EVALUATION OF ALTERNATIVE TEA (*CAMELLIA SINENSIS* L. KUNTZE) PROPAGATION AND NURSERY SYSTEMS IN THE PIEDMONT REGION OF GEORGIA

By

Jeffrey McConnaughey[1]

Under the Direction of John Ruter

ABSTRACT

In order to identify efficient methods of producing field-ready tea (*Camellia sinensis*) liners in the southeastern U.S., studies were undertaken to measure the growth of young tea liners under alternative propagation systems and their respective costs of production. Single-node tea cuttings were rooted in three rooting substrates in containers in a greenhouse as well as in native soil and a layer of sand in-ground under shaded low tunnels with or without biofumigation treatments. Strike rates, biomass, and root length were measured 20 weeks after sticking. Rooted liners were then transplanted from the ground or containers to pots or left *in situ* under 20% shade. Survival, biomass and leaf area were measured 27 weeks later in late May. Marketability rates were determined in September. Production costs for each system were then accounted and estimated across variable scales of production for cost-volume-profit analysis and the NPV of purchasing liners rather than propagating them on-farm for prospective tea growers.

INDEX WORDS: *Camellia sinensis*, Tea, Vegetative propagation, Strike rate, Organic, Marketability, Cost of production, Field nursery, Container nursery, Cooperative, Cost-volume-profit analysis, Net present value

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JEFFREY PHILIP MCCONNAUGHEY

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JEFFREY PHILIP MCCONNAUGHEY

Major Professor: John Ruter

Committee: Forrest Stegelin
Matthew Chappell

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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DEDICATION

This thesis is dedicated to my wife and children who have always stood by me and dealt with all of my absence from many family occasions with a smile.

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CHAPTER 1

INTRODUCTION

1.1 PRODUCTS OF THE TEA PLANT

Worldwide, only water is consumed in greater quantity than tea. It has a cooling, slightly bitter, astringent flavor. The most common types of tea are black, green, and oolong, but there are also less common types such as white and yellow teas. There are also compressed teas (e.g., *puerh*) as well as numerous flavored and scented teas. All of these teas have in common that they use the leaves of the same plant, *Camellia sinensis*, but they are processed in different ways. The term "herbal tea" usually refers to an infusion or *tisane* of fruit or herbs that contains little or no *Camellia sinensis*, e.g., rose hip, chamomile, peppermint, rooibos, etc. and should not be confused with tea from the Camellia tea plant.

Typically the tip, or bud, and the first two—or sometimes three—leaves are harvested for processing. Different leaf ages produce differing tea qualities, since their chemical compositions are different (den Braber et al., 2011). Green tea is steamed (Japanese method) or roasted (Chinese method) very soon after picking to prevent the oxidation process, whereby the processed leaves retain their original green color. Oolong tea is partially oxidized; it is left to oxidize, but for a shorter period of time than black tea. The color of oolong tea can vary from bright green to dark brown. Black tea is oxidized for much longer, resulting in a dark brown or black color.

White tea is made from new buds and young leaves plucked before they have fully opened, when they are still covered by fine, white hairs. The highest quality white tea is made from buds that have not yet begun to open, or 'tea needles'. Lower grades contain leaves as well as buds. Wilting and then very gently drying the leaves, which undergo minimal oxidation, produce this type of tea. The infusion of white tea is normally clear with a light green/yellow or slightly golden color.

Pure tea beverages do not have much nutritional value, contain no sodium, and almost no carbohydrates, fat, or protein. They are virtually calorie-free. Tea drinking helps maintain a proper fluid balance in the body. Since tea is made with boiled water, it is often safer to drink tea in areas where there is no clean water. Tea was probably first used in China for its medicinal values and it is still used in traditional Chinese medicine. The last 10–20 years has seen an increase in studies into the health benefits of tea, particularly green tea. For the most part, studies conducted on green and black teas have yielded similar results.

Tea leaves contain more than 700 chemical compounds, among which flavonoids, amino acids, vitamins (C, E, and K), caffeine, and polysaccharides are closely linked to human health (Moon, 2009). Fresh tea leaves contain about 4% caffeine. One of the key compounds in tea is L-theanine, which is largely responsible for tea's pleasant taste and calming effects (Nobre et al, 2011). This amino acid is found almost exclusively in tea plants where it constitutes 1-2% of the dry weight of the leaves. Much research also focuses on (tea) flavonoids, as they are believed to have antioxidant properties (Lee and Lee, 2002). Antioxidants work to neutralize free radicals that, scientists believe, damage certain cell components over time such as genetic material and lipids, and contribute to chronic disease. Tea extracts are known to have an antibacterial activity and are therefore being investigated for the preservation of processed food and the treatment of persistent bacterial infections (Nakamoto et al., 2011).

Some negative effects of tea on human health have also been reported. The high level of fluoride in tea has been linked to the high incidence of fluorosis in parts of China where people consume large quantities of tea from tea bricks (which is particularly high in fluoride) (Kung and Wong, 2004). Also, tea leaves can contain relatively high levels of aluminum. Mature leaves have been found to contain up to 30,000 ppm aluminum on a dry weight basis, but the young leaves harvested for tea contain much less (Matsumoto et al., 1976). Although a possible association between aluminum exposure and Alzheimer's disease was proposed over 40 years ago, this association is still highly controversial and there is little consensus regarding current evidence. The available data do not suggest that aluminum is a causative agent of Alzheimer's disease; however, it is possible that it may play a role in the disease development. Regardless, no significant associations have been found between tea consumption and the risk of Alzheimer's disease; although the levels of aluminum in tea are very high compared to drinking water, aluminum from this source is poorly absorbed (ATSDR, 2009).

1.1.1 Other Products from the Tea Plant

Tea seeds can be pressed to produce tea seed oil, non-drying oil that is often compared to olive oil due to a similar fatty acid composition rich in oleic acid and low in unsaturated fatty acids (Weihrauch & Teter, 1997) although there is some evidence that tea seed oils have better oxidative stability than olive oil (Chen, 2007). Oil yield from tea seeds is around 25%-30% by weight (Wang et al., 2011), similar to that of the closely related oilseed tea (*Camellia oleifera*) grown solely for its seeds (Chen, 2007). Along with many industrial applications, this oil can be used for human consumption as an edible, vegetable oil. In the cosmetic industry it is used for making hair lotions and soaps (den Braber et al., 2011). The oil cake and other residues are used as fodder, fertilizer (ASHS, 2011) and pest control (Potter et al., 2010). Green, oolong, and black teas are also used as raw materials for making industrial extracts such as dyes, detergents, and sterilization and medical agents. Tea has also traditionally been used in some parts of the world as food (den Braber et al., 2011).

1.2 Rationale and Purpose of this Study

The purpose of this study is to evaluate alternative methods and nursery/distribution systems for clonal propagation of tea plants in the Southeastern United States, henceforth referred to simply as “The Southeast”. Tea has been, and continues to be, cultivated successfully in The Southeast, although it has never achieved much commercial success as a crop. Main barriers to commercial success have been limited demand and poorly developed tea markets domestically, low commodity prices in international markets, and high labor costs. Today, domestic demand for tea is rapidly growing and tea markets have developed markedly. Key drivers of these market changes include increased convenience of ready-to-drink tea products, health consciousness and health benefits of (especially green) tea, and the growing abundance of specialty teas on supermarket shelves (TAUS. 2012). Furthermore, the demand for locally (or domestically) produced foods and other agricultural products has increased dramatically in the past decade. Over the past decade, demand for local food has grown 260% while recent surveys show that the majority of Americans care that their food is locally grown (Navota, 2012).

In combination, these factors have greatly bolstered the prospects for tea as an economic crop in the United States. Already growers in Hawaii are cashing in on these opportunities; Hawaiian-grown tea can been found today in luxury markets for over $4,000/lb (Cheng, 2012). Unfortunately, resources for commercially viable cultivars of tea plants are virtually nonexistent in the continental United States. While a handful of nurseries sell plants through retail markets, no company is actively producing tea plants to meet potential wholesale markets farmers would require. Tea plants for commercial production are normally clones produced through vegetative propagation rather than seedlings, which produce highly variable populations unsuitable to the production of high-quality tea. While seed-grown plants are commonly used in the first stages of breeding programs, prospective growers require clonal plants in large quantities to consider commercial production.

Unfortunately, genetic resources for tea plants in North America are scarce outside of Hawaii. Aside from one or two commercial cultivars (which may in fact be seedling grown offspring rather than true clones) available from retail tea nurseries, most commercially proven cultivars are maintained only in Hawaii. Southeastern farmers cannot rely on untested cultivars with which to develop commercial tea gardens and farms. This is equivalent to a corn farmer planning a corn production enterprise with only one or two ancient varieties of corn. Extensive testing is needed of existing tea genetic resources in the United States, for quality and yield under different growing conditions and processing systems. New varieties may even need to be developed for some growing regions, agronomic systems, or processing techniques. While some of this much-needed research would be conducted formally on research stations, it is the nature of the farmer to experiment; it is entirely plausible that individual growers may develop new cultivars or processing techniques, whether deliberately or inadvertently, that advance the development of such an industry as much, if not more so, than formal research.

More than anything else, low-cost, low-input methods of rapidly multiplying plant material are needed to assist research and breeding efforts and to increase the commercial availability of plant material for private endeavors. In Hawaii, while formal research activities were crucial to introducing new tea cultivars to the island and investigating their merit, a number of private growers have been equally instrumental in the industry's development, laying the groundwork for an emerging industry. In fact, given the level of involvement in a state that is mostly urbanized (only 8.5% of the Hawaiian population lives outside urban areas), this is likely to be even more important in the Southeast, whose seven traditionally included states (NC, SC, GA, FL, TN, MS, and AL) boast a rural population 108 times greater than Hawaii (USCB, 2000). Providing the means to effectively disseminate clonal plant material at very low cost may be the most important step in the development of a sustainable tea industry in the Southeast.

Therefore, this study aims to evaluate some alternative propagation methods and associated nursery/distribution systems for tea plants to this end. Chapter 2 will review the literature on the tea plant, its commercial potential in the United States, propagation methods and nursery systems of tea plants, and scientific approaches used to evaluate them. Chapter 3 discusses multiple rooting experiments in which tea cuttings were rooted (a) in alternative (soilless) media in conventional plastic containers on a mist bench in a shaded greenhouse, and (b) in sand or native soil directly in-ground with mist under shaded low tunnels. In a second experiment, rooted plants were potted up or left in-ground until field ready to evaluate alternative nursery systems. Chapter 4 then examines the economics of the rooting and nursery systems previously studied, along with alternative business models that would serve as the foundation for an emergent tea industry. Finally, Chapter 5 discusses the conclusions reached from the study and describes areas for future work in the development of the crop for the Southeast.

CHAPTER 2

LITERATURE REVIEW

2.1 Botanical Description

2.1.1 Taxonomy

Preferred scientific name and author

Camellia sinensis (L.) Kuntze

Family

The tea plant is categorized within the genus *Camellia* of the family *Theaceae* in the Ericales order. There are 100–250 recognized *Camellia* species. The wide range in the number of recognized species reflects the considerable disagreement among taxonomists about the status of many *Camellia* species. Members of the *Camellia* genus are mostly evergreen shrubs and small trees up to 20 m tall, native to south and eastern Asia (Hajra, 2001). Their leaves are alternately arranged, simple, thick, serrated, and usually glossy. Their flowers are usually large and conspicuous, 1-12 cm in diameter, with five to nine petals in naturally occurring species of Camellias. The colors of the flowers vary from white through pink colors to red while truly yellow flowered specimens can be found in South China and North Vietnam. The so-called "fruit" of camellia plants is a dry capsule, sometimes subdivided in up to five compartments, each compartment containing up to eight seeds (Dean, 1983).

The various species of camellia plants are generally well adapted to acidic soils rich in humus, and most species do not grow well on chalky or other calcareous (alkaline) soils. Most species of camellias also require a large amount of water, either from natural rainfall or from irrigation, and the plants will not tolerate prolonged droughts. However, some of the more unusual Camellias – typically species from karst soils in Vietnam—are more drought resistant (den Braber et al., 2011).

Historically, only a handful of species of the Camellia genus had any economic significance. At least two species (*C. sinensis* and *C. sasanqua*) have been grown for tea leaves while a handful of other Camellias (*C. oleifera*, *C. japonica*, and a few others to a lesser extent) have been used in the production of tea oil, a sweet seasoning and cooking oil made from the pressed seeds. Today these and many other camellias are grown as ornamental plants for their flowers. About 3,000 cultivars and hybrids have been selected, many with double flowers. The Japanese Camellia (*C japonica*) – often simply called "the camellia" – is the most prominent ornamental species in cultivation, with over 2,000 named cultivars. (den Braber et al., 2011).

Non-preferred scientific names

Older names (synonyms) for the tea plant include *Camellia thea* Link, *Camellia theifera* Griffith, *Thea bohea* L., *Thea sinensis* L., and *Thea viridis* L.

Varieties (subspecies)

Two main varieties (subspecies) of *C. sinensis* are used for tea production. Within these main varieties, there are thousands of cultivars and clones:

- Assam variety (*C. sinensis* var. *assamica*, also known as *C. assamica*) (J. Masters) Kitam, and
- Chinese variety (*C. sinensis* var. *sinensis*).

The Assam variety is native to northeastern India, Vietnam, Burma, and southern China. Most of the commercial tea production in the world comes from this variety, including most of commercially important black teas (such as Assam and Ceylon teas). Teas from this variety taste more 'malty' compared to the generally more flowery taste of teas from the Chinese variety. Tea tasters use the term malty to indicate a subtle, underlying flavor. 'Maltiness' is a desired quality in Assam teas. (den Braber et al., 2011). The Chinese variety is native to southeast China and was used to produce tea as long as 4,000 years ago. Its leaves are used to produce green tea and Chinese-type black tea. Sometimes a third variety is distinguished, the Cambodian variety (*C. sinensis* var. *parvifolia*). Since its growth characteristics are intermediate between the Assam and Chinese varieties, it is usually considered as a hybrid of these two (Hajra, 2001).

Common names

In Chinese dialects, pronunciation of the word for tea is divided into two classes based on phonetic similarity. In mandarin, tea is *ch'a*. In Xiamenese (Fujian province), tea is *tay*. Around the world, local words for tea are derived from either of these two pronunciations. The British spelled *tay* as tea, which became widely adopted in the English-speaking world. The French *the* and the German *tee* also have *tay* as their origin. However, in India and Sri Lanka the common name for tea is *cha* or *chai* (den Braber et al., 2011).

2.1.2 Botanical description

Under cultivation, tea plants are usually pruned to a height of around 1–1.5 m to make crop maintenance and harvesting ("plucking") easier, thereby increasing yields. However, in their natural state, tea plants will grow to small trees. The Assam variety can grow into a loosely branched tree about 15 m tall whereas the Chinese variety grows to a much smaller size, reaching a maximum height of 3–5 m (Dean, 1983).

Roots

Tea plants grown from seed have a strong taproot with a dense network of feeder roots. Most feeder roots are found in the upper 30 cm of soil. Taproots reach a depth of 1.5–3 m, providing good anchorage for the plants. The taproot is also important because it stores starch from the sugars produced in the leaves. The more starch stored in the taproot, the faster the plant can recover from pruning and plucking. Tea clones grown from cuttings generally lack a taproot (Hajra, 2001).

Leaves

The leaves of the tea plant are 4–15 cm long and 2–5 cm wide. Leaves from the Assam variety are normally larger than those of the Chinese variety. Usually, only new leaves are harvested for tea production. They are light green in color and have short white hairs on the underside. Older leaves are darker green. (Sharma, 2001)

Flowers

Camellia sinensis flowers are white with a yellow center, 2.5–4 cm in di11lavono, with 7 or 8 petals. The flowers are scented and occur singly or in clusters of two to four. Flowers are pollinated both by insects and the wind. Tea is mostly self-sterile and almost entirely cross-pollinated (Hajra, 2001).

Fruits and seeds

The fruits are 2–3 cm in diameter, brownish-green in color when mature, and contain one to four spherical or flattened, brown seeds. The fruits ripen in 9–12 months after which the seeds fall to the ground. Seeds are only capable of germination for 2–3 weeks (Bonheure, 1990).

2.1.3 Distribution

Native range

The exact origin of the tea plant is unclear. The Chinese variety is probably native to southeast China (Yunnan province), while the Assam variety is native to Assam (India), and northern Indochina. Naturalized tea plants can be found growing in these areas, but it is often unknown whether these trees are remnants of endemic populations or offspring from past cultivation.

Current distribution

From its center of origin, tea has been introduced to more than 50 countries in every inhabited continent on the globe. However, only a dozen countries produce over 99% of the tea on the world market. These include China, India, Sri Lanka, Kenya, Turkey, Indonesia, Vietnam, Japan, Argentina, Bangladesh, Iran, Malawi, and Uganda. In the Western Hemisphere, commercial production is mainly limited to Argentina. However, the plant has naturalized in some places along the Atlantic seaboard of the United States from Florida to North Carolina (Radford, 1980).

2.2 AGRONOMY OF TEA

2.2.1 Environmental preferences and tolerances

Climate

Tea is mainly cultivated in tropical and subtropical climates, but commercial cultivation can also be found in more temperate areas, such as the Azores Islands, The Republic of Georgia, parts of the U.S. (South Carolina, Alabama, Washington, and Hawaii), and even the United Kingdom (Yorkshire and Cornwall, England) (den Braber et al., 2011). Some tea cultivars are very hardy, to -10°F (-23°C) (Cold Hardy Tropicals, 2012; Camellia Forest Nusersy, 2013). Many of these hardy cultivars originate in central and northern China, South Korea (e.g. Yeosu) and Japan where tea has been grown for centuries. This means tea cultivation may be possible with appropriate cultivars as far north as Maryland or New Jersey; even some upland areas of the southern Appalachians (below 2500 ft. elevation) may be suitable.

Tea grows best with plentiful and evenly distributed rainfall. In the tropics, it needs at least 1,500 mm rain per year with a dry season of less than 3 months. Young transplants may require supplemental irrigation. The upper limit to the amount of rainfall is around 3,000 mm (Hajra, 2001). In Sri Lanka, however, tea grows well in certain areas that annually receive more than 5,000 mm of rain.

The minimum ideal day length for vegetative growth of tea plants is 11 hours. This means that tea can be harvested year round within 15–18° of the Equator. Outside this area, dormancy will occur at a rate of 30 days for every additional 3–5° from the Equator (Ranganathan, 1987). The ideal temperature for growth is 18–30°C. Growth is limited by temperatures above 32–35°C and below

12–13°C. Strong winds, frequent frost, hail, and excessive rainfall during the growing season are also detrimental to the production of high quality tea. Optimum shoot growth occurs between 75 and 90% relative humidity. When the air is too dry, shoots form dormant buds and the plant stops growing. High quality tea can be grown from the lowlands to 1500–2000 m elevation above sea level. Many high quality teas are grown at high elevations, where rainfall is less than 2,000 mm. In these areas the plants generally grow more slowly which can result in a better flavor, but with reduced yield. (Hajra, 2001).

Soils

Tea is grown on a wide range of soil types. Deep, well-drained soils with good structure are essential for vigorous production. High organic matter content is also important. A soil depth of 1.5–2.0 m is ideal, but in some regions (e.g., Vietnam), tea grows well on soils that are only 60–100 cm deep. With shallow soils it is important that soil moisture is maintained throughout the dry season (den Braber et al., 2011).

Tea is often grown on hillsides, but the slope must be less than 30 degrees. On steeper slopes special measures should be taken to avoid erosion (e.g., trenches for drainage, terraces), particularly with young tea plants whose root systems are still developing (Bonheure, 1990). As a consequence of serious erosion and leaching, soils often tend to become low in bases and phosphorous, and have great variability in their nitrogen concentrations.

Tea is a calcifuge, which is a plant that does not tolerate alkaline (basic) soil. The most important chemical characteristic of tea soils therefore is soil acidity. The upper pH range in which tea will thrive is 6.0–6.5. The optimum pH for tea is 4.5–

5.5. Under alkaline conditions, iron becomes less soluble. As a result, calcifuges grown on alkaline soils often develop symptoms of iron deficiency, typically leaf chlorosis or yellowing between the veins (Hajra, 2001). Growing in acidic mineral soils, tea plants accumulate large amounts of aluminum and fluoride, especially in the mature leaves. This may in turn result in high concentrations of these elements in the tea liquor (the technical term for a tea infusion in water), which may have negative effects on human health (Wong et al., 2003).

Machine harvesting can have a considerable effect on the concentration of these elements in made tea leaves. Unlike hand picking, machine harvesting can inadvertently collect many older leaves. Aluminum (Al) and Fluorine (F) concentrations in young shoots fall well below 1000 ppm (mg kg^{-1}) and 200 ppm (mg kg^{-1}), respectively (Ruan and Wong, 2001). In contrast, mature leaves have been measured containing as much as 30,000 ppm (mg kg^{-1}) Aluminum (Matsumoto et al., 1976) and over 14,000 ppm (mg kg^{-1}) Fluorine (Ruan and Wong, 2001). However, the final content of these elements in finished tea liquor is usually much lower than that found in the raw leaf, and this concentration also depends on steeping time. Barcena-Padilla et al. (2011) found aluminum concentrations in tea liquor to increase significantly by extending steeping time from 5 to 15 minutes, but even with extended steep times, the tea liquors they tested all had aluminum concentrations below 1 ppm (mg L^{-1}). Finally, liming the soil could reduce the uptake of both elements. Ruan et al. (2004) demonstrated that increasing soil pH from 4.3 to 5.4 (using 1.65 g CaO per kg soil) significantly reduced fluoride uptake.

2.2.2 Growth and Development

There are several ways to describe the different stages in the growth and development of the tea plant. The following is a description adapted from Zeiss & den Braber (2001) based on the practice in Vietnam.

Young plant stage

This stage begins when the seed or cutting is planted and ends when the young plant is pruned for the first time. Tea plants are propagated via seed, cuttings and, to a much lesser extent, grafting and air layering. Propagation is discussed in depth in chapter X. For plants grown from seed, this lasts until the end of Year 2 or the beginning of Year 3. For cuttings, this is often at the end of Year 1. The appropriate time of the first pruning is normally when the diameter of the main stem is greater than 7 mm, and the height of the plant is more than 70 cm.

Branch formation stage

This stage begins at the first pruning and ends at the last "formation" pruning, which is the last pruning made to shape the frame of the tea bush. Tea plants grown from seeds are usually pruned three times during the formation stage, while plants grown from cuttings are pruned twice.

Plants with many strong, healthy branches have high productivity and good quality. During the branch formation stage, the purpose of pruning is to develop a strong frame of branches. Pruning removes the buds at the growing tips or shoots. This stimulates the development of the side buds, which allows the frame to grow broader. The plucking table should be formed at a height of 70 cm. The width of the table should be such that the center is at arms reach from the path adjacent to the tea row. If the plant can be reached from two sides, the width of the plucking table is about 1.5 m (Hajra, 2001; Zeiss and den Braber, 2001).

Commercial stage

This stage begins after the last formation pruning and continues for as long as the tea is economically productive (often 40–50 years or longer). In this stage the main frame of the tea bush has already been established. However, the pluck ing table continues to rise from season to season. The purpose of pruning therefore is to regularly reduce the height and renew the maintenance foliage, the layer of permanent foliage (usually 20–30 cm) directly above the pruning level (Hajra, 2001). These leaves are essential for the tea bush to replenish its nutrient reserves. Plucking continuously removes new shoots and leaves from the plants and, as a result, large amounts of nutrients are being lost from the tea fields. Therefore, plants during the commercial stage need nutrients replaced, especially nitrogen, to continue producing new leaves.

Low vigor tea

When tea is not properly managed, the plants will start to show symptoms of degradation years before the end of their normal commercial productivity. In Vietnam, the moniker “aging tea” is sometimes used for this problem. However, the problem is probably caused more by bad management than by actual age, as many well-maintained plantations planted 100 or more years ago are still healthy and productive. Symptoms of degraded tea include (from Zeiss and den Braber, 2001):

- low yields
- increasing number of empty spots in the field due to plant mortality
- thin and weak branches
- increased disease infestations above and below ground
- increase in the proportion of unproductive (brown and woody) tissue on the tea plants.
- small and scarce buds and crown buds
- many shoots at the base of the bush, or sprouting up from ground level

Traditionally, when bushes in a tea field become degraded, an attempt would be made to rejuvenate the plants by heavy pruning close to the ground so that they must regrow a completely new frame of young branches. When many bushes in a field were degraded, the whole field would be either replanted or abandoned. Recent findings, however, have shown that degradation of tea plants is primarily due to reduced soil carbon stocks (Senapati et al., 2002)

2.2.3 Environmental Impacts of Conventional Tea Production

Habitat conversion is seen as the main harmful environmental impact of tea production (Clay, 2003). The reason being that the habitat for cultivation is often located in more rugged and remote areas, which tend to be those with the highest biodiversity. Converting such habitats leads to species reduction and due to the slope of the land, among other things, considerable soil is lost before the plantations are fully established to protect the soil. However even when a plantation is established soil erosion can be high. If a forest on a steep slope is replaced with a tea plantation, the same surface area may lose from 20 to 160 tons of earth each year

(Groosman, 2011), though this can be greatly abated through terracing and other erosion control measures. In countries such as Kenya, Uganda and India, extensive forests have been cleared for (predominantly large-scale) tea production (Clay, 2003).

Tea processing is energy intensive. Withering, drying, grading and packing tea requires 4 to 18 kWh per kg of made tea, which compares to 6.3 kWh for a kilogram of steel. Different types of feedstock and energy are used, such as firewood, oil, natural gas, electricity and sometimes hydroelectricity depending on the country and area. Roughly 85 percent of the total energy used is thermal energy, while the rest is in the form of electricity for the machines (van der Wal, 2008). The environmental impact of tea processing depends on such factors as the use of renewable/renewed feedstock and the energy efficiency of the machinery. Drying, the most energy-intensive phase of tea processing, is often carried out using firewood from natural forests (Clay, 2003). In some regions of India, for instance, the use of firewood has caused extensive deforestation. Tree logging for the tea sector is also a serious issue in Sri Lanka, Malawi and Kenya (van der Wal, 2008). By using high-sulfur rubber wood, the tea industry in Sri Lanka has caused high acid pollution. Some estates, for example in Sri Lanka and Kenya have initiated tree-planting schemes for feedstock. Energy efficiency is often low because the machinery used is often old and because energy costs represent only a small portion of total production costs (30% at factory level [Jayasekara and Anandacoomaraswamy, 2008]), not much attention has been given to this aspect.

Many different agrochemicals are used throughout the growing cycle on tea plantations to control tea pests and enhance productivity. The types and amounts of pesticides (herbicides, insecticides and fungicides) and fertilizers applied will vary considerably among and within countries. Tea is often produced in monoculture and plantations thus lack natural enemies and protection by diversity to pests. As a result, large amounts of pesticides are sometimes used to control pests. For example, crop losses without these control measures range between 14 and 50 percent in extreme cases in India. To combat pest attacks in this country, a huge quantity of pesticides finds its way to the industry and this has led to indiscriminate use instead of integrated pest management (Kadavil, 2008).

Soil fertility is negatively affected by the same plot being used continuously for a single crop and by erosion, which is magnified where tea is grown on slopes without terracing. To compensate for these losses, both inorganic and organic fertilizers are required. Often, tea prunings and other plant residues are removed from the field, slowly concentrating the site's stocks of carbon in the living plants at the expense of organic matter in the soil. This all leads to a downward spiral in which increasing amounts of agrochemicals are needed in order to maintain production at rates inversely proportional to the decreasing soil quality. This is especially a problem in older production sites such as in India, where estates are sometimes more than 100 years old (Clay, 2003).

