</td>
<td>Manure pick-up from Neighbor</td>
<td>Free manure; only pay per pick-up load</td>
</tr>
<tr>
<td>Irrigation</td>
<td>12 Wages</td>
<td>$7.00</td>
<td>$84.00</td>
<td>Water from channel every weeks in dry season (24 weeks)</td>
<td>Farmer only</td>
</tr>
<tr>
<td>Pruning</td>
<td>3 Wages</td>
<td>$7.00</td>
<td>$21.00</td>
<td>Ten days every year</td>
<td>Farmer only</td>
</tr>
<tr>
<td>Weeding</td>
<td>6 Wages</td>
<td>$7.00</td>
<td>$42.00</td>
<td>Once a year</td>
<td>Farmer only</td>
</tr>
<tr>
<td>Harvest</td>
<td>4 Wages</td>
<td>$7.00</td>
<td>$28.00</td>
<td>One day every two weeks, 4 months/yr</td>
<td>Wages</td>
</tr>
<tr>
<td>Post Harvest</td>
<td>16 Wages</td>
<td>$7.00</td>
<td>$112.00</td>
<td>Two days every two weeks, 4 months/yr</td>
<td>Wages (Sun-dried)</td>
</tr>
</tbody>
</table>

Total Production Costs $307.00
Some of the educational endeavors include proper record keeping, restricted and/or correct usage of pesticides and fertilizers, and scheduled mingas (volunteer work groups) on each farm for trash collecting and removal to keep them free of plastic, paper, chemicals, etc. (Nestlé, 2012; Seilema Buenaño, 2011).

Another requirement includes proper storage of all agricultural chemicals and allowing only the chemicals recommended for use on cacao by Nestlé to have their own storage at all times. Agricultural chemicals for other crops have to be separately located and away from areas growing cacao (Seilema Buenaño, 2012). Lectures are also given by staff members of Nestlé to the associations periodically on topics like proper pruning techniques, correct fertilization amounts and types, proper fermenting and drying practices of the seeds, seed selection for propagation, proper grafting methods, tree selections for planting, correct record keeping, etc. (ACDI/VOCA, 2011). The members of AAUTP meet once a month on the first Friday at 1:00 p.m. The meetings usually go for 4 to 6 hours, depending on the topics being discussed (Seilema Vaca, 2011).

In harvesting, the normal procedure for cacao is to make a complete round (circuit) of the farm every 15 days, all year long. Yields will fluctuate throughout the year according to the season. Every associate farmer is responsible for fermenting (Figures 19), drying (Figure 20) and weighing out 100 pound sacks (quintal) of their own seeds. They then bring their entire product each week on the assigned day to the association’s (Seilema’s) storeroom.

Farmers unloading their cacao have the full attention of the person in charge of the storeroom. He checks the quality of the seeds, checks for trash (superfluous organic material, rocks, etc.) and weighs each sack (Figure 21) to guarantee that the weight of each is accurate and that each associate member receives exactly what is due him (Seilema Vaca, 2011). Once all of that week’s harvest has been brought in by the associates, a smaller truck is loaned if the load is
minimal, whereas a larger one is rented if the load is more than 18 quintals. The seeds are then transported to Nestlé’s warehouse/processing plant in northeast Guayaquil (Seilema Buenaño 2012).

3.5 The Exporter’s Warehouse

Upon arriving at the Nestlé warehouse, the vehicle hauling the cacao is checked thoroughly by guards at the entrance before admittance. Identification (license, social security card, etc.) is also required of the drivers before being let in. The loaded vehicle is directed to one side of the yard where a quality control representative takes small samples from randomly chosen sacks of the cacao (Figure 22) that are in the vehicle. The samples will be taken to the lab located in the main building and analyzed.

Once there, one hundred seeds are separated out and weighed. For example, if the seeds are harvested from healthy CCN-51 plants and properly dried, their weight should be 135-140 g/100 seeds (ACDI/VOCA, 2011). The amount of debris and litter found in the sample is noted, as is coloration of the cotyledons. More than 76% of the cotyledons sampled must exhibit a correct hue, or a coloration that is derived from proper fermentation, in order to be accepted. The percent of moisture still present in the seeds is also checked and noted (Seilema Buenaño, 2012; ACDI/VOCA, 2011). The quality control process is performed each time a load of seed is brought in.

After the vehicle loaded with cacao is weighed on a drive-on scale, it is then directed to the storage/stacking area for unloading. The sacks of cacao will either be stacked for later processing or if the lab report shows the seeds have high moisture content, they will be spread out on a concrete pad for further drying, and a penalty will be docked from the total price received for the quantity of cacao weighed. Once the vehicle is unloaded, it is weighed again to give the net weight of the cacao delivered (Seilema Buenaño, 2012). Paper work ensues in the main office,
whereby a check is cut by Nestlé for the amount brought in. As most of the cacao farmers in Ecuador are poor smallholder farmers (Jano et al., 2007), 14 other cacao associations have formed and contracted with Nestlé (Nestlé, 2012). These associations also follow this process when delivering cacao to the warehouse.

The price the association members from Primavera receive for their cacao is based on the international market value per metric tonne (MT) as quoted from the New York Stock Exchange (NYSE) (ICCO, 2011; Jano et al., 2007). Generally speaking, the local exporters will use the price given for one MT of cacao at the closing of the NYSE as a base for what they will pay for quality cacao received from the farmers.

For example, if the price was $2300.00/MT at the close of trading, divide that by 22.04 (the amount of quintals per MT), and you get $104.40 for the price/quintal. Additional costs for handling, shipping, grinding, and further processing, equaling approximately 10%, are also subtracted by the exporter. The final price for one quintal is then adjusted to about $93.96 which is the amount the contracted farmers of AAUTP in Primavera would receive per quintal of cacao for that week. Nestlé will take the trading price for cacao at the market’s closing at the NYSE each Monday. The price will then change each Monday in relation to market prices (Seilema Vaca, 2011; Seilema Buenaño, 2012).

For the cacao farmers in the Primavera area, being a member of the association is the best possible deal for marketing their cacao for the time being. Selling to the local intermediaries or even the wholesale intermediaries resulted in prices well below market value. Another step that could be taken in the future, or even be considered a goal at this time by the association, would be to process their cacao seeds themselves. There are other associations in Ecuador that have done just that, like the nearby cacao association of Buenas Aires, a little west of Cumandá (Seilema
Buenaño, 2012), or the Killari Associations on the east side of the Sierras (Oppenheim, 2007).

These examples have shown that by processing their own cacao, *value-added* endeavors, or even making chocolate for retail sales, the returns can be much more profitable than just dealing directly with the exporters (Oppenheim, 2007).
Figure 17: Community hauling cacao seed to the intermediary.

