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An Assessment of Blue Mahoe (*Hibiscus elatus*) Growth Using Topographic, Soil, and Litter Properties in St. Vincent, West Indies

by

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ABSTRACT

An assessment of soil-site conditions in 27-to 36-year-old blue mahoe (*Hibiscus elatus* Sw.) plantations was conducted on St. Vincent, West Indies. Soil, litter, and topographic data was collected from eighteen sites in three different forest reserves. No single topographic factor was related to blue mahoe mean annual diameter increment or mean annual height increment based on multiple regression analyses, but basal area and volume were associated with the Mn content of the litter layer. The average litter mass accumulations for Hermitage, Montreal, and Vermont reserves were 8.1 Mg ha^{-1}, 8.6 Mg ha^{-1}, and 9.1 Mg ha^{-1}, respectively. Clearly the miscellaneous fragments were the dominant litter component followed by blue mahoe leaves, fine wood, and other species leaves. N, P, K, Ca, Mg, and Ca concentrations in the litter were statistically similar (Kruskal-Wallis H Test, $P<0.05$) among the four litter components. The surface soil variables that were significantly different among the reserves included: pH, soil organic matter, electrical conductivity, extractable P, K, Ca, Mg, Fe, Mn, and CEC.

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CHAPTER ONE: INTRODUCTION

1.1 INTRODUCTION AND RATIONALE

Currently, world trends suggest there are strong justifications for sustainable forest management to meet the escalating human needs for food, energy, and fiber. At the same time, the demands for a cleaner environment, protection of biodiversity, and space for recreation continue to rise. In the tropics, the alteration of the natural landscape by humans may be considered detrimental, but it does provide an opportunity to study the implementation of tropical forest plantations and the resiliency of forest ecosystems. The establishment of forest plantations around the world has become a necessary measure for securing a sustainable supply of wood to the increasing populations of the world. In 1996 there were approximately 31 million hectares of forest plantations in the tropics and this number is expected to increase rapidly over the next decade (Palo and Lehto, 1996).

In Latin America and the Caribbean there has been a trend towards the development of forest plantations for fuelwood, thus decreasing the pressure on native tropical forests. This is one way of managing marginal lands and more importantly convincing rural people to plant and protect trees for their own economic benefit. Small scale tree farming, such as agroforestry or community forestry has the potential to increase family income while at the same time encourage sustainable land use.

The need to manage tropical forest plantations is becoming increasingly critical for the island of St. Vincent, where one-third of its tree plantations have reached rotation age (25-35 years) (Francis, 1989). Of these plantations, approximately 70% are comprised of blue mahoe (*Hibiscus elatus* Sw.). Known for its rapid growth, toleration of dense spacings, and adaptability to a wide range of site conditions, this evergreen, angiosperm tree is a popular plantation species throughout the West Indies. In the mid to late 1960s, reforestation efforts on St. Vincent were designed to reclaim crown lands above 305 m elevations for the purpose of soil and water conservation. Although timber production was of secondary importance, Prins (1986) suggested that by the year 2000 through proper management of natural forests, agroforestry operations, and the establishment of forest plantations, these resources could reduce annual wood imports by half. These expectations support the need for sustainable development solutions and the implementation of high yielding plantation systems.

This study is part of an ongoing effort to understand the interrelationships between soil nutrient availability, litter nutrient accumulations, and growth performance of tropical tree plantations (Lugo et al., 1990; Ceuvas and Lugo, 1998; Sharma and Pande, 1989). A recent study by Strand (1996) found that young stands of blue mahoe on St. Vincent were in poor condition and suggested that secondary rainforests were more effective at controlling soil erosion and protecting slopes from mass wasting. The occurrence of several mature blue mahoe plantations in each of St. Vincent's Hermitage, Montreal, and Vermont forest reserves, provided an opportunity to assess and compare various soil-site characteristics as well as litter nutrient concentrations. The St. Vincent Forestry Division was also interested in knowing whether there were differences in size or growth rates of blue mahoe between these reserves.

The concept of sustainable production in short rotation, high yield plantation systems may become an important concern to the St. Vincent Forestry Division when intensive management begins and nutrients are removed in the harvested fiber. Questions about the performance of blue mahoe and whether it is the best tree species for these soil-site conditions is a concern. Recent studies have suggested that short rotation tropical tree plantations coupled with intensive management may lead to high rates of nutrient removal in the harvested fiber, raising concerns about long-term site quality and sustainable production (Wang et al., 1991; Lugo et al., 1990).

1.2 RESEARCH OBJECTIVES

The main objective of this research is to compare and contrast the growth performance and soil-site conditions of selected blue mahoe plantations in the Hermitage, Montreal, and Vermont forest reserves on St. Vincent. More specifically, regression equations will be developed to predict mean annual diameter increment, mean annual height increment, basal area, and volume from several topographic, soil, and litter properties. In addition, any variations in soil and/or litter chemistry that may be related to blue mahoe age will be assessed. These three sets of variables will be discussed in detail :

- Topographic factors (i.e., slope angle, slope position, and aspect) will be examined for differences in tree growth;
- Litter mass accumulations and nutrient concentrations of four litter compartments will be used to assess the differences between blue mahoe plantations; and
- Soil physical and chemical properties will be examined to determine fertility levels and nutrient availability of the mineral portion of the soil.

Together, these ecological parameters may identify major silvicultural issues, conflicts, or problems associated with the performance of blue mahoe plantations as well as provide a reference for soil-site conditions prior to the implementation of intensive management practices. This research will also form the basis for suitable forest and land management recommendations.

1.3 PREVIOUS RESEARCH

Through the support of the Canadian International Development Agency, seven graduate students from the University of Calgary have conducted studies on land use suitability, soil erosion impacts, and plantation management on St. Vincent (Kennedy, 1999; Hackman, 1998; Ciccaglione, 1998; Strand, 1996; Ewaschuck, 1995; Orban, 1990; Visser, 1989). To date, there has not been a study on the growth assessment of mature blue mahoe plantations or a comparison of the Hermitage, Montreal, and Vermont forest reserves. The most recent forest inventory of blue mahoe on St. Vincent was conducted by Birdsey et al. (1984). This inventory provided an overview of the islands forest resources including some of the blue mahoe plantations represented in this study.

The first soil survey on St. Vincent was conducted by Hardy (1934) which still remains an important reference. A more recent soil and land survey of the island was completed by Watson et al.(1958) which included less emphasis on pedological details and more emphasis on the total environment and issues of land use. These results inspired further research by Spinelli (1973), Macfarlane (1974), Ahmad (1981, 1984), Limbird (1987, 1992), Orban and Matadial (1989), Visser (1989), and Orban (1990). Most recently, Strand (1996) and Hackman (1998) quantitatively evaluated the effectiveness of blue mahoe and mahogany (*Swietenia macrophylla*) plantations in preventing soil erosion in comparison to secondary rainforests.

CHAPTER TWO: LITERATURE REVIEW

2.1 FOREST PLANTATIONS

The establishment of tree plantations is not a new management system. The idea of tree planting existed in the ancient Mediterranean world as early as 225 BC for timber and crop production (Mather, 1993). Today, it remains a sound practice for preserving and reclaiming degraded lands, dealing with watershed rehabilitation, timber production, industrial development, and most recently, carbon sequestration.

Forest plantations are defined as, "stands of trees which are artificially generated, either by afforestation of land which did not previously sustain a forest ecosystem, or by reforestation of land which carried indigenous forest before and has been replaced by other vegetation" (Food and Agricultural Organization, 1995). Throughout the world, forest plantations can vary substantially in size, species composition, and purpose. Often the objectives or reasons for which a plantation is established determines the types of species that are planted. Plantation sizes may range from under a hectare in areas where trees are used to stabilize slopes, to several thousands of hectares, when plantations are used industrially to produce timber and pulpwood.

Often the purpose for establishing forest plantations cannot be met by the local indigenous forests and instead, are supplemented by exotic species that meet the desired quantity or quality of forest product. Exotic species are plants that grow in an area in which they do not naturally occur (Zobel et al., 1987). As with any plant, growth is influenced by the genetic capabilities of a species interacting with its environment. Environmental influences include climatic factors (i.e., air temperature, precipitation, wind, and insolation); soil factors (i.e., soil physical and chemical characteristics, moisture, and microorganisms); topographic characteristics (i.e., slope, elevation, and aspect); and competition - influences of other trees, vegetation, and animals. The sum of all these variables describe the site quality, although competition is of less importance than the other factors since it is temporary and can be changed by silvicultural treatments (Husch et. al, 1972).

2.2 ENVIRONMENTAL INFLUENCES ON GROWTH AND SELECTION OF TREE PLANTATION SPECIES

2.2.1 Topography

Elevation, slope gradient, and aspect all interact to influence the physical environment and therefore, the growth rate of plantations. On islands with considerable topographical relief, the most striking landscape patterns are often associated with a change in elevation. As elevation increases, the average annual temperature decreases and precipitation increases as a result of orographic uplift (Jordan, 1985).

Together, aspect and slope gradient influence the amount of solar radiation that is received by the trees. As latitude decreases, aspect plays less of a role in the amount of solar radiation received by vegetation and more of a influence on moisture availability and exposure to passing storms. Lugo et al. (1989) recorded instantaneous measurements of soil moisture after the passage of hurricane Hugo and it was noted that windward sections of the forest plantations had been exposed to greater rainfall and damage by storms than the leeward sections.

2.2.2 Climate

Climate has two components that are of overriding importance when selecting a species to plant - amount and distribution of rainfall and temperature extremes. Few tropical tree species can be successfully grown where there is less than 700 mm of rainfall per year (Evans, 1992). In the tropics, the distribution of the rainfall during a year, especially the length and severity of a dry season, is very important in species selection. Certain species show a preference for a specific pattern of rainfall. For example, teak (*Tectona grandis*) will survive in uniformly moist tropical climates, but it grows best where there is a dry season of 3 to 4 months (Evans, 1992).

There are few places in the tropics where temperature extremes limit vegetation growth although the main influence of temperature is evapotranspiration. On tropical islands, prevailing winds are important as a driving force in bringing storms and frontal systems to the land mass. The distribution and intensity of rainfall can vary substantially from the leeward to the windward coasts of an island such as the case for St. Vincent (Limbird, 1987).

2.2.3 Soil Physical and Chemical Properties

There is great diversity in tropical soils. As Khanna and Ulrich (1989) point out during species selection, the forester is primarily concerned with the properties and local variation of soils within a project area rather than with the historical development of soil profiles or systems of classification. The main soil properties affecting tropical tree growth are usually depth, physical structure, fertility, and acidity.

Rooting depth is of first importance. If there are depth limitations such as a hard iron pan which affects drainage, the species must be tolerant of anaerobic conditions (Strand, 1996; Evans, 1992). Soil structure also affects retention and movement of water in the profile, aeration, cation exchange capacity, and penetrability by roots. Typically, loams are most favorable for tree growth but some of the best soils for trees are clays found in Central American countries which are well aggregated and have good internal drainage (Davidson et al., 1998).