The application of agrochemicals that are listed as hazardous and toxic has negatively affected the local and wider environment: moderate to severely reduced soil biodiversity and water pollution harming aquatic life and animals and people who depend on the rivers for water. There are studies showing that as much as 70% of soil life has been lost on tea plantations as compared to nearby natural habitat, especially in areas accessed by workers and machinery (Clay, 2003). Some of the tea gardens use pesticides, or did so until recently, which are banned in developed countries, such as DDT (van der Wal, 2008). There are indications that usage is more pronounced in Asia (India, Sri Lanka but also China, Vietnam, and Nepal) than in Africa (van der Wal, 2008). Because of high pesticide residue levels, exports from various Asian countries are occasionally restricted (ERS, 2006). In Malawi tea smallholders are often too poor to afford pesticides.

2.2.4 Environmentally Friendly Tea Production Systems

Due to the unfavorable health and environmental impacts in conventional farming, at present there is a widespread global interest for food crops grown under organic systems in cultivation. Organic farming is a system that avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators and livestock feed additives (Hajra, 2001). This system is also based on the dynamic interactions between the environment, soil, plants, animals and human beings. There is an increasing demand for organic tea, which is free of pesticide and other chemical residues (Ranasinghe *et al*., 2005). However, organic cultivation also has many criticisms, and the claim in decrease of productivity upon conversion to organic is an important one, amongst them. The productivity of the tea is reported to be decreased during conversion of existing conventional-inorganic systems to organic. Scientific validation and justification in use of organic tea therefore, will be extremely useful to convince and encourage tea growers (Mohotti and Mohotti, 2002).

Some such evidence can be found in the literature for tea. Senapati et al. (2002) found that earthworms and organic fertilizers brought about significant improvements in soil fertility and productivity in Indian tea plantations. They note that a mixture of tea prunings, high quality organic matter and earthworms was very effective at raising tea yields (more than application of fertilizers alone) due to its favorable effects on physical and biological soil properties; a bio-organic fertilization system increased yields from up to 276% over conventional management techniques. They also noted a significant relationship between earthworm populations present in the field and total green leaf tea yields. Similarly, Palit et al. (2008) found that organic management practices improved soil health in tea plantations by improving its physical, chemical and biological properties and thereby increased yield of fresh and made tea leaves as compared to conventional practices. The content of crude fiber was maximum in the control treatment, minimum with chemical fertilizer, and intermediate in organic treatments. They also reported that organic fertilization produced higher polyphenol levels than inorganic N fertilization. However, Mohotti et al. (2008) found little difference between organic and conventional management systems, where tea bushes tested exhibited similar yield, root distribution, growth, extension rates, mortality, mass volume flow of water and water use efficiency. Still, the organically grown tea bushes invested more roots in deeper soil layers than the conventionally grown bushes, which may increase fertilizer efficiency and improve resistance to drought.

It is noteworthy that current USDA organic certification only requires 36 months of organic management practices prior to harvest (MOSES, 2010). Because tea normally requires at least 3 years from planting until harvesting becomes economical, a grower could use any number of synthetic products during the orchard's preparation and planting, and still have its products certified organic from the first harvest. While this option can give growers more options for the establishment of a new crop, it also prevents organic certification any crops grown in the young orchard prior to first harvests.

2.2.5 Agroforestry Systems and Ecosystem Services

In China and Sri Lanka, tea is often intercropped with rubber trees, particularly to improve farmers' income in the years before the rubber can be tapped. Other popular shade trees include various *Albizia* spp., *Erythrina* spp., *Gliricidia sepium*, and *Indigofera* spp. Most of these also associate with nitrogen fixing bacteria in the soil, endowed with the ability to acquire at least some of their nitrogen requirements from the atmosphere, decreasing competition with neighboring plants. In more temperate areas where rubber and other tropical leguminous trees cannot be grown, a second system from China intercrops *Paulownia* trees with tea. This system is said to have appeared in Fujian province as early as in the Song Dynasty (960–1279 C.E.) (Li, 2001). All shade trees should be pruned periodically to manage shade levels. The wood of certain shade trees (e.g., *Paulownia*, *Grevillea*, *Acacia*) can also be used as building material or fuel wood. The trees can be harvested when they reach a desired size and replanted. Some trees regrow after cutting at the base (coppice), and often this regrowth can replace the original shade tree.

Without shade trees, yield and quality of tea in warm seasons can be limited by high leaf temperature in many hot climates. In regions with extensive dry seasons, shade trees play an important role in providing and maintaining sufficient humidity (den Braber et al., 2011). Agroforestry systems can enhance, if not provide, many ecosystem services ranging from increased biological diversity to improved nutrient cycling (Agroforestry Research Trust, 2012). A properly managed agroforestry system offers both benefits and drawbacks to the tea farmer (from den Braber et al., 2011):

The main advantages include:

- Polycultures can give multiple yields, which allows the farmer to diversify production especially before the tea reaches full productivity.
- Properly planned shade trees and ground covers often improve tea production by supplying additional nutrients to the tea, improving the soil (adding organic matter), protecting the tea from too much sun, controlling weeds, and reducing erosion.
- Shade trees and other plants grown with the tea can suppress certain pests and diseases and attract beneficial insects.
- Shade trees provide a more pleasant working environment for the tea pickers.

Disadvantages include:

- Shade trees and other intercrops may sometimes act as host to tea pests and diseases.
- Shade trees need continuous management in order to maintain an optimum level of shade.
- Overly dense shade could result in a reduction of yield or an increase in the incidence of certain tea pests and diseases (e.g., blister blight).
- High shade levels can intensify color and flavor but catechin content is reduced.
- Managing a polyculture system within different niche environments can be challenging.

2.3 Commercial Potential of Tea in the United States

2.3.1 History of tea production in the United States

Lacking a substantial industry, the United States currently imports practically all the tea it consumes. In 2008, it was the fourth largest importer in the world, with about 116,746 tons, mostly from China. Recent trends indicate the popularity of tea is growing in America. Between 2001 and 2009, the per capita tea consumption in the U.S. increased from 0.87 to 0.96 pound per year. Part of the demand for tea originates from its perceived health qualities. Packaged Facts (2012) indicates that loose-leaf tea represented 5.4% of tea sales in the U.S. in 2008. Utilizing these measures, it can be estimated that loose-leaf specialty tea sales was about $72.15 million in 2008 and that by 2014 it will be about $133.5 million. Hence, specialty tea, including the loose-leaf form, is well positioned for financial growth.

Commercial cultivation of tea began in the United States in 1744 when the Trust Garden in Savannah first planted seeds. The first recorded successful cultivation of the tea plant in the United States was on Skidaway Island near Savannah in 1772. Later, Junius Smith succeeded in growing tea commercially in Greenville, South Carolina from 1848 until his death in 1853. Dr. Alexis Forster oversaw the next short-lived attempt in Georgetown, South Carolina, from 1874 until his death in 1879.

In 1863, the New York Times reported the discovery of tea plants growing natively in Western Maryland and Pennsylvania (Bowes, 2001). This report sparked interest in cultivating the plants commercially. The US Government funded an experimental plot of tea outside Summerville, South Carolina as part of a program that ran from 1884 until 1888. The program's final report concluded that South Carolina's climate was too unstable to sustain the tea crop. That same year, in 1888, Dr. Charles Shepard established the Pinehurst Tea Plantation not far from the government's farm. Dr. Shepard secured laborers for the fields by opening a school and making tea-picking part of its curriculum, essentially ensuring a force of child labor while providing them with an education they might not otherwise obtain. Pinehurst produced award-winning teas until Dr. Shepard's death in 1915. The garden closed shortly thereafter, and Pinehurst lay unattended for nearly 50 years (Walcott, 1999).

Then in 1963, The Lipton Tea Company, worried about socio-political instability in the third world countries that produce tea, commissioned a 20-year study in the Southeast. The company paid to have the surviving tea plants at Pinehurst moved to a former potato farm on Wadmalaw Island (Franklin, 2006) along with a number of imported cultivars. Secondary "out-stations" were established in Georgia, Alabama, and Texas, but hurricanes and record cold weather took their toll at these secondary locations, ending their part in the study prematurely (Melican, 2012).

Lipton closed the Charleston station in 1986 and it was subsequently sold to Mack Fleming and Bill Hall, who converted the experimental farm into a working tea garden. The Charleston Tea Plantation utilized a converted tobacco harvester to mechanically harvest the tea (Franklin, 2006). The Charleston Tea Plantation sold tea via mail order known as American Classic Tea and also produced Sam's Choice

Instant Tea, sold through Sam's Clubs. American Classic Tea has been the official tea of the White House since 1987 (Bernstein, undated) Losing money and nearly bankrupt, in 2003 it was sold to Bigelow Tea Company at a court auction for $1.28 million (USA Today, 2003) and was temporarily closed for renovation it in order to attract tourists and boost its revenues. The garden reopened in January 2006 and gives free tours to the public (R.C. Bigelow Inc., 2005).

Today, the commercial production of tea in the southeastern United States is currently limited to two locations: the Charleston Tea Plantation in South Carolina and a much smaller operation in southern Alabama, the Fairhope Tea Plantation. Both employ cultivars derived from the 1960's Lipton study; the tea plants at Fairhope come from three plants that survived the hurricane that ended the study there (Melican, 2012). Unfortunately, little is known about the Fairhope Plantation; the farm is not normally open to the public and its owner, Donnie Barrett, does not maintain a website. What is known is the farm maintains approximately 40,000 plants that are grown without shade; harvesting and processing methods are unknown (Gulf Coast Foodways, 2011).

Unfortunately, information about costs of production and yields at Charleston has been a closely guarded secret by its owners, but it is known that clonally propagated plants grown under full sun are used in the plantation (R.C. Bigelow, Inc., 2005). The plantation is operated more or less as a commodity farm, though it has adopted more innovative marketing strategies in recent years. After all, when it started, its principle competition was the low-grade black tea that dominated American markets through much of the 20th century. The company's cornerstone product, American Classic Tea, is currently ranked 12,774th out of 19,880 reviewed teas (36th percentile) with an average rating of 75/100 (very few teas have ratings below 50) on Steepster.com (2012), the most extensive tea rating website on the Internet. While reviewers are generally not expert tea tasters, most describe its taste as "average" at best or "bitter" at worst. Other products have achieved similar ratings, with 'Island Green' tea rated 75, and 'Charleston Breakfast' rated 73. Even its annual 'First Flush' teas have mediocre scores ranging between 69 and 81 depending on the year, though these have far too few ratings to be useful. The prices for these products range between $100 and $135 per lb. ($220-$300/kg) online, much lower than prices for handpicked American-grown teas from Washington or Hawaii.

This should not suggest that it is impossible to grow high quality tea in the region, only that the Charleston Tea Plantation has not been particularly successful so far. Without information from the company, it is only possible to speculate as to the causes of its quality, which may or may not include:

- *Elevation* – tea is rarely grown below 200m elevation and the highest quality teas are often produced at very high elevations, though it has been shown that high quality tea can be grown in the lowlands
- *Soils* – sandy soils of the coastal plain may be suboptimal, localized features may be responsible
- *Lack of shade in production systems* –particularly for later harvests when temperatures are high

- *Harvesting method,* using a converted tobacco harvester rather than hand-picking or specialized machinery
- *Cultivar(s) employed*…these are currently unknown, but those employed in the Lipton tea study may have been selected primarily for productivity, with minimal quality standards
- *Tea manufacture* – high degree of mechanization may affect final product

Meanwhile, in the 1990's a farmer in Burlington, Washington planted a few acres of seedling grown tea. The Sakuma Brothers Farm now has over 5 acres planted to tea. Unlike the Charleston Tea Plantation, Sakuma Bros. tea is handpicked and manufactured by hand. Currently the farm produces green, white, and oolong teas, priced between $159 and $239 per lb. ($350-$527/kg) in their online store (Sakuma Bros., 2012). Steepster.com (2012) ratings for Sakuma tea are noticeably higher than those from Charleston Tea Plantation, with its white tea garnering an 85 rating and its green teas rated a respectable 79-80. Elsewhere, Minto Island Growers in Salem, OR maintain about ½ acre of tea plants that were originally started in the 1980s (Perez, 2013).

Off the mainland, tea was introduced in Hawaii in 1887 and was commercially grown beginning in 1892. The crop was eventually discontinued due to high wages for picking and lower costs of production on the islands of tea's main rival, coffee (Danninger, 2001). Then, in 2000 horticulturist Francis Zee found a strain of the tea plant that flourished in the tropical climate and volcanic soil of Hawaii. A joint study of commercially growing tea in Hawaii was started by University of Hawaii at Manoa College of Tropical Agriculture and Human Resources and University of Hawaii at Hilo College of Agriculture, Forestry and Natural Resource Management with the U.S. Department of Agriculture (Zee et al., 2003). With the decline of Hawaii's sugar industry, tea cultivation is seen as a possible replacement crop. In 2003 Hawaii had an estimated 5 acres (20,000 m^2) of land producing tea but by 2007 that number jumped to roughly 80 acres (320,000 m^2), with continued growth forecast for the industry (CTAHR, 2007).

Today, tea is being grown on the islands at small scales, handpicked, and processed in small batches by hand. Loose-leaf brewing tea currently being processed and marketed in Hawaiʻi carries Internet prices from $132.16 to $573.92 per pound, while selected prices in other market channels range from under $100 up to $4,800 per pound, depending on the harvest and type of tea (Nakamoto et al., 2011). Except for the University of Hawaii CTAHR research stations, all processing of tea in Hawaiʻi is currently done by hand, resulting in a highly artisanal product.

Finally, there are a few other tea farms currently in development in the U.S. that are not yet producing tea. Jason McDonald of FiLoLi farm in Brookhaven, Mississippi expects to start planting tea plants in 2014 on 10 acres there, and hopes to be producing tea by 2017 (Lasseter, 2012). In northern California, Roy Fong is experimenting with tea cultivars in hopes of finding one that will thrive in the seemingly antagonistic soils and climate there, though none of "several varieties" that have been tested have yet passed this test (Donaldson, 2013). Further north, one farm on Vancouver Island, British Columbia (Canada) has planted "hundreds of tea plants" and plans to produce tea commercially in the near future (Teafarm, 2012). Clearly there is burgeoning interest in producing tea domestically for specialty markets in the U.S..

2.3.2 Commercial Production

Methods of processing at a community or farm level

Tea processing, whether for white, green, oolong, or black teas, can be effectively done at the small family farm level (den Braber et al, 2011). As demand increases, larger manufacturing facilities may prop up depending on the specific market sector developed and interest with investors. Although simple technologies exist for small-scale black tea processing (Sato et al., 2007) and several high-quality black teas use hand rolling and other manual processing, commercial black manufacturing is done in large factories. Setting up such a factory requires major investment in equipment and facilities and also requires a relatively large production base to achieve economy of scale. In general, large companies own such factories. Very few farmer cooperatives have made the step to invest in a black tea processing factory.

Meanwhile, green tea production at a household scale is very common in Vietnam and China. In Vietnam, only a simple dryer (Figure 1.1) and sometimes a roller are used. Zeiss & den Braber (2001) gives a detailed description of green tea processing as practiced by smallholder farmers in Vietnam. Processed green tea is also used as an ingredient in ready-to-drink teas, soft drinks, ice cream, biscuits, and candies. Some of these products, for example cookies or biscuits, could also be made at household or farm level and could be a nice complement to a good quality tea made at the community or farm level.

Product quality standards

There are no quantitative standards available for tea quality, though biochemical techniques are on the horizon. Two recent developments, one using FT-NIR spectroscopy to measure taste quality (Wu et al., 2011) and another employing headspace solid phase microextraction coupled with gas chromatography-mass

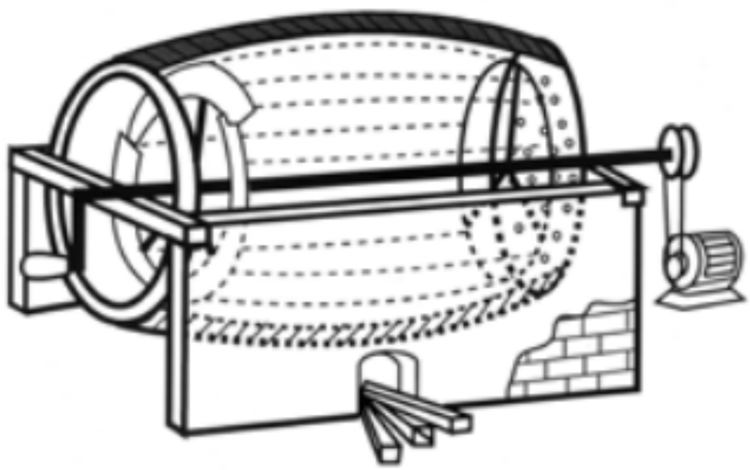


Figure 1.1 Typical drier used in Vietnam (Zeiss & den Braber, 2001).

spectrometry (HS-SPME/GC-MS) to measure aroma quality (Lin et al., 2012), have demonstrated positive results, but still the quality of tea is typically tested at the factory and/or by buyers at auction rather than in a laboratory. The evaluation of the final product depends solely on the tea taster who judges characteristics of the liquor (flavor, aroma, color) as well as the leaf color, shape, and size of the samples. The teas are qualified using specific descriptive terms created by the tea industry.

These terms include (from Nakamoto et al., 2011):

- Body: A liquor that is full and strong
- Brassy: Bitter taste.
- Brisk: A pleasing and slightly tangy taste from a well-oxidized and well-fired tea.
- Crisp: Taste quickly disappears on the tongue, a very desirable characteristic.
- Flaky: Leaf that is fragile and flat due to poor processing technique
- Malty: Thick mouth-feel flavor, desirable.
- Tippy teas: Tea harvested from young leaves; having golden buds.

To prepare the samples for tasting (also called “cupping”), a standardized procedure is followed. Sets of special tea tasting cups are used consisting of a lidded brewing cup with strainer and a bowl. ISO standards require that brewing cups are either 150 ml or 310 ml. White ceramic is used to facilitate color assessment. Cups and bowls are placed in a row, with one set per sample. A small quantity of the dry leaves is placed next to each cup. A precise measure (normally 2 g/100 ml) of the tea sample is put in the cup and just-boiled water is poured over it. This means that for the 310 ml brewing cup, 5.6 g of tea is used with 280 ml water. The cups are then covered with the lids and the tea is steeped for a fixed amount of time (6 minutes). The liquor is poured into the bowl for tasting. The remaining tea leaves are set on top of the brewing cups so that their color and aroma can be observed.

First, the dried tea leaves are examined. Then the infused leaves are checked for color and aroma. Finally, the liquor in the cup is evaluated for color and taste. Aroma plays a major role in the sensory experience. The taster inhales the bouquet of freshly brewed tea before tasting. Using a spoon, the taster slurps the tea into his mouth without swallowing. This allows that the tea with a large amount of oxygen is passed over all the taste receptors on the tongue and other parts of the mouth and so provides an even taste profile. The liquid is then usually spat out into a spittoon before moving on to taste the next sample.

Product storage requirements and shelf life

Since tea quickly absorbs moisture, it is packed after grading in airtight containers. Packaging can either be in tea chests (wood based) or specialized packaging such as foil bags or multi-layered bags that include a layer of foil. In India, only bulk packing (in wooden chest or bags) is done at the factory level and trading companies pack tea for local or export markets, whereas in Sri Lanka and Vietnam, the packing (for example, tea bags) is done at the factory level (AIT, 2002).

The shelf life of tea varies with storage conditions and type of tea. Properly stored black tea may keep for 2 years, but green tea loses its freshness usually in less than a year. Puerh teas improve with age and are kept for up to 50 years. Tea stays freshest when stored in a dry, cool, dark place in an airtight container. Storage life for all teas can be extended by using desiccant or oxygen absorbing packets, and by vacuum sealing. Improperly stored tea may lose flavor or become moldy. Tea also quickly acquires flavors or odors from other foods and should therefore be stored in proper containers, preferably away from strong smelling food.

Recommended labeling

A well-designed packaging and label are important to attract new customers and to make the product stand out in a specific marketing niche. For any market, the legal labeling and packaging requirements should be followed. For value-added purposes, it could be useful to include on the label the type of tea used, the production location, special horticultural practices applied (e.g., grown under shade), organic certification, or any special processing methods used.

2.3.3 Small Scale Production

The cultivation of tea is attractive for smallholder farmers since tea cultivation requires little investment and the risk of crop failure is limited. In many parts of the world, tea is produced by smallholders, even in countries with large tea plantations. For example, in Sri Lanka there are over 206,000 tea smallholdings, responsible for 44% of the country's production (AIT, 2002). In Kenya, 88,000 ha (or 65% of the national total area under tea) are managed by smallholders. In Vietnam most tea is produced by smallholders. The province of Thai Nguyen (the largest green tea producer in Vietnam) has a total production area of 14,500 ha, cultivated by a total of 66,000 households. Annual production of (fresh) leaf was 75,000 metric tons (MT) (den Braber, 2003).

Since every 5 kg of fresh leaves gives only 1–1.25 kg of processed (green or black) tea, volumes produced on a small farm are normally quite modest. Small-scale processing of black and green teas can be done (Sato et al., 2007) but the required manual labor will make this kind of processing only economically feasible for high-value specialty teas. Whether the tea is hand or machine processed, the art of making tea is dependent on the skills and experiences of the tea master. As has occurred in many tea-growing regions of the world, a specialty tea in the Southeast is waiting to be born.

Processing of green or oolong tea could be economically feasible even on the household level, particularly where good quality teas can be grown. Some farmers (e.g., Vietnam, Taiwan) make a good living from their individual production since their tea fetches a price that is 30–50% higher than the price of an average quality tea. For larger commercial processing, farmers may do better operating a cooperative processing unit or selling to a large factory. As with coffee, tea is usually exported at an early stage of production. The tea companies in the importing countries normally do the final blending and packaging, which is the most lucrative part of the tea trade. Tea producing countries themselves benefit little from the value adding. In Europe, 30–50% of the retail price of a tea is to cover the blending, packing, packaging materials, and promotion costs (Stamp, 2001).

Several producers have tried to add value to their products by selling processed tea in tea bags or consumer-ready packaging units but the export of these ready-for-use products is often difficult due to poor market information and the lack of funds for specific marketing activities (Stamp, 2001).

Import replacement

In countries where green tea is produced traditionally, such as China and Vietnam, farmers often use the processed tea for home consumption. However, where black or oolong teas are the main type of tea consumed, home processing is impractical. It is unlikely that local production will be able to fully replace imports in the Southeast, let alone all of North America. However, high quality regional production could replace some imports and boost the local economy as a specialty crop. Production of local specialty teas could further lead to the development of value-added products related to tea (tea pots, etc.) or tea-related agritourism. Yet, the ready-to-drink (RTD) segment of the tea market may be a realistic goal in the long-run. Profit margins on RTD are very high and cooperating growers could eventually fill much of this market segment.

2.3.4 Yields

Yields of tea vary widely among producing countries, depending on soil type, climate, and tea maintenance techniques. Total yields can vary greatly depending on the horticultural practices of the plantation in addition to whether the tea is hand or mechanically harvested. Very good plantations in India are producing 3,500 kg/ha/yr (which corresponds to some 16 MT fresh leaves/ha), while many smallholders in Vietnam do not produce more than 400 kg/ha/ yr. Comparing national averages, Kenya in 2007 produced 2,000 kg/ha/yr, while India produced 1,700 kg/ha/yr and China just 1,000 kg/ha/yr (FAOSTAT). The introduction of green revolution technologies, such as chemical fertilizers and pesticides, has in general resulted in considerable yield increases since the 1950s. However, it seems that in several tea regions these yield increases have reached their limit due to chemical, physical, and biological impoverishment of soil fertility under intensive tea production (Panigrahi, 1993, quoted in Senapati et al., 2001).

Recommended planting density

The most common planting densities are 10,000–15,000 plants/ha. Density is an important factor for yields. Lower densities favor greater individual bush productivity, whereas with higher densities individual yields decrease but total yields from the whole field is higher (Bonheure, 1990). The plant density should be adapted to the site conditions (slope, altitude, soil, etc.) and account for the incorporation of shading trees. Higher plant densities are appropriate when slopes are not too steep, on soils rich in nutrients, and when the risk of drought is low. However, close planting has the disadvantage that the individual tea plants will grow less vigorously and have lower yields, especially as the bushes age (Zeiss & den Braber, 2001)

2.3.5 Markets

Local markets

Local market sales should have high potential, especially for high quality, specialty ("boutique," "gourmet," or "origin") teas. Themed travel, including visits to tea gardens, is a new trend in tourism, not only in the more traditional tea growing countries (China, India, Sri Lanka) but also in the U.S. Examples are the Bigelow plantation in South Carolina and the Tea Hawaii and Company, which grows tea on a five-acre estate in Volcano, Hawaiʻi Island (Tea and Coffee, 2008a and 2008b). Brewed tea, whether fresh or bottled, has the highest profit margins of any widely consumed tea product, and thus may be a lucrative marketing option at farmers markets, community events, and festivals.

Specialty markets

The consumption of premium whole leaf teas (as opposed to tea bags) is rising, especially for green teas. This is primarily due to an overwhelming emphasis on green tea in many articles promoting health benefits of tea consumption. This opens up new opportunities for small producers who are otherwise not able to invest in equipment for making tea bags or more complicated processing. Over the last few years there has also been a general increase in the demand for niche products such as high quality gourmet, fair trade, and organic teas. Together with an increased interest in quality, there has also been a trend toward healthy and ethical products (den Braber et al., 2011).

Organic/Fair Trade

The number of organic tea producers and the volume of organic tea traded on the world market has increased substantially over the last few years, although production is still quite small compared to the volume of conventionally produced tea. In 2003, an estimated 13,000 MT of organic tea was produced, from a total world production area of 16,000 ha. India has the largest area under organic production, followed by China (den Braber et al., 2011).

Several factors contribute to the increase in organic tea production and consumption. Tea producers themselves have become more aware of the health impacts and environmental problems (erosion, pesticide residues, etc.) associated with intensive tea production. Consumers are becoming more concerned about pesticide residues and other health and environmental issues that have resulted from modern farming methods. Furthermore, drinking organic tea fits well with the general "health" trend in drinking tea seen by the continuing increase in the consumption of green tea. There is also much evidence that organically grown teas are generally of better quality due to the avoidance of artificial additives

(Sippo/FiBL, 2002). However, little reliable data about the organic tea market and the benefits of organic tea are available.

Most of the organic tea produced is exported to Germany, the UK, and the United States. Sippo/FiBL (2002) estimates that organic tea consumption (black and green tea) for these market destinations is estimated at 600–800 MT per year in Germany, 1,000–1,500 MT in the UK, and 2,000 MT in the U.S. All other European countries consume less than 100 MT of organic green or black tea per year. Because a large number of certified producers entered the organic tea market in the last few years, there is currently an oversupply. This situation has led to a drop in prices for producers, while consumer prices for organic tea have remained quite stable. This means, despite the existing oversupply, international traders are profiting (Sippo/FiBL, 2002).

The world market for fair trade tea is growing rapidly. While in 2004 a total of 1,964 MT of certified fair trade tea was sold globally, sales increased to 5,413 MT in 2007 (den Braber et al., 2011) Consumers interested in fair trade products are often also interested in buying organic products. In general, fair trade products that are also organically certified seem to have an advantage over products that are solely organic or fair trade. A domestic fair trade movement has even sprung up in recent years in the United States (Domestic Fair Trade Association, 2010).