Figure 18: Francisco Seilema of the Cacao Asociación de Primavera (AAUTP).

Figure 19: Two traditional methods of fermenting cacao seed.
Figure 20: Depending on climatic conditions, there are 3 ways of drying cacao seed after fermentation:

A) Drying under the sun.

B) Drying in a covered hot house.

C) Drying on a gas heated board.
Figure 21: Weighing out quintales of cacao seed.

Figure 22: Sampling for quality control of the seed at Nestlé; samples are randomly taken from the load.
Chapter 4: The Biochar/Cacao Experiment

As ACDI/VOCA and Nestlé have been working with individual cacao farmers and cacao associations in education and enhancement of production and personal income, there have been other organizations furthering these efforts through support, encouragement and action (ACDI/VOCA-News, 2013). One such organization previously mentioned is the Peace Corps, a governmental organization from the United States that exists in [a small] part to aid/facilitate in the efforts of agricultural education and development in many third world countries around the globe. This is usually performed via informative lectures, group-facilitated and personally endeavored projects. Their aim is to augment the livelihood, health, and well being of those existing in poverty and/or poor agricultural conditions (ACDI/VOCA-News, 2013; Peace Corps, 2010).

As a Peace Corp volunteer working towards my Masters in Agriculture (PCMI), I initiated an experimental farming technique in the Primavera area in 2011. The experiment included several cacao farmers from three different associations in the region. It comprised of adding fixed allocations of biochar into the soil, in designated plots of three, placed randomly in the cacao fields of those associate member’s farms. The intended goal was to demonstrate to farmers and to the community in general how a simple thing like biochar, when added to the soils in and around their crops, could ultimately enhance the fertility of the soil, substantially increase their yields, and increase their revenues.
4.1 Brief Definition and Background of Biochar

Roughly defined, biochar is nothing more than biomass (organic material also referred to as feedstock) that has been heated at various temperatures until carbonized for the specific purpose of incorporating it into soil as an amendment (as opposed to charcoal for heating and cooking purposes). The heating process is called pyrolysis. In this process, any and all biomass such as leaves, rice hulls, peanut shells, manure, wood, etc., are heated in an oxygen deprived setting, usually an enclosed or covered structure (Lehmann et al., 2009). The actual time and temperature of the pyrolysis depends on the type and the size of the biomass being carbonized, as well as the eventual product desired (IBI, 2012; Krull et al., 2009; Hottle, 2008). In any case, the obvious result is charred organic material that is added to soil as an amendment, not as a fertilizer.

The practice of adding carbon (biochar) to the soil is not new, as it is believed that it was regularly practiced by the pre-Colombian indigenous people of the Amazon basin long before the conquistadores arrived some 600 years ago. In fact, it was a farming practice by these people dating back some 2000 years (Hottle, 2008; Bechtold, 2007). For modern science, however, it is a relatively recent topic of research. The carbon-rich soils that the Amazonian indigenous people created were discovered and brought to light by Wim Sombroek, a Dutch soil scientist, back in the 1950’s when conducting research on soils in the Amazon Basin (Mann, 2010).

Interestingly enough, the vast majority of the soil in the Amazon Basin falls under the classification of Latosols (Oxisols), which are typically depleted of nutrients due to long term exposure to excess precipitation (Bechtold, 2007). Scattered all up and down the river basin area of these acidic, red stained and nutrient-poor soils, Dr. Sombroek found mounds of dark brown, less acidic soils typically 10 to 30 hectares in size (Hottle, 2008), that were extremely fertile, with
depths of up to two meters. These mounds were named *Terra Preta*, which simply means “dark earth” (Schaefer, 2013; Lehmann et al., 2009).

The content of this *Terra Preta* was found to contain up to 14% charred organic material, pottery shards and bones, as well as other materials showing the signs of human habitation, thereby exhibiting its anthropogenic origin (Bechtold, 2007). Compared to surrounding soils, they had elevated levels of macro and micro biotic life. The indigenous people of the basin area had apparently planted their crops in these unusual mounds. Although the majority of these mounds are currently covered in dense forests, research suggests that crops grown in them could have easily produced yields that supported populations larger than what is thought to have existed in the Amazon basin area (Hottle, 2008).

### 4.1.1 Ecological benefits of Biochar

Since this find by Dr. Sombroek, there have been numerous studies dealing with the incorporation of Biochar into soils which have resulted in various conclusions (IBI, 2012). In fact, there is a plethora of basic and applied experimentation being conducted the world over on various effects as well as utilitarian benefits of Biochar (IBI, 2012; Hottle, 2008). For the most part, the data shows Biochar to be incredibly beneficial ecologically as well as aiding in soil fertility. These benefits, as listed below, might naturally be extended to farmers in possibly increasing their incomes by enhancing their yields (IBI, 2012; Small, 2010; Hottle, 2008).

Ecological benefits of Biochar as a soil amendment that would indirectly merit its usage by farmers include:

1) Suppression of methane emissions (Hottle, 2008)
2) Reduction of nitrous oxide emissions, estimated at 50% (IBI, 2012)
3) Storage of carbon in a long-term, stable sink (Hammes et al., 2009)
4) Reduced aluminum toxicity (Small, 2010)
5) Increased soil aggregation due to increased fungal hyphae (Hammes et al., 2009)
6) Improved soil water handling characteristics (Small, 2010)
7) Increased soil levels of available Ca, Mg, P, and K (Chan et al., 2009)
8) Increased soil microbial respiration (IBI, 2012)
9) Increased soil microbial biomass (Small, 2010)
10) Stimulation of symbiotic nitrogen fixation in legumes (Hottle, 2008)
11) Increased arbuscular mycorrhizal fungi (Thies et al., 2009)
12) Prevention of ground water pollution (Hottle, 2008)

Biochar also provides a method of managing animal and crop wastes that can pose a serious environmental pollution problem via its surface charges / covalent interactions (Smernik, 2009). Last but not least, the production of biochar produces a clean, renewable energy. That is to say, the addition of biochar to soil (as opposed to burning it) initially reduces the energy efficiency of biochar production, but reduced emissions associated with its incorporation into soils are greater than the use of petroleum products as fuel (Lehmann et al., 2009).