In general, the success of plantations often is measured in terms of their nutrient supply. All soil nutrients important to tree growth have a unique behavior which is controlled by its own rate of cycling. Consequently, of the 15 mineral elements (N, P, K, Ca, S, Mg, Na, Mn, Fe, Zn, Cu, Mo, Co, Se, and Cl) known to be essential for regular growth of plants, deficiencies of all except Mo, Co, Se, Na, and Cl have been reported in forest plantations (Binkley, 1986; Mengal and Kirkby, 1979). Comparisons between plantations at different sites has revealed appreciable differences in nutrient availability. It seems that generally soil nutrient supply would have a greater influence on the concentration of nutrients in the tree tissues than do the genetic factors (Bowen and Nambiar, 1984; Miller 1984). Some specific variations in different components of the tree may be related to the morphology and physiological function. For example, the blue mahoe has a self-pruning mechanism that focuses its nutrient transport to younger and higher branches where photosynthesis is maximized.

In the tropics, it is often soil nutrient deficiencies rather than excesses that affect tree growth. Most commonly it is P, Zn, Bo, and sometimes N that are limiting. In volcanic soils, P is often limiting because of the presence of allophane and its ability to fix P into unavailable forms (Visser, 1989; Brady and Weil, 1996). Aluminum has been known to occur in excess which can greatly restrict growth. In the past, nutrient deficiencies in the soil have modified species choice but today they can be corrected easily through proper management and fertilization.

Soil acidity is important because it affects availability of nutrients. Pines (*Pinus* spp.) generally grow well on moderately acidic soil (pH 3.5-6.0), while mahogany (*Swietenia macrophylla*) is a particularly useful species for calcareous soils in the more humid tropics (Hackman, 1998).

Other site factors that may influence the choice of species and success of plantation growth are: resistance to insects and disease, competition with other vegetation, areas at risk of hurricanes and tropical storms, special protection needs, and fire resistance. Many of these factors can be overcome by selecting genetically superior species that can successfully use the environmental resources and convert them into more valuable products.

2.3 NUTRIENT CYCLING IN TROPICAL TREE PLANTATIONS

2.3.1 Factors Controlling Nutrient Release

It is known that climate is the single most important influence on the distribution of vegetation which distinguishes the tropics from other parts of the world. Temperatures in the tropics are consistent and seasons are denoted not by changes in temperatures but rather variations in precipitation. High annual temperatures and large amounts of rainfall can mean that the growing season for some plants is continuous provided no other factors are limiting. A continuous growing season results in high rates of forest productivity and large quantities of nutrients are being cycled through the system (Jordan, 1985). In return, an abundant amount of biomass is produced for herbivores, and organic matter on the forest floor is consumed and nutrients are released into the soil. The latter step of decomposition is critical so that nutrients are constantly available and other microbiological processes such as nitrification can occur year round.

2.3.2 Rates of Nutrient Cycling In Plantations

In order to ensure soil nutrients are being used efficiently and that fertilizers are having their greatest effect, the forest manager requires an understanding of the role of nutrient cycles in forest productivity. Some trees (e.g., *Leucanea leucocephala*) have an ability to alter their surroundings when soil nutrients are limited by increasing production of biomass and maximizing usage and retention of essential nutrients (Sawyer, 1993). Nutrient ions taken up by a tree may be translocated into and out of a variety of tissues, they may become immobilized in accumulating structural tissues or released through litter, or absorbed by root depth or crown leaching (Miller, 1984). As tissues senesce, as at leaf abscission or during heartwood formation, nutrient ions are withdrawn back into the living tissues. This process begins the formation of the soil organic layer so long as soil fauna decompose the forest floor litter.

The rates of nutrient cycling in tropical forest ecosystems have been summarized by Vitousek and Sanford (1986) and Grubb (1989). According to their research, the differences between forests on moderately fertile and infertile lowland soils is greatest for Ca and least for N. However, some soil-site conditions do circulate large quantities of nutrients. For example, xeromorphic forests on strongly leached lateritic soils in the Rio Negro region of Venezuela contained comparatively less P than most lowland forests. On the other hand, forests of similar character and structure, on podzolized sands had significantly smaller amounts of N in circulation.

The mechanical and chemical weathering of litter and soil organic material releases nutrients as forms that are available to plants and microorganisms. Although the rate is related to temperature and moisture levels, decomposition is much slower in tropical forests that are nutrient poor (Edwards, 1977; Anderson et al., 1983). The general pattern of nutrient release from decomposing leaves in temperate and boreal forests involves the early immobilization (net accumulation) of N and often P, followed by net nutrient release (Brady and Weil, 1996; Vitousek and Sanford, 1986). A similar pattern of immobilization is observed (especially for P) in leaves from tropical infertile sites, but not those from fertile sites (Anderson et al., 1983). Decomposers on infertile sites accumulate P from an extremely limited supply in the soil, so P immobilization probably places decomposers in competition with plants.

2.3.3 Nutrient Concentrations in Litter

Foliage usually accounts for 75 to 95% of the litter on the forest floor followed by branches, bark, and reproductive organs (Perry, 1994). The amount of litter and the concentration of nutrients in the litter can vary substantially in tropical forest plantations. Lugo et al. (1990) found that Caribbean pine (*Pinus caribaea*) had low nutrient concentrations in litter but high mass, while blue mahoe stands contained large amounts of nutrients in the litter but less mass. These differences in litter nutrient quality can affect the soil chemical composition. Gosz (1984) provided some evidence that differences in soil organic matter quality may be a function of root mass rather than litter mass. Furthermore, Went and Stark (1968) supported the idea that trees on very poor soils obtain nutrients directly from the litter via the mycorrhizal fungi of their roots.

Sharma and Pande (1989) found that concentrations of Ca and N were greater than K, Mg, and P in all fractions of litter for sal (*Shorea robusta*), teak (*Tectona grandis*), and pine (*Pinus roxburghii*) plantations. Typically, the accumulation of Ca increases with tree age as they absorb Ca from the soil and it becomes immobilized in cell walls (Binkley, 1986; Perry, 1994; Mengel and Kirkby, 1979). Little is known of the rates of S and P release from the organic matter; a high proportion of any P released is likely to be immobilized by inorganic absorption sites or taken up by microorganisms before plants can reabsorb it. The patterns of nutrient accumulation in litter can reflect the different development stages of the tree. For any given development stage, rates of accumulation are proportional to growth rate, which is usually a function of latitude and species (Miller, 1984; Sharma and Pande, 1989; Cuevas and Medina, 1986).

2.3.4 Nutrients in Throughfall

The net throughfall is defined as "the amount of nutrients added to the precipitation as it passes through the canopy" (Bush, 1997). The nutrients returned to the soil through crown leaching and stem flow are generally <10% of total nutrient pools (Vitousek and Sanford, 1986). In tropical forest ecosystems, throughfall is a relatively minor contributor in the N, P, and Ca cycles but it is a major pathway for K and Mg. In data collected from montane and lowland rain forests, throughfall accounted for half the K in circulation and more than one-third of the Mg. Meanwhile, less than one-third accounted for N, P, and Ca (Vitousek and Sanford, 1986). Similar results were found for a study on Sitka spruce (*Picea sitchensis*) where the atmosphere was identified as a major source of Ca and Mg and crown leaching was contributing large amounts of K (Bowen and Nambiar, 1984). Crown leaching is a significant process but its importance varies by element. In addition, the levels of precipitation and seasonal variation makes these values difficult to measure.

2.3.5 Nutrient Behavior Within the Tree

Before leaves fall to the forest floor or during formation of the cambium, nutrient ions are translocated into younger tissues in order to maintain efficient use of resources. A comparison study done on tropical montane rain forests in Jamaica and New Guinea showed that N content between living leaves and leaves in freshly fallen litter decreased from 48 to 14%, respectively (Grubb, 1977). Theoretically, any nutrients that are transferred by litter are considered unnecessary or unavailable for the overall growth of a tree, provided that the plant is taking up what is needed to meet demand. Most trees vary in the efficiency with which they use nutrients depending on nutrients stored in the tree and the amount of soil nutrients available.

Tree age will affect the amount of nutrient that is required and also the amount that will be translocated to younger foliage. Miller (1984) points out that 60 to 84% of the nutrients in foliage may be withdrawn prior to leaf fall, which may satisfy 50 to 60% of the nutrient demand of new growth.

Cuevas and Lugo (1998) found that environmental factors such as strong winds or heavy rains can force non-senesced leaves to break and fall to the forest floor contributing to variations in N and P quantities in forest litter. This higher quality litter can provide a small pulse of available nutrients to decomposers and plants.

2.3.6 Nutrient Use Efficiency

The nutrient use efficiency of a stand can be determined based on the amount of organic matter produced per unit of nutrient taken up. Boerner (1984) and Kost and Boerner (1985) evaluated the nutrient use efficiency of several tree species by measuring the amount of biomass produced during a growth period and the nutrient content in these tissues at different times of the year. A second method measured the total amount of dry mass biomass produced per unit of nutrient lost in litter. A review by Medina (1989) suggested that the method used by Boemer (1984) was simply a measurement of nutrient concentration which may be unreliable because of the difficulty of establishing when the leaves had expanded fully and the exact time of full canopy development. It is known that N and P vary throughout the growing season and are reduced as tissues senesce and nutrients are reabsorbed prior to leaf fall (Miller 1984). In order to determine the efficiency of nutrient use within a stand, Vitousek (1982, 1984) calculated the amount of biomass lost as litter and divided it by the nutrient content.

It was originally thought that nutrient cycling in tropical forests was characterized as "efficient" and "confined" relative to temperate forests. However, Vitousek (1984) discovered that tropical forests cycled large amounts of N and Ca relatively inefficiently as compared to temperate forests. Most tropical forests cycled P much more efficiently than temperate forests which suggests that available P in tropical soils may be limited.

The premise behind efficient and inefficient within stand nutrient use is described by Vitousek (1982, 1984) in two ways. Firstly, efficient nutrient use occurs when stands produce relatively large amounts of litter with low nutrient concentrations in litter, wood, and root litter. A high C to nutrient ratio suggests that more C is released per unit of nutrient in litter or because active translocation of nutrients has occurred from senescing tissue. The litter:nutrient concentration ratio increases as the amount of nutrient absorption back to the tree increases, indicating that nutrient use efficiency tends to increase on nutrient-poor sites. An efficient within stand nutrient economy supports the possibility of nutrient limitation due to environmental stress creating a higher nutrient efficiency use ratio, while an inefficient stand suggests nutrient availability is adequate or better (Medina, 1989; Vitousek, 1982, 1984; Wang et al., 1991; Cuevas and Lugo, 1998). Secondly, nutrient cycling in tropical forest ecosystems could be efficient if most of the nutrients released from litter were retained within the system with minimal losses from leaching and consumption of herbivores.

