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A Review of Laurel (*Cordia alliodora*) in Forest Management Systems

Abstract:

This paper is an extensive review of laurel [*Cordia alliodora* (Ruiz and Pav.) Oken]. Included are a detailed plant description, a preferred site description, and the biological factors that affect the rate and dimensions of tree growth. This is also a review of the forest management systems in which laurel is grown. It is clear from studies of these management systems that the management style has significant effects on the growth of laurel trees. In addition to the reasonably well-known forestry and agroforestry type management systems, this review also covers newly re-discovered traditional management methods used by indigenous peoples in the past and present, and from different regions in the tropics.

Laurel is native to Central and South America and ranges from Mexico to Argentina, 25^{o} North to 25^{o} South. However, laurel can be found as an exotic species in the tropical zones of the Pacific region and the African continent, as well as the southern tip of Florida, where it is often planted as an ornamental due to its prolific flowering. Laurel is often used in agroforestry plantations of a small to medium size because the seeds are readily available. Plantings can be initiated from seed, as seedlings, or as stump plants, which are specially pruned seedlings. Laurel produces a fine quality lumber and so acts as a savings account for poor farmers. Laurel is a medium to tall tree and does not grow as large as many other species; but the tree form and biological growth factors make it well suited for specific goals in particular management systems.

1. Introduction:

1.1. General Forestry

Forestry today is evolving to meet the needs of people and societies. The natural environment has become a greater concern as we realize how easily it can become unbalanced and unhealthy. Societies need forest products, individuals need the forest lands to support their livelihoods, and we all need thriving ecosystems that support biodiversity and provide clean air and water. In the tropics, land use becomes more critical because the natural balance of environmental factors is more fragile in the tropics than in the temperate zone (Myers 1980). When natural forests in the tropics are destroyed, desertification sets in and reforestation becomes difficult at best (Evans 1992, Parrotta 1992).

There are many approaches to land treatments, each with its own set of goals and problems. Land can be used for agriculture, pure tree plantations, natural forest stands and a myriad of management systems that combine these disparate uses. Scientists have seen what many indigenous peoples have already accomplished in various systems of agroforestry. Some scientists have taken these traditional indigenous methods and established experimental plots to determine their efficacy on farms of various sizes and in different countries (Hellin et al. 1999). The addition of trees to agricultural lands is beneficial for crops that require some shade and they also provide a supplementary income in the event of crop failure (Greaves and McCarter 1990). There have been many research studies conducted especially in the tropics and in Asia that test the growth and yield of plants, find the best combinations of tree and crop species, and match the correct plant species with the best site conditions for that species (Evans, 1992).

In choosing a tree for a particular site, lumber production is not the only criterion of importance. According to Evans (1992), “In addition to wood, trees provide many other benefits for which they are planted, e.g. food for humans and animals, clothing, fencing materials, shelter and shade, soil improvement, raising silk worms, bee-pasturage, bark products, and so on. The choice of species is determined by the product or benefit sought and frequently personal preference. Often multipurpose [tree] species (MPTS) are used…" This review is about one such tree.

1.2. Cordia alliodora

Laurel [*Cordia alliodora* (Ruiz and Pav.) Oken] is a fast growing tropical hardwood with a large natural range extending from Mexico to Argentina, 25^{o} North to 25^{o} South (Liegel and Whitmore 1991). It is one of the most popularly planted tree species among plantations and small to medium sized farms in the tropics (Alder 1999, Piotto et al. 2002) It is an important timber species (Liegel and Whitmore 1991). Laurel is also important in climate research in the tropics because, unlike many tropical species, it has annual rings based on the wet/dry seasons. Laurel trees are diffuse porous, which means that there are large vascular bundles intermittently scattered among much smaller vascular tissues (Devall et al. 1996). The wood is generally strong and comparable to mahogany (Liegel and Stead 1990). There are different varieties of Laurel based on the light versus dark coloring of the wood, hence the additional variety of common names such as laurel blanco (white) in Belize and laurel negro (black) in Honduras, Nicaragua, and Costa Rica (Grieves and McCarter 1990). The dark heartwood is favored by carpenters, and is somewhat more resistant to termites and rot than the light heartwood (Liegel and Whitmore 1991). Laurel negro has light sapwood and dark brown heartwood, which is variegated much like walnut. It is used for construction lumber since the wood is rated above average in hardness and toughness (Johnson and Morales 1972).

Laurel is useful for veneer, plywood, flooring, boats, fencing, mulch, furniture, animal fodder, and fuel (Liegel and Whitmore 1991). In Brazil, laurel is used in the production of ethanol (Liegel and Stead 1990). It is frequently used in agroforestry as shade for cacao, coffee, other agricultural crops and farm animals (Liegel and Whitmore 1991). Laurel grows a profuse amount of flowers that are not only attractive to honey bees but also to people in urban residential areas for use as an ornamental. The fruits are edible while the seeds and leaves are used for medicinal purposes (Liegel and Stead 1990).