4.1.2 Benefits for the Smallholder Cacao Farmer

In addition to the stated ecological advantages, individual farmers who opt to incorporate biochar applications into their farming practices also stand to benefit from its influences in soil. Soil fertility can be enhanced by the addition of biochar alone, or in combination with organic compost, manure, or even synthetic chemicals (IBI, 2012). Therefore, direct benefits to farmers using this practice would be:

1) Enhanced plant growth via enhanced soil fertility (Small, 2010).
2) Reduced fertilizer requirements as much as 10%, thereby decreased application costs (IBI, 2012; Hottle, 2008).
3) Reduced leaching of nutrients via surface charge or covalent interaction (adsorption) of nutrients to the biochar (Smernik, 2009; Major et al., 2009).
4) Improved soil water handling characteristics; i.e. drainage vs. retention (Small, 2010)
5) A reservoir for water and shelter for microorganisms (IBI, 2012; Major et al., 2009).
6) Increased Cation Exchange Capacity (IBI, 2012; Hottle, 2008)
7) Reduced (or buffered) soil acidity; raising pH (for the most part) thereby lessening the severity of Aluminum toxicity and increasing the availability of phosphorous (Small, 2010; Chan et al., 2009).
8) Turning biomass (organic waste) into value-added products, possibly creating jobs and generating revenue (IBI, 2012; Hottle, 2008).
The difference between Biochar and “organic compost” should be explained. Compost is the “biological decomposition and stabilization of organic matter derived from plants, animals, or humans by the action of diverse microorganisms under aerobic conditions” (Fischer and Glaser, 2012). Although used as an agent for soil amelioration, compost is used also as a source for organic fertilizer (Fischer and Glaser, 2012; Hottle, 2008; Blackwell et al., 2009). Compost also decomposes relatively fast (labile) in relation to biochar (recalcitrant) due to the mineralization process by soil microbes (Gaunt and Cowie, 2009).

Biochar, on the other hand, is generally regarded as primarily a soil amendment. Being recalcitrant in nature, decomposition can take hundreds to thousands of years (Lehmann et al., 2009). Finally, it is a poor source of readily available nutrients for plants, and not to be used as fertilizer. The inclusion of both organic compost and biochar, however, could provide both long and short term benefits to plants (Small, 2010; Blackwell et al., 2009).

4.1.3 Reasoning for the Experiment

My primary goal for this experiment was to investigate if the incorporation of biochar in soil could be a simple yet practical method of improving crop yields long term, while decreasing the quantity of chemical usage needed for those crops at the same time. If by adding biochar to the soil fertility is increased along with yields, and with decreased usage of fertilizers, then this simple practice could benefit smallholder farmers, especially those in Primavera, by increasing their overall annual income (Hottle, 2008).

The next step then would be to source enough biochar to perform the experiment. Although modern technical equipment for pyrolyzing organic material is not usually available in the third world, it is not a necessity in producing biochar. In fact, many people in under-developed countries already produce charcoal for cooking, heating or selling in the market (Brown, 2009). In some areas, production methods have been established for centuries (US-IBI, 2009). Nevertheless,
these traditional methods, albeit not the most efficient way to produce Biochar ecologically (Hottle, 2008), were used in this experiment to verify the ease of production in primitive, rural settings. It was also important to demonstrate this process to the participants/community in order to show them how they could produce Biochar themselves.

Secondary goal of this experiment was to collect scientific data, which would be used to support the primary goal. This secondary goal included detecting and documenting changes to the soil pH, to soil organic matter percentages (SOM), and the availability of nutrients (N, P, K) in each trial plot over a period of two years, the planned duration of the experiment. Any superfluous factors or incidences that may influence the results were to be observed and noted.

The overall outcome of this experiment would then be presented to the participants, the cacao associations, and other interested parties with intent to educate, while using the scientific data gathered as reference. This would take shape in the form of presenting casual town lectures, in cacao association meetings, and actualized demonstrations *in situ*.

### 4.1.4 Various Biochar Production Methods

To initiate this experiment, a quantity of consistent and well produced biochar would be needed. The feedstock would need to be practically and affordably procured, and the method and materials for carbonization would have to be easy to access and produce. For this part of the experiment, four very basic methods of pyrolyzing were tried and analyzed for advantages and failures.

**Trial 1: The Double Drum Kiln**

The first attempt at making biochar was performed not for quantity or quality as much as it was to evaluate its feasibility and practicality. The method was fondly dubbed the “Double Drum Cooker”. A 55 gallon metal drum (58 cm x 88.3 cm) was purchased along with another barrel of about a third the size (48 cm x 72 cm). The large drum was modified by having 8 vents (slits) 8 cm
in length cut into its sides down around the bottom. Handles were welded onto the sides near the top, and a chimney of 10.5 cm in diameter by 80 cm in length was made to fit a collared hole of the same diameter that had been cut and welded into the lid (Figure 23).

The smaller drum was filled tightly with organic material and left open ended. The feedstock in this case was miscellaneously cut wood and branches gathered from around the area, averaging around 5 to 8 cm in diameter and 55-60 cm in length. The larger drum, without the lid was turned upside down and then placed over the smaller one. Both were then turned back over once again simultaneously with the smaller drum inside the larger one, upside down. By having the smaller drum upside down inside the larger one, the oxygen was severely limited, hence keeping the feedstock from braking into flames.

The 8 cm gap between the two drums around the sides was firmly packed with kindling and tinder, from the bottom up and over the lip of the large drum. The kindling material on the top was then lit. Once a fire was established, the lid to the larger drum was placed on top and secured. The chimney was then set in its place on top of the lid.

The kiln was allowed to burn itself out and then re-opened 24 hours later. Still exhibiting hot temperatures, the contents were emptied. The result was that approximately 50% of the organic feedstock in the smaller drum had been carbonized (Figure 24). The poor result was thought to be from insufficient tinder due to a lack of adequate space between the two drums. Given more room, more tinder would have been placed, allowing for a longer, hotter and a more successful burn.

Another drawback to this method is that the initial manufacture of the kiln had a cost, one that a smallholder farmer might not be able to easily afford. The cost of the two drums purchased in Quito amounted to roughly US$40.00. The modifications to the drums cost another US$25.00, where any more changes to the kiln design (enlarging) would easily double the costs. Sourcing the
drums, labor and materials for the modification, as well as transporting it in rural areas could also be very difficult. These are all undesirable aspects of this method.

**Trial 2: The Pit Kiln**

The next attempt at finding a suitable, yet practical method of pyrolyzing organic material was a pit kiln (Brown, 2009). A 60 cm diameter hole was dug down into the ground of a back yard area. At about 50 cm in depth from the surface, the oven chamber area flared to a width of 2 m and 1.5 m from the floor to the inside ceiling. Two vents were then placed on opposite sides, running at a 45° angle from the floor level up to the ground surface (Figure 25). Corrugated steel sheets were placed on the floor and sides of the oven chamber. In this trial the feedstock used was organic waste (empty seed pods) from the cacao plant, which is plentiful in the Primavera area.

Tinder wood from dried cacao branches was then laid tightly on the bottom of the chamber to a depth of 30-40 cm. Cacao leaves were used as kindling to set the wood afire. When an established burn was obtained, empty cacao pods left over from harvest were then placed on top of the fire. The chamber hole was covered by a plow disc, as to make it virtually air tight. The vents on either side of the oven chamber were used to control (limit) the amount of oxygen the burn received (Figure 26).