Although it might seem obvious that greater nutrient use efficiency will be associated with plants on the poorest sites, Grubb (1989) offers a persuasive argument that one might expect a greater efficiency in plants on richer sites. Grubb argued that stem growth is increased relative to leaf growth and stem tissues generally have lower concentrations of most nutrients. The same usually holds true for roots. Typically, nutrient concentrations are lower for roots than in leaves. Lugo et al. (1990) and Tanner (1981) support this idea for aboveground tree parts.

Litter is a major mechanism for transferring nutrients from aboveground vegetation to soils. Vitousek and Sanford (1986) reviewed litter nutrient concentrations on different soil types in the tropics. It was clear that forests on moderately fertile soils returned more litter at higher nutrient ratios, than did forests on other soils. Forests in the Oxisol and Ultisol group returned smaller amounts of P and Ca as an indication of the significantly higher nutrient ratios. Vitousek and Sanford (1986) evaluated the importance of nutrient retranslocation by comparing nutrients in active leaves with nutrients in leaf litter. Although this data was sparse, the results suggest that sites with high dry mass to nutrient ratios also have high ratios in the active leaves.

2.3.7 Influence of Understory Vegetation

Many exotic tree species are often believed to be allelopathic. In some manner they may release chemical toxins into the soil so that understory vegetation and other trees do not grow well. Although evidence is mostly circumstantial, it is commonly believed that blue mahoe suppresses the growth of understory species (McLeod, 1999; Strand, 1996). In fact, many people believe that indigenous species cannot be grown in pure plantations because of allelopathic effects. Some species such as eucalyptus (*Eucalyptus* spp.) are renown for their allelopathic effects because of oils in the leaves that poison the soil (Zobel et al., 1987).

Maclean and Wein (1977) found the understory plants in jack pine (*Pinus banksiana*) stands formed from 1 to 6% of the ecosystem biomass in 57-year-old stands to 88% in 16-year-old stands, respectively. Similar results were found by Lugo (1992) in tropical tree plantations where understories developed high species richness and had a higher proportion of the total nutrient inventory than did the understory in paired secondary forests. Interestingly, this author points out that understory species often accumulate certain elements and may have an even greater impact on nutrient immobilization and cycling than their biomass indicates.

2.4 PREDICTING SOIL-SITE FOREST PRODUCTIVITY

The association between soil-site factors and tree growth has been apparent for quite some time. Studies have shown that the soil characteristics significantly related to tree growth are not the same everywhere. The advantage of relating topography and soil characteristics to site productivity is that both are comparatively stable. The most common technique used for soil-site investigation has consisted of a multiple regression analysis with height or site index as the dependent variable and numerous soil and other environmental factors as the independent variables (Husch et al., 1972).

The use of soils information in the evaluation of site productivity has produced some inconsistent results when techniques such as multiple regression analysis have been used. In some cases, regression analysis has failed to demonstrate significant relationships between logical soil properties (e.g., available soil water, N, and P). Three major concerns outlined by Gale et al. (1991) when using regression and multivariate analysis were (1) multicollinearity between soil variables, (2) a small sampling range of soil characteristics, and (3) failure to incorporate soil property interactions into the model. To further assess relationships between biomass estimates and site quality, current forestry research has developed models that address the above statistical concerns (Huang, 1996; Lenthall, 1986). Multiple regression analysis is effective if major factors such as climate, topography and soils are controlled and variables with multicollinearity are tested separately within the model.

Although few studies in tropical tree plantations have been conducted using multiple regression analysis, it has been extensively applied in Canada and the United States. Mader (1976) found that prediction of white pine (*Pinus strobus*) in Massachusetts was extremely poor for topographic variables but soil variables with stand age accounted for 80 to 90% of the variation in height. Similarly, Jokela et al. (1988) found that topographic properties made little or no contribution to a predictive model for Norway spruce (*Picea abies*) in New York. Typically, soil physical factors contributed more explanation to overall growth than soil chemistry in both of the above studies. Soil texture and percentage of coarse fragments in the A and B horizons appeared to enhance productivity through better aeration and internal drainage (Bates et al., 1992; Harding et al., 1985; Pregitzer et al., 1983).

CHAPTER THREE: STUDY AREA

3.1 INTRODUCTION

St. Vincent is part of the windward islands located at 13° 15' N latitude and 61° 12' W longitude in the Caribbean Sea. St. Vincent is found between the islands of St. Lucia to the north and Grenada to the south (Figure 3.1). It is approximately 29 km long and 18 km wide at its maximum extensions and has a total area of 345 km^2. The State of St. Vincent and the Grenadines includes a chain of islands, cays, rocks, and submerged reefs extending 60 km south to Petite St. Vincent. The largest and most proximate island to St. Vincent is Bequia followed by Mustique, Canouan, Mayreau, and Union. Palm and Petite St. Vincent, the most southerly islands, are privately owned under St. Vincent jurisdiction. Many of the islets and rocks are uninhabited, including the renowned Tobago Cays.

3.2 PHYSIOGRAPHY AND GEOLOGY

St. Vincent is a volcanic island which emerged from a narrow submarine ridge in the late Miocene epoch (Wadge, 1994). Volcanic activity has continued until recent, producing a series of extinct volcanoes that run south to north dividing the windward and leeward sides of the island. St. Vincent is well known for its active stratovolcano, Soufriere, that dominates the northern part of the island and rises up 1,220 m. The most recent eruption of Soufriere was in 1979 which destroyed both the crater lake and the volcanic dome. Soufriere is separated from the rest of the mountains by a deep trough to the south that has been incised by the Wallibou and Rabacca Rivers. The south-central mountains extend for about 15 km. Highest elevations along the ridge are on Richmond Peak at 1,075 m in the north and Grand Bohnomme at 960 m in the southern part of the island.

A relatively short geologic history which involved the submergence and intermittent uplift of St. Vincent, has created a diversity of landscapes. Marine submergence is most evident on the southeast portion of the island where a series of terraces have been eroded, producing a

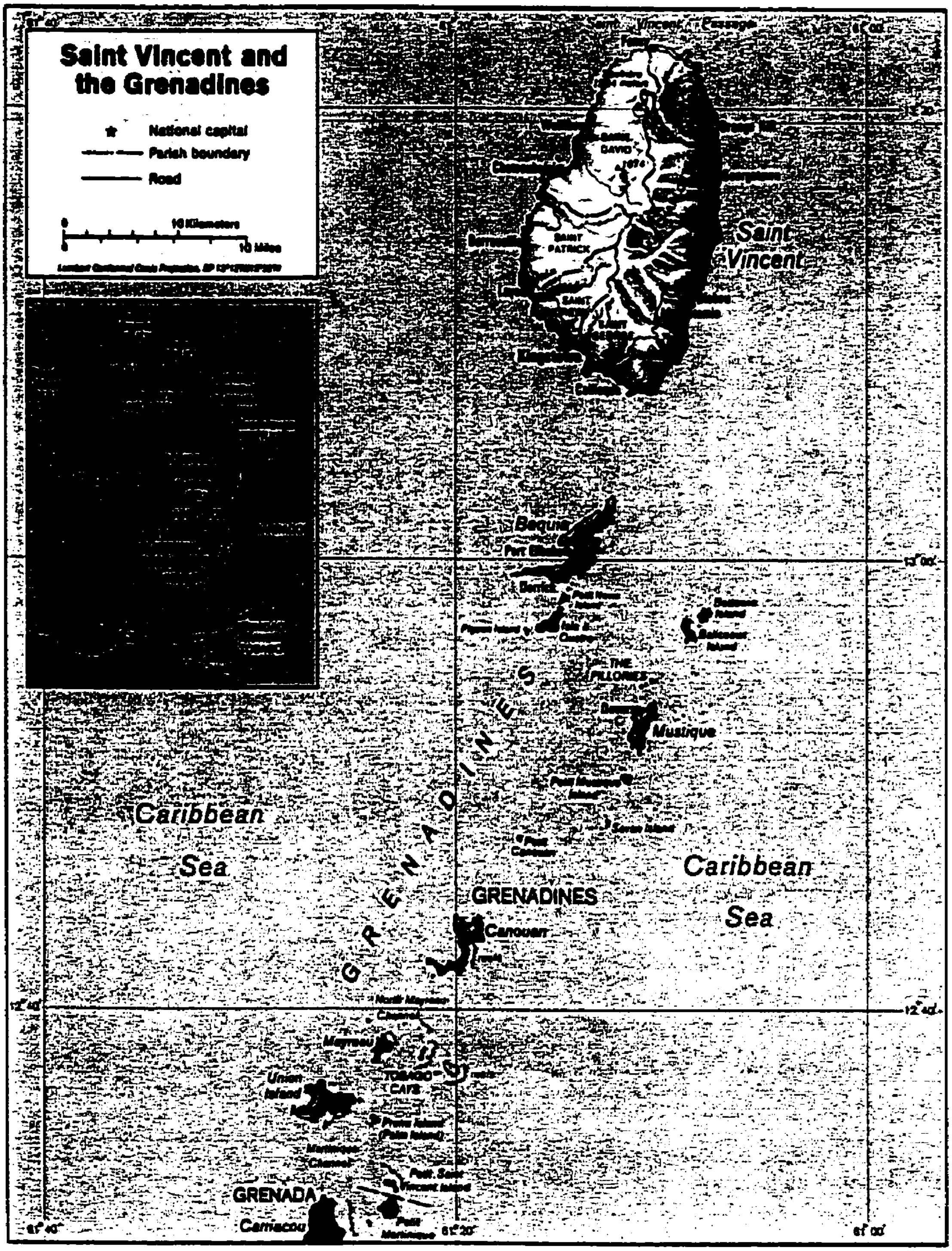

Figure 3.1. Map of St. Vincent and the Grenadines

stepped landscape. Towards the south, the land becomes progressively older, with deeper and wider valleys and lower ridges. The central mountains have been carved and eroded into lateral ridges that dominate the island. Over 50% of the land has a slope gradient >30° and only 20% has slopes <20° (Caribbean Conservation Association, 1991). On the leeward coast, steep parallel ridges create deep narrow gorges which make it difficult to traverse by road. In contrast, the windward coast has wider, flatter valleys that form fairly extensive coastal plains near Biabou, North Union, and Georgetown.

St. Vincent is composed almost entirely of pyroclastic material ranging in age from the Pleistocene to present times (Bouyesse et al., 1990). The center of the island is composed primarily of basaltic andesites and basalts which have solidified to become "tuffs", or have remained unconsolidated cinders or ashes (Limbird, 1992; Ahmad, 1984). The unconsolidated pyroclastic debris, underlying agglomerates and lava flows provide little resistance to downcutting by rivers (Figure 3.2). The streams and rivers on St. Vincent generally are described as short, straight, deep, and narrow with the occasional meander at lower elevations. The landscape is strongly influenced by the slope gradient of the major streams which originate in the central mountains and fall 610 to 1,220 m to sea level, often over distances of <10 km (Limbird, 1992). Major rivers include the Colonarie and Yambou on the windward side and the Cumberland, Wallilabou, and Richmond on the leeward side. Most of the streams on St. Vincent have coarse beds that produce overland flow only during periods of intense rainfall (Hackman, 1998) (Figure 3.3).