Branding possibilities

Local branding gives smaller plantations or farmer groups opportunities to develop niche markets for their products. Some teas are very unique for a specific location and can be sold at high prices. Popularity is enhanced where consumers are sensitive to the idea of local products or specific cultural aspects of production. Combining local tea products with other local specialties is a good strategy for expanding sales. In Hawai'i, local tea growers are combining their product with locally made chocolate truffles, baked goods, and honey (den Braber et al., 2011). Introducing local teas through restaurants specializing in local cuisine is another interesting option.

Potential for Internet sales

Because tea is lightweight and lacks special shipping requirements, it is well suited for Internet sales. Tea also stores well in the absence of aromatic compounds. In fact, tea is increasingly being sold through the Internet either by conventional retailers and specialized Internet tea retailers both here and abroad. The majority of tea growers in the U.S. market at least some of their products online, though some of the very smallest do not.

2.3.6 Economics of Tea Production

Costs of production

Cost of production is difficult to generalize since tea producing operations vary greatly among producing countries. One main difference is the scale of production, whether it is a household level or large-scale plantation. In countries such as India and Sri Lanka, corporate tea producers often provide services to their staff and laborers that their governments cannot offer. Apart from salaries, they pay for medical care, fuel, education, housing, and other benefits to staff and laborers. As a result, labor costs are relatively high for these companies. For example, in Sri

Lanka the cost of production was US$1.37 per kg produced during the 2003/2004 season. Of this amount, 44% was for salaries and other benefits of the field workers, 16% for manufacturing (factory labor and fuel), and 6% for field materials and tools, such as fencing, control of pests and diseases, manure, etc. In India, the cost of production is US$1.62/kg, while the production costs in other major tea producing countries is lower, such as in Kenya US$1.16/kg, Vietnam US$0.96/kg, and Indonesia US$0.58/kg (den Braber et al., 2011).

During the first 3–5 years, until the tea is mature and can be harvested, further investments are required, including fertilizers, pesticides, costs for weeding, irrigation and the application of fertilizers and pesticides, as well as crop maintenance. Only after this period, will tea harvests begin to recover this initial investment. In addition to production costs, the cost of processing and the processing equipment should be considered as well.

Expected income

Worldwide, Export tea prices differ based on quality but also based on production country, even for the same quality of tea. For example, in 2008, the price was highest for teas from Kenya (US$2.30/kg) and Rwanda (US$2.24/kg) but teas from Zambia fetched only US$0.70/kg while the price of teas from Tanzania, Malawi, and Mozambique were also far below the average (EATTA, 2009). The price Vietnamese farmers received in early 2009 when selling fresh leaves to a factory was US$0.14–0.17 (den Braber et al., 2011). When farmers process the tea themselves into green tea, they receive US$1.75–2.65/kg when sold to the local market, or even higher prices for the best qualities (Zeiss and den Braber, 2001).

In contrast, the price Nakamoto et al (2011) used in their financial analysis of Hawaii-grown tea was US$880/kg ($400/lb.). At this price, tea was found to have a net profit margin of 33-78% after 5 years depending on planting density and whether or not the grower elects to purchase equipment to build a certified kitchen in order to mechanize the processing of tea. Of course, yields will be less in Georgia than Hawaii, but high net profit margins still appear likely. Experimental plots should be established in a variety of potentially suitable ecoregions in the Southeast to enable a thorough financial analysis of small-scale tea production, especially white, green, and oolong types. Shade should be incorporated where possible to gauge their importance in the 'unstable' climate of the Southeast.

2.3.7 Tea Genetic Resources in the United States

There are hundreds, if not thousands, of named tea cultivars, each with their own unique characteristics and flavor profiles. Since propagation by seed does not give the required uniformity, commercial tea cultivars are all propagated vegetatively, yielding identical clones. In regions where tea has been grown for decades, it may be advisable to continue with normally accepted cultivars. Where tea cultivation is new, such as in the Southeast, the tea market will eventually determine the most appropriate cultivars among those that can be grown in the region.

While most botanical gardens in the southeast contain at least one specimen of seedling-grown varietal *Camellia sinensis*, a surprisingly modest number of named cultivars are maintained in the United States, either at botanical gardens or by commercial nurseries. While private nurseries in the United States have offered at least a dozen named cultivars for sale in recent years, at present only two are currently available commercially, and one of these ('Rosea', with pink rather than white flowers), has been bred specifically for use as an ornamental and is not likely suited to productive applications. See Table 2.1 for a complete list of varieties.

Table 2.1: Commercial tea cultivars currently maintained in the United States. Location Key: 1 = Coastal Botanical Gardens at the Historic Bamboo Farm in Savannah, GA; 2 = Atlanta Botanical Garden, Atlanta, GA; 3 = Lyon Arboretum and Botanical Garden, Manoa, HI; C = maintained by commercial nurseries. Note that a handful of ornamental cultivars are omitted in this list.

Variety	Cultivar	Origin	Location
Sinensis (Chinese)	'Grimball Point'	Georgia, USA, 18th c., China?	1
	'Azores'	Azores Islands, pre-1900	2
	'Yabukita'	Japan, 1908	3
	'Yutaka Midori'	Japan, c. 1960	3
Assamica (Assam)	'Old Savannah'	Georgia, USA, 18th c., India?	1
	'Sochi'	Republic of Georgia	C
	'Benikaori'	Japan c. 1955	3
	'Bohea'	Unknown, may be varietal name	3
Sinensis referred to as	'de Renne'	Georgia, USA, unknown	1
Parvifolia (Cambodian)	'Chin Shin Oolong'	Taiwan, unknown	3

2.4 PROPAGATION

2.4.1 Propagation of *Camellia spp.*

The propagation of plants in the Camellia genus is done by seeds, cuttings, and grafting. Camellias grown from seed will vary substantially from the parent and take many years before they bloom. Camellia cuttings are taken from the plant the grower wishes to reproduce. The cutting needs to be four inches with five leaves taken from new growth that is light brown not new growth green. These semi-ripe cuttings are usually taken in early- to mid- summer. Two types of grafting are also sometimes employed with Camellia propagation. Cleft grafting –a technique that allows the union of a rootstock limb that is much larger in size than the scion piece—is conducted in late winter when both the rootstock and scion are in a dormant condition. Approach grafting—in which two independently growing, self sustaining plants are grafted together—using either stems or branches is conducted during the growing season. Finally, air layering—in which a portion of an aerial stem is enticed to grow roots while still attached to the parent plant and then is detached as an independent plant—is sometimes used to produce a good sized plant in relatively little time; it is most commonly performed in the spring as the plant is beginning to grow (Peper, 2012; King, 2012).

Propagation of *Camellia sinensis*

Like other Camellias, tea plants are propagated both vegetatively (mostly by cuttings, but grafting and layering are also possible), and from seeds. Traditionally, tea has been propagated from seed, with many seedling-grown tea gardens still in existence, particularly among smallholders. Since tea plant is an 'outbreeding' cross-pollinator and thus produces highly heterogeneous offspring, plants grown from seed have uneven growth rates, vigor, and highly variable processing qualities. Therefore, in the main commercial tea production areas of the world, the use of cuttings has in recent times replaced the use of seeds for propagation. However, many small farmers in countries such as China and Vietnam still use seed and this is one of the reasons for the relative low average yields in these countries. Of course, seeds can be used if one is interested in having a few tea plants for backyard enjoyment as hedges or potted plants or even for home processing (Zee et al., 2003).

In order to produce a uniform crop with predetermined characteristics, the practice of vegetative propagation of selected clones from single-node cuttings has now been widely and successfully adopted as the most economic method of vegetative propagation. While bi-nodal cuttings have been shown to be superior to single node cuttings in rooting and subsequent growth, in view of the large numbers plants required in tea gardens and plantations, the single-node cuttings have been found to be most economical (Hajra, 2001). Green, semi-hard wood with one leaf and an internode is taken from the stem of specially prepared plants, where terminal buds are commonly removed 15 to 21 days prior to shoot harvest and often sprayed with a 1% aqueous solution of zinc sulfate. Success ranges from 40 to 80 percent (Hajra, 2001). The cultivar, season, growth medium, type of cutting material, moisture, and temperature of the rooting environment can affect root development (Zee et al., 2003).

Cuttings should be severed with a sharp knife, hand pruners, or razor blade. The middle portion of the shoot, which is neither too soft nor too hard, makes the best cuttings. Cuts should be made 2–3 mm above each leaf node, leaving about 3–4 cm of stem below the node (about 2–3 nodes per stem section). The leaves should be sprayed with cool water and held in an airtight plastic bag under cool conditions until sticking. Golding et al (2009) found that it is possible to store harvested propagation material for up to 18 weeks in plastic bags at 0° C for two varieties tested.

When sticking, cuttings are inserted into a pre-made hole with leaf tips nearly vertical, afterward firming the surrounding soil to avoid air pockets. Rooting occurs in the following 10-12 weeks under favorable conditions, and in as little as 4 weeks with optimal conditions (Hajra, 2001; Golding et al., 2009).

2.4.2 Favorable Conditions for Root Formation

Environment, Substrate

For the successful propagation of tea cuttings, the rooting medium must be acidic ($pH < 5.5$) and have good drainage. Cuttings form callus and roots best when the medium's pH is just below 5.0 (Zeiss & den Braber, 2001). Optimal temperature conditions lie between 15-20°C, though optimal substrate temperatures are approximately 5°C higher. The provision of heavy shade is also important during the rooting process. Allowing less than 50% of light to fall on the cuttings is crucial (Hajra, 2001). Cuttings are sometimes dipped in zinc sulfate before 'sticking' to hasten rooting, though evidence justifying this practice is scarce.

Plant Growth Regulators (Hormones)

Indole butyric acid (IBA) has been shown to be the only hormone that improved root formation and growth in cuttings (reviewed in Hajra, 2001). Optimal rates of IBA pretreatment have been found to vary considerably. Optimal rates of IBA pretreatment have been found to vary considerably, from 75 ppm (Rout, 2006) to 5000 ppm (Rajasekar and Sharma, 1989) at the extremes. Apparently, this optimum is cultivar-specific (Hajra, 2001).

2.4.3 Pathogens and diseases of young tea plants

The pathology of green tea in the southeastern United States is limited. Current information has been generated from overseas sources with no formal studies confirming the identity and causal nature of potential pathogens to Asian tea cultivars grown under conditions in the Southeast. However, previous studies with ornamental Camellias in the region have demonstrated similar fungi causing stem dieback, root rots and leaf blights (Popenoe, 2008).

Overseas records of foliar and shoot diseases of tea are somewhat confusing due to nomenclatural inconsistencies (different names given to the same fungi), taxonomic problems where different fungi are morphologically very similar, and differing common names applied to diseases. In Japan, the disease Anthracnose is caused by the fungus, *Colletotrichum theae-sinensis* (Miyake) Yamamoto. 'Yabukita' is the most popular green tea cultivar and is susceptible to this disease, and since it dominates tea plantings in Japan (> 70%) it is considered to be a significant cause of losses (Takeda, 2003; Yoshida and Takeda, 2006). The disease reduces the depth of leaf layers and the number of branches resulting in decreased first flush yields. Disease outbreaks occur from summer to autumn following penetration by the fungus through trichomes and into new shoots. This fungus was formally known by another name, *Gloesporium theae sinensis* Miyake. In Vietnam this fungus name is maintained as causing the disease, Wet Leaf Blight of tea (Zeiss and den Braber, 2001). However, three other fungi are recognised as causing Anthracnose in Vietnam (also described as Bud Decay and Bud Blight): *C. theae-sinensis*, *Glomerella cingulata* (Stoneman) Spauld and H. Schrenk. which has the anomorphic names, *C. gloeosporioides* (Penz.) Penz. & Sacc. and *C. camelliae* Massee, and *Phyllosticta gemiphilae* (Zeiss and den Braber , 2001). In a phylogenetic study of internal transcribed spacer region 2 and 28s rDNA gene sequences of 25 *Colletotrichum* species from Japan, Moriwaki *et al*. (2002) determined that *C. theae-sinensis* formed a discrete group that suggested it should belong to a separate genus.

The other major disease that is prevalent in Japan is Tea Grey Blight, caused by the fungus *Pestalotiopsis longiseta* (Spegazzini) Dai et Kobayashi (Yoshida and Takeda, 2006). In Vietnam, the disease Grey Blight (also called Brown Blight) is caused by several fungi that includes: *C. coccodes* and *Pestalotia theae* Sawada [this latter fungus is also known as *Pestalozzia theae, Pestalozzia guepini* and *Pestalotiopsis theae* (Sawada) Steyaert] (Zeiss and den Braber , 2001; La Rue and Bartlett, 1922; Chandra Mouli, 1996). In the American Phytopathological Society list of common names of plant diseases (Chandra Mouli, 1996), *G. cingulata* is noted as causing the Brown Blight of tea while there are three further *Phyllosticta* species listed causing foliar diseases. The list also includes *Pestalotiopsis adusta* Ellis & Everh. causing a leaf spot disease. To a lesser extent, similar confusion is found in international records of root diseases of tea. A thorough taxonomic study will be required to clarify the pathogens and diseases currently on tea in Southeast.

In the United States, the principle diseases of young Camellias consist of root rots caused by fungal pathogens *Phytopthora spp., Pythium spp., and Rhizoctonia solani*, none of which are noted by Japanese officials as major pathogens of tea. Susceptibility of tea plants to these diseases are unknown, but all are caused by prolonged periods of saturated soils and moderate temperatures, and can usually be managed by proper irrigation scheduling and adequate drainage in tea soils. (Popenoe, 2008).

Control of Soil-borne Pathogens and Pests of Tea

Fumigation is sometimes recommended if high levels of soil-borne pathogens are present in the propagation area (Yamasaki et al., 2008). Historically, soil fumigation has been performed using methyl bromide gas. Not only is the compound prohibited under USDA organic statues, but it has also begun to be phased out by policy makers around the developed world in light of the fact that the gas contributes to stratospheric ozone depletion. Soil solarization and biofumigation have both been put forth as low-cost, organic-allowable alternatives to chemical fumigation for weed and pathogen control in infested soils. Solarization consists of the creation of a bed-sized solar oven, tightly covering the ground with clear plastic sheeting.

Biofumigation involves the incorporation of plant material from various Cruciferous vegetables into the soil where they release large quantities of glucosinolates, which hydrolyze into isothiocyanates—toxic compounds that have been shown to control a broad spectrum of soil pests and pathogens. High heat conditions encourage this reaction. As a result, these methods of solarization and biofumigation combine to form a potent alternative to chemical fumigation. Together, their effectiveness is similar to that of conventional fumigants, but biofumigation also improves soil and plant characteristics (Bello et al., 2002).

2.4.4 Tea Propagation Systems

In North America and other highly developed parts of the world, vegetative propagation of Camellias is generally done in containers with soilless media under glass. Combinations of sand, vermiculite and/or perlite have been the most popular substrate ingredients for rooting plants under glass, though bark-based substrates are gaining popularity in recent years.

Meanwhile, in many tea-producing areas, cuttings are instead commonly planted into polyethylene sleeves about 3 inches in diameter and 10 inches deep filled with low-pH subsoil amended with phosphorus. The filled sleeves can be kept from falling over by surrounding them with a frame. One cutting is placed in each sleeve, with the leaf and bud just above the soil level. Leaves are oriented so as to not overlap. (Hajra, 2001). Cuttings prepared in such a manner should be watered well, kept cool, and then watered about once every two weeks. Heavy shade is supplied, whether from thatching, bamboo, or more elaborate structures.

Elsewhere, alternative propagation systems have been developed that have been shown to be quite effective. A prominent example involves the use of a low tunnel covered with heavy (80%) shade cloth, in which cuttings are rooted directly in the ground (Yamasaki et al., 2008). This procedure also uses clear polyethylene sheeting underneath the shade cloth, but this method appears to be inappropriate where average daily temperatures exceed 25° C (77° F) when mist sprayers are required to maintain humidity instead. Landscape fabric can be used to minimize weed pressure. Placing cuttings into the soil through small slits in the fabric also help support the cuttings as rooting is initiated (Liam Bell, pers. comm.). While reports from Hawaii growers suggest rooting cuttings into raised beds of native soil, a report from Vietnam suggests sticking cuttings into a 4.5-6.5 cm (2-3 in.) layer of sand laid on flat ground (Zeiss and den Braber, 2001).

Each of these propagation systems is ultimately part of some implied distribution system. High-input glasshouse systems are appropriate for high-value crops or nurseries serving very large wholesale markets. Polyethylene sleeve systems work for plantations where the plants do not require long-distance transport on their way to the field. In-ground systems seem to be most common among smallholders. To date, the relative economic efficiency these systems have not been formally compared, since each tea producing country tends to support one system or another, rather than competing systems existing together. The following chapters will compare two of these systems along horticultural and economic lines.

CHAPTER 3

SUBSTRATE AND ROOTING LOCATION INFLUENCE THE ROOTING AND SUBSEQUENT GROWTH OF SINGLE NODE TEA (*CAMELLIA SINENSIS*) CUTTINGS

3.1 Introduction and Literature Review

Based on recent success cultivating and marketing high-quality tea produced in Hawaii (Cheng, 2012), the prospects for the development of a small-scale, environmentally friendly commercial tea industry in the United States look promising. However, a lack of plant material and nursery infrastructure presents a formidable barrier to this development. In North America, only a handful of nurseries produce named cultivars of tea plants commercially, and none are known to have the capacity to produce quantities suitable for wholesale markets, necessary for industrial development. Therefore, the evaluation of alternative propagation systems is needed to identify the most efficient methods of increasing plant material suitable to commercial production.

Two main varieties (subspecies) of C. sinensis are used for tea production:

(1) Assam or large-leaf variety (*C. sinensis* var. *assamica*, also known as *C. assamica*) (J. Masters) Kitam, and (2) Chinese or small-leaf variety (C. *sinensis* var. *sinensis*) (Monks, 2000). The Chinese variety is native to the northern slope of the Himalayan Mountains of southeast China and was domesticated as long as 4,000 years ago (Gepts, 2003). The Assam variety is native to southern slopes of the Himalayan Mountains of northeast India, Burma, Vietnam, and southern China (Gepts, 2003). This variety was domesticated in the 19th century from hybridizations between wild tea plants from northern India and cultivated Chinese plants (Gautier, 2005). The Assam variety can grow into a loosely branched tree about 15 m tall whereas the Chinese variety grows to a much smaller size, reaching a maximum height of 3–5 m (den Braber et al., 2011).

Like other Camellias, tea plants are propagated both vegetatively (primarily by cuttings, but grafting and layering are also possible), and from seeds (Peper, undated; King, undated). Since tea plant is an 'outbreeding' cross-pollinator and thus produces highly heterogeneous offspring, plants grown from seed have uneven growth rates, vigor, and highly variable processing qualities. Therefore, to produce a uniform crop with predetermined characteristics, the practice of vegetative propagation of selected clones from single-node cuttings has now been widely and successfully adopted as the most economic method of vegetative propagation (Zee et al., 2003).

In North America and other highly developed parts of the world, vegetative propagation of Camellias is generally done in containers with soilless media under glass (Midcap and Bilderback, 2002). Combinations of bark, sand, and/or perlite have been the most popular substrate ingredients for rooting plants under glass, though bark-based substrates have become standard in recent years (Ruter, 2002). Meanwhile, in many tea-producing areas cuttings are instead commonly planted into polyethylene sleeves about 3 inches in diameter and 10 inches deep filled with low-pH subsoil amended with phosphorus (Wight, 1955; Hajra, 2001). The filled sleeves can be kept from falling over by surrounding them with a frame. One cutting is placed in each sleeve, with the leaf and bud just above the soil level. Leaves are oriented so as to not overlap. (Hajra, 2001). Cuttings prepared in such a manner should be watered well, kept cool, and then watered about once every two weeks. Heavy shade is supplied, whether from thatching, bamboo, or more elaborate structures (Hajra, 2001; Wight, 1955).

Elsewhere, alternative propagation systems have been developed that have been shown to be quite effective. A prominent example involves the use of a low tunnel covered with heavy shade cloth, in which cuttings are rooted directly in the ground (Yamasaki et al., 2008). This study reportedly achieved strike rates of at least 80-85% over five trials conducted beginning in 2004. This procedure uses clear polyethylene sheeting underneath the shade cloth, but this method appears to be inappropriate where average daily temperatures exceed 25° C, where polyethylene has been replaced with overhead mist irrigation by at least one Hawaii grower (Liam Bell, pers. comm.).

Landscape fabric can be used to minimize weed pressure. Hawaii tea grower Liam Bell stated that placing cuttings into the soil through small slits in the fabric also helps support the cuttings as rooting is initiated (personal communication, 2011). A report from China found that the use of plastic mulch increased survival rate of cuttings as well as the height and width of the shoots (Lu & Sun, 2000). While reports from Hawaii researchers suggest rooting cuttings into raised beds of native soil (Yamasaki et al., 2008), a report from Vietnam suggests sticking cuttings into a 4.5-6.5 cm layer of sand laid on flat ground is at least equally successful (Zeiss and den Braber, 2001).

For the successful propagation of tea cuttings, the rooting medium must be acidic (pH < 5.5) and have good drainage (Hajra, 2001). Cuttings form callus and root best when the medium's pH is just below 5.0 (Zeiss & den Braber, 2001). Optimal temperature conditions lie between 15-20°C, though optimal substrate temperatures are approximately 5°C higher (Hajra, 2001). The provision of heavy shade is also important during the rooting process. Allowing less than 50% of solar radiation to reach the cuttings is crucial (Hajra, 2001).

Plant growth regulators are commonly used with vegetative propagation of plants. Indole butyric acid (IBA) has been shown to be the only hormone that improved root formation and growth in tea cuttings (reviewed in Hajra, 2001). Optimal rates of IBA pretreatment have been found to vary considerably. Optimal rates of IBA pretreatment have been found to vary considerably, from 75 ppm (Rout, 2006) to 5000 ppm (Rajasekar and Sharma, 1989). Apparently, this optimum is cultivar-specific (Hajra, 2001).

When propagation activities are conducted in the field, fumigation is sometimes recommended if high levels of soil-borne pathogens are present in the propagation area (Yamasaki et al., 2008). Historically, soil fumigation has been performed using methyl bromide gas. Not only is the compound prohibited under USDA organic statues (Code of Federal Regulations, title 7, sec. 205.15) but it has begun to be phased out by policy makers around the developed world in light of the fact that the gas contributes to stratospheric ozone depletion (Bello et al., 2002). Soil solarization and biofumigation have both been put forth as low-cost, organic-allowable alternatives to chemical fumigation for weed and pathogen control in infested soils.

Solarization consists of the creation of a bed-sized solar oven made by tightly covering recently moistened ground with clear plastic sheeting (Grinstein and Hetzroni, 1991). Biofumigation involves the incorporation of plant material from various Cruciferous vegetables into the soil where they release glucosinolates. Aliphatic glucosinolates, in particular, will hydrolyze into isothiocyanates—toxic compounds that have been shown to control a broad spectrum of soil pests and pathogens—catalyzed by the myosin enzyme (Kumar, 2005). Moist, high heat conditions encourage this reaction (Gimsing and Kirkegaard, 2009). As a result, these methods of solarization and biofumigation combine to form a potent alternative to chemical fumigation. Together, their effectiveness is similar to that of conventional fumigants, but biofumigation also improves soil and plant characteristics (Bello et al., 2002). While the pathology of green tea in the southeastern United States is limited, previous studies with ornamental Camellias in the region have found a number of soil-borne fungi causing stem dieback, root roots, and leaf blights that affect young plants (Popenoe, 2008).

During favorable weather, cuttings may take 4-8 weeks for callusing and 10-12 weeks for rooting (Hajra, 2001). After roots have grown, it is recommended that rooted plants be transplanted to larger (10-15 cm) sieves or containers where they are held (finished) until they are until the time is right for field establishment (Hajra, 2001). In the tropics, this period can last as little as 8 weeks after rooting has concluded, but plants generally require at least one year in the nursery before they are ready for the field (Zeiss and den Braber, 2001). While no studies could be found in the literature that have formally investigated growth and development during finishing in-ground, Yamasaki et al. (2008) obtained 100% survival rate in most trials transplanting plants 9 months after sticking, and reported good survivorship from plants held up to 2 years in the rooting bed.

Each of these propagation systems is ultimately part of implicit marketing, distribution, and production systems of tea. Container/greenhouse systems are mainly used for retail markets, high-value crops or nurseries serving very large wholesale markets (Hartmann et al., 2002). Polyethylene sleeve systems are more appropriate for plantations where the plants do not require long-distance transport on their way to the field (Hajra, 2002). In-ground systems seem to be most common among smallholders (Zeiss and den Braber, 2001). To date, the effectiveness of these systems has not been formally compared. The objective of this experiment is to compare rooting substrates as well as other in ground and container/greenhouse rooting factors, including the use of biofumigation, to identify those which maximize strike rates, survival, and growth rates of rooted tea cuttings.

3.2 Materials and Methods

3.2.1 Rooting experiments

In early July 2011, semi-hardwood cuttings of each of three available tea cultivars (var. *assamica* 'Old Savannah', var. *sinensis* 'Grimball Point', and var. *sinensis* 'De Renne') were collected from the Coastal Georgia Botanical Gardens at the Historic Bamboo Farm in Savannah, GA (lat. 31°59'45" N, long. 81°16'10" W; USDA hardiness zone 9a [USDA, 2012]). Semi-hardwood cuttings were selected from mother plants, lightly sprayed with water, and stored in 2 mil black plastic bags at 8°C for 10 days.

Single node cuttings were prepared and stuck on 18-19 July 2011 at the University of Georgia Horticulture Farm in Watkinsville, GA (lat. 33°52'59" N, long. 83°25'9" W; USDA hardiness zone 8a [USDA, 2012]) using a 1-s quick dip of 1000 ppm solution of Indole-3-butyric acid potassium salt (K-IBA) (Sigma-Aldrich, St. Louis, MO) and deionized water. In each experiment, mist irrigation timing was supplied for ten hours per day (09:00 - 19:00), at a frequency that ensured foliage was not allowed to dry for prolonged periods, performed daily through visual observation throughout the day for the duration of the experiment.

Soil and substrate physical and chemical properties were measured using a variety of standardized procedures. Substrate bulk density was measured following the procedure outlined by Niedziela Jr and Nelson (1992). Organic matter content was measured using the loss of weight on ignition method described by Storer (1984). Electroconductivity (EC) was measured using a ThetaProbe ML2x (Delta-T Devices, Cambridge, UK). Cation exchange capacity (CEC) was measured using the

$BaCl_2$ compulsive exchange method described y Gillmen and Sumpter (1986). Soil acidity (pH) was measured using the procedure outlined by McLean (1982) using a HI2210 pH Meter (Hanna Instruments, Smithfield, RI).

Air and soil temperature as well as relative humidity were monitored at 20 minute intervals with three Hobo® U12-012 environmental data loggers (Onset, Bourne, MA) placed with the cuttings for 10 weeks following sticking on the mist bench and in each of the shaded low tunnels corresponding to in-ground rooting media. Soil temperature probes were placed at 2 cm depth in each in-ground medium and the EllePot™ sphagnum-based rooting medium.

In-ground rooting experiment:

The in-ground rooting experiment was arranged using a split-split-plot layout and randomized complete block design within plots. Main plots consisted of either sand or soil treatments, separated by 6.1 m to enable tractor entry and exit between them. Sub-plots (biofumigation treatments) were spaced 2 m apart to ensure that biofumigation compounds and heat from solarization did not interfere with areas that were not subjected to biofumigation/solarization. Sub-subplots consisted of cultivar treatments, with no additional spacing between cultivar blocks within them. In sub-sub-plots, samples were placed in three-row blocks (rows aligned perpendicular to the bed) consisting of 5 plants spaced 15 cm apart within and between rows.