After 48 hours, the lid was taken off and the charred material was lifted out. Unfortunately, very little of the material was charred. This could have occurred for any number of reasons, including the possibility of the vents being obstructed by the local children playing around the pit during the burn, and dropping rocks down the tube. Another reason for lack of any decent carbonization may have been the fact that the pods were still very green when placed into the chamber. Results may have been different if they had been dried first, or if the heat during the burn had been greater.
Still a third and most probable reason for the lack of any substantial pyrolyzed material may have been due to the fact that the water table was approximately 10 cm below the floor of the chamber. This could have hampered the burn, preventing the necessary heat level (≥350°C) recommended for pyrolysis (Downie et al., 2009). A major drawback is that any one or all of these factors could reasonably occur in other burns using this method. So although this has potential, another method might prove to be more effective for pyrolyzing in rural areas.

**Trial 3: The Single Drum in the Pit**

Due to the prior failed attempts at producing qualitative as well as quantitative amounts of well-charred material efficiently, a third method was tried. This method combined the basic design concepts of the previous two. The oven chamber’s mouth was widened to 1 m in diameter. It was cleaned out and re-stocked with tinder, this time from the Guaba tree, (*Inga feuilleei*, also known regionally as Pacay, or Guabo). This tree is regionally popular for being a much harder wood, producing a charcoal that provides a longer, hotter burn. A 55 gallon drum with a sealable lid was obtained. Small round vents of 5-8 cm were then cut into its sides; two near the bottom and two near the top. Handles were welded onto the upper sides to facilitate maneuverability. A metal stand 60 cm³ in size was made to allow the drum to sit over the fire in lieu of on it (Figure 27).

After the fire was lit in the pit, the drum was filled with empty cacao pod shells (green), sealed shut and placed down into the pit, over the fire and on top of the stand. Tinder was then added to the pit, around the sides of the drum and over the top of it. As the flames started rising up out of the pit, it was covered with corrugated steel sheeting and sealed with soil piled up over its edges. After 24 hours, the pit was uncovered. The fire was stoked, re-stocked with more kindling, and then covered a second time for another 24 hours (Figure 28).
On the third day, the pit was uncovered and the drum was lifted out. The contents, when removed, showed the organic material to be evenly charred; light and fragile. This method was successful in producing adequate biochar, although it too had a few disadvantages. For one, the quantity of feedstock (empty cacao mazorcas) that had been placed in the drum (full) was reduced by 75% of its original volume, amounting to about 10 kg of charred product. The quantity of biochar needed for the experiment would require approximately 15 burns with this method. Even if another feedstock was used, the amount of tinder needed for all of the necessary burns seems to totally negate the benefit of carbon sequestration that the biochar itself provides. Although this method could be used if nothing else proved superior, a more efficient and practical method of pyrolyzing was needed.

**Trial 4: The Mound Method**

The final attempt at producing biochar practically and affordably took shape in the form of a mound (Brown, 2009). A dead Guaba tree was cut down, with the majority of its branches being cut 0.5 to 1 m in length. They were then stacked in Tepee form, starting from the center and working outward, leaving an open space in the center along with a small passage way of 30 cm in height to access the center. The logs were stacked tightly and no taller than 1.4 m in height.

When all the wood had been placed, rice straw was spread out to cover the wood structure 10 cm to 15 cm thick. Water was sprinkled onto the straw to make it easier for the soil to adhere to it. Soil was thinly dispersed over the mound (Figures 29).

A shirt tightly wound around the end of a pole was ignited using an accelerant (diesel). It was carefully thrust into the passage way, until reaching the center cavity of the structure. After a few minutes, smoke began to seep profusely through the straw and soil. Whenever flames broke out through the surface of the mound, soil was thrown onto it, which immediately suffocated the flame, while restricting the oxygen getting into the mound at the same time. The burn was
managed in this way for 3 days and 3 nights. The mound size shrank noticeably due mostly to “volatile organics” (Downie et al., 2009). On the 4th day enough soil was shoveled onto the mound so as to completely suffocate the burn.

On the 5th day, a rake was taken to the mound, which by this time was about 60% soil. Using the rake, the mound was slowly gleaned, and all chunks and pieces of carbon were separated and pulled out. For the char that was still burning, water was sprinkled on to it, arresting any continuing carbonization. This was the most efficient and productive method, requiring the least amount of fuel input (Brown, 2009). The outcome of this single burn yielded over 182 kg of Biochar, providing more than enough for the experiment. It also produced quality Biochar, evenly carbonized. And instead of burning vast amounts of fuel for a small amount of char, the organic material for the char was also the fuel.

4.2 Methods

4.2.1 The Experiment

There were five sites (farms) that ultimately participated in this experiment spread out over 4 different villages. Although a number of cacao farmers were invited to participate, the sites were chosen on the basis of the farmers’ interest and willingness to follow the guidelines of the experiment, i.e., no chemicals on or within one meter of the experimental area for 2 years.

Of the five, two farms were chosen in the area of Primavera, one chosen in Rocafuerte, one in San Francisco, and the last farm in the village of Ines Maria. In all of these participating farms, one randomly designated area was marked off for the trial, and all the trials were located in
cacao fields with the CCN-51 as the principle cultivar. The exception to this was the farm in San Francisco which had 3 different trials on one farm.

The trial design was not in Completely Randomized Design (CRD) for the following reasons; apart from low funds, there was an initial reluctance/refusal on the farmers’ behalf for having more than one small experimental trial. Another issue was getting the chemical applicators (farm workers) to cooperate and work around the experiments, which proved unmanageable. With these issues in view, I have to say that it is more important to the Peace Corps to work with the farmers at their level of comfort rather than to be scientifically accurate, and I agree. Being respectful and comprehensible improves cooperation, hence trust, etc. So the experimental design was compromised in favor of these qualities.

The experimental trial on any one farm had a minimum of three $3 \text{ m}^2$ plots, linearly adjacent to one another. The size of the trial plot was based on the average planting density for cacao. Each plot had at least one cacao tree in its area, and no more than two. The ages of the cacao trees were the same within each site, but varied from farm to farm, ranging from six months (one month newly transplanted) to less than eight years.