The age and form of geologic materials found on St. Vincent are important to understanding the stream flow for each of the watersheds. Pyroclastic materials that are Pleistocene to Recent age are porous which allow for continuous stream flow in the Buccament and Colonarie watersheds. Parent materials that are derived from the older Richmond Peak / Mount Brisbane volcanoes during the late Pliocene to early Pleistocene are weathered and have reduced porosity, therefore, the movement of groundwater is reduced (Limbird, 1992; Cummings and Lawrence, 1988).

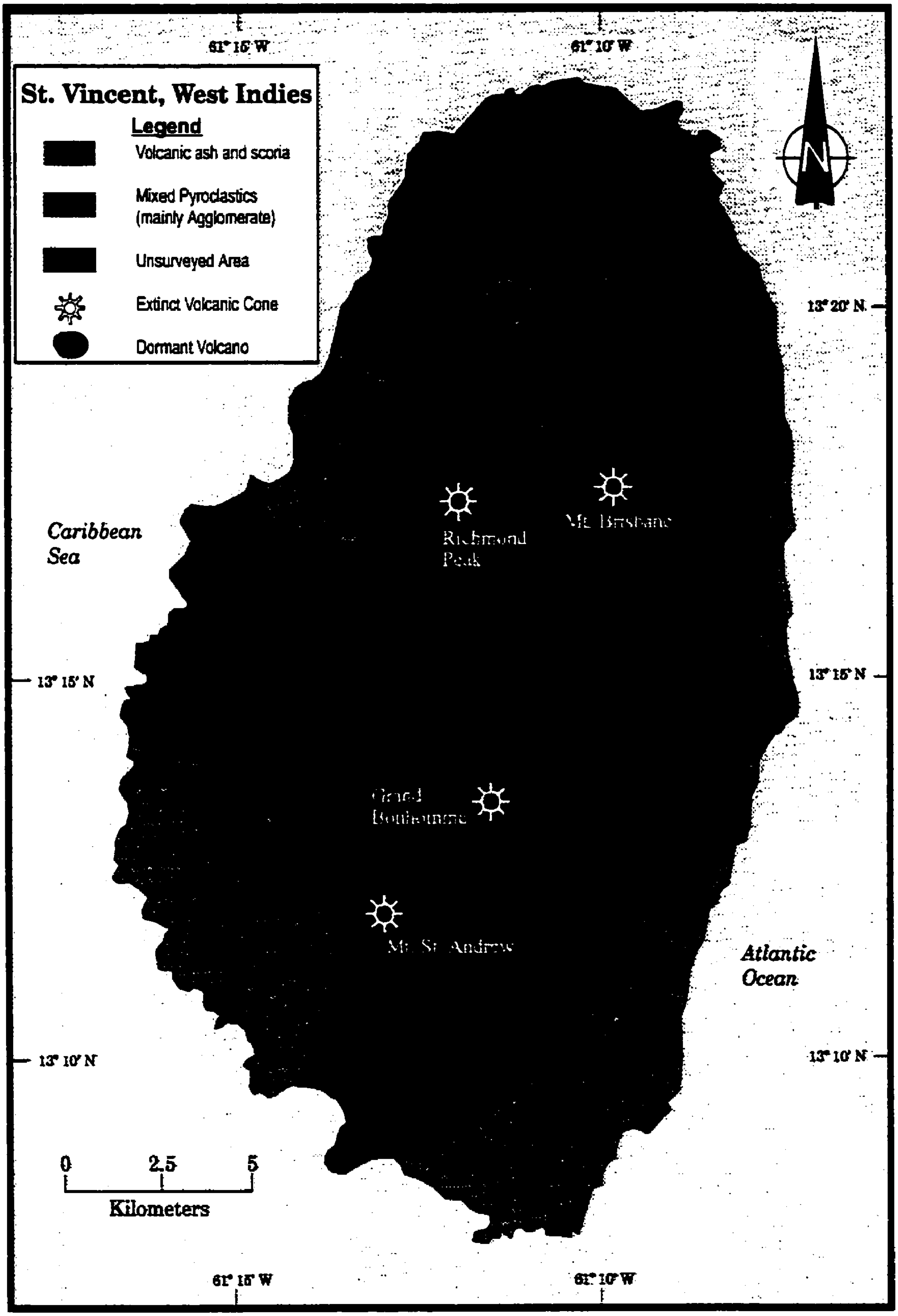

Figure 3.2 Surficial Geology of St. Vincent (modified from Caribbean Conservation Association, 1991 and Strand, 1996).

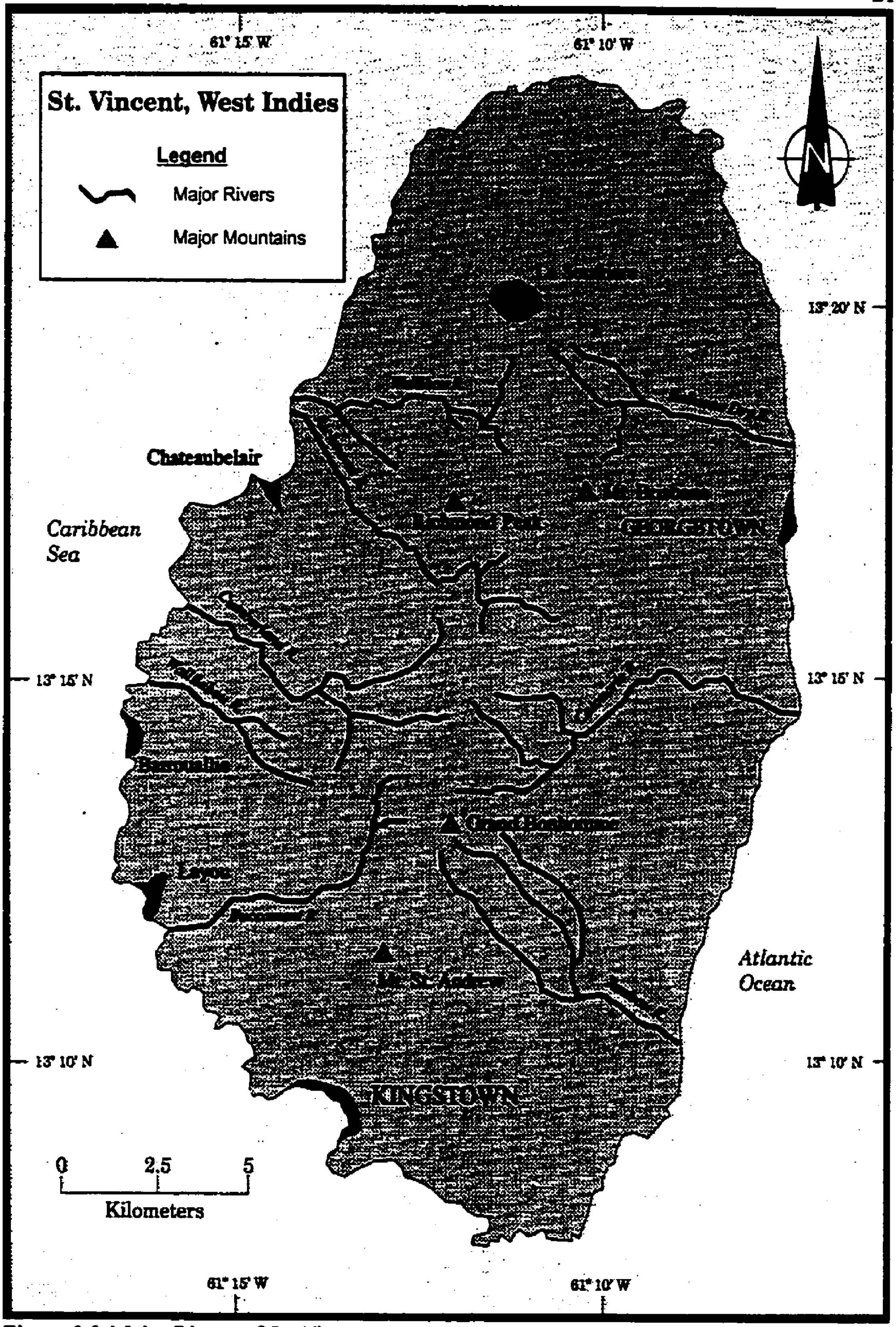

Figure 3.3 Major Rivers of St. Vincent (modified from Caribbean Conservation Association, 1991 and Strand, 1996).

3.3 CLIMATE AND VEGETATION

The regional climate of St. Vincent is classified as humid tropical (Af) to sub-tropical (Afa), according to the Koppen classification system (Christopherson, 1995). The mean annual temperature on St. Vincent is 26.7°C (Watson et al., 1958; Caribbean Conservation Association, 1991). Typical of small tropical islands, the climate is warm and moist with slight seasonal or diurnal variation. The rainfall distribution is influenced mainly by the subtropical anticyclone belt and the migrating inter-tropical convergence zone. January to May is typically referred to as the dry season when the subtropical high pressure cell becomes apparent in the region. The wet season extends from June to December when the inter-tropical convergence zone is at its most northerly position over the Caribbean Sea. Over 70% of the annual rainfall on St. Vincent is received during this period (Watson et al., 1958).

The variability in topography introduces a diversity of microclimates throughout the island. The numerous ridges and mountains on St. Vincent act as topographic barriers to migrating warm, moisture laden air. The air is forced upwards to cool at approximately 1.0°C 100 m^{-1} where it condenses and contributes to an average annual rainfall of 3,180 mm in the central part of the island. Rainfall is greatest in the upper elevations and decreases near the coastline to approximately 1,500 mm yr^{-1} (Watson et al., 1958). The driest regions are located on the southeast coast which is marked by four to six months of dry weather (Figure 3.4).

Tropical storms and hurricanes are prevalent in the eastern Caribbean Sea from June through October. During this time, easterly atmospheric waves often collide with the northeast trade winds which carry large amounts of precipitation (Ahrens, 1994). Occasionally, these easterly waves develop into a hurricane but tropical disturbances are more common on St. Vincent.