Prior to propagation activities, a crop of radishes (*Raphanus sativus* 'Nero de Tondo') was grown in the rooting bed. Radishes were chosen since they were found to have the greatest concentrations of aliphatic glucosinolates of all economically important members of the family Brassicaceae (Verkerk et al., 2009). This cultivar was selected based on the results from Hanlon and Barnes (2011), which showed this selection of radish to have concentrations of aliphatic glucosinolates (227 μg g^{-1} dry weight) comparable with crops sold as high-glucosinonlate containing *Sinapis alba* cultivar 'Ida Gold' for biofumigation (271 μg g^{-1} dry weight) (Masiunas et al., 2009). Unlike 'Ida Gold', the radish cultivar is well suited to spring sowing in the Georgia piedmont climate (SARE, 2012), making it an ideal choice in this study. These radishes were planted on 6 April using 7.5 cm in-row spacing with rows separated by 23 cm. In six plots (corresponding to three replications in each of the two soil media treatments tested), the radishes were lifted, shredded with a flail mower, and incorporated into the soil with a rotovator in early June. Elsewhere, the radishes were removed and discarded. After a rain wetted the soil, clear plastic was laid tightly over the bed for solarization, and was promptly removed from areas where solarization was not to be performed, with the plastic extending half way through buffer areas separating the plots. The plastic was left in place for four weeks.

After biofumigation, the Cecil (Fine, kaolinitic, thermic Typic Kanhapludults) clay-loam soil was tilled and either shaped into a raised bed of native soil or left flat and covered with a 10 cm layer of river sand. In each, the soil was fertilized with colloidal rock phosphate (The Espoma Co.; Millville, NJ) at a rate of 785 $g \cdot m^{-1}$ as recommended by Hajra (2001) while ferrous sulfate monohydrate (Monterey AgResources; Fresno, CA) was used to adjust soil pH 5.0. Non-woven black landscape fabric (DeWitt Co., Sikeston, MO) was laid tightly over the soil and secured with 30.5 cm lawn staples. A low tunnel was erected using 0.61 m long pieces of rebar, and 3.0 m pieces of 1.3 cm wide PVC pipe (Lowe's, Inc.) covered with 80% shade black knit shade cloth (ShadeClothStore.com, Libertyville, IL).

Five hundred forty single-node cuttings (2 soil treatments x 2 biofumigation treatments x 3 cultivars x 3 replications x 15 cuttings = 540 cuttings) were rooted in-ground, following the procedure outlined by Yamasaki et al. (2008) with slight modifications (replacing the enclosed polyethylene cover with mist irrigation and using non-woven landscape fabric to control weeds). In Hawaii, while polyethylene covers are recommended in highlands where temperatures remain mild, they are not recommended in warmer, lower elevations (Zee et al, 2003). It was expected that hot summer temperatures in the Georgia piedmont region would be too great for successful tea propagation under enclosed polyethylene. These suspicions were confirmed by Zhang et al (2009) who rooted *Camellia oleifera* cuttings under low plastic tunnels in southern China during the spring, inducing rooting percentages of only 22.5% to 55%, far below the commercial production average of 90%.

Overhead mist irrigation was controlled with a DIG 710-075P Propagation timer (DIG Corp., Vista, CA) and supplied via 180° polypropylene misting nozzles (0.32 L/minute discharge) spaced every 0.91 m along each side of the low tunnel in an offset configuration. Water was supplied at a frequency of 2 minutes every 20 minutes (6 minutes per hour) during the summer, reduced to 1 minute every 20 minutes (3 minutes per hour) in late September, and was turned off completely in mid-November.

Container/greenhouse rooting experiment

At the same time as in-ground propagation activities, 405 single-node cuttings (3 cultivars x 3 substrates x 3 replications x 15 plants) were placed in standard 275602C 50-cell plug trays (T.O. Plastics; Clearwater, MN) on a mist bench in a double-poly greenhouse equipped with a cooling pad and heating system. Three rooting media were used: (1) EllePots™ (40 mm wide x 60 mm tall) comprised of 70% peat, 20% perlite, and 10% vermiculite (OBC Northwest, Inc.; Canby, OR), (2) organic materials-based Root Riot™ 38 mm x 60 mm (w x h) organic plugs (Hydrodynamics International; Lansing, MI), and (3) a 9:1 mixture of composted pinebark—sifted through a 95 mm screen—and perlite (Figure 3.1). Each was used in standard 25.4 cm x 50.8 cm, 50-cell deep plug trays (TO Plastics; Clearwater, MN) consisting of round cells 49 mm wide x 59 mm deep (110 cm^3 volume each). In the experiment, 15 cuttings of each cultivar were placed in blocks comprising 45 cells in each tray with one substrate. To maintain a low pH necessary for callus and root formation, the non-acidic Root Riot™ cubes were pre-soaked in white distilled vinegar (5% Acetic Acid) (Phyto Technology Laboratories; Shawnee Mission, KS) and bottom watered biweekly with a 10% solution (100 $ml \cdot l^{-1}$) of white distilled vinegar and deionized water. Trays were placed in randomized blocks containing each substrate and cultivar on a mist bench and monitored to ensure even distribution of mist spray on the foliage.

Shading consisted of 75% black woven shade cloth (ShadeClothStore, Libertyville, IL), laid over the mist bench inside of the double-poly greenhouse. Mist was supplied via Delvan™ 360° solid-cone oil-burner overhead mist nozzles (0.65

L/minute discharge) (Goodrich Corp.; West Des Moines, IA) spaced 76.2 cm apart down the center of a mist bench. During the summer misting was set to occur at a frequency of 12 seconds every 8 minutes (6 per hour), reduced in late September to 8 seconds every 15 minutes (32 seconds per hour), and reduced further to 8 seconds every 30 minutes (16 seconds per hour) from mid-November through mid-February.

Data collection and analysis

For both experiments, on 18 November the number of cuttings successfully rooted 18 weeks after sticking was recorded. A plant was considered rooted if it had at least one root > 1 cm in length. Additionally, two plants per replication were randomly sampled, measuring the length of the longest root. Root biomass was determined using a CPA6202p precision scale (Satorius AG, Göttingen, Germany) after drying at 66°C for 48 hr. Data are expressed as mean ± standard error of the mean (SEM). The data were analyzed by two-way ANOVA using general linear models procedure in SAS, and means were compared using least squared means procedure using SPSS software (SAS Institute, Inc., Cary, NC). A probability value of less than 0.05 was considered statistically significant. When hither-order interactions were non-significant, data were pooled and significant lower-order interactions or main effects are presented.

3.2.2 Finishing Experiment

Of the 478 rooted plants from the previous experiments, 343 (240 rooted in-ground and 103 rooted in containers) were deemed to be healthy and vigorous enough to be used in a follow-up experiment to investigate subsequent plant growth. This was determined using shoot growth, absence of noticeable chlorosis or other discoloration of cutting leaf (less than 20% of leaf area), and no visible rot on leaf, stem, or roots as criteria. Of these, 135 (90 rooted in-ground and 45 rooted in containers) were selected randomly for experimentation.

On 23 November 2011, 45 plants rooted in-ground and 45 rooted in containers (15 of each cultivar) were removed from their rooting substrate and potted up into black plastic C300S #1 Squat (2.5 l) Nursery Pots (Novosel Enterprises; Oberlin, PA) using bark-based organic potting media (Georgia Ground Cover, Inc.; Bogart, GA) amended with Pre-Plant Plus™ 7-5-7 organic pelleted fertilizer (Peaceful Valley Farm Supply; Grass Valley, CA) at a rate of 9 kg m^{-3} growing medium. An additional 45 plants that had been rooted in-ground were selected similarly, left in place at 15 cm spacing, and tagged for identification. Potted plants were supplemented with Phytamin™ All Purpose 4-3-4 liquid fertilizer (Organic Valley Farm Supply, Grass Valley, CA) at a rate of 85 ml l^{-1} water applied bi-weekly and blood meal (BioFert Manufacturing Inc.; Langley BC, Canada) dissolved in water at a rate of 20g l^{-1}, applied bi-monthly from March onward, applied in 1.0 l doses with a 1 liter watering can.

Plants left *in situ* were fertilized with Phytamin™ All Purpose 4-3-4 liquid fertilizer (Organic Valley Farm Supply, Grass Valley, CA) at a rate of 47 ml l^{-1} employing a Dosatron® fertilizer injector (Dosatron International, Clearwater, FL) via Chapin™ Twin-Wall™ Marathon $^7/_8$ " (2 cm) drip tape (Jain Irrigation Systems Ltd.; Jalgaon India), applied once every week for 1 hour (discharge rate of 3.72 l h^{-1}

m^{-1} from late February through the end of the experiment. Blood meal was also top dressed at first sign of flushing (March 10) at a rate of 150 g m^{-2} to provide additional nitrogen to flushing plants. As shown in Table 3.1, amounts of macronutrients provided to plants finished in situ and in containers are within 5% of one another, allowing for accurate comparison of the effects of finishing locations, cultivar, and interactions without significant differences in this variable.

The plants were grown under 30% shade cloth (ShadeClothStore.com, Libertyville, IL),, and protected from the cold with Agribon® AG-30 medium-weight floating row covers (Polymer Group, Inc.; Charlotte, NC) draped over the low tunnel or laid directly on plants in the high tunnel from late November through February. Following Nakamura and Morita (2006), plants were pruned at the appropriate height in the spring to encourage new branch formation. Exposed to rainfall and fertigation, supplemental irrigation was not required for plants finished *in situ* thanks to ample rainfall for the duration of the experiment, which saw average, soil moisture levels (12-inch depth) above 6% (GAEMN, 2012) though container plants required supplemental irrigation 1-2 times per month from March through June applied by hand using a hose.

Data collection and analysis

On 20 June 2012, after plants had flushed, five plants per replication were harvested, taking care to keep roots intact. Leaf area was measured using a LI-3050 conveyor leaf area meter and LI-3000 scanning head (LI-COR Biosciences; Lincoln, NE). Additionally, the total shoot length and number of branches over 1 cm length was recorded. The plants were dried in brown paper bags in an unshaded greenhouse for 10 days, when above- and below-ground biomass was measured using a CPA6202p precision scale (Satorius AG, Göttingen, Germany). Final marketability rates were measured on 28 October 2012 using a visual rating index, assigning plants a rating on a scale from 1-10, with a 1 representing a plant with no aboveground growth and a 10 a plant greater than 30 cm in height with well developed leaves and shoots. Plants receiving a rating of 6 or greater on this scale were considered marketable.

Data are expressed as mean ± SES. The data were analyzed by two-way ANOVA using general linear models procedure in SAS, and means were compared using least squared means procedure using SPSS software (SAS Institute, Inc., Cary, NC). A probability value of less than 0.05 was considered statistically significant. When hither-order interactions were non-significant, data were pooled and significant lower-order interactions or main effects are presented.

3.3 Results and Discussion

3.3.1 In-ground rooting experiment

Daily maximum and minimum air temperatures inside the shaded low tunnels were 31 ± 7 °C and 19 ± 4 °C, respectively, while daily maximum and minimum soil temperatures inside the shaded low tunnels were 28 ± 3 °C and 23 ± 3 °C, respectively (Table 3.2). Daily maximum and minimum relative humidity inside the shaded low tunnel with sand substrate were 96 ± 2 % and 71 ± 26 %, respectively (Table 3.3), while in that with native soil these daily extremes were 93

± 2 % and 68 ± 23 % respectively (Table 3.4). All measured substrate characteristics were different ($P \leq 0.05$) among the three substrates (Table 3.5).

Biofumigation had no effect on any of the root parameters measured among treatments either alone or interacting with other treatments ($p \geq 0.840$, data not shown). Therefore, for further statistical comparisons, this treatment variable was omitted, doubling the number of replications from three to six. All parameters measured were affected ($P \leq 0.05$) by at least one of the remaining treatments tested (Table 3.6). Additionally, two-way interactions were found for root dry weight and longest root length.

Strike rate (rooting percentage) of cuttings rooted in-ground was significantly ($P \leq 0.01$) affected by substrate (Figure 3.2), but not cultivar (data not shown). While strike rates are known to vary considerably among cultivars of *C. sinensis* (Hajra, 2001), there are no published reports of strike rates for these varieties to contradict or confirm this study's findings. Strike rates ranged from ~78% in raised beds of native soil to ~85% in sand on flat ground. While rooting substrates or cultivar treatments did not affect root dry weights, this parameter was affected by the interaction between these factors ($p \leq 0.01$). This interaction appeared to be due in part to differences ($P \leq 0.01$) in root biomass among cultivars rooted in sand and a difference ($P \leq 0.05$) in root biomass of rooted cuttings in sand and soil of the *assamica* cultivar 'Old Savannah' (Figure 3.3). While cuttings of the 'De Renne' cultivar produced greater root biomass rooted in sand than others tested, the 'Old Savannah' cultivar produced more developed root systems in soil than in sand. This result indicates that the sensitivity of root development in *C.*

sinensis cuttings to substrate water holding capacity varies among cultivars and, possibly, varieties. While higher water-holding substrates have been shown to yield rooted cuttings with higher quality root systems (King et al., 2011), this result suggests that this attribute varies intraspecifically in this species, though this may be a result of initial varietal domestication and/or subsequent cultivar selection practices.

Main effects of substrate and cultivar both significantly affected length of longest roots of tea cuttings rooted in-ground ($P \leq 0.05$) due to respective differences between substrate treatments and the cultivars 'Grimball Point and 'Old Savannah' (Figures 3.4a and 3.4b). This result, combined with that of root biomass previously discussed, is similar to that found by Foster et al. (1985), in which cuttings rooted in lower water holding capacity substrates (e.g. sand) produced relatively few long taproot-like roots to reach the moister substrate below at the expense of more broadly developed root systems. Goldfarb et al. (1998) note that this kind of plant is likely to have less vigorous initial growth than one with a more broadly developed root system and is more likely to experience mortality. However, this parameter was significantly affected ($p \leq 0.05$) by an interaction between cultivar and substrate which appeared to be a result of lacking differences among rooting substrate treatments in cultivars 'Grimball Point' and 'Old Savannah' (Figure 3.4c), suggesting that the previous conclusion—that low water-holding capacity properties of the sand cause long, yet poorly developed root systems—may apply only to some tea cultivars.

3.3.2 Container Rooting Experiment

Daily maximum and minimum ambient temperatures were 33 ± 8 °C and 21 ± 4 °C, respectively (Table 3.3) and substrate daily maximum and minimum soil temperatures were 38 ± 13 °C and 21 ± 4 °C, respectively (Table 3.5). Daily maximum and minimum relative humidity readings were 79 ± 12 % and 60 ± 29%, respectively (Table 3.4). Initially, all measured substrate characteristics were significantly different ($P \leq 0.05$) among the three substrates (Table 4). The pH was not significantly different between Ellepots™ and composted bark/perlite mix. An initial difference in pH between Root Riot™ root cubes and other container rooting substrates was negated after soaking in a 5% vinegar solution (Table 3.7).

Both root dry weight and root length were significantly affected ($P \leq 0.05$) by one or both of the treatments tested, while strike rates were not influenced by main treatment effects from either. Meanwhile, two-way interactions influenced all parameters measured (Table 3.8). Container substrates significantly ($P \leq 0.001$) affected root length (Figure 3.5), but failed to influence strike rates or root biomass (data not shown). The relatively low bulk density of the Root Riot™ root plugs is indicative of a relatively high water holding capacity, suggesting this characteristic yielded rooted cuttings with higher quality root systems. However, root length measurements alone cannot provide an adequate assessment of root system quality (King et al., 2011). Therefore, lacking significant results that container-rooting media influenced other growth parameters, this conclusion cannot be drawn with much certainty.

Tea cultivar treatments significantly ($P \leq 0.05$) influenced both root dry weight and root length measurements (Table 3.6), but failed to affect strike rates (data not shown). The cultivar 'De Renne' was in the highest statistical class for each of the significant growth parameters (Figure 3.7). The cultivar had a mean biomass measurement 87.1 mg (75%) greater (Figure 3.6a), and mean length of the longest root 14.1 mm (39%) greater (Figure 3.6b) than the next greatest cultivar mean, though the latter was not significant. In contrast, the cultivar 'Old Savannah' was in the lowest statistical category for both of these measurement parameters, both significant ($P \leq 0.05$) results.

An interaction between container substrate and cultivar were found to be statistically significant ($P \leq 0.001$) for root biomass (Table 3.6) but not strike rates or root length (data not shown). This interaction is likely due to significant ($P \leq 0.01$) differences among rooting media for cultivars 'De Renne' and 'Old Savannah' and an unusually high mean root biomass for 'Old Savannah' cuttings rooted in Root Riot™ organic plugs, which placed this combination of treatments in the highest statistical class for this parameter with rooted 'De Renne' cuttings in all media (Figure 3.7), while significantly ($P \leq 0.05$) exceeding that of 'Grimball Pont'. These interaction effects contrast sharply with those of main effects of either treatment, which correspond with the findings of Larcher and Scariot (2009) who found similar interaction effects on root quality and aboveground chlorophyll content among *C. japonica* cultivars. This highlights the influence of genotype on cultivation response, and suggests that repeated use of a given rooting technique may exert selection pressures within this genus.

3.3.3 Finishing Experiment

Environmental conditions during the finishing period were unusually warm during the winter and spring of 2011-12. Mean daily temperatures between 25 November 2011 and 20 June 2012 were 1.8°C higher than the 1971-2000 average (GAMN. 2012). March was particularly warm, with mean daily temperatures 4.4°C higher than the 1971-2000 average. Again, all measured substrate characteristics were significantly different ($P \leq 0.05$) among the three substrates (Table 3.7). In the experiment, all parameters measured were significantly affected ($P \leq 0.05$) by at least one of the treatments tested (nursery system and cultivar) except shoot length (Table 3.8). Additionally, two-way interactions were found for leaf area, and biomass.

Nursery system significantly ($P \leq 0.05$) affected all measured parameters except shoot length. Leaving cuttings that had been rooted in-ground *in situ* resulted in mean leaf area measurements that were double that of either transplantation treatment, a strongly significant ($P \leq 0.001$) result (Figure 3.8). Leaving plants *in situ* also significantly ($P \leq 0.05$) affected biomass, increasing mean dry weight by at least 261 mg (20%) over transplantation treatments (Figure 3.9a). Root:shoot ratio was also affected by this treatment, with observed ratios reduced significantly ($P \leq 0.05$) with container/container system compared with in-ground/container system while leaving plants *in situ* increased this ratio less significantly ($P \leq 0.10$) (Figure 3.9b). Finally, improved survival of plants left *in situ* was highly significant ($P \leq 0.01$), with survival rate of this treatment increased by more than 10% over other treatments. (Figure 3.9c). While data on finishing tea plants *in situ* is scarce, the negative physiological effects of transplant shock on woody plants are well reviewed in the literature (e.g. Close et al., 2005), and include mortality and/or impaired growth soon after transplantation. While care was taken to minimize these effects, it came as no surprise that leaving the plants *in situ* improved some growth parameters of most cultivars tested.

Cultivar effects were significant ($P \leq 0.05$) on leaf area and dry weight of finished plants. The cultivar 'Grimball Point' had significantly less leaf area ($P \leq 0.05$) and biomass ($P \leq 0.01$) than other cultivars (Figure 3.10a). Differences in leaf area appear to be attributable to significant ($P \leq 0.001$) differences in Leaf Area Indices between cultivar 'Grimball Point' and other cultivars tested (Figure 3.10b). Main effects of cultivar were insignificant for shot length, root:shoot ratio, and survival of rooted cuttings ($P \geq 0.183$). While no studies could be found that look at plant growth of young plants in-ground, these results again closely follow those of Larcher and Scarlot (2009) who found that *C. japonica* cultivars exhibited significant differences in several growth parameters, revealing the strong influence of genotype on cultivation response well past earliest stages of plant growth.

Significant ($P \leq 0.05$) interactions between cultivar and nursery systems were detected for leaf area and dry weight. For leaf area measurements, this effect again was attributable to large and significant ($P \leq 0.01$) differences between the 'Grimball Point' cultivar and other cultivars left *in situ* (Figure 3.10a). Interactions affecting biomass also were a result of significant (P ≤ 0.05) differences among cultivars among plants left *in* situ. This result contradicts the otherwise positive main effects of avoiding transplantation reviewed by Close et al. (2005) and may, in the former instance, reveal more about the 'Grimball Point' cultivar's leaf characteristics than anything else, as there were no significant ($P \leq 0.05$) differences in the number of leaves per plant among varieties, nursery systems, or interactions between these treatments (data not shown). For both growth parameters, these results follow genotype x environment interactions that have been directly linked with leaf size in *Arabidopsis thaliana* (Cookson et al., 2006) and citrus (Iwata et al., 2002) suggesting these results are not atypical.

Finally, while finishing location had no effect ($P > 0.05$) on marketability rates of rooted plants 11 months after rooting parameter data were gathered (data not shown), cultivar (variety) effects were highly significant ($P \leq 0.005$) with marketability rates for var. *Assamica* 'Old Savannah' approximately 50% of either var. *sinensis* cultivar (Figure 3.12). Differences between var. *sinensis* cultivars were insignificant ($P > 0.05$).

3.4 Conclusions

It can be concluded that optimal substrates for rooting *C. sinensis* cuttings are environment- and cultivar- specific. The choice of which substrate to use to root cuttings thus depend on the cultivar and the cost of propagation systems and availability of the materials used in each. Considering both technical and economic factors, rooting plants in-ground and leaving them *in situ* may be a good alternative to conventional container rooting and finishing nursery systems. Further study into yields and finished tea quality of these, and other, cultivars is needed to determine those for which propagation and nursery systems should be optimized to serve in the development of a tea production industry in North America.

3.5 TABLES

Table 3.1: Weekly delivery (g/plant) of macronutrients, March - June

	Fertilizer	N	P	K
In-ground	Phytamin™	2.052	2.735	2.052
	Blood Meal	0.032	0.000	0.000
	TOTAL	**2.084**	**2.735**	**2.052**
Container	Phytamin™	1.913	2.550	1.913
	7-5-7	0.065	0.091	0.065
	Blood Meal	0.104	0.000	0.000
	TOTAL	**2.081**	**2.641**	**1.977**
Variation:		0.12%	3.58%	3.75%

Table 3.2. Average maximum, minimum, and overall air temperatures in experimental rooting locations. Weather station statistics (GAEMN, 2012) are included for comparison

Temp (°C)	Sand	Soil	Greenhouse	Weather Station
Max	28.1	28.6	33.3	31.33
Min	20.6	20.7	22.5	20.8
Avg.	24.3	24.6	27.9	26.0

Table 3.3. Average maximum, minimum, and overall relative humidity (RH) in experimental rooting locations.

RH (%)	Sand	Soil	Greenhouse
Max RH	96.3%	93.5%	89.3%
Min RH	82.5%	79.9%	55.6%
Avg.	89.4%	86.7%	72.5%

Table 3.4. Average minimum, maximum and average 2cm depth soil temperatures in experimental rooting locations.

Soil Temp. (°C)	Sand	Soil	Greenhouse
Max	27.4	27.6	35.2
Min	23.2	23.6	22.3
Avg	25.3	25.6	28.7

Table 3.5. Characteristics of the top 5 cm of two rooting substrates used in the in-ground asexual propagation of *C. sinensis* via cuttings; pH = 4.9

Substrate	Bulk Density ($g\cdot cm^{-3}$)	Organic matter (%)	CEC ($cmol_c\ kg^{-1}$)	EC ($mS\cdot cm^{-1}$)
Sand	1.86 ± 0.11 a[z]	0.1 b	2.1 ± 0.09 b	0.6 b
Cecil soil	1.38 ± 0.06 b	2.9 a	8.2 ± 0.97 a	1.3 a

Table 3.6. Levels of significance of analysis of variance effects for rooting parameters in-ground

Source of variation	Strike Rate (%)	Root dry weight	Longest root length
Substrate	**[z]	NS	*
Biofumigation	NS	NS	NS
Substrate x biofumigation	NS	NS	NS
Cultivar	NS	NS	*
Biofumigation x cultivar	NS	NS	NS
Substrate x cultivar	NS	**	NS
Substrates x biofumigation x cultivar	NS	NS	NS

[z]Significant at P ≤ 0.05, 0.01, 0.001 = *, **, ***, respectively; NS = non-significant at P ≤ 0.05.

Table 3.7. Characteristics of three rooting substrates used in the asexual propagation of *C. sinensis* via cuttings in the container rooting experiment

Substrate	Bulk Density ($mg\cdot cm^{-3}$)	Water holding capacity (%)	pH	EC ($\mu S\cdot cm^{-1}$)
EllePots™	101.7 a[z]	69.3 b	4.31 b	161.4 b
Root Riot™ cubes	36.2 c	82.3 a	6.91 a 4.69*b	65.1 c
Bark/Perlite	141.1 b	58.7 b	4.53 b	296.7 a

[z]Means within columns followed by the same letter are not different using least squred means comparisons at P ≤ 0.05. Values represent means of three observations.
EC = electrical conductivity
*after soaking in 5% vinegar solution

Table 3.8. Levels of significance of analysis of variance effects for rooting parameters in containers

Source of variation	Strike Rate (%)	Root dry weight	Longest root length
Substrate	NS[z]	NS	***
Cultivar	NS	*	*
Substrate x cultivar	NS	***	*

[z]Significant at P ≤ 0.05, 0.01, 0.001 = *, **, ***, respectively; NS = non-significant at P ≤ 0.05.

Table 3.9. Characteristics of two rooting substrates used in the finishing of rooted *C. sinensis* cuttings.

Substrate	Bulk Density ($g \cdot cm^{-3}$)	Organic matter (%)	CEC ($cmol_c\ kg^{-1}$)	EC ($mS \cdot cm^{-1}$)
Cecil soil	1.92 ± 0.18 a[z]	1.8 b	8.1 ± 0.7 b	1.4 b
Nursery mix	1.56 ± 0.25 b	35.7 a	17.3 ± 1.2 a	0.9 a

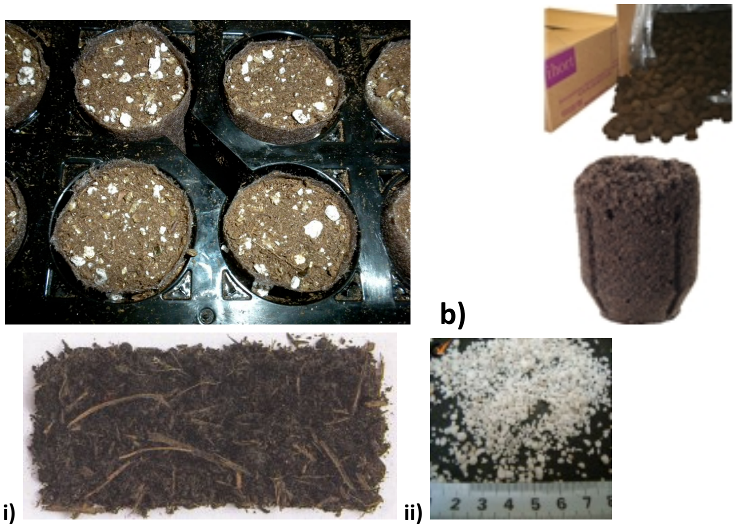
[z]Means within columns followed by the same letter are not different using least squred means comparisons at P ≤ 0.05. Values represent means of three observations.
EC = electrical conductivity

Table 3.10. Levels of significance of analysis of variance effects for finishing parameters

Source of variation	Leaf area (cm^2)	Shoot length	Dry weight	Root:shoot ratio	Marketability
Nursery system	***[z]	NS	*	*	NS
Cultivar	*	NS	**	NS	**
Nursery system x cultivar	*	NS	*	NS	NS

[z]Significant at P ≤ 0.05, 0.01, 0.001 = *, **, ***, respectively; NS = non-significant at P ≤ 0.05.