For each trial, one $3 \text{ m}^2$ plot had untreated (raw) biochar applied, while another $3 \text{ m}^2$ plot had treated biochar applied (treated vs. untreated biochar is discussed in 4.2.3), and the third $3 \text{ m}^2$ plot was a control (Table 8). There was no set format for the order in which the three plots were arranged within the block. The experiments were set away from all farm property lines, roads, building structures and pathways to help lessen possible variances in the results. There were seven experimental trials on five farms, where one farm had three trials located on its property, totaling 21 plots.
Table 8: Example of Biochar Experiment Design BEJL-01 (Biochar Experiment of Jorge Leon)

<table>
<thead>
<tr>
<th>Plot 1</th>
<th>Plot 2</th>
<th>Plot 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treated Biochar</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedstock from Guaba</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Untreated Biochar</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedstock from Guaba</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Biochar added</td>
<td></td>
<td>Cacao tree</td>
</tr>
</tbody>
</table>

4.2.2 Soil Sampling

Initially, soil samples were taken from each individual plot and sent away for basic analysis after the areas had been marked off, and before any char material was applied. Each plot was cleaned of debris, organic litter, and plant material from the surface before soil sampling began. Within each 3 m² plot, five samples were taken from different points throughout, each being 3 cm in diameter, and to a depth of 30 cm. Those five subsamples taken from a single plot were then pooled to create a composite sample for analysis. The 21 samples from all of the plots were then analyzed by the soil laboratory at the Instituto Nacional de Investigaciones Agropecuarias (INIAP) in Boliche-Guayas. Two additional sampling dates (at 11 months, then again 22 months after initiation) were scheduled to be collected in the same manner from each of the 21 plots. Ultimately, data collected over the two year period would be studied to detect any consistent improvements in soil physical and chemical properties associated with biochar treatment.

4.2.3 Treated vs. Untreated Biochar

After enough biochar had been collected from the Mound burn, it was ground down and screened through a 2.5 cm mesh (Figure 30). The application rate of biochar per plot was 9.8 kg, based on a volume of 10 metric tonnes per hectare (Blackwell et al., 2009). The experiment
consisted of a total of 21 plots; seven plots were control (untreated), so biochar was weighed out in 14 groups weighing 9.8 kg each and sacked.

The 14 sacks of char were then divided into two groups; seven bags of untreated or fresh biochar (new) and seven bags of treated biochar. The treatment consisted of each one of the seven designated bags being soaked in Biol, an organic liquid fertilizer derived in this instance from worm composting (Lumbriculture) that had been locally produced (Figure 31). The intent of this was to satiate the substantial negative charge that fresh Biochar tends to exhibit (Downie et al., 2009), and would hopefully been evident in the analysis’ of the next two consecutive samplings.

The purpose for the Biol treatment of the char (vs. untreated) was based on reports that the acclimation process of fresh biochar in soils takes an extended time period (i.e. 2 to 3 years), and would be accelerated by the addition of fertilizer (Chan et al., 2009; Hammes et al., 2009). This was hypothesized to give the impact of biochar a head start in the soil (IBI, 2012).

4.2.3 The Application

The chosen plots were marked out using re-bar stakes for the corners, and string was used to outline the trial area (Appendix 1). A 9.8 kg bag of biochar, treated or untreated, was then spread out evenly around the pre-designated 3 m² plot by hand. The char was then incorporated into the top 30 cm (root zone) of soil by using a common spade shovel (Figure 32). The control plots also had the top 30 cm of surface soil turned over in the same manner. The chart below (Table 9) shows a list of the trials initiated along with the soil types in each.

<table>
<thead>
<tr>
<th>Trial No.</th>
<th>Farmer</th>
<th>Location</th>
<th>Soil type</th>
<th>pH</th>
<th>Initiated</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEFS-01</td>
<td>Seilema</td>
<td>Primavera</td>
<td>Silty-Loam (28% sand, 49% silt, 23% clay)</td>
<td>6.4</td>
<td>6/20/11</td>
</tr>
<tr>
<td>BEJL-01</td>
<td>Leon</td>
<td>Primavera</td>
<td>Loamy Sand (71% sand, 24% silt, 5% clay)</td>
<td>6.0</td>
<td>7/15/11</td>
</tr>
<tr>
<td>BERJ-01</td>
<td>Jaramillo</td>
<td>Rocafuerte</td>
<td>Sandy-Loam (76% sand, 19% silt, 5% clay)</td>
<td>7.3</td>
<td>6/24/11</td>
</tr>
<tr>
<td>BEEJ-01</td>
<td>Jara</td>
<td>Ines Maria</td>
<td>Silty-Loam (38% sand, 41% silt, 21% clay)</td>
<td>6.0</td>
<td>6/21/11</td>
</tr>
<tr>
<td>BELG-01</td>
<td>Leonor</td>
<td>San Francisco 1</td>
<td>Silty-Loam (44% sand, 43 % silt, 13% clay)</td>
<td>6.3</td>
<td>6/24/11</td>
</tr>
<tr>
<td>BELG-02</td>
<td>Leonor</td>
<td>San Francisco 2</td>
<td>Silty-Loam (38% sand, 49 % silt, 13% clay)</td>
<td>6.3</td>
<td>6/24/11</td>
</tr>
<tr>
<td>BELC-01</td>
<td>Leonor</td>
<td>San Francisco 1</td>
<td>Silty-Loam (32% sand, 49 % silt, 19% clay)</td>
<td>6.3</td>
<td>6/24/11</td>
</tr>
</tbody>
</table>

(Soil classifications and pH from INIAP, Boliche. 2011)
Each trial was checked twice a month for any problems or events that may have occurred. The farmers were contacted at these times for updating, detailing, and as a common courtesy. As was stated earlier, soil samples were scheduled to be collected at 11 months and then again at 22 months after the date of initiation. In each case, all samples were to be taken to the soil laboratory at INIAP in Boliche-Guayas to maintaining consistency in the analysis process.

The projected duration of the experiment was for 2 years. However, after 18 months, and because of physical injury to my shoulder, returning to the United States was deemed necessary by the Peace Corps, and the experiment was abandoned. The last round of data in this experiment could not be collected. This hinders my ability to draw any solid conclusions from this experiment. In any case, the data that had been collected before my departure is discussed below.

4.3 Results

The data received from the second soil analysis was documented along with the data from the first set of analysis results. Results for the trial BELG-01 reflect only the control plot for the second analysis in 2012, because at the time of sampling, the area was inundated with water. The treated and untreated plots in this trial were completely flooded, making soil collection impossible. There were no definitive or consistent findings regarding the relationship of soil pH, SOM and nutrient availability in regards to the biochar applications, either from the information gathered from the field, INIAP, or with the SAS System analysis (Appendix 2).

The analysis from INIAP showed that 61% of the plots increased in acidity, 33% of them became more alkali, and 5% showed no change (Appendix 3). Differences in soil organic matter percentages between the first soil sampling and the second also failed to reveal any conclusive
evidence that biochar addition increased the fertility of those plots. The data shows that 55% of the plots decreased in soil organic material (SOM), and 44% increased (Appendix 4).

The available nutrient levels echo the same inconsistent results observed for pH and SOM. There were no clear patterns in nutrient levels associated with biochar addition, with the exception of soil nitrogen levels. In 94% of the samples taken nitrogen levels increased, the largest increases in percentage being observed in the untreated biochar field plots (Appendix 5).