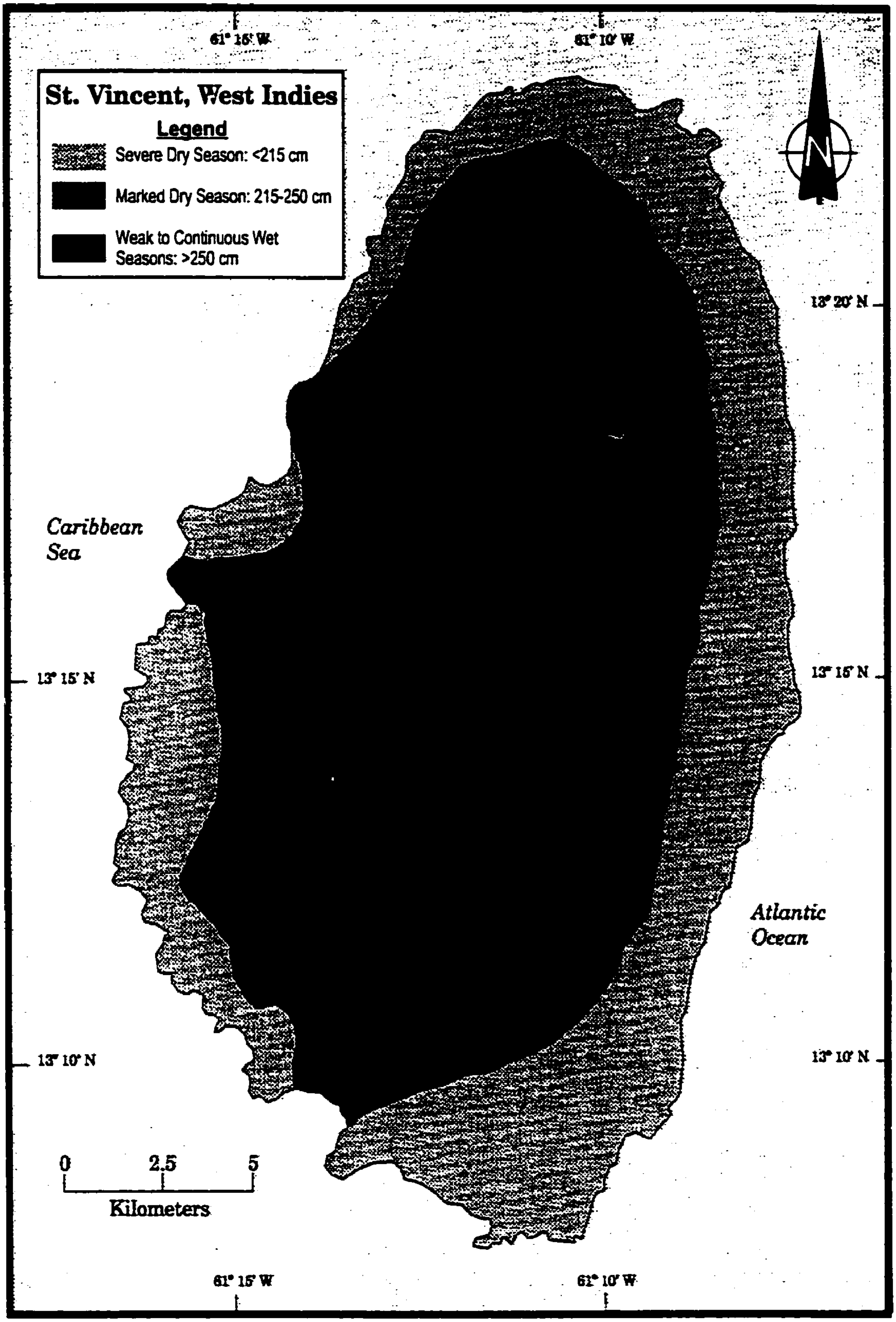

Figure 3.4 Precipitation Zones of St. Vincent (modified from Caribbean Conservation Association, 1991 and Strand, 1996).

The influence of elevation on temperature and levels of precipitation also correlate with natural vegetation patterns on St. Vincent (Figure 3.5). The vegetation has been described in detail by Beard (1949) and theoretically proposed by Watson et al. (1958). Beard's system defined the species on St. Vincent by the climax natural vegetation types on the basis of physiognomy, structure, and lifeform. Furthermore, the vegetation was arranged along several environmental gradients and categorized according to floristic composition (Beard, 1949). Five broad classes of vegetation were proposed for St. Vincent. The dominant species are listed for each vegetation type (Table 3.1).

Table 3.1. Dominant plant species in St. Vincent vegetation types.

PRIMARY RAINFOREST	
Mountain Cabbage (*Euterpe spp.*)	
Grommier (*Dacryodes excelsa*)	
Sweetwood (*Lauraceae spp.*)	
Wild Cocoa (*Meliosma herbertii*)	
Wild Star Apple (*Micropholis chrysophyylloides*)	
DRY SCRUB WOODLAND	**PALM BRAKE**
Red Birch (*Bursera simaruba*)	Palm (*Euterpe globosa*)
Loblolly (*Pisonia fragrans*)	Ironwood (*Sloanea truncata*)
Gru Gru (*Acrocomia sp.*)	Mountain Gunstock (*Freziera hirsuta*)
Cactus Scrub	Spanish Ash (*Inga ingoides*)
ELFIN WOODLAND	**SECONDARY RAINFOREST**
Charianthus coccineus	Waterwood (*Chimarrhis cymosa*)
Didymopanaz attenuatum	Bumline (*Sapium caribaeum*)
Mountain Gunstock (*Freziera hirsuta*)	Spanish Ash (*Inga ingoides*)
Caloisianthus frigidus	Trumpet Bush (*Cecropia peltata*)
Anthurium sp.	Candlewood (*Micronia guianensis*)
Carludovica sp.	

Primary or natural vegetation only remains on the interior of the central mountains and on the leeward coast between 305 and 610 m elevations. At approximately 490 m elevation, the rainforest grades into a sub-climax vegetation known as Palm Brake which is often

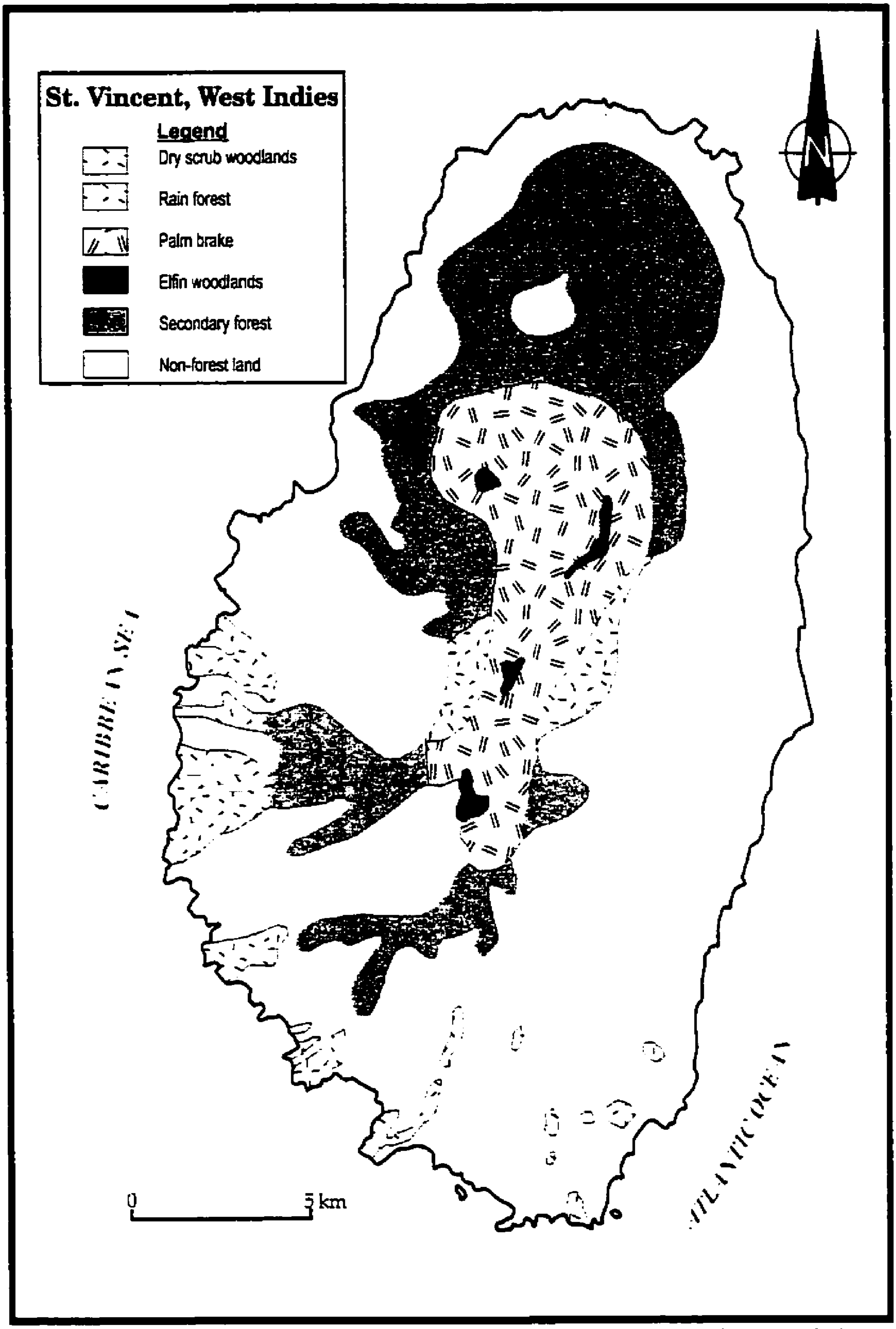

Figure 3.5 Vegetation of St. Vincent (modified from Caribbean Conservation Association, 1991 and Strand, 1996).

associated with areas of disturbance. Associated with Palm Brake vegetation are Elfin Woodlands which are found near summits where strong winds and cooler temperatures predominate. Presently, only 13% of the total forested lands are primary, moist rainforest (Strand, 1996). Secondary Rainforests, Dry Scrub Woodlands, and forest plantations comprise 67% of the forested lands (Hackman, 1998). Dry Scrub Woodland is mainly found on the leeward coast along the rocky slopes with isolated stands occurring in the southern part of the island (Beard, 1949). The limited growth of these Dry Scrub Woodlands is due to the poor development and the low water holding capacity of the soil which limits plant colonization in these areas.

Very little remains of the dry evergreen Littoral Woodland ecosystem on St. Vincent and the Grenadines. These ecosystems are primarily comprised of seagrape (*Coccoloba uvifera*), button mangrove (*Conocarpus erectus*), and manchineel (*Hippomane mancinella*). Littoral Woodlands once occupied small isolated strips along the coastlines (Beard, 1949).