3.6 Figures



a) b) c) i) ii)

Figure 3.1. Rooting media employed in greenhouse rooting experiment: a) Ellepots™, b) Root Riot™ Organic plant starter cubes, and c) standard mix comprised of composted pine bark (i) and perlite (ii).

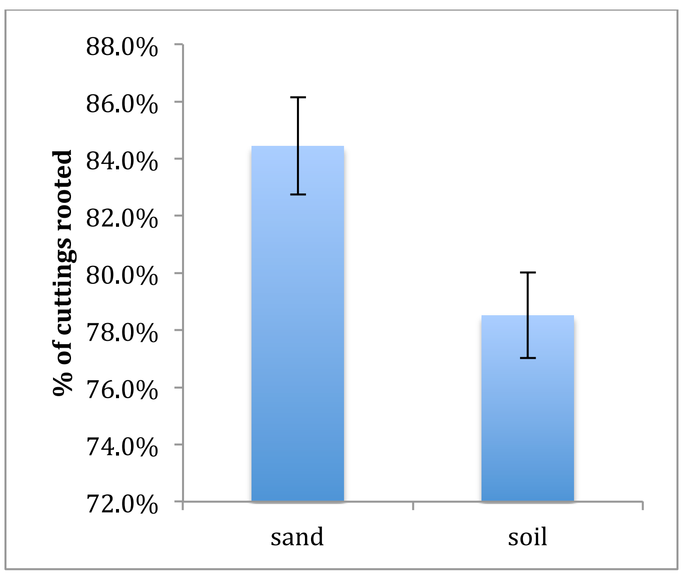


Figure 3.2. Mean (± SEM) percentage of rooted cuttings for each of two in-ground rooting substrates tested (sand on flat ground or raised bed of native soil), n = 90.

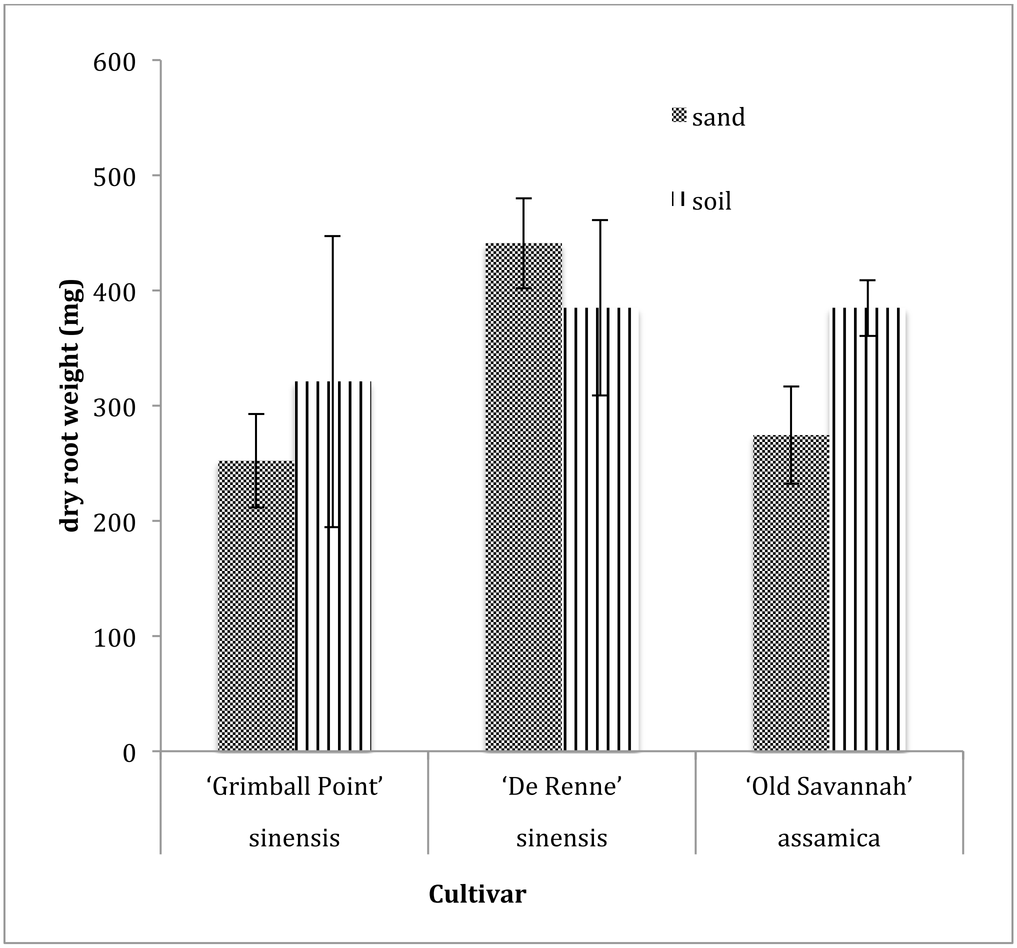


Figure 3.3. Mean (± SEM) root dry mass of cuttings of three cultivars placed in one of two rooting substrates tested (sand on flat ground or raised bed of native soil), n = 12.

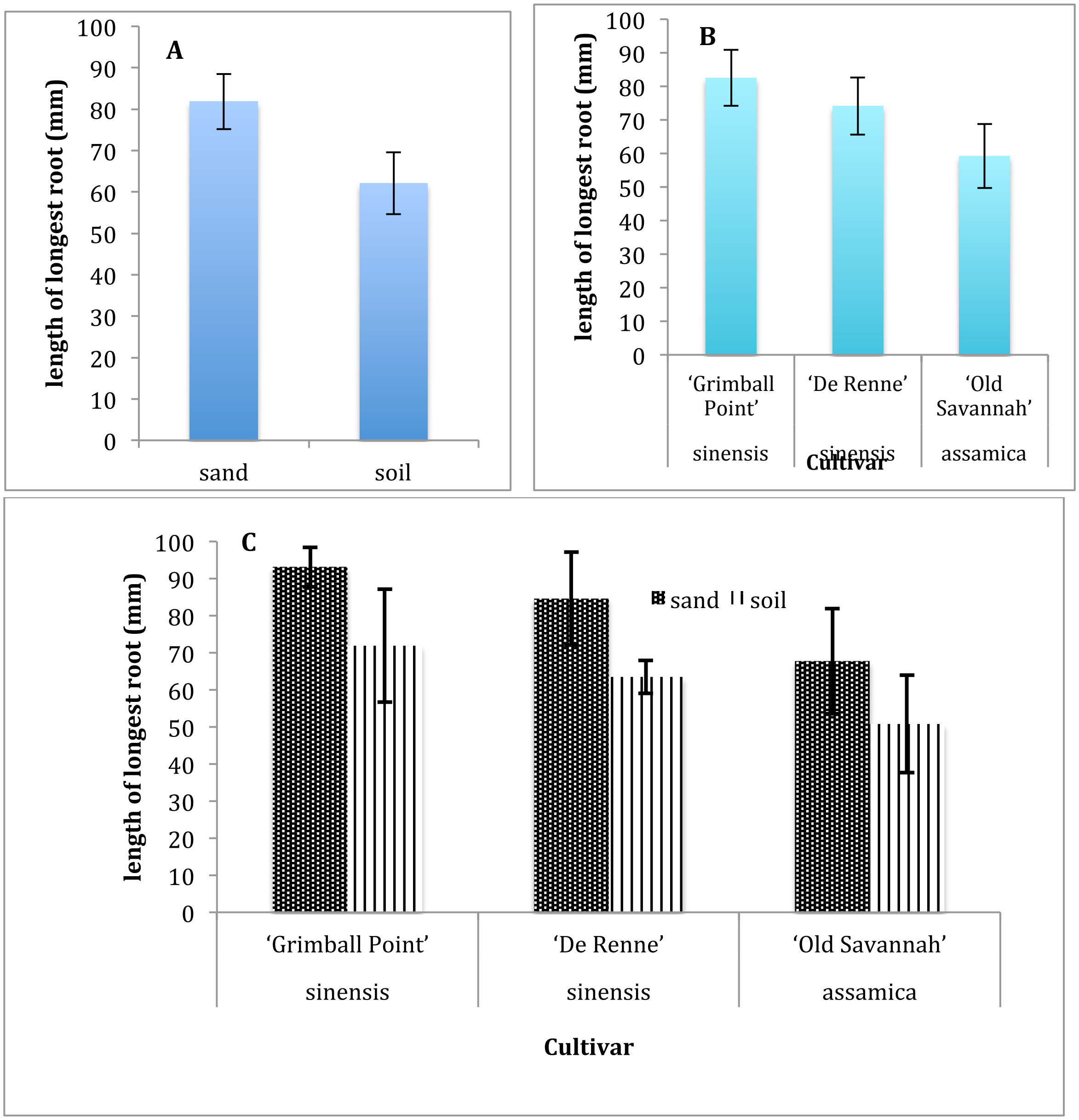


Figure 3.4. Mean (± SEM) length of longest root of cuttings: (A) between in-ground rooting substrates, n = 36; (B) among cultivars, n = 18; and (C) among all treatment combinations, n = 12.

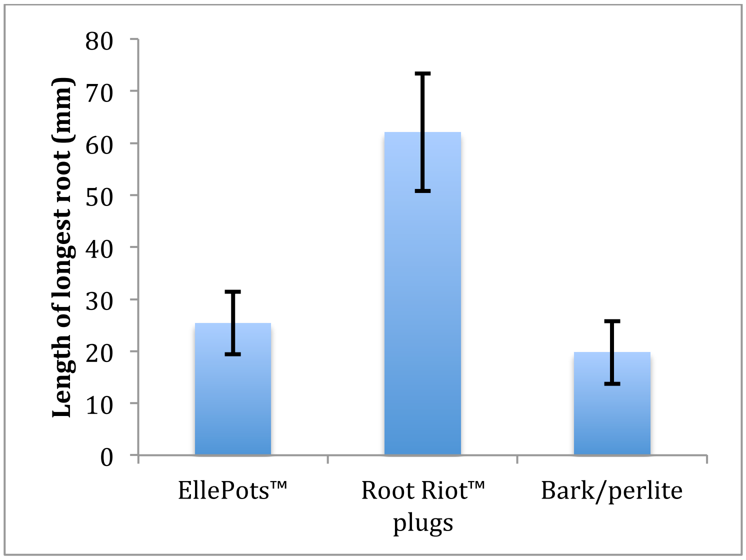


Figure 3.5. Mean (± SEM) length of longest root of cuttings placed in three rooting substrates tested, n = 12

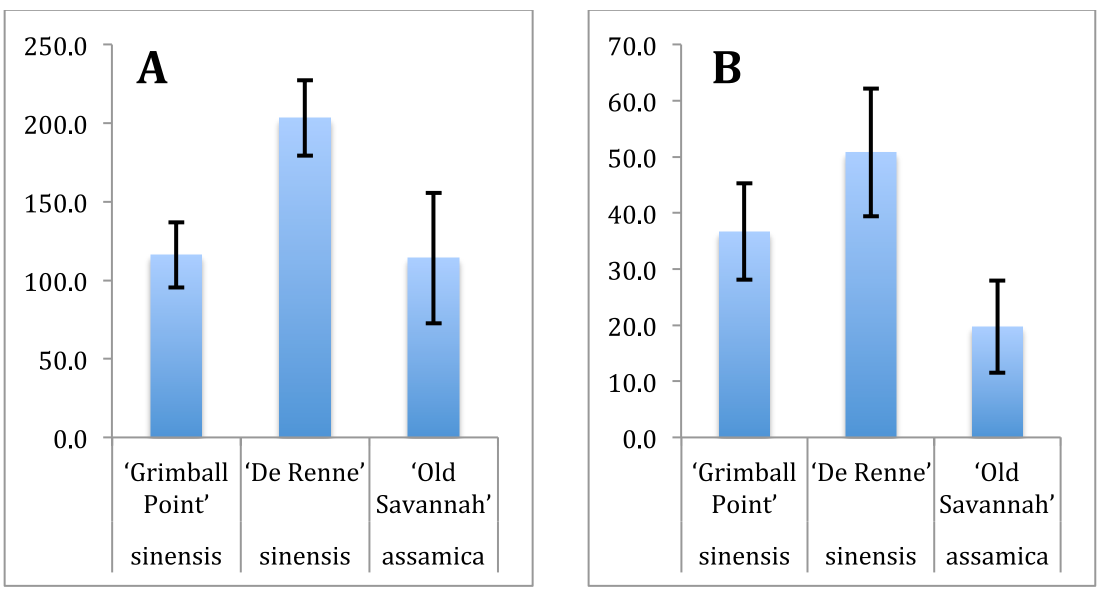


Figure 3.6. Mean (± SEM) root biomass (A), and length of longest root (B) for each of three cultivars tested, n = 9

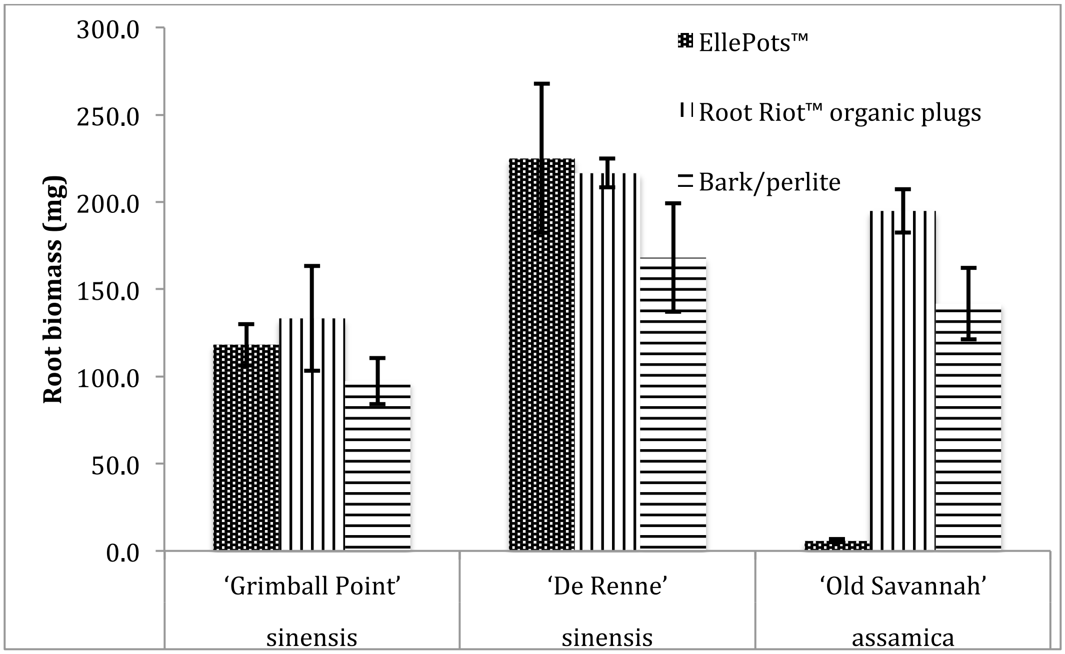


Figure 3.7. Mean (± SEM) root biomass for each of three *C. sinensis* cultivars tested rooted in one of 3 rooting substrates in containers, n=9

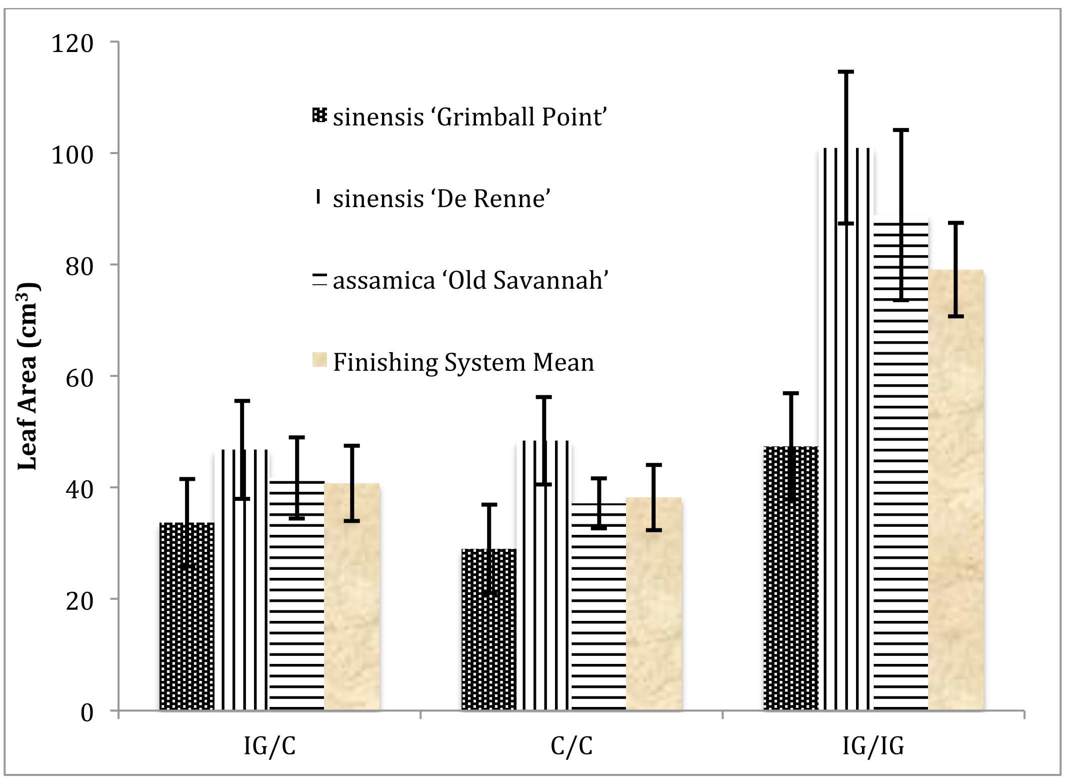


Figure 3.8. Mean (± SEM) total (A) and leaf area (cm^2) for each of three nursery systems tested (rooting/finishing locations: IG/C = in-ground/container, C/C = container/container, IG/IG = in-ground/in-ground), n = 15

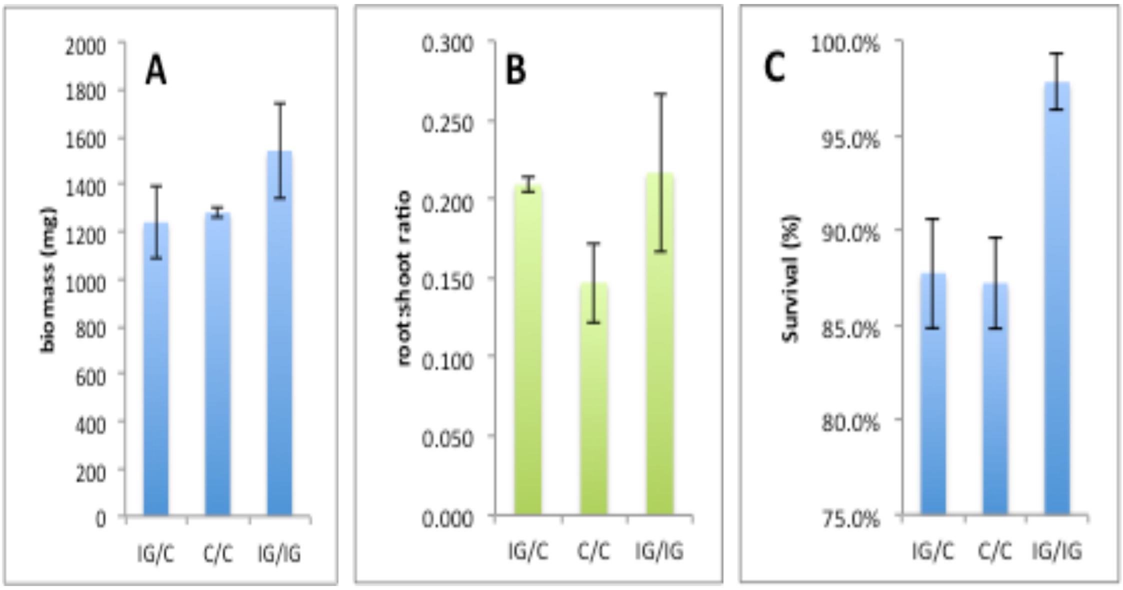


Figure 3.9.Mean (± SES) biomass (A), root:shoot ratio (B), and survival % for each of three nursery systems tested (rooting/finishing locations: IG/C = in-ground/ container, C/C = container/container, IG/IG = in-ground/in-ground) n = 10.

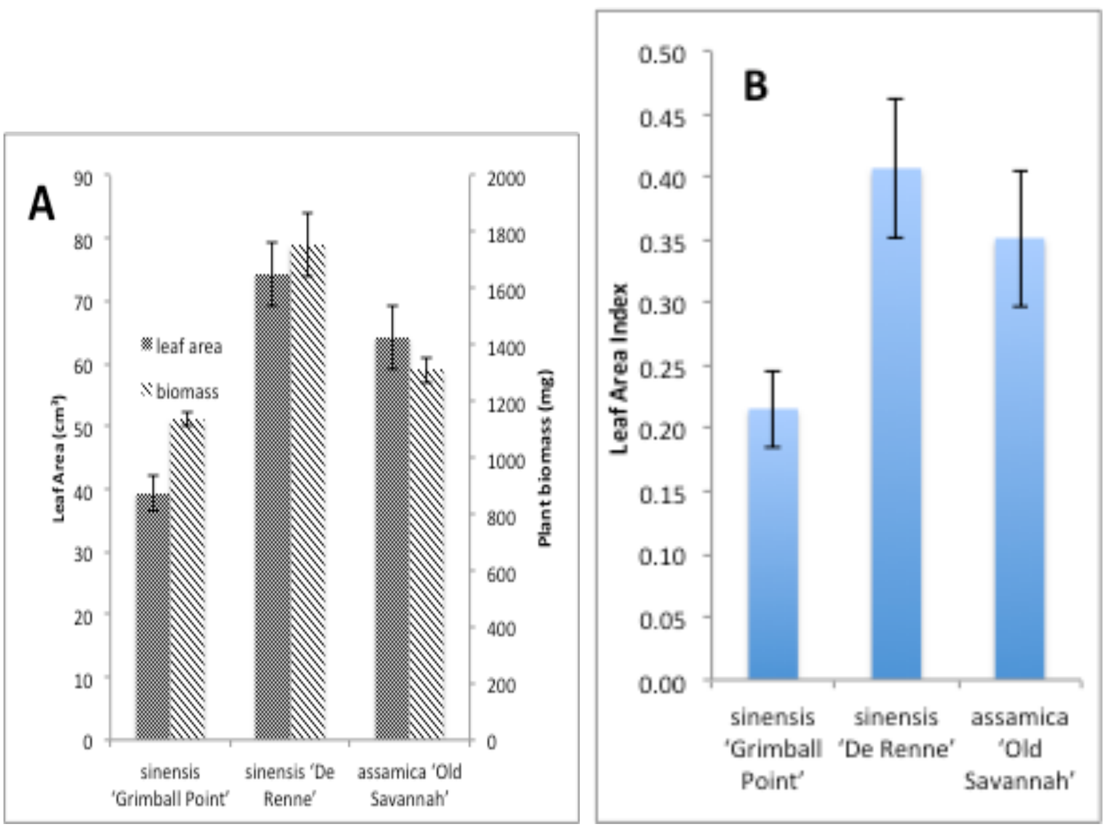


Figure 3.10. Mean (± SEM) leaf area and biomass (A) and Leaf Area Index (B) for each of three *C. sinensis* cultivars used in the finishing experiment, n = 15.

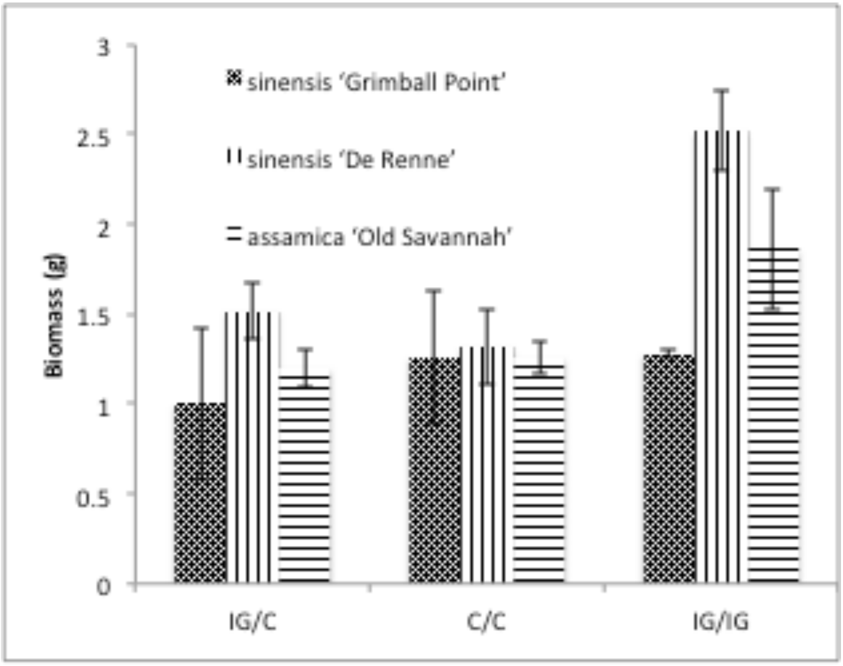


Figure 3.11. Mean (± SEM) biomass for each of three cultivars grown under three nursery systems tested (rooting/finishing locations: IG/C = in-ground/ container, C/C = container/container, IG/IG = in-ground/in-ground) n = 10.

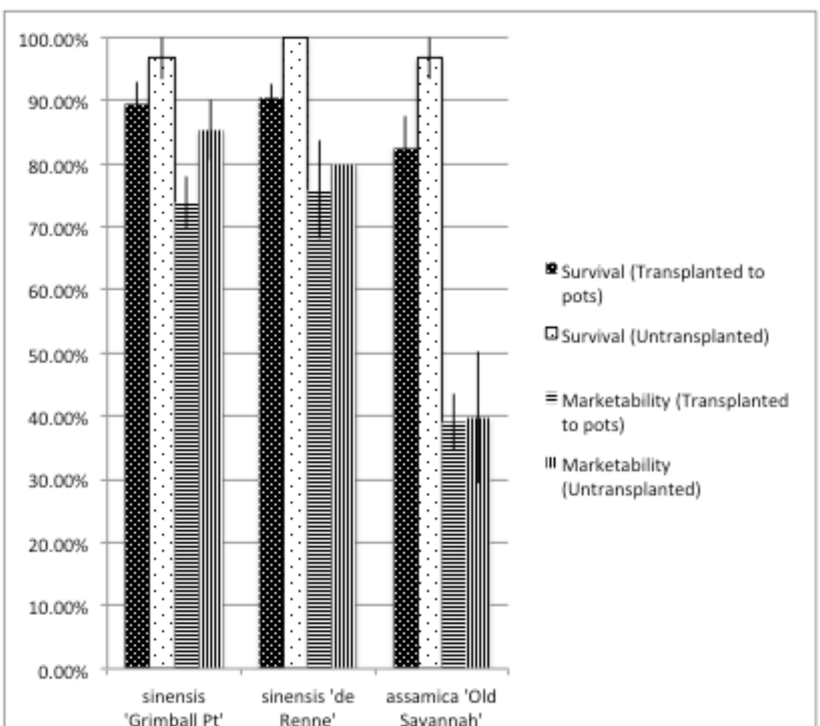


Figure 3.12. Mean (± SEM) survival and marketability rates for each of three cultivars finished for 11 months (n = 45). A marketable plant was one receiving a visual index rating (VIR) score of 6 or greater on a scale from 1-10.