4.4 Discussion

The data provided no evidence for consistent changes in soil properties due to biochar application. I would speculate that there are a few probable causes for these observations. For one, there were insufficient temporal data points to accurately reflect changes in soil characteristics as a result of biochar amendment. As was mentioned, this was due to my untimely but necessary departure from the area, before the last set of sampling could be completed. This leaves unresolved all of the data that had hitherto been collected.

Another potential contributor to the ambiguous results included factors like the unforeseen severe weather, and the unexpected and unwarranted applications of agricultural chemicals on many of the trial plots. I had observed that fertilizer applications on the cacao farms of the Primavera area are more of a schedule and availability of chemicals based endeavor than it is one of necessity. This is possibly supported by the variable pH levels shown, as well as the nutrient levels of the field trial plots, treated, untreated and in the control.

In other such research trials performed elsewhere, additions of biochar to the soil have been shown to buffer soil acidity (Hammes et al., 2009; Lehmann et al., 2009; Blackwell et al., 2009). Yet in this experiment, 61% of the trial plots showed increases in acidity. The reasons for
this may be that three out of the five farmers (BEJL, BERJ, and BEEJ) admitted to having applied fertilizer during the period between 2011 and 2012, and that it was very probable the trials were included in those applications based on personal observations of labor practices.

Moreover, the principal fertilizer used, especially by the cacao farmers throughout the area, was Urea. Being sold at artificially low prices (as of 2012) by the Ecuadorian government, it is very affordable, easily attainable, and usually generously applied. This, coupled with the extraordinarily heavy rains that occurred in April 2012 that created high soil moisture levels, could have acidified the soil due to the nitrification process (Smith, 2001). This may possibly be the explanation as to why some of the field plots showed a decrease in pH levels.

Again, this same scenario may also account for why almost every one of the plots in the experiment, save one control plot, showed increases in nitrogen. In any case, it is impossible to conclude from the existing data that the additions of biochar (treated or untreated) to the soil had any relationship to the levels of soil pH or increase in nitrogen levels. The effects of even a single application of fertilizer might be sufficient to alter the results, thereby rendering them inutilile.

Likewise with the disordered readings of SOM (Appendix 4), there was no evident correlation, if any, with biochar applications. The variable and inconsistent levels of SOM could be a result from a series of heavy rains that occurred for a period of a month in 2012 (Braudeau, 1975; Moreno et al., 1968). The lack of reliable data here is unfortunate in that I feel this would have been an important issue to observe, as cacao trees prefer higher levels of SOM. Biochar has demonstrated in other research to be a catalyst for sustainable levels of organic material, if not increases, in soils (Steiner, 2006; Hottle, 2008).

In conclusion, it is likely the case that any increase or decrease in SOM or other measured parameters as a result of biochar amendment would not have been observed after only one year.
Reactions of biochar in soil are not immediate, but usually occur over time (Hammes et al., 2009). Further experimentation to determine the impact of biochar amendments on soil fertility, and ultimately on cacao yields would be required to resolve these issues. If biochar added to soils does, in fact, increase soil fertility primarily (IBI, 2012; Lehmann et al., 2009), and crop yields as a secondary result of that fertility (Blackwell et al., 2009; Hottle, 2008), the advantage to the smallholder cacao farmer would be invaluable. This advantage could be taken even further in that the feedstock used for biochar could be the organic waste removed from the cacao fields for phytosanitary purposes (i.e. pruned branches, mazorca shells, etc.) decreasing the rate of diseases.

I was able to test the accessibility and ease of producing sufficient amounts of biochar for field application and determined that biochar is easily and inexpensively produced, and would be feasible to incorporate as a farming practice in rural areas with limited access to resources, such as Primavera. My hope is that the farmers in this area will continue to experiment with biochar amendments to determine if they will improve crop yields and ultimately produce higher incomes for cacao farmers.
Figure 23: Double Drum Kiln outline

Figure 24: Double Drum Kiln producing biochar (L), and the product (R).

Figure 25: The Pit Kiln outline
Figure 26: Pit Kiln set to burn (L) and producing biochar (R).

Figure 27: The Single Drum in the Pit outline.

Figure 28: Single Drum (L) and the Single Drum producing biochar (R).
Figure 29: Mound method of producing biochar.

Figure 30: Biochar being screened to ≤ 2.5 cm.
Figure 31: Biochar being treated (L) and stacked for transport to the experiment sites (R).

Figure 32: Biochar being incorporated into soil at BERJ (L) and BEFS (R).
References:


ACDI/VOCA. 2011. Ecuador-SUCCESS Alliance: Resumen de las Escuelas de Campo (ECA’s) ACDI/VOCA. Washington D.C.


Appendices

Appendix 1: Details of the 7 Biochar Field Experiments.

**BEFS: Biochar Experiment Francisco Seilema**

**Location:** Recinto La Primavera, Naranjito-Guayas, Ecuador.

**Date Initiated:** June 20, 2011

**Soil Type:** Silty Loam (28% sand, 49% silt, 23% clay)

**Crop Cultivated:** Theobroma cacao L. (Cacao tree) **CCN-51**

- Age of cacao field; 1 Month, Plant density 2.5m x 3m (1330/ha)
- Type of farming; Conventional
- Furrow Irrigation

**Biochar Feedstock:** Pyrolysized Guaba Wood

- Amount of Biochar applied; 9.8 kg/plot
- Depth of application; 25-30 cm
- Size of Biochar; ≤ 2.5 cm

Size of experiment; each plot 3 m x 3 m, three adjacent plots/location

![Diagram](Theobroma cacao L.)

**BEJL: Biochar Experiment Jorge Leon**

**Location:** Recinto La Primavera, Naranjito-Guayas, Ecuador.

**Date Initiated:** July 15, 2011

**Soil Type:** Loamy Sand (71% sand, 24% silt, 5% clay)

**Crop Cultivated:** Theobroma cacao L. (Cacao tree) **CCN-51**

- Age of cacao field; 12-15 Months, Plant density 3m x 3m (1110/ha)
- Type of farming; Conventional
- Sub-foliar Irrigation

**Biochar Feedstock:** Pyrolysized Guaba Wood

- Amount of Biochar applied; 9.8 kg/plot
- Depth of application; 25-30 cm
- Size of Biochar; ≤ 2.5 cm

Size of experiment; each plot 3 m x 3 m, three adjacent plots/location

![Diagram](Theobroma cacao L.)
**BERJ: Biochar Experiment Ruben Jaramillo**

**Location:** Recinto Roca Fuerte, Naranjito-Guayas, Ecuador.

**Date Initiated:** June 24, 2011

**Soil Type:** Sandy Loam (76% sand, 19% silt, 5% clay)

**Crop Cultivated:** *Theobroma cacao* L. (Cacao tree) **CCN-51**
- Age of cacao field: >4 months, plant density 2.5m x 2.5m (1400-1600/ha)
- Type of farming: Conventional
- No Irrigation