Laurel, *C. alliodora*, is a member of the family Boraginaceae, subfamily Cordioideae, genus *Cordia* Linn., and section Cerdanae (Greaves and McCarter 1990). There are 250 species ranging in size from shrubs to trees in the genus *Cordia*. Of all of the species within this genus, laurel is the most widely distributed (Liegel and Whitmore 1991). The type specimen of this tree, which was collected in Peru, was first described by Ruiz and Pavon in 1799 as *Cerdana alliodora* and was later placed under the genus *Cordia* by Oken in 1841. Sometimes the authority Chamisso is commonly found in place of Oken because De Candolle incorrectly cited this reference in a publication dated 1845. Oken is the correct author citation because his date of publication was earlier. This plant has been renamed correctly and incorrectly numerous times, as many as fifteen or more; so when researching historical documents, it is necessary to become familiar with the botanical synonyms (Greaves and McCarter 1990). There are just as many if not more common names for *C. alliodora*. The two commonly used commercial names found in journal articles today are laurel, used in the Americas, and salmwood, used in the United Kingdom (Johnson and Morales 1972). One of the original authorities of laurel was Hipólito Ruiz, a Spanish botanist who traveled in Peru and Chile between 1777 and 1788. The following quote is a translation of a portion of his diary when he encountered laurel for the first time.

> *Cerdana alliodora*, called árbol del ajo (garlic tree) in reference to the odor of the leaves and bark, which Indians use in condiments. These trees are tall but not very solid, and are visited by a kind of small ant. The bite of this ant produces a rash that lasts 16 to 20 hours, stinging severely at first but soon abating.
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> These ants completely destroy the leaves of the garlic tree; they cut them into triangular bits, carry the pieces to their burrows, and place them symmetrically one upon the other without wasting any space. To carry these leaf bits to their hills, the ants grasp them by the shortest angle, putting the sharpest and longest up and the third forward, and walk swiftly. Thus they look like many tiny boats with lateen sails bending to all sides, depending upon the way the wind blows. It matters little that the leaf fragment be six times the size of the ant.
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> There are so many insects engaged in this activity all day long that they have worn paths about 9 inches wide leading from the trees to the anthills. Opening up and studying several hills, I sometimes found more than 50 pounds of leaves neatly arranged, one overlapping the other; even though some water might leak in, only the upper layers can be wetted, for the rest are placed like tiles and shed the water. The natives call these ants tragineras (carriers) because of the ceaseless labor (Schultes et al. 1998).

This tree was named after its strong scent of garlic. The name *alliodora* is derived from *Allium*, the genus name of garlic. Laurel does have a relationship with ants. In fact, laurel has nodal swellings or ant domatia on all of the small branches and twigs. Fifty-four different species of ant are known to have an association with laurel and of these, forty-four have been found living in the domatia. Outside of the Ruiz account of the leaf cutters, there is no record of damage to laurel by ants. In many cases, the ants actually protect the tree from other insect invaders. When laurel is planted as an exotic species outside of its natural range, the tree continues to develop domatia but ants usually do not develop a relationship with laurel in that region (Greaves and McCarter 1990). In one small area of Panama, 212 different species of insects were found on the tree. Many insects can be considered pests but none of them are known to be devastating enough to kill the tree (Johnson and Morales 1972).

Laurel is a medium to tall tree. It grows 20-25 m in height and 60-100 cm in diameter under optimum conditions. More commonly, it reaches 20 m in height and 46 cm in diameter (Liegel and Whitmore 1991). The diameter of laurel varies widely whether the trees are located in plantations or in natural stands, usually due to heavy competition among trees in a densely populated stand. There is a high correlation between diameter growth and moisture conditions. Moisture stress has a negative impact on shoot formation. The date of shoot flushing can vary in laurel up to a four-month period between April and July. While under moisture stress, the number and size of leaves are reduced, thereby reducing the crown size. Ultimately, diameter growth is slowed due to the limited photosynthetic capacity of the tree crown and possibly due to altered hormonal relationships that are initiated in the foliar organs. It is believed that shoot flushing is a phenotypic character since the phenology of shoot growth can be determined at an early age. Those seedlings that have a shoot flushing prior to the moisture stresses of the dry season will tend to show greater diameter growth; and thus these are the best choice seedlings for nursery out-plantings (Blake et al. 1976).

Laurel has a generally straight and cylindrical bole. The branches are plagiotropic or downward slanting. They grow in whorls of five and form a conical shaped crown with distinct horizontal layers of foliage. There are more horizontally positioned leaves at the top of the crown and wider branching at the bottom of the crown. Since there is little overlapping of leaves, laurel is able to procure high productivity in the first several years of growth. This widely dispersed pattern of leaf growth allows the tree to capture a great amount of resources per unit of leaf area. Leaves measure about 33 cm^2 in area (Menalled and Kelty 2001). Laurel is self-pruning, usually clear of branches for fifty to sixty per cent of its total height, even in open growing conditions (Johnson and Morales 1972, Grieves and McCarter 1990). This is good in agroforestry systems, in which wide spacing is required between trees for crops. Many trees have to be manually pruned or planted closely together (high density) in order to artificially force the tree to self-prune and grow straight (Evans 1992).