3.4 SOILS

The soils on St. Vincent are classified as Andosols according to the Food and Agricultural Organization (Ellis and Mellor 1995) and Andisols in the United States Soil Taxonomy (United States Department of Agriculture, 1996). Globally, they comprise of <2% of the earth's total soil area. However, to the people of St. Vincent they are important productive soils that support intensive agriculture. Andisols are formed on volcanic ash and cinders, and commonly are found near the volcano source or downwind, where ash has been deposited during recent eruptions. The Soufriere volcano last erupted in 1979, blanketing some areas of the island with ash that will weather and release important minerals. Older volcanic soils that take on a rich weathered red hue are often heavily leached and depleted of nutrients. This process involves the transformation of volcanic ash into iron hydroxide and ferrihydrite to produce amorphous or poorly crystallized silicate minerals such as allophane and imogolite (Brady and Weil, 1996). Overall, these soils have a high water holding capacity and high natural fertility. But the availability of P is severely limited by the extremely high retention capacity of the andic materials (Limbird, 1992; Visser, 1989).

The soil forming factors identified on St. Vincent were originally studied by Hardy (1934) and later by Watson et al. (1958). The concentric zones of precipitation and vegetation on St. Vincent strongly influence the development of soils. Also, the elevation and submergence of the island influenced by tectonic shifting has added to the zonation of soils. Watson et al. (1958) suggested the increase in rainfall due to increased altitude was the most important soil forming factor throughout the island. In response to these factors, four main soil groups have been characterized: Yellow Earth, Recent Volcanic Ash, Shoal, and Alluvial soils (Figure 3.6). In addition, there are aeolian deposits mixing with Yellow Earth beach deposits along the coastlines.

3.4.1 Yellow Earth Soils

The Yellow Earths are subdivided into High and Low Level Yellow Earths. The High Level Yellow Earths are classified as Andepts (United States Department of Agriculture, 1996) and occur above 200 m. The High Level Yellow Earths are the oldest soils on St. Vincent but are periodically rejuvenated by ash falls from Soufriere volcano. The addition of the fertile ash does not allow the soil to become depleted in cations. However, the availability of nutrients can vary across the island. Potassium can vary from deficient to excessive, according to Ahmad (1984). Their pH is generally >5.0. The available P is always low because of the Andisols ability to convert added P to unavailable forms which limits the uptake of nutrients by vegetation (Ellis and Mellor, 1995). The organic matter content is usually high and very stable so that there is unlimited cycling of plant nutrients such as N and S (Ahmad, 1984). The High Level Yellow Earths have a stable soil structure and are not naturally erosive. These physical characteristics allow for a high soil permeability rate and high water retention capacity.

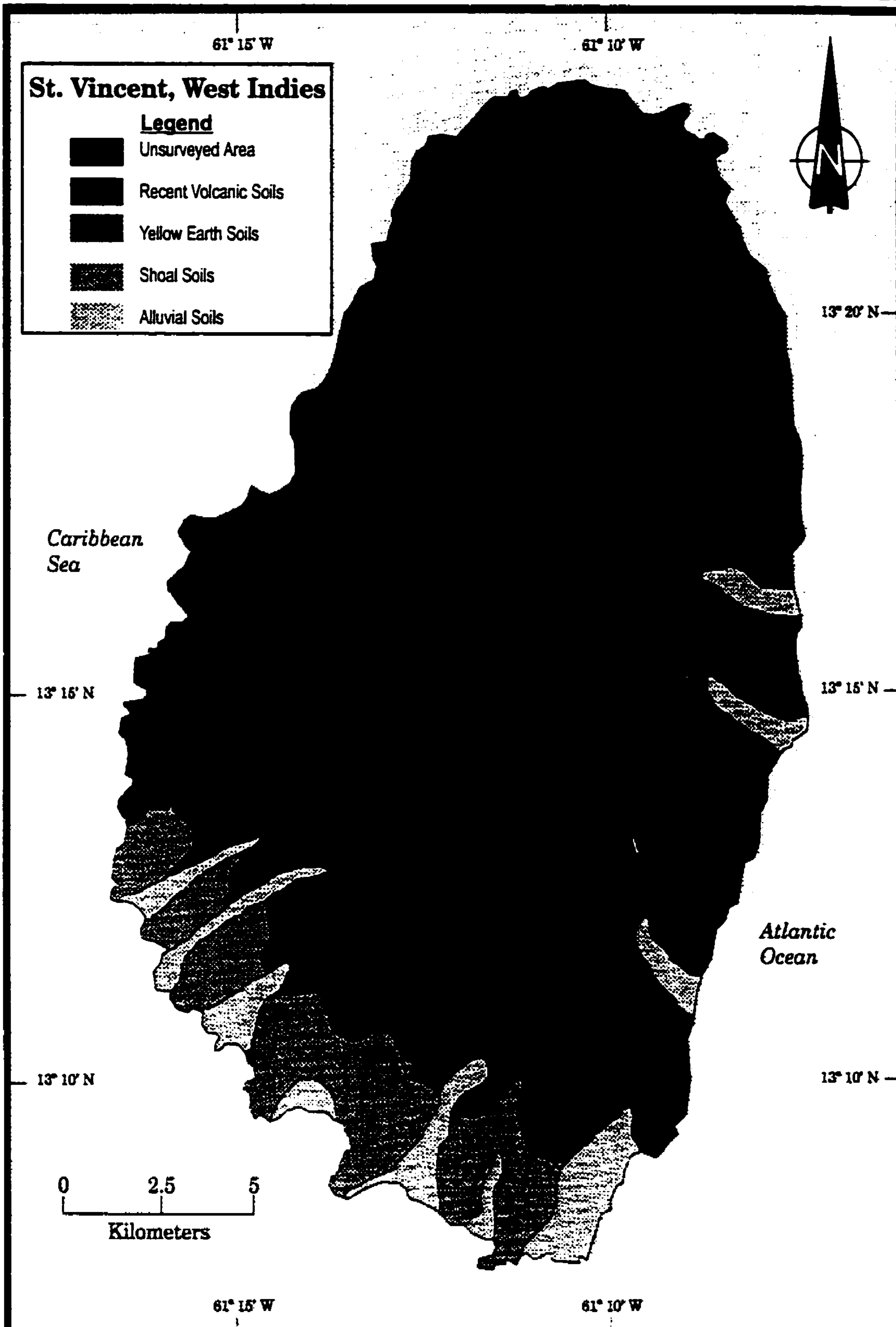

Figure 3.6 Soils of St. Vincent (modified from Caribbean Conservation Association, 1991 and Strand, 1996).

The Low Level Yellow Earths are Alfisols (United States Department of Agriculture, 1996) rich in kaolinite and halloysite. They are typically less leached than the High Yellow Earths because of less rainfall. They generally have pH values between 5.5 and 6.5. The K availability for Low Level Yellow Earths is variable depending on the parent materials (Ahmad, 1984). Low Level Yellow Earths have less favorable physical properties than the High Level Yellow Earths but they are still highly desirable agricultural soils on St. Vincent.

3.4.2 Recent Volcanic Ash Soils

The Recent Volcanic Ash soils are relatively young in comparison to other soils on the island. Mostly surrounding the cone of the Soufriere volcano, these soils have been derived in part from the 1902 eruption and have not developed a characteristic profile. These soils are grayish in color and coarse in texture (Limbird, 1992). The coarser materials occur on gently sloping sites, while finer materials are found on steeper slopes where cultivation is unsuitable due to the higher potential for erosion.

3.4.3 Shoal Soils

The Shoal soils are strongly influenced by the wet and dry climatic cycle. The dark colored surface horizon of these fine texture soils have expanding and contracting qualities that impede drainage. The parent material originally was developed over old extinct volcanoes and ash which have become cemented together. These soils are primarily found in the southwestern parts of St. Vincent and are generally described as difficult to cultivate because of cracking in the dry season and expansion during the wet season (Caribbean Conservation Association, 1991).

3.4.4 Alluvial Soils

Alluvial soils develop from parent materials that were transported by streams and rivers from higher elevations in the upper watersheds. The transported debris often proves to be very productive on St. Vincent and occurs on approximately 800 ha of land (Watson et al., 1958). The soils are coarse-textured and may contain large cobbles and boulders that restrict cultivation. These mature soils occupy lower valleys mainly on the southwest part of St. Vincent. They occur in the most intensely cultivated portion of St. Vincent.

3.5 ECONOMY AND LAND USE

The forested lands on St. Vincent play an important role in the social needs of Vincentians and less so for the economy of St. Vincent. Timber is by far the most desirable product that can be harvested from the forests. Trees such as gommier (*Dacryodes excelsa*), mahogany (*Swietenia macrophylla*), and white cedar (*Tabebuia pallida*) are commonly used to make furniture, boats, and buildings. Forests provide firewood or charcoal for an estimated 40% of the households on St. Vincent (Caribbean Conservation Association, 1991).

The relatively fertile soils make this island particularly favorable to a variety of crops. By far, agriculture remains the most influential and productive sector of the national economy. With over two-thirds of the labour force employed in this sector, most arable lands up to 305 m elevations are occupied by bananas, sugar cane, sweet potatoes, tannia, eddoes, dasheen, plantains, and arrowroot. For 30 years, bananas have been the foundation of the economy, accounting for approximately 40% of all export earnings (Caribbean Conservation Association, 1991). This percentage has declined since the preferential trade agreement between St. Vincent, Geest Industries (the exclusive supplier), and United Kingdom came to an end in 1992. St. Vincent and other West Indies countries (e.g., St. Lucia and Dominica) now compete with Central American countries on the world banana market.

Tourism has always been an important and dominant industry in the Grenadines but in St. Vincent the growth has been slow. Of recent, with governmental mega-projects like the construction of the cruise ship dock and leeward highway it is expected to become a desirable sector in the economy. St. Vincent is also hoping to capture some of the millions of dollars spent on eco-tourism in the region by developing special protected areas like the

Vermont Nature trails where the only remaining wild St. Vincent parrots can be seen. Development of a nature based tourism industry will be important for the local economy which finds it difficult to compete with other Caribbean islands that boast large inclusive resorts and white sand beaches.

3.6 ST. VINCENT FOREST RESERVES

3.6.1 Hermitage Forest Reserve

The Hermitage forest reserve is located along the upper confines of the Cumberland watershed on the central leeward side of the island. It is between 330 and 400 m of elevation and covers 20.6 ha. Precipitation is high due to orographic effects and is relatively constant year round, with an annual average of 3,100 mm. The Cumberland River supplies water to north windward communities and to the VINLEC hydroelectric plant.

Soils in this area are Montreal Loam and Clay Loam and can be distinguished by its deep profile development over "tiff" and "tuff" layers of contrasting texture, consistence, and its relatively low to moderate soil fertility. The parent material consists of mixed volcanic rock overlaid by a layer of volcanic ashes (Figure 3.7).

Tree plantations consist of blue mahoe, mahogany, Caribbean pine *(Pinus caribaea)* and "miracle tree" *(Leucaena leucocephala)*. Of which 83% of the plantings are blue mahoe. Most plantations were thinned in 1975 to 691 trees ha^{-1} with suppressed trees removed in 1985. Historical records indicated the land was used to produce root crops up until 1964 and was then reclaimed.