CHAPTER 4

TEA NURSERY ECONOMICS: AN ANALYSIS OF THREE PRODUCTION/DISTRIBUTION SYSTEMS

4.1 INTRODUCTION

After water, tea is the most widely consumed beverage in the world (Hajra, 2001). Tea (*Camellia sinensis*) is an evergreen woody shrub that grows in humid subtropical to tropical climates. Moderately hardy, tea is produced commercially in parts of China, South Korea, and Japan where extreme low temperatures reach down to 0°F, comparable to areas as far north as Tennessee and Virginia (World Climate, 2010). In most parts of the southeastern US, adequate rainfall enables the crop to be grown without irrigation, but supplemental irrigation would be recommended for most areas in dry years to increase yields (Hajra, 2001). It can be grown in any upland soils and unlike many crops, and can be grown on relatively steep slopes normally unsuitable to agricultural purposes (Hajra, 2001).

Better yet, in recent decades Americans have increasingly developed a taste for tea; whether for its taste or its numerous health benefits, the consumption of tea in the US has quintupled in the past 20 years (den Braber et al., 2011). During this time many Americans have also developed a taste for artisanal food products produced locally, regionally, or domestically that are not normally available in supermarkets (Martinez, 2010). Together, these trends have positioned American-grown tea favorably; handpicked American-grown tea currently retails from anywhere between $240 and $4,200 per pound (Sakuma Bros., 2012; Cheng, 2012). This is very high for a crop that yields hundreds of pounds of product per acre each year; many tea-producing nations average close to 1,000 lbs. per acre of made tea. Unfortunately, North America lacks the productive capacity to supply prospective tea growers. As commercial cultivars become more accessible, the next logical step involves multiplying and distributing liners to prospective growers.

Underlying the development of a sustainable tea industry in the southeastern United States (or, more simply, the Southeast), the development of efficient and appropriate propagation and distribution systems of liners to aspiring growers is needed. Currently tea liners are generally available only through a few retail container nurseries in the United States, an untenable option for those looking to acquire the thousands of liners needed to start a commercial tea orchard. To better understand this situation, the costs of production of tea liners using alternative propagation systems were calculated at multiple scales of production, applying both private (e.g. corporation) and semi-public (cooperative) business models.

While field nurseries are generally fewer in number than container nurseries for woody ornamentals in the Southeast, there is some evidence that field nurseries are more profitable, on average, than container nurseries. A recent analysis of ornamental plant nurseries in Florida found that 100% of field nurseries of woody ornamentals in the state were highly profitable (with returns to capital of at least 15%) compared with only 24% of container nurseries of this plant type (Hodges et al., 1997). Based on the results of propagation experiments conducted by McConnaughey and Ruter (unpublished), field propagation methods appear to be a viable, if not preferable, alternative to conventional container/greenhouse methods for Camellia liner production. These methods could be applied to the conventional, wholesale nursery business model, where liners are rooted in-ground and then shipped to the customer. These techniques may also make on-farm propagation systems (where propagation activities occur on-farm rather than in nurseries) a viable alternative to centralized, wholesale nursery production for easy to root plants like Camellias. In this model, cuttings would be supplied to growers instead of liners, and the grower would handle propagation activities with a limited amount of technical support. The cost of producing, handling, and delivering cuttings is expected to be a small fraction of that for rooted liners, presumably bringing startup costs within the comfort range of (prospective) small farms in the region.

Alternative production systems in the Southeast have been analyzed economically in the literature, but these have primarily been comparisons of pot-in-pot production systems with conventional in-field and above-ground container systems (e.g. Adrian et al., 1998; Hall et al., 2002). These all rely on conventional container propagation systems for liners that are potted up and grown on to #1 or #3 liner sizes. Mid-Southern US nurseries may gain a competitive advantage if they can produce their own nursery liner stock plants rather than outsource them. While this study did not address the production of more commonly grown woody plant species in Southern nurseries, it can provide some insight into the economics of integrating stock plant liner production with conventional nursery production, particularly for ornamental Camellias.

Traditionally, nurseries provide ready-to-plant liners because propagation is often difficult with woody plants, requiring specialized equipment and knowledge. Like many Camellias, tea stands in exception to this rule. Plants are very easy to propagate from cuttings and could be effectively done by any experienced horticulturist or farmer. Cutting material could be marketed instead of finished liners, similar to selling seed to a crop farmer. The costs of liner production—beyond the maintenance of stock plants and distribution of cuttings—become costs of tea production rather than liner production. This alternative distribution system could greatly lower investment costs of tea as a new crop, at least in the short term.

Furthermore, economic studies on nursery systems in the literature are characterized by heavy reliance on chemical fertilizers and pesticides rather than organic or Integrated Pest Management (IPM) programs. While economic theory has identified thresholds that delineate when treatments become more economical than inaction and visa versa, these have been primarily explored in the literature for agronomic crops rather than nursery species. Estimations of costs associated with IPM programs in nurseries were not found in the literature, though horticultural aspects of IPM programs in Southern nurseries have been discussed (Mizell and Short, 2008; Driver and Greer, 2001). The adoption of IPM programs by nurseries in the US has been surveyed extensively but recommended practices are generally determined by their popularity (Chappell et al., 2011) or the desires of growers (Sellmer et al., 2004) rather than economic estimations. This study incorporates organic liner production methods and an IPM program in the maintenance of stock plants using tea IPM guidelines from Zeiss and den Braber (2001). While direct comparisons between these alternative horticulture systems and conventional production systems are not made, the costs of production can be compared with those from other studies to determine whether significant differences exist.

Microeconomic theory holds that firms decide the quantity to be produced (or scale of production) based on marginal costs and sales price, which do not consider fixed (investment & overhead) costs. Marginal costs are the changes in total costs that arise when the quantity produced changes by one unit. In other words, it is the cost of producing one more unit of the good (Sullivan and Steven, 2003). The range of viable scales of production for a firm is limited by marginal costs relative to the selling price of the good. If marginal costs of production are lower than marginal revenues then accounting profit is being generated; if market power can be harnessed to raise prices beyond average total costs then economic profit is generated.

By comparing marginal costs with marginal revenue, or the additional revenue that would be generated by increasing product sales by one unit, optimal and shutdown scales of production can be identified based on unit product prices. In a perfectly competitive market, a firm sets prices according to the marginal revenue function at a given level of output. However, an emerging tea liner market in the USA would not be expected to be very competitive for many decades, if ever. Instead, this market would most likely exhibit characteristics of a monopolistic market, where firms can set prices above marginal costs, set instead at or above average (unit) total costs. While prices can be set above average total costs in the short run, it cannot exceed this in the long run due to freedom of entry of new firms (Sullivan and Steven, 2003).

Ultimately, the objectives of this research were to estimate costs of production for field-ready tea liners at variable scales of production in USDA plant hardiness zone 8 (USDA, 2012) of the Southeast employing alternative liner production systems and business models in order to identify viable scales of production and the impact of propagation system/business model factors on investment cost for aspiring tea farms.

4.2 Materials and Methods

Three different economic models were developed for this evaluation of tea nursery and liner distribution systems. Two conventional model liner nurseries were developed, using either container or field propagation methods. A third model was developed in which the model's central "nursery" solely serves to provide cuttings to growers who propagate them on their own land. These models will henceforth be referred to as "container nursery", "field nursery" and "cooperative", respectively.

In the cooperative model, producer and consumer share the costs of liner production. Here, on-farm costs of liner production are calculated separately from nursery (stock plants) costs. These growers are not producing liners; they are producing tea. Their investment is in tea production of which liner production is but one small part. This is similar to a vegetable farmer electing to start a crop from seed rather than purchasing field-ready liners. Key farm investments like tractors, vehicles, and other equipment are part of a larger investment in tea (and possibly other crops) and can thus be excluded from the grower's costs of liner production.

While nursery and growers are cooperating in this model, such an entity may or may not utilize the cooperative business structure. One party with enough stock plants could simply sell cuttings to interested growers. A cooperative model, however, can provide some proprietary control on the cultivars beyond limitations in the USDA plant variety protection statutes. Whichever business model is employed, the model will be referred to as the cooperative model. The term "cooperative nursery" will only be used in reference specifically to the central repository of stock plants and trial plots where cuttings are produced, and not the model as a whole. An outline of major components of each model can be found in Table 4.1.

4.2.1 Enterprise Budgets and Evaluative Criteria

Enterprise budgets were developed using Microsoft® Excel™ spreadsheet software for each of the models for analysis. An enterprise budget includes all the costs and returns associated with producing one enterprise in some particular manner (Cross et al., 1988). In this study, tea cuttings or liners are the enterprise, and separate budgets were developed for establishment of stock plants and research activities in each of the models employed in the analysis. The budgets are presented in income and expense format in Appendix C in which product and inputs are grouped by category. Each enterprise budget is for a calendar year, and all budgets are prepared as of the end of their respective years. Model costs of production are evaluated based on two criteria: (1) from the nursery perspective, using profitability as the primary criteria, and (2) the impact on the cost of investment for a farmer adopting tea as a new crop in the Southeast using the net present value (NPV) of each investment option.

Production of tea liners propagated asexually from cuttings is derived practices and studies reviewed by Hajra (2001), nursery cost accounting studies for other woody plants in the Southeast (e.g. Jeffers et al, 2010; Hinson et al., 2008) and, more critically, from data collected and costs incurred by McConnaughey and Ruter (unpublished). In the latter, single-node tea cuttings were propagated in three rooting substrates in plastic containers in a large greenhouse under mist as well as in-ground in raised beds of native silty clay-loam Cecil soil or an 4 inch layer of river sand, covered in landscape fabric in shaded low tunnels with mist.

Costs of production were calculated for four production levels: (a) low (22,500 liners/year), (b) medium (225,000 liners/year), (c) high (1,125,000 liners/year) and (d) very high (2,250,000 liners/year). The Capital Recovery Method was used to compute depreciation and interest (Boehlje & Eidman, 1984) on capital costs. Costs at these production levels were used to estimate annual accounting cost functions for scales of production within this range.

Costs are calculated per unit (liner) and per unit area. Liner/cutting prices were set using either total unit costs of production or observed prices of substitutes (e.g. blueberry liners) using price elasticity of demand calculations for wholesale liners of other woody crop species (Pennis et al., 2012). The net present value (NPV) of monetary impacts on farmer investment costs of purchasing, rather than propagating, liners were calculated using the incremental cost method (Garrison et al., 2012)

4.2.2 Variable and Fixed costs

Before identifying the variables that are necessary for production, it is first necessary to understand the economic significance of variable and fixed costs. Variable costs change with the level of output and from year to year. They are a function of the amount produced, and they occur only if the producer produces a product. Examples of such costs common to many farming operations are seed, fertilizers, pesticides, fuel, hourly labor, etc. Fixed costs occur whether or not the producer decides to produce and regardless of the level of production. Producers can benefit from economies of scale as fixed costs are spread evenly across more units of production per unit of area, reducing the unit costs of production. Examples of fixed costs are salaried labor, depreciation, interest, insurance, rent, etc.

The distinction between variable and fixed costs is important in decision-making. A general principle in economics is that a manager should consider only variable costs when making short-run production decisions, as the fixed costs will remain regardless of the level of production (Boehlje & Eidman, 1984). The variable inputs required for production cycles of 15-19 months will comprise the variable costs for the model enterprise. Some of these variable costs will be incurred only once, while others will be linked with more than one period of production. Fixed costs that are incurred by either economic model would be spread out among tea seedling production.

4.2.3 Growing System Descriptions

Each model was designed to contain up to 2 acres of stock plants and trial plots and to have the ability to produce quantities of tea liners up to its respective scale of production. While production levels of greater than 1,125,000 liners/year may or may not be economically viable, very few wholesale nurseries operate at such immense scales of production (USDA, 1999; Williamson and Castle, 1989). Therefore, scales of production beyond this quantity were included for evaluation purposes, but were considered infeasible in the short term. Major components of each model are depicted in Table 4.1.

In each model, around 11,500 single node cuttings are used to produce 9,000 stock plants of 2-3 cultivars from nurseries in Hawaii. Cuttings are propagated according to the model's propagation system and established on site during 4 years preceding the start of production activities. This quantity provides enough propagation material to produce up to 2.5 million liners/year based on estimations of 150-300 semi-hardwood cuttings per plant reported by Zeiss and den Braber (2001) and observed by McConnaughey and Ruter (unpublished). These liners are then established in the field for 3 years until the plants are mature enough to sustain regular harvesting of cutting material. Stock plants are grown in double, offset rows with plants spaced 4-ft apart in 6-ft-wide rows. Very similar to field establishment of plants for commercial tea production, this process used establishment costs of tea from Monks (2000) for subtropical conditions in Tasmania.

Cutting material is harvested by hand, sprayed with water from a hand-held spray bottle, placed in durable black plastic bags, and stored up to 8 weeks in a cooler maintained at 4°C until ready for sticking or shipping. Tea cuttings maintained in this manner show little to no damage after in this period of time and root at no different frequency than freshly collected shoots (Golding et al., 2009). Cuttings are harvested in mid-June and stuck in late June, standard for Camellia propagation in the Southeast (Peper, 2012). Single node cuttings are prepared from semi-hardwood prunings and placed into a plastic cooler with coolant packs. These are transported to the propagation area where cuttings are stuck in either containers or directly in-ground in the field, and overhead mist irrigation initiated.

Production blocks in each model were designed based on the resources required to produce 22,500 field-ready plants according to the model's production methodology. This is the average quantity prospective tea growers were assumed to require based on the average scale of tea production enterprises started in the USA since 1990 (approximately 2.5 acres).

In the model container nursery, production blocks consisted of 2,880 ft^2 of climate controlled greenhouse space, 14,400 ft^2 of shaded areas, and mixing and flat/pot filling areas to total 19,200 ft^2 or 0.45 acre rounded up to ½ acre below large scales of production to account for space between greenhouses. At small and medium scales of production, standalone one-door double-poly Quonset greenhouse and five 30-ft x 96-ft two-door shaded high tunnels, both with landscape fabric-covered gravel floors are used. At larger scales of production, multispan greenhouses with polycarbonate roofing and multiple doors are used. Within the greenhouse, cuttings are propagated in 50-cell plastic trays on 10-ft x 5-ft plastic stationary mist benches arranged so propagation areas occupy 70% of the standalone greenhouse and 75% of the multispan, whereas containerized plants occupy 65% of shaded areas. Cuttings are rooted in conventional substrate comprised of composted pine bark mixed with perlite (9:1 ratio by volume) on mist benches in greenhouses where they remain from late June through early winter (36 weeks). Propagation greenhouses are thus partially empty beginning in January and completely empty by mid-February until mid-June (16 weeks), when the facilities may be used to for another economic activity, such as producing annual bedding plants for spring sale. Beginning in late January, rooted liners are transplanted to 6-inch (13.2 cm) pots and moved to protected shaded areas (20% shade) during periods of mild weather. High tunnel-frame shade houses are used for production levels up to 250,000 liners/year. Higher production levels utilize more permanent net houses made of durable wooden or steel posts and a steel cord frame roof. Containerized tea liners would occupy shade houses for 35-52 weeks per year, depending on their destination.

Meanwhile, the model field nursery and on-farm component of the model cooperative use shaded low tunnels equipped with overhead mist sprayers to root tea cuttings. Cuttings are rooted directly in raised beds of native soil; rooted liners are left *in situ* until field-ready. Field preparation activities are extensive: the mature cover crop (most likely buckwheat) is mowed with a flail mower and incorporated into the soil with a disk harrow in late May/early June. A week or two later, fertilizer and soil amendments are applied as needed and the field is tilled and shaped into raised beds. Drip irrigation lines are laid by hand and landscape fabric is laid mechanically. For calculations of work time required, tractor operations were calculated performed at 2-3 mph depending on type of operation, based on mechanical limitations, and are assumed to involve an assistant for any precision work (e.g. fertilizer spreading).

Just prior to sticking, the low tunnel frame is erected, overhead mist irrigation system installed, and securely covered with shade cloth. Cuttings are placed at 6 inch spacing in offset rows at the rate of 15 per linear foot with 4-ft-wide beds. For each cutting, a small cut is made into the fabric and the cutting set in place through it. Including wheel-rows from tractor operations (6-ft-wide rows), this requires 14,940 sq. ft. of land (0.34 acres) to produce 22,500 marketable rooted liners given strike and marketability rates used in the analysis, given in Table 4.2. Field-grown liners are harvested beginning in September the year following propagation, 15 months after sticking. To prevent disease build up in the model field nursery where propagation activities are ongoing, a 4-year rotation system is employed, trebling the propagation area requirements. Field-ready liners are generally 12-24 in. (30.5-71 cm) in height, optimally straight and erect, with a pencil thick and brown main stem at the collar region (Hajra, 2001).

4.2.4 Assumptions

Capital: While many growers use their own capital to fund long-term investment and operating expenses, we include expenses for working capital and investments in machinery and equipment. Interest rates used are 3% for operating capital and 2% for intermediate and long-term capital. These represent real interest rates over the previous 5 years (2007-2012) that have an average value of 2.5% (Trading Economics, 2013) and. Real interest rates are determined by subtracting inflation rates from nominal interest rates. Real interest rates are appropriately used in evaluating the costs and returns of establishing stock plants over a 14-year period of time when price levels are held constant. For each model nursery, operating capital interest is treated as a cash expense. Intermediate and long-term capital are assumed to be provided by the owner, so interest on this capital is treated as a non-cash expense. In cooperative model, the grower's vehicles and basic farm equipment (tractor, rotovator, chisel plow, flail mower, manure spreader, and disc harrow) are assumed to be sunk costs to the grower rather than costs of production.

Land: Prices of land and property taxes are based on averages for mostly rural counties in the state of Georgia (UGA, 2012). The property tax rate for the model container nursery assumes greenhouses are considered real estate. Costs of land used for on-farm propagation are considered sunk costs to the grower. At maximum feasible capacity, the model container nursery was designed to encompass 23.5 acres with 19.8 acres used for production and the remaining 3.7 consisting of facility structures, a pond, and roads. The model field nursery encompasses 55 acres with 51.5 acres in production and 3.5 acres of facility structures, a pond, and roads. In contrast, the model cooperative nursery comprises only 5.5 acres, consisting of stock plants, roadways, facility structures, roadways, and a pond. The medium scale nurseries were about half this size, while small-scale nurseries about half of that, or a quarter of the large-scale nursery. Land costs are the primary overhead expense associated with farms in the cooperative model; average cash rent prices paid in Georgia for irrigated land ($1,485.84/acre/year) was used (Escalante, 2010). While only 0.34 acre is required for the field propagation of liners, in the on-farm component of the cooperative, this was rounded up to 0.5 acres for the calculation of annual rent.

Labor: Growers and their family members provide some of the labor force. Additional labor is hired by the hour as required for getting activities completed in a timely manner. Hired employees usually are a combination of full time and part time. All hours required for production activities are charged to the enterprise, but the on-farm propagator does not allocate funds for overhead costs (e.g. salaries and office expenses) prior to the first year of harvesting tea for sale. Based on observations made in the McConnaughey and Ruter (unpublished) study, sticking rates per worker were assumed to be 200/h for field propagation and 300/h for container propagation with the help of media mixing and tray filling machines found only in this model.

In both nursery models, 1 hourly worker is employed per 100,000 plants produced throughout most of the year and an additional 3-4 employed during sticking in June-July, peak harvest time in September-October and 2-3 during transplanting in the winter. Six additional wage workers/22,500 plants are employed during shipping times. General hired labor used in establishment and production is valued at $11.30 per hour. This wage rate can be thought of as the net cost for hired labor paid a cash wage of $10.00 per hour—the overall average hourly wage reported for laborers in the Florida horticulture industry (Hodges and Haydu, 2012)—plus an additional $1.30 per hour for payroll expenses. The cash-flow analysis assumes all general labor is hired as a cash expense, paid weekly. At medium and largest scales of production in this analysis, supervisory labor costs are required at a rate of 1 supervisor for every ten production blocks (±5) in operation. In addition to overseeing up to 10 workers at a time during busy periods, supervisors also have clerical and other duties to assist the manager. These supervisors are paid an annual salary of $17,673.50 that includes $12,000 after-payroll expenses ($13,429 total) plus $4,244 annually for single healthcare coverage (employee pays $1,053 annually of the $5,297 total cost) (Claxton et al., 2012).

Both of the conventional model nurseries employ 2 primary salaried employees (manager and plant propagator) at very small scales of production (< 225,000 plants/year) and 2 secondary salaried employees (assistant manager and secretary) plus 1 labor supervisor per 225,000 plants produced annually above this level. The baseline owner-operator salary, after payroll expenses, is assumed to be $36,000 for each nursery model and $18,000 for the cooperative model, at the smallest scale of production. These are doubled for the medium scale and quadrupled for the largest scale. These costs are increased by 10% plus $229.50 for payroll expenses that include 4% for workers compensation insurance (GADOI, 2013), 2.7% on the first $8,500 earned per employee for Georgia State Unemployment Insurance tax (GADOL, 2011), and 5.87% for Federal Unemployment taxes (IRS, 2012). An additional $15,199 for family healthcare insurance (Claxton et al., 2012) is also included. Thus total annual owner-operator salaries including payroll expenses and healthcare costs are $55,028.50 and $35,228.50 for the smallest-scale nursery and cooperative models analyzed, respectively. Secondary salaried employees (assistant manager, clerical workers Employee salaries double for every scale increase in production (e.g. from small to medium).

Machinery: Machinery and equipment operation costs are based on agriculture engineering estimates (Cross et al., 1988; Schnitkey, 2012). Purchase prices, salvage values, useful lifespans, annual hours of use, and field capacities were obtained from experienced growers and machinery dealers. The budget assumes that growers who purchase cuttings for on-farm propagation own, or have access to, a 50 PTO HP tractor, rotovator, chisel plow, flail mower, manure spreader, and disc harrow, reflecting the assumption that prospective tea growers will already be involved in some sort of crop farming. Tractor requirements assume it is powerful enough to operate a 6 ft (1.8m) wide, 2-inch (5.1 cm) straight point chisel plow at a depth of 12 inches (30.5 cm) at a speed of 3 mph (4.8 kmph) in clay-loam soil, allowing for a tillage speed of 1.8 acres (0.73 ha) per hour (Sumner and Williams, 2007).

One or more ½ ton pickup truck and/or gas utility vehicle is used in both nursery models for tasks related to tea liner production and general maintenance, depending on scale of production, based on reports by McConnaughey and Ruter (unpublished), Monks (2000), and Brumfield (2008). New pickup trucks were priced between $25,000 and $35,000 each depending on the quantity purchased. In each model, the truck is used to transport workers, supplies, and cutting material between the stock plants field and central storage facility. The edge of the stock plants field is assumed to be at least ½ mile (and no more than 2 miles) from the production areas to prevent the transmission of pests or diseases the stock plants or their soil may harbor. The truck is also used periodically to pick up supplies as needed from a local hardware store, irrigation/garden supply center, etc. assumed to be 15 miles from the farm. The model container nursery also uses the truck for repairs and other maintenance tasks associated with greenhouse upkeep, and to transport soil media, fertilizers, and containers from the storage facility to the greenhouses. Each model also uses one or more gas-powered utility vehicle for stock plant maintenance and to collect cutting material from stock plants and transport them to a central storage facility. The model field nursery also uses utility vehicle(s) for transporting cuttings and workers during sticking as well as to collect bare-root liners from the field and transport them to a central packaging facility. In the model container nursery, one additional truck and utility vehicle is required for every 10 greenhouses in production, or per 225,000 plants produced annually. The model field nursery only requires an additional truck at or near productive capacity (900,000 plants/year was used) but requires additional utility vehicles for every 90,000 plants produced annually. The model cooperative nursery does not require more than one truck at any scale of production, and additional utility vehicles are required for each 450,000 plants produced annually. Truck and utility vehicle mileage is broken down by use in Table 4.3.

Materials re-usage: Low tunnel materials and irrigation systems used in field propagation systems can be re-used for multiple production cycles. The exact amount of re-usable material available for each new production cycle was calculated using the standard exponential decay function. In the model field nursery, the total quantity of these materials is maintained at the assumed production level, but as much material as possible is re-used from previous production cycles. Once a material has passed its "half life" – the number of production cycles after which at least half of the original supply is expected to have been irreparably damaged – the remaining used material was replaced to avoid high failure rates during production. Half-lives of rebar, shade cloth, and PVC were assumed to be 20, 7 and 2 production cycles, respectively. Lifespans of irrigation supplies varied by part, with half-lives ranging from one (mist nozzles) to six cycles (multi-stage irrigation timers). In the model cooperative, materials with half-lives of five or more production cycles would be returned to the central nursery after each cycle and re-used in preceding cycles.

Irrigation: Stock plants are irrigated using drip irrigation during and after establishment in all models. Also in each, overhead mist using poly mist nozzles with emission rates of 0.5 gpm is employed during the 3-4 month long rooting phase. While the container nursery model employs conventional overhead irrigation during the 10-16 month finishing phase, both models using field (in-ground) propagation instead employ drip irrigation during this production phase. The water source was assumed to be a well of about 200 feet (this would vary according to location). The primary irrigation system, for liner production areas, was adapted from Hinson et al. (2008) in which a 5hp electric pump supplies water to liner production areas, with backup from a tractor power takeoff (PTO). A secondary well with a 1hp electric pump supplies water to the distant stock plants. Water was pumped directly onto the crop or into a pond, depending on need and well production capability. Custom installation of the irrigation system, including service to the field and layout in the field, was assumed. Appropriate filters and underground piping from the well to the greenhouses or head of the field were included. The costs for installation and materials, including lateral lines, risers, heads, other miscellaneous expenses, totaled about $51,500, or between $896 and $1,981 per acre for both nursery models at the large scale of production. The irrigation systems employed in each model were designed to serve its nursery at seasonal rates specified in Table 4.4. Pumping costs were calculated by season in the budget.

Indoor mist systems use PVC header pipes and emitters and 9gph 360° mist nozzles (Orbit Irrigation Products, Bountiful, Utah), tensiometer (Irrometer Co., Riverside, CA), solenoid valves (Sprinkler Warehouse, Houston, TX) and cycle timers with control boxes (Phytotronics, Inc.; Earth City, MO). Outdoor mist systems use 2-in PVC header pipes, check valve and pressure reducer connectors, 1-in poly transmission pipe, and 9gph 360° micro-sprayers connected with spaghetti tubing. Battery-operated, 1- or 4-zone propagation timers with 2-in valves (DIG Corp., Vista, CA) control irrigation; in this system 1 zone can serve up to 5 production blocks.

The overhead irrigation system used in the model container nursery uses 1-in PVC header and transmission lines from buried 2-in PVC pipe via 2-arm brass sprinklers.

Stock Plant Maintenance: Since organic management of stock plants is not required for organic liner production, the establishment and maintenance costs of tea plants were derived from Monks (2000) while Newman et al. (2010) provided costs for cover crop establishment and maintenance. Annual costs during establishment years are considered in this analysis as fixed, investment costs. These include only the land, labor and equipment necessary for the propagation, establishment, and maintenance of stock plants and experimental trial plots, including owner salary and basic overhead expenses. This includes the cost of acquiring initial cuttings from Hawaii, a storage barn, fertilizer equipment, sprayers, carts, vehicle(s), etc. While stock plants managed for cutting production may also produce seed as a by-product from which high-quality oil can be extracted and sold, this possibility was not investigated. It was assumed that stock plants were managed solely for propagation material. However, since management systems are practically identical, pest control costs from Hong et al. (2013) were used.