In seasonally dry lowland tropical forests, most tree species lose their leaves during the dry season; but in Panama, laurel becomes deciduous for several months after the rains begin. Many people even assume that the entire forest becomes deciduous at the beginning of the rainy season where laurel is a primary species (Foster 1985). It is now understood that laurel is "evergreen as a seedling, semi-deciduous (in the dry season) as a sapling, and deciduous (in the wet season) as a mature tree" (Menalled et al. 1998). The phenology varies with location. In high altitude wet areas, laurel trees flower earlier than in low altitude dry areas (Liegel and Whitmore 1991).

Laurel produces a copious amount of white flowers that form dense clusters on terminal panicles (Liegel and Whitmore 1991). In other words, at the ends of branches, there are multiple inflorescences with flowers that mature from the bottom upwards; so that the flowers at the tip of the branches are the least mature (Harris and Harris 1994). The flowers are perfect, male and female organs on the same flower. There are five white stamens that extend beyond a two-forked stipe and each fork has broad stigmas. The flowers measure 10 to 30 cm in width. The cylindrical calyx has eleven prominent ribs and the white corolla has oblong lobes that are persistent after senescence so that they act as a parachute and aid the mature seeds in wind dispersion (Liegel and Whitmore 1991).

Laurel is homostylous, a characteristic unlike other members of the genus *Cordia*, which are either heterostylous or dioecious (Grieves and McCarter 1990). Homostylous flowers have styles that are generally of the same length (Harris and Harris 1994), which makes them partially self-compatible. The self-compatibility of laurel is one explanation for its wide ranging distribution (Grieves and McCarter 1990). The flowers are pollinated by wind dispersal, bees, and Lepidoptera (Liegel and Whitmore 1991).

Laurel is a prolific seeder. It can produce 2 to 8 kg of seeds at 42,000 to 100,000 seeds per kg. Unripe seeds are unviable so it is necessary to shake the tree limbs and catch the falling mature seeds (Liegel and Whitmore 1991). If the seeds are dried to below 10 percent moisture content and stored at $2^{o}C$, then they can remain viable for at least ten years (Grieves and McCarter 1990). Laurel is a long day plant, it needs 14.5 hours of day light or 9.5 hours of darkness to germinate. The seeds also germinate best when they are held at a constant temperature of $30^{o}C$ (Johnson and Morales 1972). Germination takes 10 to 30 days and is hypogeous (Liegel and Whitmore 1991). In other words, the cotyledons remain below the surface of the ground during germination (Harris and Harris 1994).

Initial seedling growth is rapid, up to 2 meters in the first year under optimum conditions (Johnson and Morales 1972). Laurel can be established by direct seeding, planted as a seedling, or planted as a stump plant, although natural regeneration is common in abandoned fields where laurel is present (Liegel and Whitmore 1991). A stump plant is a special kind of cutting that is about 20 to 25 cm in length, of which about 80 percent is root and 20 percent is leafless shoot (Evans 1992). Various countries have different rules for optimum seedling size or age for transplanting; however, seedling size may have no effect on the survival of laurel (Liegel and Whitmore 1991).

Laurel is a gap pioneer species in that it tends to be one of the first to invade clearings such as abandoned agricultural sites, pastures, burned areas, and new gaps in the forest. Pioneer species, including laurel, emerge in gaps of all sizes, but are usually restricted to gaps over 150 m^2. Other tree species can exist as suppressed saplings in a closed forest until a gap forms, and then accelerate in growth (Brokaw 1982). Although Laurel reacts poorly to being shaded out, it does have the advantage of "high initial productivity and rapid canopy and root-system closure" (Haggar and Ewel 1995); unlike another pioneer species, *Eucalyptus deglupta* Blume, which when slightly overtopped, can quickly become suppressed and die (Evans 1992). Thus differing requirements of seedlings and saplings of various species lead to different growth rate patterns e.g. a fast or slow growth rate with an upturned or down-turned trend (Parresol in review). A laurel tree that germinates in a gap typically has adequate resources at the time of germination and early growth. As the forest grows and the gap disappears, laurel occupies an intermediate to suppressed canopy position, and is then at a competitive disadvantage. Gaps in the moist tropics tend to revegetate quickly, small gaps achieving canopy closure sooner than large gaps (Knight 1975, personal communication, Bernard Parresol, USDA Forest Service Southern Research Station 2002). Menalled and Kelty (2001) determined that from the measurements of long-term development of plantations containing laurel that the canopies closed between the ages of 1.5 to 2.0 years.

By age seven, laurel trees have normally entered their maturity phase. Most species have lost their capacity to respond aggressively, that is, with a burst of growth, to a release event after becoming mature. It is not unlikely that a young suppressed laurel tree would suddenly begin growing rapidly in the event of a new gap in the forest near the tree, but new growth after maturity is rare (Clutter et al. 1983). My own research has revealed that some laurel trees display an upturned growth pattern. The age range at which renewed growth occurred was between 7.4 and 14.5 years in 20% of 21 trees tested (Parresol, in review). To be sure, many species will respond positively to release from competition, but not to the extent of achieving sustained higher growth rates (Clutter et al. 1983). An extensive literature search found only one article that reported an upturned growth pattern. Bredenkamp and Gregoire (1988), in studying *Eucalyptus grandis* Hill ex Maiden in South Africa, found a resurgence of growth in stands that had experienced heavy mortality. It would appear that *C. alliodora* has the same ability, an ability few species seem to possess.