3.6.2 Montreal Forest Reserve

Unlike the Hermitage forest reserve, the Montreal reserve is located on the windward side of the island and is approximately 10.1 ha in area. Montreal tree plantations are located along

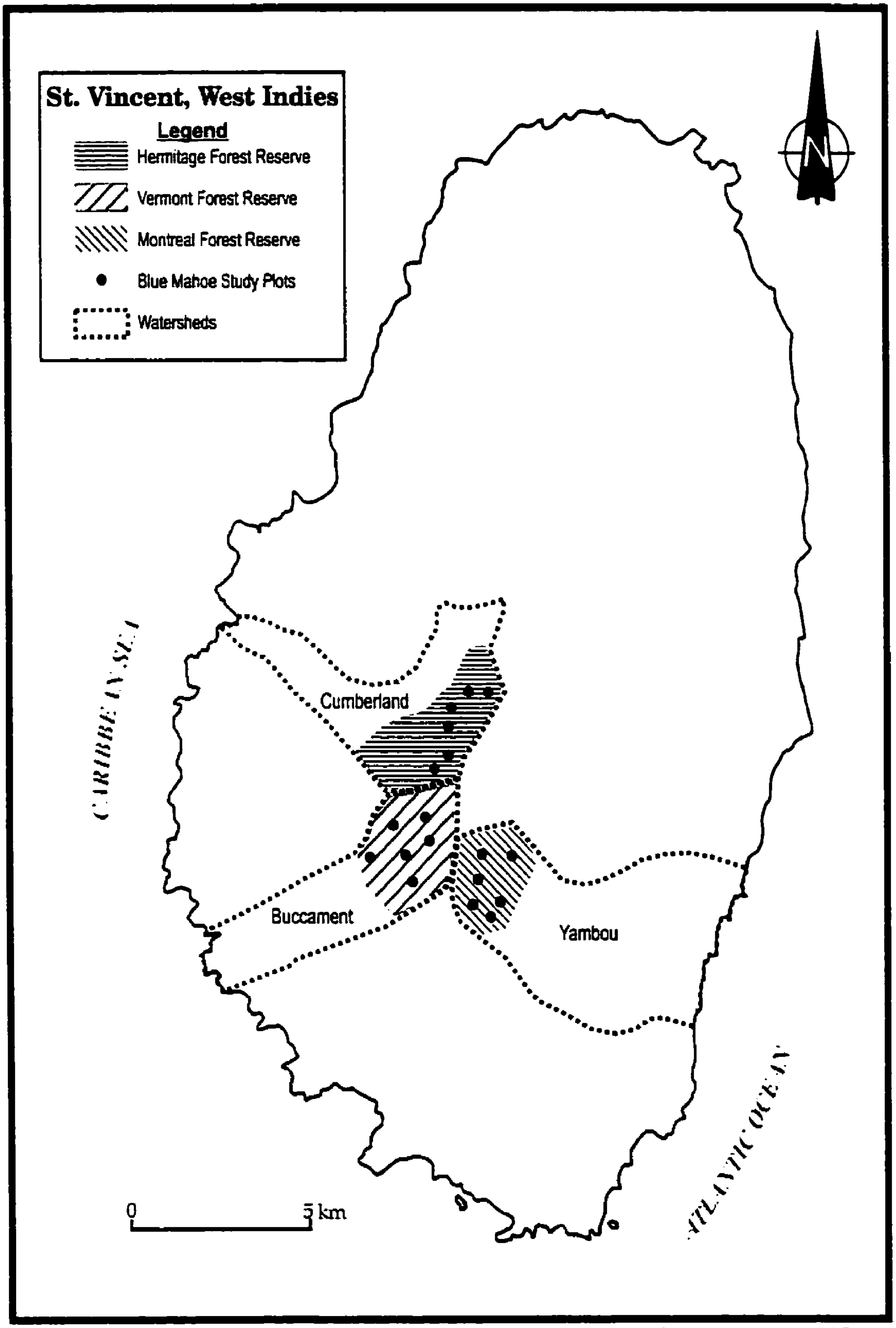

Figure 3.7 St. Vincent Forest plantation reserves and general area of study plots (modified from Caribbean Conservation Association, 1991 and Strand, 1996).

the upper confines of the Yambou watershed. The Montreal reserve has predominantly concave slopes that take on the shape of, what some locals believe, was the crater of an extinct volcano. Slightly higher in elevation than the Hermitage, these plantations are located between 450 and 480 m. Precipitation amounts are approximately 3,000 mm year^{-1}. This catchment area supplies water to the Mesopotamia valley and to the area from Peruvian Vale to Villa. Soils in this area are Montreal Loam and Clay Loam which have deep profile development over "tiff" and "tuff". This region contains some of the most arable lands on the island; however, poor management of soils, excessive agrochemical use, and livestock pasturing near streams threaten the sustainability of the soil and water resources.

Montreal forest plantations were established between 1966 and 1967. Three species make up these tree plantations: blue mahoe accounts for 62% of the acreage, Caribbean pine 37%, and mahogany 1%. Lands in this area were previously used as "kitchen gardens" prior to being reclaimed (Johnson, 1999)

3.6.3 Vermont Forest Reserve

The Vermont forest reserve is part of the Buccument watershed and is located between 250 and 425 m elevations on the southwestern portion of the island. This reserve is approximately 18.6 ha in size. These plantations and other forested lands were set aside in 1987 to establish a nature trail to help educate local people about the forests and for the protection of the endemic St. Vincent parrot.

The precipitation ranges from 2,850 to 3,000 mm yr^{-1}. The Vermont reserve receives less rainfall than the Montreal and Hermitage reserves during the dry season when moisture is because of a slight "rain shadow" effect on the leeward coast of the island. The Dalaway River is the primary stream in the region and provides 45% of the national water supplied to populations in Campden Park, Lowmans, Vermont, and Villa.

Soils in this area are classified as Greggs Loam and Clay Loam series (Watson et al., 1954) and its profile is characterized by a dark brown colour, a coarse texture, and a parent material derived from agglomerate and lava.

The Vermont forest reserve was private land purchased in 1971 by the St. Vincent government to establish water catchment facilities. The cleared lands were reclaimed using blue mahoe, Caribbean pine, galba (*Calophyllum antillanum*), eucalyptus, and mahogany to prevent soil erosion and siltation of the Dalaway River. Blue mahoe is the dominant plantation species in the reserve accounting for 69% of the total acreage. Most plantations were established between 1971 and 1973 with a small stand of blue mahoe planted in 1989.

CHAPTER FOUR: METHODS

4.1 FIELD PREPARATION

An extensive literature search and review was conducted at the University of Calgary over a four month period prior to arriving in St. Vincent. Blue mahoe plantations in each reserve were selected in consultation with the Director of Forestry, Deputy Chief of Forestry, and other senior forestry officers on July 19, 1999. At this time, historical management records were provided for most of these plantations.

4.2 FIELD METHODS

The study sites were selected with the aid of topographic maps (1:25,000) delineating elevation, plantation locations, and terrain units. Larger scale soil maps (1:10,000) provided information on slope gradients, erodible surfaces, parent materials, and soil units (Watson et al., 1958). In order to compare the soil-site conditions of blue mahoe plantations, it was important to select sites of similar age, climate, soil type, stand density, and management practices. A reconnaissance of the forest reserves was completed prior to site selection to ensure the accuracy of historical data and plantation maps. In addition, hand sketched maps completed by St. Vincent Forestry officers were useful for detailing access to forest plantations

Six 10 m by 10 m, randomly located plots were established in each of the reserves for a total of 18 plots. Slope gradient, slope position, and slope aspect were controlled during the selection process. Two plots were established in each reserve to represent lower, middle, and upper slope positions as well as similar slope gradients.

The general objective was to select areas where plantings were neither too poorly stocked nor too highly stocked, also to select areas where mortality, disturbance, and edge effects were minimal. In each sampling plot the diameter of all blue mahoe trees >12 cm at breast height (dbh = 1.3 m above ground) was measured to the nearest 0.5 cm. Tree heights were measured with a relascope to the nearest 0.5 m. Vegetation cover estimates were completed for ground cover (0-0.5 m), shrub layer (0.5-1.5 m), understory layer (1.5-3.0 m), and overstory canopy (>3.0 m). Tree spacings were measured in each plot to the nearest 0.05 m. All dominant vegetation species in the plots were identified and recorded.

Four pairs of soil samples were randomly collected from each plot at depths of 0-15 cm (4 pits) and 15-30 cm (4 pits). These samples were used for chemical and textural analysis. In addition, bulk density samples were collected at both depths. Two soil pits were used in each reserve for soil profile description and classification.

Litter was collected by placing a 30-by-30 cm frame at two random locations on the forest floor within each field sampling plot. All litter samples were oven dried at 65°C to a constant weight. Samples were then separated into four litter fractions: blue mahoe leaves, leaves of other species, fine wood, and miscellaneous fragments. Few flowers and fruits were found on the forest floor and therefore were not separated into a litter compartment. After separation, samples were weighed and ground through a 0.85 mm (20 mesh) stainless steel sieve. The ground material was used for chemical analysis. The field sampling was conducted between July 19, 1999 and August 16, 1999.

4.3 LABORATORY ANALYSIS

Mineral soil and litter samples were kept moist and refrigerated at 2°C in St. Vincent. Immediately upon arrival at the laboratory in Calgary a portion of each sample was frozen, while the rest of the sample was air-dried at 20 to 25°C at a relative humidity of 20 to 60%. Although most determinations were made on air-dried samples, it was more desirable to measure pH, nitrate (NO_3-N), and ammonium (NH_4-N) on field moist samples (McKeague, 1978). All the soil samples were ground with a mortar and pestle and passed through a 2 mm sieve, except those samples used for bulk density determinations. Soil samples used for bulk density determination were dried to a constant mass at 105°C.

4.3.1 Soil Texture Analysis

The percentage of coarse fragments was determined by passing the mineral soil samples through a 2 mm sieve and weighing the fragments in the sieve. Soil samples needed to be passed through a 1-mm sieve for particle size determinations by a Particle Size Analyzer (Mastersizer, 1999). Each sample was riffled and 0.6 g of soil was combined with 2 mL of 30% H_2O_2 and left overnight to digest the organic matter. The next day, 5 mL of Calgon (50 g L^{-1}) solution and 5 mL of distilled water were added to each sample. Each sample was dispersed in the Particle Size Analyzer to the correct concentration and then transferred to the optical unit. The detector array within the optical unit collected and measured the light scattering from the soil particles. The results were presented as volume-based values expressed in microns. Percent sand (>0.2 mm), silt (0.002-0.02 mm), and clay (<0.002 mm) were calculated and classified into textural categories in accordance with the Canadian textural triangle (Survey Committee on the Canadian System of Soil Classification, 1987).