Strike/marketability rates and economies of experience: While strike rates observed by McConnaughey and Ruter (unpublished) are within ranges published in the literature (Hajra, 2001; Monks, 2000; Golding et al., 2009), mean strike rates for container-rooted single node cuttings in the experiments were at the low- to very low range, respectively. Furthermore, liner mortality after successful rooting of tea cuttings is usually negligible (Hajra, 2001; Yamasaki et al., 2008). Therefore, mean rates for liners propagated in-ground reported by McConnaughey and Ruter (unpublished) is used only for the on-farm component of the cooperative model. Median rates from the literature, or optimal strike rates, are ultimately achieved for both conventional nursery models (Table 4.2). This is realistic since the lead author, while highly experienced with many vegetable and field crops, had little experience with woody plant, let alone Camellia, propagation prior to the study. For nursery models, initial marketability rates are based on the best results reported in McConnaughey and Ruter's (unpublished) container propagation experiment Finally, in a specialized nursery, economies of experience would improve strike- and marketability rates somewhat over time. Therefore, it is assumed that these initial rates for nursery models improve linearly over five years to an optimal rate, the median rates reported in the literature (Monks, 2000; Hajra, 2001).

Weed Control: In both models that employ field propagation systems, landscape fabric is used to control weeds in liner production areas that are managed at or beyond current USDA organic standards. However, stock plants are managed less stringently, where heavy bark mulch and glyphosate herbicides are used to control weeds during establishment of stock plants, after which heavy shading by the mature plants largely control weed growth. (Hajra, 2001; den Braber et al., 2007)

Selecting propagation areas that are free of perennial invasive weeds is critical to reducing weed pressure without chemical herbicides. If this is not possible, one option is to employ herbicides during field establishment until weed pressure has presumably diminished when alternative weed control techniques can be implemented. While this would delay organic certification by a few years, this may not affect sales much since plants would be being managed organically by the time production had begun. While the use of chemical herbicides is usually cheaper and/or more convenient than alternative methods where large populations of persistent noxious weeds are present, their very presence is often due to mismanagement and/or persistent chemical controls. Therefore it is assumed that the location of the nursery is selected with this criterion foremost in mind, and as a result chemical weed control methods are not required.

Non-woven black landscape fabric and periodic hand weeding are used to control weeds in propagation areas of the model field nursery and on-farm in the cooperative model. In these models, plowing is performed infrequently and at least one year prior to in-ground propagation activities, while annual cover crops are used extensively in the crop rotation to prevent weed infestations.

Disease and insect control: Integrated Pest Management (IPM) programs that do not rely on the use of chemical pesticides are employed in each model. Organic certification is the aim, but this is primarily important in liner production areas. With current USDA organic regulations, the use of chemical pesticides or fertilizers only on a separate stock plant area would not prevent organic certification of field-ready liners (USDA, 2012).

In all models, production and surrounding areas (within ⅛ mile) are kept free of other plants in the taxonomic order Ericales (e.g. ornamental Camellias, Azaleas, blueberries, etc.) and any others known to harbor pests of tea. Pest pressure is expected to be highest in stock plant fields of each model, where pest populations have the opportunity to build up over time. Cutting material is harvested from the season's new growth and a pest outbreak during this time could severely limit yields and thus productive capacity. Even after cutting material has been harvested, tea stock plants must be closely monitored to prevent the buildup of many insect pests that target the new growth of the plant. These costs are assumed to be 25% of mechanical tea harvesting reported by Monks (2001) since pruning is performed half as frequently as plucking with equipment that works at least twice as fast since prunings are not being collected.

Pesticide usage in liner production areas was based on reports from Camellia nurserymen (Gene Philips and Kai Mei Parks, pers. comm.) and observations made by McConnaughey and Ruter (unpublished). Both nurseries reported minor outbreaks of aphids or similar sucking insects on an annual basis and the buildup of scale insects requiring control measures every 2-3 years, but both also reported that organic control measures were adequate for this purpose. However, both nurseries maintain year-round stocks of various Camellia liners and mature stock plants within, or in close proximity to, nursery production areas. Habitat modification is an important component of Integrated Pest Management (IPM) systems, either to deprive it from pests on a periodic basis or to provide it to beneficial insects that prey on pests (Dent, 2000). Therefore in all models, stock plants are maintained far (1500 ft.) from liner production areas. The field nursery employs a 4-year crop rotation system that keeps alternating liner crops separated by at least 500 ft.

Pest pressure in the model container nursery was assumed to be moderate (pest outbreaks that require extensive spraying happening twice every 5 years), since production areas are stationary and in nearly continual use. In contrast, pest pressure on liner production in both the model field nursery was assumed to be light (one pest outbreak requiring extensive spraying every 6 years) whereas on farm, the pressure was assumed to be negligible (one pest outbreak requiring extensive spraying per 25 production units). Crop rotation is expected to provide adequate protection against the buildup of pests and diseases in liner production areas of the model field nursery, though infrequent applications of biological or organic pesticides may be required for isolated insect pest infestations and are included in cost accounting; biofumigation can be used in organic production systems to control soil born diseases, but this is not included.

Fertilization: In both nursery models, only USDA organic-certifiable products are used in propagation areas. Stock plants are managed less strictly, using some synthetic fertilizers (e.g. urea) in conjunction with organic matter. Also, chemical pesticides are available as a last resort in the event of a catastrophic pest outbreak that would affect the productive capacity of the nursery.

In the model container nursery, granular 3-5-3 organic fertilizer, blood meal, and kelp meal were mixed with the potting media used for finishing the plants. Dissolved blood meal was also used as needed to manage iron chlorosis. In the two models employing field propagation, ferrous sulfate, rock phosphate, and kelp meal were used in preparation for field propagation, and hydrolyzed fish and liquid kelp were delivered via irrigation during finishing. In the field, fertilizer was applied based on soil tests and expected release specifications of the product. Inclusion of these specific products in the analysis does not imply their endorsement.

Harvesting, packing and shipping: In both nursery models, at least fifteen-month-old, field-ready tea liners are shipped bare-root between September and March. In both model nurseries, field-ready liners are removed from their growing medium and placed in buckets with some water to keep the roots hydrated and help remove excess substrate/soil. The bare roots of 5-6 plants are surrounded with a small amount of moist sphagnum moss and wrapped with a moist paper towel and plastic sealing wrap. The leaves are sprayed with an anti-desiccant (e.g. ABA foliar spray such as Moisturin™) based on the findings of Sharma and Kumar (2005) who demonstrated that foliar applications of ABA reduced leaf water potential and photosynthesis rate in tea plants significantly over the control, mimicking the natural drought response of the plant that lasted 7-14 days after application. Their results suggest that this treatment is an effective means to prevent negative symptoms of drought and light deficiency during transplantation and transport. The entire plant is then wrapped in a tight cone of newspaper for protection and placed in corrugated cardboard boxes surrounded by starch packing peanuts. This method ensures 100% survival of plants for one week or longer without supplemental watering (Englert et al., 1993). In contrast, in the cooperative model, cutting material is packaged and shipped to growers in late June. Unprepared cutting material is sprayed with water and packaged in plastic bags in insulated, Sofribox® boxes (Sofrigam, Rueil-Malmaison, France) with blue eutectic ice packs to maintain temperatures below 8°C for up to 4 days of transport (Sofrigam, 2013).

Other overhead costs: Additional overhead costs include marketing, upkeep/repair, electricity, office expenses, cellphone and landline/internet charges, dues and subscriptions, travel and entertainment costs, professional fees, truck licensing fees and equipment rental costs, truck, tractor, and utility vehicle maintenance expenses, contributions, and bad debts used data from Thomas & Thomas (1999) and Brumfield (2008). Furthermore, the successful propagation of liners was guaranteed in the model cooperative. Strike rates lower than 65% that cannot be explained by farmer neglect would result in the free replacement of enough cuttings to achieve original plant requirements. These costs are considered as “bad debt” in the financial analysis, at a rate of one grower in 10 requiring a resupply of some cuttings (20% of original total, on average) and 1 in 50 requiring a full resupply due to complete failure. Crop insurance premiums are based on a nursery crop insurance plan (e.g. Skinner’s Crop Insurance Services, Inc., Cairo, GA) that provides 65% protection, but no scenario involving a catastrophic loss is included in this analysis. Finally, costs of organic certification were provided by the Georgia Crop Improvement Association (2001).

Markets for tea plants: The number of tea liners that a nursery can sell depends on two factors: the number of prospective tea farmers that will buy liners and the number of liners each grower would require. The latter is more important since it ultimately determines the number of prospective growers that can be served by a given scale of production. Based on the average scale of production employed in successful tea cultivation endeavors in the US over the past two decades, it is expected that the scale of production for individual growers will be quite small—between 1 and 4 acres, or 2.5 acres (1 ha) on average. Recommended planting rates depend on planting configuration, slope, and whether other woody species (e.g.

shade trees) are included (Hajra, 2000). High-density plantings made in Hawaii (9,680 plants/acre [23,919 plants/ha]) have been shown to maximize profit margins per unit area (Nakamoto et al., 2011), and were thus used for this analysis. Since shade trees would be recommended for most Southeastern growers, it was assumed that the average prospective grower requires 22,500 plants/ha, the scale of one production block within each model.

Because optimal planting times differ significantly between climate zones in the Southeast, it is necessary to make assumptions about where the plants would be going. In this analysis, 10%, 70% and 20% of liners or cuttings are sold to growers in USDA hardiness zones 7, 8, and 9 (USDA, 2012), respectively. It is thought the majority of prospective tea growers will be in USDA zone 8 for two reasons: (1) USDA hardiness zone 9 is characterized by very low elevation and sandy soils, factors that are thought to be antagonistic to producing high quality tea, which will likely decrease interest in this region, and (2) in USDA hardiness zone 7, skepticism about the crop's hardiness is sure to depress adoption rates by growers, at least initially. However, it is reasonable to assume tea can be grown in even the coldest parts of this region, as some tea cultivars are hardy to -10°F (USDA zone 6a), which makes even the coldest parts of USDA hardiness zone 7 a safe place to grow at least some tea cultivars (Cold Hardy Tropicals, 2012; Camellia Forest Nusersy, 2013). Many of these come from southern parts of South Korea (e.g. Yeosu) where climate conditions are comparable with those recorded over the past 30 years in Asheville, NC, Baltimore, MD, or Jackson Experiment Station, TN, three locations situated within USDA hardiness zone 7 (World Climate, 2010). Nevertheless, growers in this region will likely be more reluctant to invest in this crop than those in warmer areas.

Prices and revenue from tea liner sales are based on two price settings: (1) average total costs assuming a monopolistically competitive market structure in which the nursery firm charges unit prices equal to total (variable plus fixed) unit costs, and (2) constant at the price of a substitute woody crop currently available in wholesale quantities, specifically, blueberry liners.

4.2.5 NPV Analysis

Competing investment opportunities are commonly compared using the net present value (NPV) method. This method acknowledges that a dollar today is worth more than a dollar tomorrow due not only to inflation, but to the opportunity cost of not having the dollar to spend today. While the costs of production for tea are well documented, the value of the final product—made tea—is harder to estimate. Monks (2000) used nominal values equivalent to $35 and $100 per lb. today while Nakamoto (2011) used a value of $400/lb. Sakuma Farms in Washington, the only producer of handpicked tea on the continental US, sells their tea for $240/lb. Our value of $160/lb. can therefore be considered a conservative estimate. Yields are assumed to be 500 kg/ha (445 lbs/acre). This is quite low relative to global tea producers, below that of China whose tea yields are among the worst in the world at around 650 kg/ha (Thomas et al., 2005). Establishment and maintenance costs of tea production from Monks (2000) in Tasmania were used, while picking and processing costs from Nakamoto (2011) were employed. Average yields of tea from

China (Sehata et al., 2004) were used, adjusted downward by 20% with prices of made tea set at $10/oz. or $160/lb. Finally, a 10% discount rate was used.

4.3 Results and Discussion

4.3.1 Costs of production

Overall costs of production were lowest for the cooperative model at all viable scales of production (Table 4.6). At maximum feasible nursery output (1.125 million liners/year), unit costs of production in the cooperative model (including farmer costs) were 38.6% and 44.6% of those of the container and field nursery models, respectively. Variable costs of production in the cooperative model were 65%-70% of those of the nursery models at the smallest scale of production, decreasing at approximately 0.25% per 22,500 liners produced (data not shown). Within feasible scales of production (≤ 1,125,000 liners/year), liner costs of production were at least $2.33 less per liner than nursery models on average; variable costs in the cooperative model were $0.66-$0.78 lower on average within these levels of production. From just the perspective of the centralized nursery, the cooperative nursery functioned at a small fraction of the costs of either conventional nursery. Total operational costs for the cooperative nursery were about 20% of those of either nursery while variable costs were only 10% of those incurred by nurseries (Table 4.6).

Both nursery models rely on high production volumes or high prices to stay operational. In order to cover total costs in a monopolistically competitive market, the nursery models had to produce 1,023,058 and 973,869 liners per year for container and field nurseries, respectively (Figure 4.1). Even facing these market conditions, the cooperative nursery could cover its total costs at only 30,068 liners produced annually. Meanwhile, the container nursery could not produce quantities below 887,324 liners/year while covering its variable costs unless the unit price the market would bear was higher than $2.83 per liner, the current average price of wholesale blueberry liners (Figure 4.2). Similarly the field nursery could not cover its variable costs below 768,154 liners/year at this price. In contrast, at this price the cooperative nursery met its variable costs at only 26,128 liners produced annually.

These results indicate that the nursery models in this study could only operate within a tea liner market that was growing rapidly or would bear much higher prices for tea liners than comparable substitutes. Furthermore, these nurseries would have to operate within a relatively narrow range of production levels. If the production capacity of a centralized nursery is around 1,125,000 liners/year, both nurseries would have to produce at least 80% of this quantity for the firm to stay viable. Meanwhile, only the cooperative nursery could afford to operate at virtually any level of tea liner production.

The proportional allocation of variable costs as a percentage of total costs was highest for the model field nursery at scales of production above 112,500 plants/year, exceeding 50% at once 292,500 plants/year are produced (Figure 4.3). While this proportion was highest for the cooperative model at very low scales of production, at scales of production above 810,000 plants produced/year, both nursery models exceeded it. Meanwhile, because the cooperative model decentralizes variable costs of production among growers, the proportion of variable to total costs for the nursery share of the cooperative nursery never exceeded 25% at any scale.

Contribution margins were moderate to low for nursery models evaluated. Whether price was set according to average (unit) total costs or fixed at the average price of blueberry liners ($2.83/liner), contribution margin ratios for tea liners did not exceed 50% at any viable scale of production. In contrast, contribution margin ratios did not fall below 60% at any scale of production for the cooperative nursery model. When price was set according to average (unit) costs, the contribution margin ratio remained fairly constant, at around 85%, but when price was set at $2.83 (minus farmer cost of production) contribution margin ratios reached close to 100% at large (>225,000 liners/yr.) scales of production.

Since optimal production levels for both nursery models are beyond the feasible threshold we have set at 1.125 million liners per year (Figures 4.1 & 4.2). Therefore the optimal feasible scale of production for nursery models is at this limit, the profit-maximizing scale of production within feasible scales of production. At this level of output, total costs per unit area did not differ much between nursery models, over $2/liner for both model nurseries (Figure 4.1a,b). In contrast, the cooperative model appeared to have decreasing costs of production at all scales analyzed (Figure 4.1c). Considering the decentralized nature of the cooperative model, such large scales of production may actually be feasible.

These differences in production costs are primarily due to two main factors that are excluded from the cooperative model: (a) Packing and shipping costs associated with liner distribution, and (b) some farmer investment and overhead costs. Bare-root liner packing and handling costs are considerable; labor and materials costs for packing and handling represent 30%-49% of total costs, higher at higher scales of production. Most investment costs to the farmer were considered sunk costs of tea production. These costs are accounted for in the farmer's tea business plan that includes much more than just the cost of liners. Owner-operator salaries and payroll costs in both nursery models were also significant, consisting of 12%-15% of total costs of production at maximum feasible scale of production. Together, these costs represent up to 63% of total costs of production in nursery models. In contrast, packing and handling costs in the cooperative model were no more than 2% of total costs of production while owner salary and payroll costs ranged between 8% and 15% of total costs. At the annual scale of production of 1.125 million liners, these combined costs only represent 10% of total costs of production in the cooperative model.

Even when all costs are accounted for, the container nursery model cost per unit of $2.61 per plant (data not shown) is comparable with that of 1-gal blueberry liners based on average wholesale prices of $2.83 from 3 prominent wholesale nurseries in the Southeast (trueBLUE plants, Hudson, FL; Alma Nursery, Alma, GA; Bottoms Nursery, Concord, GA). However, it should be noted that tea plants have expected lifespans 2-5 times that of blueberries (Hajra, 2001; Fonsah et al., 2005), closer to that of Pecans (*Carya illinoensis*) at 100+ years (Anderson and Crocker, 2012). Unit costs of production of pecan whips (made by splice-and-tongue grafting pecan cultivars on native seedlings) are much higher, reportedly $10.29 or $17.20

for white tunnel and field-propagated liners, respectively (Safia et al., 2011). Based on net present value (NPV) of tea production over 20 years calculated using cumulative cash flows estimated by Nakamoto et al. (2011) with 9,680 plants/acre using purchased equipment to process tea, the NPV of tea production was at least 465 times greater than that of improved pecans estimated by Springer et al. (2011) and at least 16 times that of blueberries in North Carolina (Safley et al., 2011). This indicates that the market may very well bear prices for tea liners at the upper end of this spectrum.

Jeffers et al (2010) found that fixed costs/ft^2 of producing liners of other woody ornamental plant stock on a 10-acre liner nursery were around \$0.92/ft^2, much lower than total costs of production we calculated. This is because Jeffers et al (2010) did not include management salaries, shipping costs, or capital costs in their assessment. With these costs removed from the equation, base costs of production of tea liners were \$1.26 and \$1.20 for the container and field nursery, respectively (Table 4.7). Base production costs of the cooperative model were calculated slightly differently; since packing & handling costs are an integral, if minor, part of the production process, these costs were included. Despite this, these base costs of production for the overall cooperative model were at least 5% lower than either nursery model at \$1.14/ft^2.

4.3.2 NPV of Alternative Tea Liner Acquisition Strategies for Commercial Tea Production

Ten years after startup, tea liners have a positive NPV when compared with on-farm propagation only for liner unit prices below $5.63 (Figure 4.5). By purchasing field-ready tea liners, the hypothetical farmer can begin harvesting the mature plants a year earlier than one who opts to propagate the plants on-farm. However, even if the market would bear prices approaching $6/liner, the model container and field nurseries would still need to annually produce and sell at least 555,129 and 450,030 liners, respectively, just to cover their variable costs at this price while the cooperative model can operate profitably at any scale of production.

4.4 Conclusions

Field propagation systems can lower costs of production for container nurseries by 5-10%. Existing liner nurseries with Camellias in their production cycle should consider this cost-saving alternative technology. Conventional container or field nurseries can produce tea liners economically, but only at large scales of production or for high prices. An alternative economic model in which propagation activities are decentralized can produce tea liners for around half the costs of a centralized nursery at nearly any scale of production. However, the high price of domestically grown, handpicked tea may justify the additional costs of nursery-produced liners. Unfortunately, the availability of cutting material is a serious issue. The absence of publically available populations of modern commercial tea cultivars undermines any propagation effort. A tea research center should be established to collect and study tea cultivars, production systems, and processing in the Southeast.

Ultimately, no conclusions can be drawn as to the necessity of a cooperative business structure to an on-farm propagation system. Couldn't a private party just sell tea cuttings? While anyone with enough stock plants could theoretically sell cutting material, they would have to do it *instead of harvesting tea*. To produce good cutting material, plants cannot be plucked for tea for about one year; instead, they are left to grow freely. This decreases revenue and increases pest management costs since consistent plucking removes many pests before their populations can grow, but also decreases labor inputs associated with plucking and making tea (Zeiss and den Braber, 2001). Also, since the plants are allowed to grow freely during the year prior to cutting harvest, seeds may be harvested in the fall from which oil can be extracted (seed production is very light for plucked plants). Farmer costs would also be higher since purchasing materials individually loses the buying power of the cooperative. Property rights issues may arise here as well, depending on the proprietary nature of the cultivar in question.

However, the cooperative business architecture may be socially preferable to private alternatives, since it also provides a platform from which tea producer cooperatives may be formed, a step that may prove crucial during later stages of development of a specialty tea production industry on the US mainland. As growers adopt the crop, high-value direct markets will become more competitive, causing prices to fall. A cooperative business framework can allow growers to effectively develop value-added products (e.g. bottling and/or black tea factories) affording continued growth of the industry even as it begins to mature. Additionally, a cooperative business model offers unique opportunities to ensure consistency in the quality of American-grown tea, promote and market this new product, provide financial supports for aspiring growers, invest in research and education focused specifically on this agricultural product, develop new and related tea products, and provide new community development opportunities in rural areas of the Southeast.

4.5 TABLES

Table 4.1. General model specifications; *q* = quantity of production blocks in operation

Budget Category	Container Nursery	Field Nursery	Cooperative
Land (acres [ha])	3.5 + 0.5*q*	3.5 + 1.33q	3.5 + farmer land
Propagation structures	Freestanding dbl-poly Quonset or multipspan greenhouse w/climate control system 20% shaded high tunnels or net house w/overhead irrigation	Shaded low tunnels with timed overhead mist (5 cycle lifespan)	Shaded low tunnels with timed overhead mist (3 cycle lifespan)
Vehicles & Machinery	Truck(s), Electric generator, Emergency heaters	Truck(s), 175 PTO hp Tractor, cultivation implements	Truck
Other Equipment	Flat/pot filling equipment, greenhouse climate control systems, fuel tank	Chisel plow, disc harrow, flail mower, rotovator, and manure spreader	
Variable costs	Rooting medium, finishing medium, fertilizer, pesticides, labor, liner packing materials, overhead irrigation system (liners)	Fertilizer, pesticides, labor, tractor expenses, liner packing materials, drip irrigation system (liners)	Fertilizer, pesticides, labor, cutting packing materials; propagation structure materials handling & storage

Table 4.2. Strike and finishing rates used in cost analysis

	Strike rate		Finishing rate		Marketability %	
	inital	Year 5+	Initial	Year 5+	initial	Year 5+
Greenhouse Nursery	74.0%	80.0%	94.7%	99.0%	73.3%	79.2%
In-ground Nursery	81.5%	89.6%	99.0%	99.0%	88.8%	88.7%
On-farm in-ground co-op	81.5%	81.5	98.2%	98.2%	80.0%	80.0%

Table 4.3. Vehicle miles used in cost accounting*; q = the number of production blocks in operation for a given year.

Miles driven annually:	Container Nursery	Field Nursery	Cooperative Nursery
Truck:			
Materials pickup	240+27.5q	180+16.5q	90+3.3q
Cutting Harvest	2.7q	2.7q	0.3q
Low tunnel construction/demolition	NA	0.11q	NA
Sticking cuttings	0.8q	NA	NA
Potting up	5.6q	NA	NA
Liner harvest	0.9q	14.9q	NA
Truck Total:	**240+34.1q**	**180+31.3q**	**90+5.7q**
Utility Vehicle:			
Sticking cuttings	NA	0.4q	NA
Liner maintenance	0.9q	2.9q	NA
Stock plant maintenance	21.5q	21.5q	2.4q
Other	22.0q	33.0q	5.5q
Utility Vehicle total:	**40.3q**	**52.5q**	**7.2q**

*Based on assumptions of 16 and 25 mpg (1.8 and 1.0 gallons/h) for the truck and utility vehicle, respectively, and of 1760 ft. (536 m) between storage shed and the edge of the stock plant area, 150 ft. (30.5 m) between storage area and shade houses, and 200 ft. (71 m) between field propagation areas and storage/packing building for its respective model. These distances are quintupled for each ten-fold increase in production. For these calculations, it was assumed that the truck is assumed to carry 5,625 freshly harvested cuttings, 1,600 field-ready bare root liners in 5 gallon buckets, enough supplies (pots, growing media, fertilizer, etc.) for 2,500 unrooted cuttings or 250 liners to be potted up. The utility vehicle can carry 2,250 prepared single node cuttings in coolers, or ¼ the supplies of the truck.

Table 4.4. Water requirements in model production blocks* and calculation of pumping hours for tea liner production areas, 2011-12. C = Container system, F = Field system

	Summer (1 June to 30 Sept)		Fall (1 Oct to 30 Nov)		Winter (1 Dec to 28/29 Feb)		Spring (1 March to 31 May)	
(C)ontainer or (F)ield system:	C	F	C	F	C	F	C	F
Total days in season	120		60		90		60	
Irrigation days: mist	120	120	60	30	30	0		
overhead/drip	**110**	20	**48**	6	**25**		**72**	15
Gallons/day/acre: mist	1,600	6,000	1,400	5,000	800	0	0	0
overhead/drip	**20,00**	2,500	**15,000**	1,900	**7,500**	0	**15,000**	1,900
Thousand gal/acre*	2,392	770	816	161	212	0	1,080	29
Pumping rate (gal/hr)	←25,000→							
Hours/acre	**96**	**31**	**33**	**8**	**8**	**0**	**43**	**2**

* gallons/acre of active production areas only. To calculate gallons/total nursery area (excluding stock plants; see table 3.5) multiply the qty. used in the container system by 2 or divide the qty. used in the field system by 2.

Table 4.5. Water requirements and calculation of pumping hours for tea stock plants 2011-12.