Laurel can grow at altitudes ranging from sea level to 2000 meters; although, it rarely grows above 1000 meters and it commonly grows at or below 500 meters (Johnson and Morales 1972, Liegel and Whitmore 1991). Tree growth best occurs in Tropical Moist to Tropical Wet Forest life zones (Liegel and Whitmore 1991). Laurel grows within a rainfall range of 1,500 and 2,000 mm and at temperatures between 24^{o}C and 30^{o}C (Johnson and Morales 1972); but the best growth occurs when the mean annual rainfall exceeds 2000 mm and the mean annual temperature is about 24^{o}C (Greaves and McCarter 1990). Laurel can tolerate many soil types (Greaves and McCarter 1990); but it grows best on well-drained, medium textured soils as typified by the Atlantic lowland sites, which Johnson and Morales (1972) considered optimal for laurel. Laurel is common on the thin-layered soils throughout the hills of Panama but it rarely grows near streams, due to possible flooding (Greaves and McCarter 1990). Laurel does not require special treatments or sterilization of the soil (Liegel and Whitmore 1991), but the soil can be sterilized by burning the site, and thus help laurel seedlings by reducing initial competition with weeds (Johnson and Morales 1972). It should be noted that when weeds are wanted for purposes of creating a biologically diverse habitat, fire should not be used.

It is well known that laurel does not tolerate poor internal drainage or water-logging and that growth is severely limited on compacted soils (Liegel and Stead 1990, Liegal and Whitmore 1991, Somarriba et al 2001). Soils that are rich in clay, such as is found in the hills of Panama, are highly susceptible to soil compaction; so in areas where cattle may also be grazing, there would be a negative effect on tree growth because of laurel's "behavior of developing only a lateral, superficial root system within its first years" (Bergmann et al 1994). Grazing also has a negative effect on biodiversity since understory regeneration is significantly reduced under these circumstances (Haggar et al. 1997).

The roots of a mature laurel tree are far reaching in depth and in lateral growth (Haggar and Ewel 1995). Laurel develops a strong taproot in deep soils and this is the main factor in its ability to remain wind firm in the event of hurricane or cyclone force winds; however, if the taproot cannot be established due to a thin soil layer such as on shallow coralline soils, the tree becomes more susceptible to blowing over under the stress of high winds (Grieves and McCarter 1990). The lateral roots have a limited amount of branching, a structure that is typical for plants that require large amounts of nitrogen. In fact, concentrations of nitrogen as high as 4% have been found in the leaves of *C. alliodora* in Costa Rica (Bergmann et al 1994, Menalled et al 1998). Even the wood is known to contain a high content of nitrogen (Johnson and Morales 1972). It is suggested that in plantation settings, laurel should be mixed with nitrogen fixing species to improve afforestation practices (Bergmann et al 1994); however, some studies show that additional fertilization with nitrogen has a negative effect on laurel growth (Johnson and Morales 1972), perhaps because of the reduced need to grow more to attain the needed nutrient. In any case, laurel is an excellent species choice at agroforestry sites where erosion and nutrient cycling are a problem because nutrient losses due to leaching are low for laurel when compared to other tree species (Gerwing 1995).

2. Interspecies Relationships:

Laurel has difficulty with weed competition in regards to nutrient absorption (Menalled et al 1998). Growth is particularly reduced in the presence of monocots, possibly due to the high density of the fine roots of monocots that compete with the lateral roots of laurel (Haggar and Ewel 1997). Some grasses, such as *Melinis minutiflora* P. Beauv., can even have an allelopathic effect on laurel (Grieves and McCarter 1990, Liegel and Stead 1990). Since laurel has a narrow, self-pruning tree crown, a fairly large diversity of plants can grow beneath it (Hummel 2000b).

It is well known that laurel requires a great amount of light and space for initial growth. In order to determine the best density at which to plant laurel seedlings with the crop plants corn (*Zea mays* L.) and cassava (*Manihot esculenta* Crantz), Schlönvoigt and Beer (2001) used an altered Nelder-fan design plot to study the effects of tree-crop distance on the growth and development of laurel. The Nelder-fan is a circular design plot that allows the plants to be spaced at ever increasing distances in order to study density relationships. In the altered Nelder-fan design, the intra-row distance between trees was held constant and less than the shortest inter-row distance. It was designed so that the competition between trees remained the same while the tree-crop distances were varied. This design was only effective as long as the trees were small enough so that they did not begin to compete with one another.

There was no significant difference between the growth of the seedling when it was planted with corn versus in a monoculture, where all of the trees are of the same species and no crop plants are added. However, laurel was completely inhibited while it grew under the shade of the crop plant cassava. Cassava grows twice as high as corn. The tree crowns never penetrated the crowns of cassava, but it is interesting to observe how the laurel seedlings reacted to the harvesting of the cassava plants in this study since it might mimic the conditions of a sudden clearing in a natural forest stand. Once the cassava plants were harvested, the suppressed seedlings continued to grow well (Schlönvoight and Beer 2001).