**Biochar Feedstock:** Pyrolyzed Guaba wood
- Amount of Biochar applied: 9.8 kg/plot
- Depth of application: 25-30 cm
- Size of Biochar: ≤ 2.5 cm

**Size of experiment:** each plot 3 m x 3 m, three adjacent plots/location

---

**BEEJ: Biochar Experiment Emilio Jara**

**Location:** Recinto Ines Maria, Naranjito-Guayas, Ecuador.

**Date Initiated:** June 21, 2011

**Soil Type:** Silty Loam (38% sand, 41% silt, 21% clay)

**Crop Cultivated:** *Theobroma cacao* L. (Cacao tree) **CCN-51**
- Age of cacao field: 4 years, Plant density 2.5m x 3m (1330/ha)
- Type of farming: Organic
- Sub foliar irrigation

**Biochar Feedstock:** Pyrolyzed Guaba Wood
- Amount of Biochar applied: 9.8 kg/plot
- Depth of application: 25-30 cm
- Size of Biochar: ≤ 2.5 cm

**Size of experiment:** each plot 3 m x 3 m, three adjacent plots/location
**BELC: Biochar Experiment Leonor-Cacao**

**Location:** Recinto San Francisco, Naranjito-Guayas, Ecuador.

**Date Initiated:** June 24, 2011

**Soil Type:** Silty Loam (32% sand, 49% silt, 19% clay)

**Crop Cultivated:** *Theobroma cacao* L. (Cacao tree) CCN-51 and National

- Age of cacao field: >5 years, plant density 2.5m x 2.5m (1400-1600/ha)
- Type of farming: Conventional
- No Irrigation

**Biochar Feedstock:** Pyrolyzed Cacao Mazorca (Pod)

- Amount of Biochar applied: 9.8 kg/plot
- Depth of application: 25-30 cm
- Size of Biochar: ≤ 2.5 cm
- Size of experiment: each plot 3 m x 3 m, three adjacent plots/location

---

**BELG-1: Biochar Experiment Leonor-Guaba**

**Location:** Recinto San Francisco, Naranjito-Guayas, Ecuador.

**Date Initiated:** June 24, 2011

**Soil Type:** Silty Loam (44% sand, 43% silt, 13% clay)

**Crop Cultivated:** *Theobroma cacao* L. (Cacao tree) CCN-51 and National

- Age of cacao field: >5 years, plant density 2.5m x 2.5m (1400-1600/ha)
- Type of farming: Conventional

**Biochar Feedstock:** Pyrolyzed Guaba wood

- Amount of Biochar applied: 9.8 kg/plot
- Depth of application: 25-30 cm
- Size of Biochar: ≤ 2.5 cm
- Size of experiment: each plot 3 m x 3 m, three adjacent plots/location
- No Irrigation
**BELG-2: Biochar Experiment Leonor-Guaba**

**Location:** Recinto San Francisco, Naranjito-Guayas, Ecuador.

**Date Initiated:** June 24, 2011

**Soil Type:** Silty Loam (38% sand, 49% silt, 13% clay)

**Crop Cultivated:** *Theobroma cacao* L. (Cacao tree) **CCN-51** and **National**
- Age of cacao field: >5 years, plant density 2.5m x 2.5m (1400-1600/ha)
- Type of farming: Conventional
- No Irrigation

**Biochar Feedstock:** Pyrolyzed Guaba wood
- Amount of Biochar applied: 9.8 kg/plot
- Depth of application: 25-30 cm
- Size of Biochar: ≤ 2.5 cm
- Size of experiment: each plot 3 m x 3 m, three adjacent plots/location

*Theobroma cacao L.*

```
<table>
<thead>
<tr>
<th></th>
<th>3m</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td></td>
</tr>
</tbody>
</table>
```

- Biochar Untreated
- Control
- Biochar Treated
Appendix 2: The SAS System Results

Soil pH on Yr2-Yr1

The GLM Procedure

Class Level Information

<table>
<thead>
<tr>
<th>Class</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>trt</td>
<td>3</td>
<td>Ctrl, treatd, untrtd</td>
</tr>
<tr>
<td>block</td>
<td>7</td>
<td>BEEJ, BEFS, BEJL, BELC, BELG01, BELG02, BERJ</td>
</tr>
</tbody>
</table>

Number of Observations Read 21
Number of Observations Used 21

The SAS System

Dependent Variable: soil pH

The GLM Procedure

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>block</td>
<td>6</td>
<td>42.61619048</td>
<td>7.10269841</td>
<td>3.27</td>
<td>0.0381</td>
</tr>
<tr>
<td>trt</td>
<td>2</td>
<td>4.09523810</td>
<td>2.04761905</td>
<td>0.94</td>
<td>0.4163</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td>26.03809524</td>
<td>2.16984127</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected</td>
<td>20</td>
<td>72.74952381</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R-Square  Coeff Var Root MSE soilpH Mean
0.642086 -222.5453 1.473038 -0.661905
## Soil N on Yr2-Yr1

The GLM Procedure
Tukey's Studentized Range (HSD) Test for soil pH

**Note:** This test controls the Type I experiment wise error rate, but it generally has a higher Type II error rate than REGWQ.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>0.05</td>
</tr>
<tr>
<td>Error Degrees of Freedom</td>
<td>12</td>
</tr>
<tr>
<td>Error Mean Square</td>
<td>2.169841</td>
</tr>
<tr>
<td>Critical Value of Studentized Range</td>
<td>3.77289</td>
</tr>
<tr>
<td>Minimum Significant Difference</td>
<td>2.1006</td>
</tr>
</tbody>
</table>

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
<th>Tukey Grouping</th>
<th>Mean</th>
<th>N</th>
<th>trt</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-0.0429</td>
<td>7</td>
<td>Ctrl</td>
</tr>
<tr>
<td>A</td>
<td>-0.9000</td>
<td>7</td>
<td>treatd</td>
</tr>
<tr>
<td>A</td>
<td>-1.0429</td>
<td>7</td>
<td>untrtd</td>
</tr>
</tbody>
</table>
Nitrogen

Soil N on Yr2-Yr1

The GLM Procedure

Class Level Information

<table>
<thead>
<tr>
<th>Class</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>trt</td>
<td>3</td>
<td>Ctrl treatd untrtd</td>
</tr>
<tr>
<td>block</td>
<td>7</td>
<td>BEEJ BEFS BEJL BELC BELG01 BELG02 BERJ</td>
</tr>
</tbody>
</table>