	Summer (1 June to 30 Sept)	Fall (1 Oct to 30 Nov)	Winter (1 Dec to 28/29 Feb)	Spring (1 March to 31 May)
Total days in season	120	60	90	90
Irrigation days	20	10	0	20
Gallons/day/acre	4,000	3,200	NA	4,800
Total Gallons	80,000	32,000	0	96,000
Pumping rate gal/hr	10,000			
Hours/acre	8	3.2	0	9.6

Table 4.6: Total accounting costs of tea liner production at 3 hypothetical scales of tea liner production: (A) 22,500 (B) 225,000 and (C) 1,125,000 (max feasible)

A – 22,500 Annual Costs	Container Nursery	Field Nursery	Coop Nursery	Coop (Farmer)	Total Coop
Capital Costs	**$146,125.34**	**$92,568.00**	$51,427.99	$0.00	**$51,427.99**
Direct raw materials	**$225,864.06**	**$188,516.34**	$2,578.23	$124,405.31	**$126,983.54**
Direct labor	**$198,138.62**	**$202,673.25**	$25,307.51	$65,439.44	**$90,746.95**
Fixed overhead	**$14,309.88**	**$14,309.88**	$14,309.88	$742.92	**$15,309.88**
Variable overhead	**$303,848.44**	**$306,435.99**	$91,439.01	$90.52	**$91,439.01**
Total Costs:					
Primary Production costs	**$424,002.67**	**$391,189.58**	$27,885.74	$189,844.74	**$217,730.48**
Overhead expenses	**$318,158.32**	**$320,745.87**	$105,748.89	$833.44	**$106,582.33**
Total Production costs	**$742,161.00**	**$711,935.45**	$133,634.63	$190,678.18	**$323,479.38**

B – 225,000 Annual Costs	Container Nursery	Field Nursery	Coop (Nursery)	Coop (Farmer)	Total Coop
Capital Costs	**$518,695.42**	**$214,843.68**	$151,333.25	$0.00	**$151,333.25**
Direct raw materials	**$1,017,338.66**	**$849,540.14**	$11,428.26	$514,340.94	**$525,769.20**
Direct labor	**$839,659.23**	**$858,692.11**	$56,033.80	$294,477.47	**$350,511.27**
Fixed overhead	**$14,309.88**	**$14,309.88**	$14,309.88	$7,429.20	**$21,739.08**
Variable overhead	**$596,494.29**	**$609,102.03**	$154,705.69	$905.22	**$155,610.91**
Total Costs:					
Primary Production costs	**$1,856,997.89**	**$1,708,232.25**	$67,462.05	$808,818.42	**$876,280.47**
Overhead expenses	**$610,804.17**	**$623,411.91**	$169,015.57	$8,334.42	**$177,349.99**
Total Production costs	**$2,467,802.07**	**$2,331,644.16**	$236,477.62	$808,818.42	**$1,045,296.04**

C – 1,125,000 Annual Costs	Container Nursery	Field Nursery	Coop (Nursery)	Coop (Farmer)	Total Coop
Capital Costs	**$1,546,423.36**	**$409,406.30**	$226,160.93	$0.00	**$226,160.93**
Direct raw materials	**$1,526,007.99**	**$1,274,310.22**	$22,856.52	$1,028,681.89	**$1,051,538.41**
Direct labor	**$1,259,488.84**	**$1,288,038.17**	$84,050.69	$588,954.94	**$673,005.64**
Fixed overhead	**$22,364.52**	**$22,004.64**	$21,464.82	$37,146.00	**$58,610.82**
Variable overhead	**$1,420,895.41**	**$1,676,134.08**	$219,871.53	$4,526.10	**$224,397.63**
Total Costs:					
Primary Production costs	**$3,713,995.79**	**$3,416,464.51**	$134,924.11	$1,617,636.83	**$1,752,560.94**
Overhead expenses	**$1,443,259.93**	**$1,698,138.72**	$241,336.35	$41,672.10	**$283,008.45**
Total Production costs	**$5,157,255.71**	**$5,114,603.23**	$376,260.46	$1,659,308.93	**$1,993,897.29**

Table 4.7. Base costs of production per unit and ft^2 at optimum feasible nursery scale of production (1,1125,000 liners/year) for A) model container nursery, B) model field nursery, and C) Cooperative model split into nursery and farmer shares. Figures exclude management salaries and packing & shipping costs.

A **Container Nursery**	**Per liner**		**Per sq ft**	
Variable Costs	Qty.	Price	Qty.	Price
Labor (hrs)	0.03	$0.25	0.03	$0.28
Water (gal)/pumping costs	100.18	$0.00	111.18	$0.00
Other overhead costs		$0.27		$0.30
Fertilizer (lbs)	0.16	$0.10	0.18	$0.11
Pesticides, hormones		$0.01		$0.01
Pots		$0.09		$0.10
Media		$0.15		$0.17
Machinery fuel (gal)	0.0002	$0.00	0.0002	$0.00
Total Variable Cost		**$0.87**		**$0.96**
Total Fixed Cost		**$0.22**		**$0.24**
Total Cost of Production		**$1.08**		**$1.20**

B **Field Nursery**	**Per liner**		**Per sq ft**	
Variable Costs	Qty.	Price	Qty.	Price
Labor (hrs)	0.02	$0.27	0.04	$0.40
Water (gal)/pumping costs	21.52	$0.00	32.39	$0.00
Other overhead costs		$0.29		$0.43
Fertilizer (lbs)	0.15	$0.09	0.22	$0.13
Pesticides, hormones		$0.01		$0.01
Pots		$0.00		$0.00
Media		$0.00		$0.00
Machinery fuel (gal)	0.0002	$0.00	0.0004	$0.00
Total Variable Cost		**$1.03**		**$0.97**
Total Fixed Cost		**$0.19**		**$0.29**
Total Cost of Production		**$1.22**		**$1.26**

C **Cooperative**				
Nursery	per plant		per sq ft	
Variable Costs	Qty.	Price	Qty.	Price
Labor (hrs)	0.05	$0.05	0.19	$1.61
Water (gal)/pumping costs	0.0002	$0.00	5.97	$0.00
Other overhead costs		$0.05		$1.74
Fertilizer (lbs)	0.01	$0.01	0.31	$0.18
Pesticides, hormones		$0.00		$0.01
Pots		$0.00		$0.00
Media		$0.00		$0.00
Machinery fuel (gal)	0.000	$0.00	0.00	$0.00
Packing and shipping materials		$0.00		$0.11
Total Variable Cost		$0.31		$3.54
Total Fixed Cost		$0.09		$2.76
Total Cost of Production		$0.40		$6.30
Farmer				
Labor (hrs)	0.03	$0.49	0.05	$0.79
Water (gal)	21.33	$0.00	34.68	$0.00
Other overhead costs		$0.00		$0.00
Fertilizer (lbs)	0.13	$0.17	0.21	$0.27
Pesticides, hormones		$0.01		$0.02
Pots		$0.00		$0.00
Media		$0.00		$0.00
Machinery fuel (gal)	0.00	$0.00	0.00	$0.00
Total Variable Cost		**$0.67**		**$1.07**
Total Fixed Cost		**$0.00**		**$0.00**
Total Cost of Production		**$0.67**		**$1.07**
Total Variable Costs		**$0.99**		**$1.01**
Total Fixed Costs		**$0.09**		**$0.13**
Total Annual Cost of Production		**$1.07**		**$1.14**

4.6 FIGURES

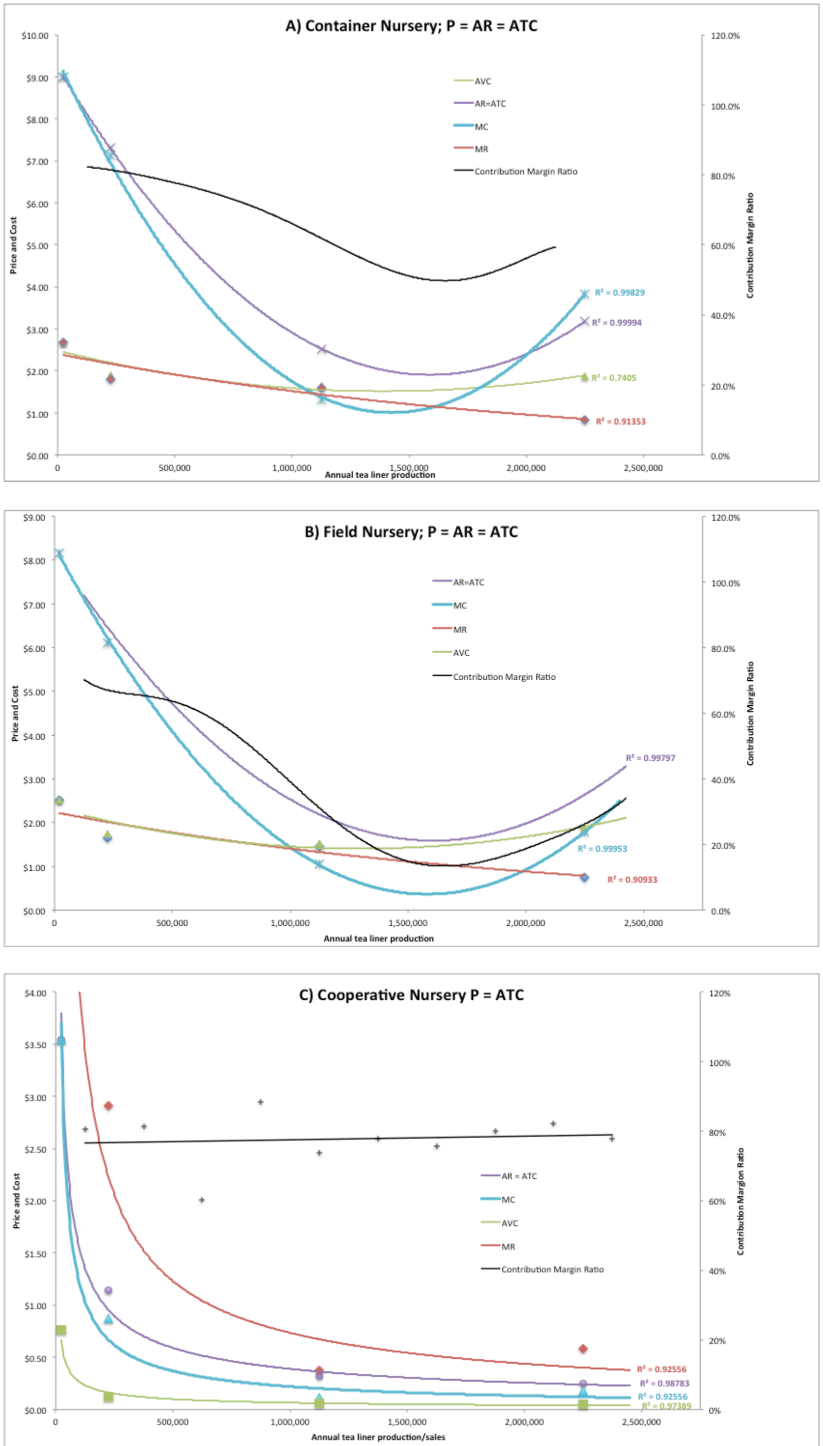


Figure 4.1: Average and marginal costs of production when price is set equal to total unit cost (ATC), with contribution margin ratios for (A) model container nursery, (B) model field nursery, and (C) model cooperative nursery. AR = Average Revenue (unit price), ATC = Average (unit) Total Cost, AVC = Average (unit) Variable Cost, MC = Marginal Cost, MR = Marginal Revenue, P = Price

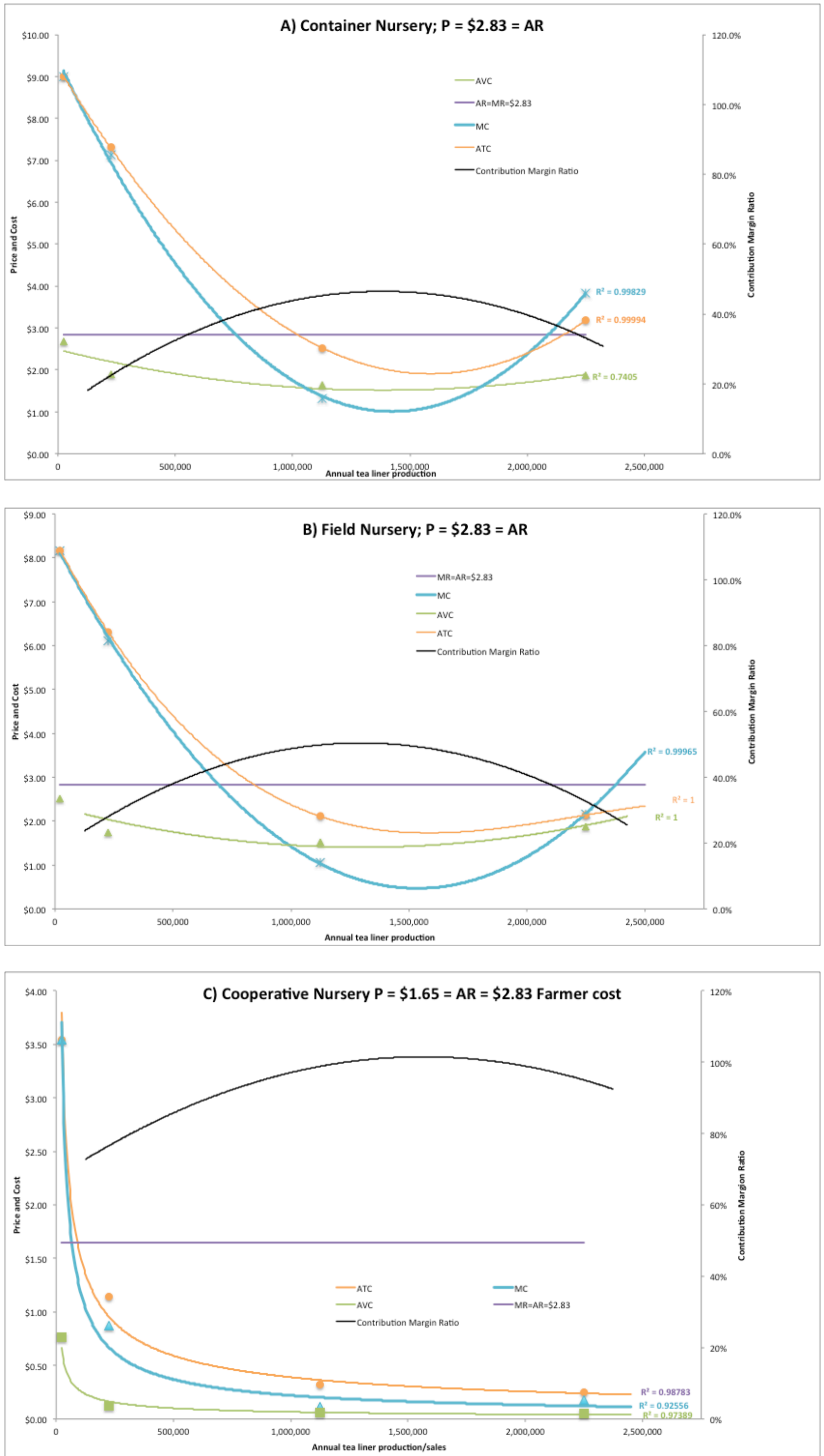


Figure 4.2. Effects of constant pricing on average (unit) and marginal costs of production when price is set equal to that of wholesale blueberry liners ($2.83) with contribution margin ratios for (A) model container nursery, (B) model field nursery, and (C) model cooperative nursery. AR = Average Revenue (unit price), ATC = Average (unit) Total Cost, AVC = Average (unit) Variable Cost, MC = Marginal Cost, MR = Marginal Revenue, P = Price

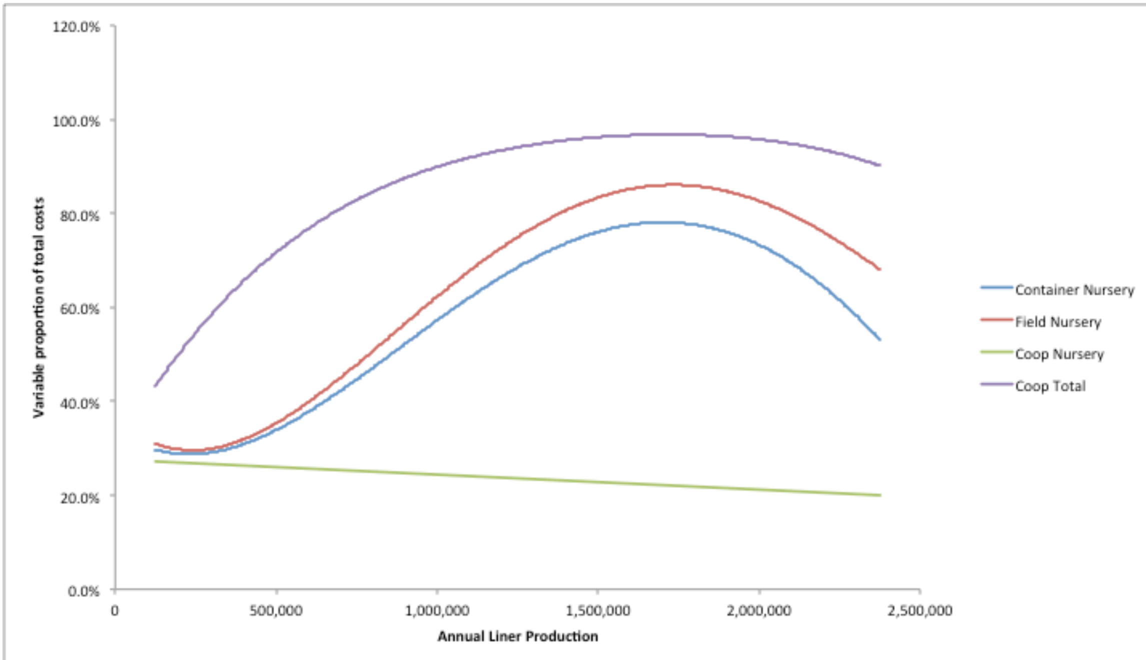
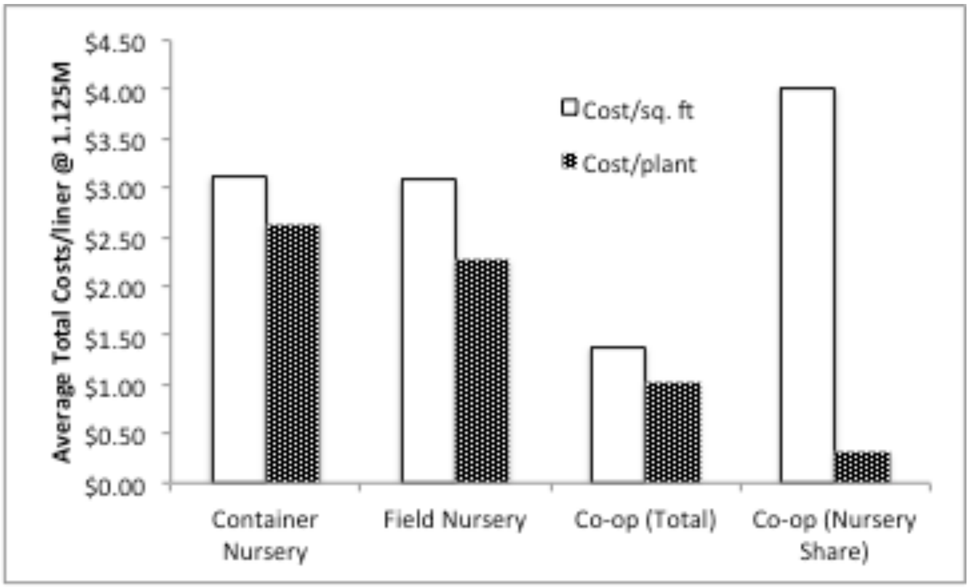


Figure 4.3. Estimated proportion of variable costs to total costs for model production/distribution systems at variable scales of production

A



B

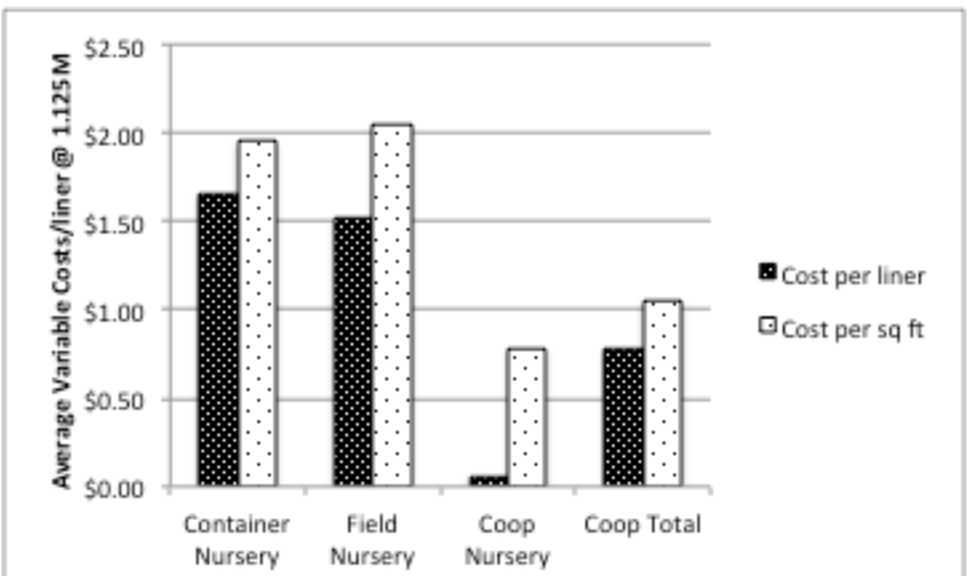


Figure 4.4. Annual total (A) and variable (B) costs of production per ft^2 and per plant for the two nursery models, the cooperative model, and the nursery share of the cooperative model at optimal feasible scale of nursery production producing 1,125,000 liners/year.

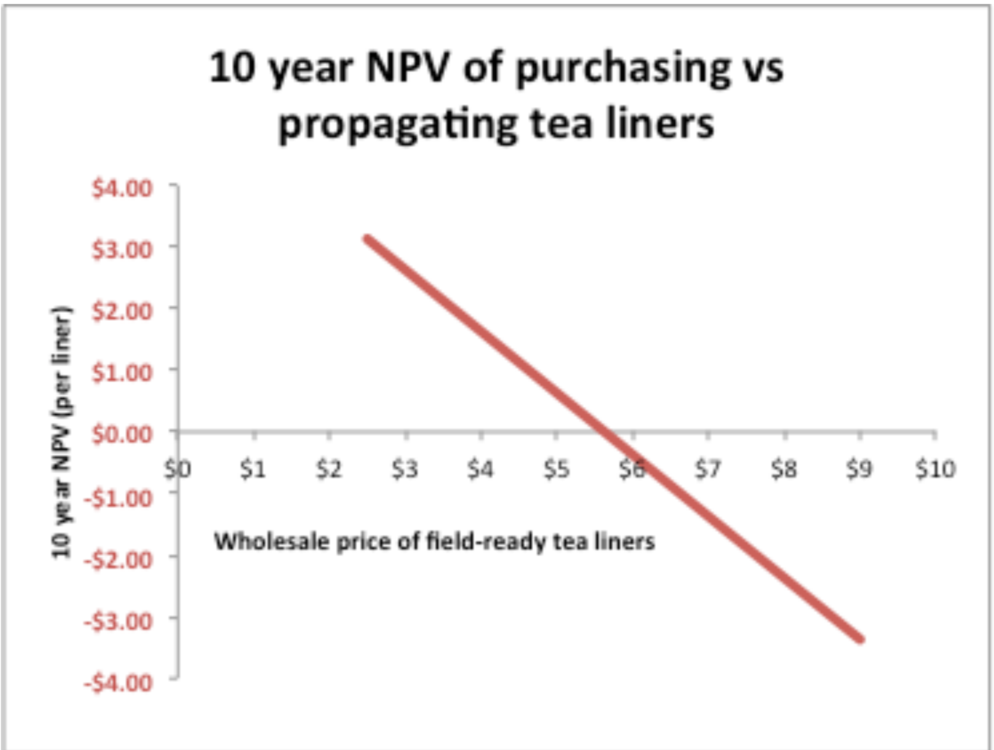


Figure 4.5. Ten-year Net Present Value (NPV) of individual purchased tea liners, relative to the alternative of propagating them on-farm, based on wholesale field-ready liner price.

CHAPTER 5

CONCLUSIONS

5.1 Concluding Discussion

On the back of what some are calling the “specialty tea boom” tea is proving to be a viable, if not lucrative, crop in areas of the U.S. with humid, subtropical or tropical climates, and acidic soils. Unfortunately, the scarcity of tea liners from nurseries in the U.S. is a major obstacle for aspiring tea growers. Furthermore, the investment costs associated with greenhouses and other materials involved with conventional container nursery systems are all but unjustifiable for a single propagation project. Luckily, alternative propagation and distribution systems exist that could bring investment and production costs within the comfort range of many aspiring tea growers.

This research has shown that in-ground propagation systems are a viable means for propagating tea in the Southeast comparable with, if not preferable to, conventional greenhouse/container systems. Environmental conditions under shaded low tunnels were found to be more favorable for rooting cuttings than normal greenhouse conditions. Furthermore, by propagating tea in a location where it does not have to be moved, growth of young tea liners was significantly improved. However, optimal propagation systems for tea appear to be cultivar specific and this system cannot be endorsed for all cultivars in all situations.

In-ground propagation and field nursery systems were also found to reduce costs of production compared with greenhouse propagation and container nursery systems by up to 10%. However, nursery costs of tea liner production were found to be higher than current prices of substitute woody shrub crops (e.g. blueberries) except at large scales of production. Excluding capital costs, a conventional container nursery cannot produce tea liners for less than $5/liner except at annual levels of production exceeding 440,000 liners. Unfortunately, no startup tea farm has exceeded 10 acres in the past 25 years, the equivalent of 30,000 to 90,000 liners depending on planting density, far below this quantity.

However, an alternative model—in which only cutting material is produced centrally and growers propagate them in-ground on their own farmland with materials supplied by a central cooperative—can produce field-ready tea liners for a small fraction of conventional nurseries. In this model, it was found that liners can be produced for as little as $2.83/liner at annual production levels as low as 50,000 liners, quantities more in line with tea farms that have been started in the U.S. in the past few decades.

Despite these differences in accounting costs, the high price for domestically grown specialty tea may offset high liner production costs. Handpicked U.S. grown tea currently retails for anywhere between $200 and $4,200 per lb. while machine-harvested teas sell for $60-$160/lb. At $160/lb., unit liner prices up to $5.63 would be offset by the additional year of harvesting available to those who purchase, rather than propagate, liners during the first 10 years of production after which differences become negligible.

As more and more growers find success with the crop, demand for liners is expected to grow very rapidly. Unfortunately, the quantity of mature plants available for cutting production in North America is very limited. Furthermore, the availability of cultivars that will produce good crops of high quality tea is virtually unknown. On the continent, it appears that all farms using clonal tea plants derive their stock from the Lipton study from the 20th century; this study emphasized yields over quality since high-value tea markets had yet to develop. This suggests that available cultivars may be poorly suited to serving specialty tea markets in the future. Farms employing seed-grown plants may have more to offer, since their stocks represent a large amount of genetic diversity from which new cultivars may be selected. Finally, modern commercial varieties from Japan have been collected and are in cultivation in Hawaii, presenting a new source of genetic material from which growers stocks may be produced.

5.2 Future Directions for Research

Very little information is available as to the relative quality of any of these cultivars when grown in the Southeast. Additional research is needed to screen these and other cultivars for yield and quality under alternative production systems. While growth rates of un-transplanted, field-grown liners exceeded those transplanted to containers, differences between the establishment of bare-root and container tea liners in the field is unknown in Southeastern conditions. This needs to be investigated, along with various alternative establishment techniques along both horticultural and economic parameters.

Economically, the production of tea in the U.S. has not been formally compared with alternative crops to estimate economic costs of production, including opportunity costs. On the supply side, the labor and price elasticities of supply need further study. On the demand side, price elasticities of demand and overall demand for locally/domestically grown tea also warrants additional research. The effect of alternative management systems, organic/fair trade certifications, alternative harvest and processing methods, and general quality on the demand for tea should be thoroughly investigated. This information will likely be crucial to the success of new tea farms targeting specialty- and other niche markets. Finally, the rate of return of tea research should be estimated.

A center for sustainable tea research could be established in the Southeast to answer these questions and initiate a breeding program for cultivars for the region. Multiple out-stations in major eco-regions of the Southeast would also contribute to this objective, as cultivar x environment interactions are very strong with the tea plant. Distinct cultivars may be appropriate for specific eco-regions, site characteristics, management systems, and even processing methods. Conventional production systems (using chemical pesticides and fertilizers and mechanized harvest and processing) should be investigated along side alternative production (agroforestry, organic, fair trade, IPM, etc.), harvesting, and processing systems. With the potential for U.S. tea growers to replace imports of specialty teas (and coffee to some extent) and infiltrate the $1 billion+ ready-to-drink tea market in North America, the rate of return on tea research in the Southeast should prove very high. Finally, tea production in other areas of North America and the Caribbean should be investigated. Many highland areas of the tropical Americas may be ideal locations for tea cultivation.

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