Somarriba and Beer (1987) also conducted studies to compare the growth rate of laurel when planted together with other popularly grown crops in an agroforestry site. Laurel grows best when planted with cacao (*Theobroma cacao* L.) and less so with coffee (*Coffea arabica* L.), sugar cane (*Saccharum officinarum* L.) and pasture (various grasses and forbs), respectively, in descending order. The high growth rate of laurel with cacao is attributed to good soil and laurel's preferred life zone. The reasonable growth rate of laurel with coffee is attributed to good soil and intensive management of weed control. The low growth rate of laurel with sugar cane is attributed to damage to the trees during the harvesting of the sugar cane. The poor growth rate of laurel with the grasses and forbs in the pasture lands is attributed to poor nutrient levels in the soil and due to soil compaction caused by grazing cattle.

In comparative studies with *Cedrela odorata* L. and *Hyeronima alchorneoides* Allemão, laurel was shown to have the ability to exploit a larger soil volume per unit of structural carbon investment, or root volume. Laurel has the deepest and most laterally extensive root system of the three species (Gerwing 1995). Growth rate of trees in general depends on mineral nutrition. Foliar nitrogen, magnesium, and potassium/magnesium ratios are significantly related to height increments per month (Bergmann et al. 1994). Laurel has the highest foliar nitrogen concentrations of the three species, even though its leaf life span is intermediate, with *Hyeronima* having the longest lived leaves (Hiremath 2000).

Like most trees, a laurel sapling is deciduous in the dry season when photosynthesis is limited by moisture stress; so nearby evergreen plants are aided by the moisture availability during the dry season due to the reduction of the evapotranspiration of laurel. When laurel matures, it is deciduous in the wet season; and thus the roots of laurel are not affected by any lack of available moisture. In any case, the dry season in the tropics is only dry in relation to the annual cycles in the tropics. The precipitation levels are still high during the dry season in the tropics in comparison with temperate life zones (Menalled et al. 1998).

The crown diameter of *Hyeronima* is large and the tree is evergreen, but it grows beneath the crown height of laurel; thus when *Hyeronima* is grown together with laurel, the understory plants are suppressed by the heavy shade cast by *Hyeronima.* The roots of *Hyeronima* also grow to different soil depths so there is little or no competition between the two species. Laurels leaves decompose slowly so nutrient turnover does not occur quickly in monocultures, where only *C. alliodora* trees are planted together in a plantation site. The extraordinary growth of laurel in a polyculture of all three species could be accounted for by the increase in the rate of nutrient cycling by the other two species, in addition to the reduced understory root competition afforded by *Hyeronima* (Menalled et al. 1998). This combination of species is great if the primary goal of the forest manager is lumber production; however if biodiversity is the primary goal, then *Hyeronima* should not be planted directly near laurel (Hummel, 2000b).

Laurel was also compared with *Acacia mangium* Willd. In a growth study that tested the trees in pure monoculture plots and agrisilivicultural plots as well as pure crop plots. The crops that were tested were corn, ginger (*Zingiber officinale* Roscoe), and the perennial fruit shrub araza (*Eugenia stipitata* McVaugh). *Acacia mangium* encountered so many initial problems that a total of 101% of the seedlings had to be replaced within the first nineteen months; while only 11% of the laurel seedlings had to be replanted. The loss of laurel trees was due, in particular, to poor drainage. On average, *A. mangium* reached greater heights than laurel but there was no significant difference in height between *A. mangium* and laurel when laurel was planted with crops. Laurel grows better in all dimensions when planted in agrisilvicultural plots. At age five, the diameter at breast height of the polyculture laurel trees was 61% greater than the laurel trees in pure monocultural plots, probably due to the reduced inter-tree competition and improved site conditions. Like *Hyeronima*, *A. mangium* has a greater crown diameter than laurel and thus casts a greater amount of shade. Araza, in particular, is sensitive to light. For araza, light is a limiting factor, in that reduced lighting leads to reduced fruit production. Although *A. mangium* is a nitrogen-fixing species, which contributes to soil nutrient quality, laurel may be the better choice of the two in an agroforest plantation system where available lighting is a growth factor for the understory plants (Kapp and Beer 1995).

3. Management Systems:

A number of studies of laurel growth have been conducted. Some studies have concluded that there are several factors that contribute to the survival and growth of *C. alliodora*, including physical and chemical soil characteristics, site physiography, and the management of the trees with associated crops (Menalled et al. 1998, Hummel 2000a, Somarriba et al. 2001). Somarriba et al. (2001) determined that the style of plantation management accounted for 56% of the variation in the site index values; while soil and mineral factors accounted for only 3 to 10% of the variation in the site index values. Site index is the average height of the dominant and co-dominant trees in an even-aged stand. The index age is normally chosen to be around the mid-point of the life of the tree species or harvest age. In their case, the index age was five years The plantation types that offered the greatest amount of open space in well drained, fertile soils were most likely to have the largest amount of growth.