Number of Observations Read 21
Number of Observations Used 21

The SAS System

Dependent Variable: soil N

The GLM Procedure

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>block</td>
<td>6</td>
<td>7097.333333</td>
<td>1182.888889</td>
<td>15.14</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>trt</td>
<td>2</td>
<td>69.809524</td>
<td>34.904762</td>
<td>0.45</td>
<td>0.6499</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td>937.523810</td>
<td>78.126984</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>20</td>
<td>8104.666667</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R-Square  Coeff Var  Root MSE  soilN Mean
0.884323  53.03368  8.838947  16.66667
Soil N on Yr2-Yr1

The GLM Procedure
Tukey's Studentized Range (HSD) Test for soil N

**Note:** This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

<table>
<thead>
<tr>
<th>Alpha</th>
<th>0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error Degrees of Freedom</td>
<td>12</td>
</tr>
<tr>
<td>Error Mean Square</td>
<td>78.12698</td>
</tr>
<tr>
<td>Critical Value of Studentized Range</td>
<td>3.77289</td>
</tr>
<tr>
<td>Minimum Significant Difference</td>
<td>12.604</td>
</tr>
</tbody>
</table>

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
<th>Tukey Grouping</th>
<th>Mean N trt</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18.714 7 Ctrl</td>
</tr>
<tr>
<td>A</td>
<td>17.000 7 untrtd</td>
</tr>
<tr>
<td>A</td>
<td>14.286 7 treatd</td>
</tr>
</tbody>
</table>
**Phosphorus**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>block</td>
<td>6</td>
<td>6355.238095</td>
<td>1059.206349</td>
<td>23.74</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>trt</td>
<td>2</td>
<td>152.666667</td>
<td>76.333333</td>
<td>1.71</td>
<td>0.2219</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td>535.333333</td>
<td>44.611111</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>20</td>
<td>7043.238095</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**R-Square** 0.923993  **Coeff Var** 92.88891  **Root MSE** 6.679155  **soilP Mean** 7.190476

The SAS System

The GLM Procedure

Tukey's Studentized Range (HSD) Test for soil P

**Note:** This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

<table>
<thead>
<tr>
<th>Alpha</th>
<th>0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error Degrees of Freedom</td>
<td>12</td>
</tr>
<tr>
<td>Error Mean Square</td>
<td>44.611111</td>
</tr>
<tr>
<td>Critical Value of Studentized Range</td>
<td>3.77289</td>
</tr>
<tr>
<td>Minimum Significant Difference</td>
<td>9.5246</td>
</tr>
</tbody>
</table>

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
<th>Tukey Grouping</th>
<th>Mean</th>
<th>N</th>
<th>trt</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>11.000</td>
<td>7</td>
<td>untrtd</td>
</tr>
<tr>
<td>A</td>
<td>5.429</td>
<td>7</td>
<td>Ctrl</td>
</tr>
<tr>
<td>A</td>
<td>5.143</td>
<td>7</td>
<td>treatd</td>
</tr>
</tbody>
</table>
Potassium

**Soil K on Yr2-Yr1**

The GLM Procedure

### Class Level Information

<table>
<thead>
<tr>
<th>Class</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>trt</td>
<td>3</td>
<td>Ctrl treatd untrtd</td>
</tr>
<tr>
<td>block</td>
<td>7</td>
<td>BEEJ BEFS BEJL BELC BELG01 BELG02 BERJ</td>
</tr>
</tbody>
</table>

Number of Observations Read 21  
Number of Observations Used 21

The SAS System

Dependent Variable: soil K

The GLM Procedure

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>block</td>
<td>6</td>
<td>0.20402857</td>
<td>0.03400476</td>
<td>2.32</td>
<td>0.1009</td>
</tr>
<tr>
<td>trt</td>
<td>2</td>
<td>0.00458095</td>
<td>0.00229048</td>
<td>0.16</td>
<td>0.8569</td>
</tr>
<tr>
<td>Error</td>
<td>12</td>
<td>0.17568571</td>
<td>0.01464048</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>20</td>
<td>0.38429524</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

R-Square  Coeff Var  Root MSE  soilK Mean  
0.542837  -876.1912  0.120998  -0.013810
Soil K on Yr2-Yr1

The GLM Procedure
Tukey's Studentized Range (HSD) Test for soil K

**Note:** This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

<table>
<thead>
<tr>
<th>Alpha</th>
<th>0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error Degrees of Freedom</td>
<td>12</td>
</tr>
<tr>
<td>Error Mean Square</td>
<td>0.01464</td>
</tr>
<tr>
<td>Critical Value of Studentized Range</td>
<td>3.77289</td>
</tr>
<tr>
<td>Minimum Significant Difference</td>
<td>0.1725</td>
</tr>
</tbody>
</table>

Means with the same letter are not significantly different.

<table>
<thead>
<tr>
<th>Tukey Grouping</th>
<th>Mean</th>
<th>N</th>
<th>trt</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.00000</td>
<td>7</td>
<td>Ctrl</td>
</tr>
<tr>
<td>A</td>
<td>-0.00714</td>
<td>7</td>
<td>untrtd</td>
</tr>
<tr>
<td>A</td>
<td>-0.03429</td>
<td>7</td>
<td>treatd</td>
</tr>
</tbody>
</table>
Appendix 3: Levels of pH in the 7 Biochar Trials; 2011 and 2012.
Appendix 4: Percentages of Organic Matter (SOM) in the 7 Biochar Trials; 2011 and 2012.
Organic Matter (BELC)

Nitrogen
Nitrogen (BELC)

<table>
<thead>
<tr>
<th>Year</th>
<th>T</th>
<th>U</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>18.0</td>
<td>0.0</td>
<td>12.0</td>
</tr>
<tr>
<td>2012</td>
<td>18.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2013</td>
<td>26.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

ppm
Phosphorous

Phosphorous (BEFS)

Phosphorous (BEJL)

Phosphorous (BERJ)

Phosphorous (BEEJ)

Phosphorous (BELG-1)

Phosphorous (BELG-2)
Phosphorous (BELC)

<table>
<thead>
<tr>
<th></th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011-T</td>
<td>10.0</td>
</tr>
<tr>
<td>2012-T</td>
<td>10.0</td>
</tr>
<tr>
<td>2013-T</td>
<td>2.0</td>
</tr>
<tr>
<td>2011-U</td>
<td>0.0</td>
</tr>
<tr>
<td>2012-U</td>
<td>0.0</td>
</tr>
<tr>
<td>2013-U</td>
<td>0.0</td>
</tr>
<tr>
<td>2011-C</td>
<td>5.0</td>
</tr>
<tr>
<td>2012-C</td>
<td>0.0</td>
</tr>
<tr>
<td>2013-C</td>
<td>0.0</td>
</tr>
</tbody>
</table>