The six plantation systems that Somarriba et al (2001) evaluated were pure plantation, line planting, Taungya, new cacao, old cacao, and cacao-laurel-plantain. Pure plantations have high initial densities of a single specie tree. It is crucial to manage tree population to allow trees to extend their crowns vertically and laterally in order to maintain the capacity for rapid diameter growth. A line planting is also called a living fence. Some of the line planting plots in this experiment were shaded on one side by a nearby secondary forest or abandoned cacao trees. Individual trees were also shaded by their neighbors on either side, thus reducing the available amount of much needed light. These trees showed the highest rate of mortality (52%), partly due to the shading and partly due to poor soil quality and/or poor drainage. Both of these plantation types are considered monocultures. The remaining four plantation types are polycultures because there is more than one species of plant, whether tree or crop.

Taungya is a Burmese word that means cultivated hill plot. It is a system of forest plantations where subsistence crops are grown together with young tree seedlings. As the trees mature, the plots evolve into pure plantations. The Taungya system was developed in Europe during the Middle Ages but it was also developed independently in many places in the tropics. This is a useful method for countries with a population of poor farmers who need to grow what they eat and sell the surplus (Mastrantonio and Francis 2002). Some small to medium sized farms will plant an understory of useful shrubs at about the third to fifth year. In this study, araza was planted during the fifth annual cycle. Corn was planted for the first three annual cycles and ginger was planted in the fourth annual cycle. Laurel was also planted in association with the tree *Acacia mangium.* There were four plots; one of pure plantation laurel, one of pure plantation *Acacia*, one of laurel with crops and one of *Acacia* with crops. All four plots made up one block. There were four blocks (Somarriba et al. 2001).

In the new cacao plantations, the cacao trees and the laurel trees were out-planted as seedlings. Laurel prefers full sunlight but cacao requires shade; so corn was planted as a temporary shade for the young cacao seedlings. As the cacao trees grew taller, the corn plants were replaced by pigeon pea [*Cajanus cajan* (L.) Millsp.] or cassava until the laurel trees were large enough to provide shade. In the old cacao plantations, laurel was planted under established cacao trees as replacements for the original shade canopy that had become unproductive. The cacao trees were pruned during the first two years and the original shade trees were thinned progressively with the laurel development. The old cacao plantation type had an intermediate mortality rate of 26%.

The plantation type with the lowest mortality rate, only 2% in six years, was cacao-laurel-plantain. The laurel density was held constant and the proportions of cacao and plantain varied. There was no thinning performed on the laurel trees due to the low initial density of 69 trees per hectare. Corn, pumpkins (*Cucurbita maxima* Duch) and cassava were planted in cycles to shade the cacao tree seedlings until the laurel trees were established. The results of the study of the growth rate of laurel under the conditions of these different plantation types was significant. The order of the best growth rate of laurel is as follows in descending order: cacao-laurel-plantain > Taungya > new cacao > old cacao > line planting > pure plantation (Somarriba et al. 2001).

Laurel is only one of many species of valuable hardwood trees that are native to the tropical forests from Mexico to South America. Until 1987, laurel was the only native species along with the three exotics, *Gmelina arborea* Roxb., *Pinus* spp. and *Eucalyptus* spp., which were used in forest plantations on the Atlantic lowlands of Costa Rica. They made up 94% of Costa Rican plantations (Piotto et al. 2002). The plantation or forest manager must take many things into consideration when choosing one or more species for a site. In a more recent study in Costa Rica and Panama, Kapp et al. (1997) showed that growth is slower in laurel than in several other popularly recommended timber species such as *Eucalyptis deglupta*, *Terminalia ivorensis* A. Chev., and *Tectona grandis* L. f. A slower growth rate and a smaller size may be enough criteria to determine that laurel is unsuitable for monocultural plantation timber production; however, laurel has other positive attributes that can compensate for its drawbacks in other types of management systems.

Laurel has a fairly dense crown when it is young, which leads to the initial rapid growth of the tree. However, as the tree matures, the crown becomes thinner (Neil and Jacovelli 1985). Among this group under study by Kapp et al. (1997), laurel develops the smallest crown, which leads to reduced photosynthetic activity and slower growth. Even so, a small crown is a positive attribute for an agroforestry tree, which must allow adequate light to pass to the understory. This natural growth habit is favorable for the neighboring crops around laurel trees (Neil and Jacovelli 1985, Kapp et al. 1997). Laurel not only grows reasonably well with crops but it is also a valuable commercial tree species in and of itself. Even today, farmers and merchants prefer laurel because they are familiar with the timber and because they know that laurel is such a prolific seeder that it will generally establish itself in abandoned fields and cleared lands. There is such an abundant source of seeds that, even if the farmer wants to control the plantings, laurel is an easily available tree (Kapp et al. 1997).

Between 1990 and 1995, 88% of the plantations established in Costa Rica made use of more native species. The non-governmental organization projects conducted at La Selva Biological Station of the Organization for Tropical Studies (OTS) demonstrated that some previously overlooked native species performed well for silvicultural purposes. Native species generally grow better than exotics at sites with poor soil conditions and limited management (Piotto et al.

2002), unlike laurel, which needs well drained, fertile soil and managed weeding for full potential growth. The logging pressures on natural forests can be significantly reduced by using medium to high quality native species in reforestation projects and forest plantations. Without government incentives, poor farmers do not have the resources to establish and maintain sustainable reforestation. Trees have a long rotation and are therefore a high financial risk (Piotto et al. 2002). An agroforestry management system combines enough variety of crops that the economic risk can be reduced for small farmers.

In some areas, such as where *Cordia alliodora* is an exotic species, laurel is a suboptimal choice for agroforestry. In the Pacific region, on various islands of Vanuatu, laurel has become subject to certain problems that normally do not occur in its natural range (Neil and Jacovelli 1985). Namely, laurel succumbs to a severe attack of root rot caused by the native soil fungus *Phellinus noxius* (Carter) G. H. Cunn. The initial symptoms of this fungal attack appear as chlorosis or yellowing of the leaves followed by the loss of leaves. The lateral root system near the surface becomes encased in a brown fungal sheath. Once the initial symptoms begin, laurel trees do not recuperate and there appears to be no heritable resistance in laurel to *P. noxius* attack. There is, however, a possible preventative solution to the problem. The indigenous population of Vanuatu has a traditional practice of using "blocking plants" such as *Plectranthus amboinicus* (Lour.) Spreng, commonly known as Spanish Thyme, Cuban Oregano, or Indian Borage, as well as *Coleus scutellaroides* (L.) Benth. in their cultivated plots to prevent the spread of fungal diseases. Further research is being conducted in respect to the traditional uses of these herbaceous species (Neil 1988).

The largest plantations of the exotic laurel trees established in the Pacific region have been planted among the islands of Vanuatu (Grieves and McCarter 1990), because the natural forests in that area are generally lacking in the variety of tree species of commercial value. In fact, certain tree species in these natural forest stands act as carriers of *P. noxius*, which deters the growth of commercially valuable trees. Many of the islands of Vanuatu have good soils but some sites have soils that are severely leached, thus leading to the trees' weakened resistance (Neil 1988). Plants like laurel, that take up high amounts of biologically fixed nitrogen, act as buffers against nutrient losses due to leaching. However, short-lived understory scavenger plants are particularly adept as storing high concentrations of nutrients in their leaves and other plant structures, which are later released to the plantation system as slowly decomposing litter and soil organic matter. An understory is thus a valuable management tool for plantation systems. In addition, a natural understory tends to lead to the development of a mixed secondary forest which is necessary to the development and protection of biological diversity (Parrotta 1992). The Vanuatu islands are also subject to damages caused by hurricanes, such as strong winds and flooding. The combination of disease risk, poor soils, and extreme weather disturbances together form an inhospitable habitat for laurel (Neil 1988).

It is interesting to note that whether the manager is interested in biodiversity or lumber production, laurel grows best in a polyculture as long as there is plenty of light and managed weeding. Polyculture, or mixed-species plantations are advantageous for landowners because they reduce market risks by diversifying forest products and by allowing one species to compensate for another in the event of damage due to pests or disease (Menalled 1998). Laurel can present some problems to agroforestry farmers in that certain soil conditions such as shallow depth and nutrient fertility encourage laurel to develop a large lateral root system that can out-compete the roots of agricultural crops (Neil and Jacovelli 1985). However, the benefits of utilizing polyculture plantations out-weigh the problems. Polyculture plantations are also advantageous for wildlife habitat and for aesthetic purposes (Menalled 1998).

Pure plantations and agroforestry plantations are excellent solutions to world society's forest needs; however, natural forests are also necessary to maintain biological diversity and a healthy environment. Removed from forest competition and capable of developing vigorous root systems on agricultural soil, agroforestry planted laurel grows better than in natural stands like at Gigante Peninsula, Panama, and compare favorably with optimal natural sites like the Costa Rican Atlantic lowlands. Puerto Rico is at the northern boundary of the species' natural range, although this may or may not have any bearing on the species' growth potential there. The site at Guánica State Forest in Puerto Rico is listed as subtropical dry, which would explain its slower growth, as laurel does not do as well in drier areas (Johnson and Morales 1972, Liegel and Stead 1990, Liegel and Whitmore 1991).

Forest managers have many things to consider and various organizations of priorities. In addition to the financial concerns of farmers, governments also need to be concerned about the environment, the sustainability of their forest products, and the cultural needs of its citizens. In some areas such as Vanuatu, the national government has established constitutional policies that have relegated the land back to the traditional land tenure pattern, where the land is generally held in common ownership by family clans. The large plantation holdings of the mid-nineteenth century have been phased out since the land itself holds a cultural and spiritual meaning to the indigenous population (Neil and Jacovelli 1985).

The government of Vanuatu recognizes the need for national forest plantations for local supply as well as for industrial production, but the national government has taken a more friendly approach toward traditional land use patterns such as subsistence gardening in order to enlist the cooperation of local landowners. The people's needs are met when forestry and agriculture work together to create a healthy environment that is both profitable and culturally meaningful (Neil and Jacovelli 1985). A healthy environment is a biologically diverse landscape. In order to develop this kind of environmental quality in plantation sites as well as in natural stands, a species-rich habitat must be established in the understory of the trees (Haggar et al. 1997).

Secondary forests, which have been formed as a consequence of human impact on forested lands, are fast growing ecosystems made up of species that coincidently have life cycles that are in sync with human needs. Secondary forest production turnover is twice as fast as that of primary forests; thus the wise management of secondary forests contributes to the conservation of primary forests. In addition, secondary forests tend to foster diverse understory species that eventually grow into mature ecosystems. Species richness is important for biological diversity, so the use of a tree such as laurel, which allows a generous amount of light to reach the ground, is beneficial.

The management of a secondary forest can be tricky since the manager must balance the need for production harvests and the maintenance of the nutrient quality of the soil. The pioneer trees of a secondary forest generally take over abandoned agricultural lands that are nutrient deficient. These species then provide a quick turn-over of soil organic matter in the form of leaf, stem, and root litter. Secondary forests are not as efficient as primary (mature) forests in their recycling of nutrients to the forest floor, regardless of soil type and age (Brown and Lugo 1990). However, laurel leaves do decompose slowly for a pioneer species and thereby preserve the nutrient supply of the forest for longer periods than is typical in a secondary forest (Menalled et al. 1998). It is suggested by foresters that a native understory be allowed to develop so that once a tree crop has been harvested, a natural forest stand can develop and mature (Brown and Lugo 1990).

This idea of a biologically diverse landscape is not new. Ancient Mayan people managed large tracts of land in the Yucatan Peninsula in Mexico so that what were in fact secondary forests appeared to be primary forests. Many modern botanists were fooled as they classified the great variety of plants that typically occurs in a primary forest. The charcoal, pottery shards, and other human artifacts found in soil profiles proved that these lands were in fact utilized to meet the food and fiber needs of the Mayan people. Many of these traditional methods are being lost in societies' quest for more products and services (Brown and Lugo 1990).

In the mid-1990s, the focus of agroforestry research drifted from on-farm plantations to indigenous agroforestry systems in order to study the advantages and draw-backs of procedures that are already in use in any particular area. Often times, the indigenous peoples of any particular locale have traditional practices that eliminate many of the problems that occur at non-traditional agroforestry sites. One such study by Hellin et al. (1999) was of the Quezungual system from western Honduras. This system is used by small landholding farmers with 2.5 hectares or less of available land. Where there is a scarcity of available land, the slash and burn method of agriculture is not an option. Often times, the region is mountainous and the farmers have to cultivate terraces on steep slopes. In this system, many of the trees and shrubs are pollarded. In other words, the top branches are cut back to the trunk so as to stimulate new shoot growth. Laurel trees are an exception to this practice because they are self-pruning and naturally attain a narrow crown. Laurel is usually a dominant tree species in this system. The laurel trees are typically harvested after seven years and the timber is either sold or used for house construction. Other timber trees are also generally spared of this practice.

The pollarded materials are left to dry on the ground; and when the rains begin, the crops are sown through the dead material. The pollarded material acts as a mulch that protects the soil from erosion, conserves soil moisture, reduces the incidence of some diseases, and increases the level of organic matter in the soil. This system is not labor-intensive and the plots where this system is used can be cultivated for longer periods than normally cultivated plots, which must have more frequent periods where the fields are left in fallow. Some of the problems encountered with this system include the attraction of birds that inevitably feed on crops as well as the fruits of the trees and shrubs, the incompatibility of animal use in land preparation due to the presence of the trees and shrubs, and the excess accumulation of moisture from heavy rainfall, leading to fungal infections. Generally, this system meets the needs of small, local farmers and is also environmentally friendly with its conservational effects (Hellin et al. 1999). Further research is needed by ethnobotanists as well as foresters in order to better understand the rich history and tried methods of native peoples before their knowledge has been usurped by the methods of modern society.

4. Conclusions:

Laurel is a good choice for fine hardwood timber production; but it is a better choice for agroforestry sites. Its natural growth habits are conducive for allowing more available light and water for plants growing beneath it, whether they be planted crops or biologically diverse species of weeds and such. Cattle grazing is harmful to the extensive lateral root system of laurel as well as to the existence of an understory; but the soil compaction can be tolerated by laurel at the expense of better growth. Laurel is a pioneer species, and as such, requires full sunlight. It tends to fall into an intermediate to suppressed condition when over-shaded; but laurel is resilient enough to bring on renewed growth under better site conditions even after maturity begins at about age seven. Laurel is a good choice for farmers because this tree is a multi-purpose tree species (MPTS).

In addition to the farmers' needs, the natural environment also has special needs. An appropriate habitat is needed for wildlife; people need a recreational habitat that brings adventure or peace of mind; and society needs the opportunity to have new and undiscovered pharmaceuticals, which also need a natural habitat. It is important to maintain forest plantations for lumber and agricultural needs; but it is also important to maintain natural forest stands to fulfill these alternate habitat needs. Biological diversity is necessary for a healthy environment. This can be achieved in forest plantations as well as in natural stands by allowing understory regeneration and reducing cattle grazing within the stands. However, where lumber is the primary concern, cattle grazing is a preferred treatment in pure monoculture plantations to reduce the nutrient competition of an understory. A forest management system reflects the primary goal of the forester, and the species selection should be studied carefully in order to further the goals of the chosen management style. Forest industry must more fully evolve to satisfy the variety of social, economic and environmental needs.

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