4.3.2 Soil Organic Matter

Organic carbon was determined by using a modified version of the Walkley-Black wet digestion procedure. In this procedure, 10 mL of $K_2CR_2O_7$ and 20 mL of concentrated H_2SO_4 (>96%) were added to 1 g of soil. The solution was mixed with 70 mL of distilled water and was filtered through a Whatman #2 filter paper. The solution was then transferred into a cuvette and placed in a Perkin-Elmer Lambda 3 UV/VIS Spectrophotometer. The transmission readings were calibrated at 610 nm, measured and converted to percentage organic matter (McKeague 1978). Roughly, 75% of the organic matter present was oxidized, thus the results are only approximations (Page, 1982).

4.3.3 Soil pH and Electrical Conductivity

Soil pH and electrical conductivity values were determined using distilled water as the suspension liquid. A 1:2 soil-to-liquid mixture of dry weight equivalent of field moist soil and distilled water were stirred thoroughly for one hour. The soil pH was determined on field moist soils since it has been shown that air-dried soils can cause changes in pH through oxidation of sulfides (Kalra and Maynard, 1991). The solution was measured using a Fisher Scientific pH meter. Since the pH values were determined immediately upon arrival to the laboratory, minimal alteration in the soil chemistry should have occurred relative to field conditions. The same solution was used to determine electrical conductivity except the sample was placed in the centrifuge for ten minutes, or until the sediment had settled to the bottom. Using a Fisher Scientific Accument, readings for soluble salts were obtained in units of micro-Siemens (μS).

4.3.4 Soil Cation Exchange Capacity and Exchangeable Cations

Chemical extractions for exchangeable Ca, Na, K, Mg, Fe, Mn, and Al were made by the $BaCl_2$ method (Hendershott and Duquette, 1986). The extracted solution was based on 1 g of air-dried soil mixed with 30 mL of 0.1M $BaCl_2$. The extracted solution was mixed for two hours and then filtered through a Whatman #42 filter paper. A 1:10 extract-to-distilled water solution was required for Ca, Mg, Na, and K cations. Dilution was not necessary for Fe, Al, and Mn. A Unicam 939 Atomic Absorption Spectrophotometer was used to analyze the soil extracts. The Atomic Absorption readings were in parts per million but were later converted to milliequivalents per 100 grams. Cation exchange capacity (meq. 100 g^{-1}) was obtained by summing the concentrations of Ca, Mg, Na, K, Al, Fe, and Mn.

4.3.5 Soil Extractable Phosphorus

Extractable phosphorus (PO_4-P) was determined using Bray and Kurtz No. 1 method (also know as Bray 1) (Bray and Kurtz, 1945). Available P was extracted from 5 g of dry weight equivalent of field moist soil using 25 mL of acid ammonium fluoride (NH_4F) which dissolves aluminum and iron phosphates by formation of complexes with these metal ions (Kalra and Maynard, 1991). Four grams of black carbon were added to reduce the interference of organic matter by absorbing it on activated charcoal. After the solution was mixed for two minutes, it was filtered through Whatman #2 filter paper and mixed with a color developing reagent. The solution was transferred into a photometer cuvette and the transmittance was recorded from the Perkin-Elmer Lambda 3 UV/VIS Spectrophotometer calibrated at 400 nm (Bray and Kurtz, 1945). The P concentrations (mg L^{-1}) were interpolated from a curve derived from six standards: 0, 0.04, 0.10, 0.20, 0.30 and 0.40 mg L^{-1}, respectively (Kalra and Maynard, 1991).

4.3.6 Soil Extractable Nitrogen

Extraction of ammonium (NH_4-N) and nitrate (NO_3-N) was based on 2 M KCl. The extract was prepared with 2 g of field moist dry weight equivalent soil mixed with 20 mL of KCl for 30 minutes. The extract was filtered through Whatman #42 filter paper and diluted (1:10; extract-to-distilled water) prior to being analyzed with a Technicon Autoanalyzer. The Technicon Autoanalyzer used the Cadmium Reduction Method and Technicon Industrial Method No. 100-70W/B procedure for sample analysis.

4.3.7 Soil Allophane

Allophane is an aluminum silicate mineral which has a high surface area that creates an abundance of anion and cation exchange sites. The presence of allophane was determined by using a spot test with toluidine blue (Wada and Kakuto, 1985). For this method, 10 to 15 g of air-dried soil was placed on a white spot plate and 4 mL of 0.02% toluidine blue was added. The mixture was stirred and observed for a characteristic color change from blue to purplish red. Because the toluidine blue is absorbed from aqueous solution on negatively charged colloids it remains blue when allophane is present (Wada and Kakuto, 1985).

4.3.8 Total Cations in Litter

Ground litter samples were analyzed for Ca, Na, K, Mg, Fe, Mn, and Al with a Unicam 939 Atomic Absorption Spectrophotometer using the dry ashing (ignition) method recommended by Kalra and Maynard (1991). In this method, 0.50 g of ground litter in a crucible was incinerated for 16 hours at 470°C. The residual ash was moistened with 8 to 10 drops of distilled water followed by 3 mL of 5 M HCl so that mineral elements were brought into solution. The crucibles were placed on a hot plate at low temperature (80°C) and 0.025 mL of concentrated HNO_3 added. The solution was evaporated to dryness. Again, 3 mL of 5 M HCl was added to moisten the dried salts and heated for 10 minutes. The solutions were filtered though Whatman #42 filter paper and analyzed with a Unicam 939 Atomic Absorption Spectrophotometer. The results were provided in parts per million but were converted to mg g^{-1} using the following formula (Page, 1982):

$$Cs = Ce \times Ve \times (1/Wd) \times DF$$

Where, Cs = concentration of the cation in the litter (mg g^{-1})
Ce = concentration of the cation in the extract (mg L^{-1})
Ve = volume of the extract (L)
Wd = dry weight of litter (g)
DF = dilution factor

4.3.9 Total Nitrogen and Extractable Inorganic Phosphorus in Litter

The wet digestion sulfuric acid-hydrogen peroxide method was used for total N and extractable inorganic phosphorus content determination (MacKeague, 1978). Litter material (0.25 g) was digested with 5 mL of concentrated H_2SO_4 for two hours. In order to oxidize the organic matter 4 to 5 drops of H_2O_2 was added and digested for an additional five minutes. This latter step was repeated until the solutions became clear. Lastly, 50 mL of distilled water was added to each solution and passed through the Technicon Autoanalyzer using the Technicon Industrial methods No. 94-70W (Orthophosphate) and No. 98-70 W/A (Ammonia in Water and Waste Water).

4.4 STATISTICAL ANALYSIS

The use of descriptive statistics was essential for organizing and summarizing field and laboratory data. Descriptive statistics provided a basis for identifying initial trends and relationships among soil nutrients, litter nutrients, and tree growth parameters as well as evaluating the data for normality. Normality was assessed by statistical and graphical methods. Typically, a distribution is perfectly normal when the values of skewness and kurtosis are zero (Tabachnick and Fidell, 1996). However, Wetherill (1981) suggested that if the kurtosis values were between -0.4 to 1.8 and skewness between -0.9 to 0.9 the data was considered to be normally distributed.. Several data sets did not lie within this range and were therefore distribution free. In addition, for statistical comparisons the sample sizes for individual forest reserves were small (n=6) which made it difficult to demonstrate normality.

4.4.1 Correlation Analysis and Linear Regression

Correlation analysis was used to examine associations between two sets of variables and to identify concerns with autocorrelation and multicollinearity during multiple regression analysis. The most common measure of correlation for interval or ratio variables is the Pearson's product moment correlation coefficient (Pearson's r). Typically, X and Y variables are graphed in a scatter plot. Each observation or pair of data (X, Y) represents one dot in a scatter plot. When all points in a scatter plot lie on a positively sloped line $r=1$, negatively sloped lines $r=-1$, and if the points have no pattern $r=0$.

Regression analysis can be broadly defined as the analysis of statistical relationships among variables (Burt and Barber, 1996). The degree of change in the dependent variable (Y), for a given change in the independent (X) variable is indicated by the parameters of the regression equation.

$$Y = a + bX +/- e$$

Where, Y = predicted value on the dependent variable
a = y intercept
b = slope
X = independent variable
e = error term

The regression line of *best fit* is a straight line representing the degree of explanation between the variables. The "fit " of the line is determined through the means of X and Y which minimizes the sum of the squared residuals, also known as the least squares method (Burt and Barber, 1996). This method completes the regression equation by solving for the *a* and *b* values.

4.4.2 Multiple Regression Analysis

Multivariate regression is an extension of bivariate regression in which several independent variables instead of just one are combined to predict the value of a dependent variable (Tabachnick and Fidell, 1996). It allows you to develop an equation that summarizes the relationship between one dependent variable and several independent variables. The regression equation takes the following form:

$$Y' = a + b_1X_1 + b_2X_2 + \ldots\ldots + b_k X_k$$

where, Y' is the predicted value on the dependent variable, "a" is the Y intercept, the Xs represent the various independent variables (of which there are k), and the "b" coefficients are the values assigned to each of the independent variables during regression.

The commonly used measure of goodness of fit in a linear model is R^2, sometimes called the coefficient of determination. If all the observations fall on the regression line, R^2 is 1. However, if R^2 is zero it does not necessarily mean that there is no relationship, instead it recognizes there is no linear relationship. In the SPSS 6.0 output, the adjusted R^2 value was used to explain the variability in the dependent variables from sets of independent variables since it attempts to correct R^2 to more closely reflect the goodness of fit of the model in the population.

Stepwise statistical regression was used to order the independent variables based solely on statistical criteria. This procedure looks for the combination of independent variables which best explain the variation in the dependent variable and ranks them in order of importance. Important variables were included in the equation if the probability for entry was <0.05. The independent and dependent variables included in the regression analysis are presented in Table 4.1.

The soil variables were entered into the regression equations as two sets, representing the Ah and AB horizons. The litter nutrient concentrations were averaged between the four litter components and entered into the equation. The mass-weighted nutrient concentrations (nutrient concentrations x litter mass) were summed and then entered into the equation for each nutrient. The results in Table 5.8 were calculated using the following formula:

TOTAL NUTRIENT CONTENT (g) = [Concentration of blue mahoe leaves (mg g^{-1}) • weight of blue mahoe leaves(g)] + [Concentration of miscellaneous fragments (mg g^{-1}) * weight of miscellaneous fragments (g)] + [Concentration of other species leaves (mg g^{-1}) • weight of other species leaves (g)] + [Concentration of fine wood (mg g^{-1}) • weight of fine wood (g)]

4.4.3 Kruskal-Wallis H Test

The Kruskal-Wallis H test is a non-parametric test for deciding whether there is a significant difference between three or more samples. This test does not rely on a normal distribution of variables.

The null hypothesis of the H test indicates that the samples were taken from populations with identical distributions. Any differences between the samples are due to chance variation inherent in the process of random sampling (Ebdon, 1977). Acceptance of the

Table 4.1. Summary of variables included in the stepwise regression equation.

INDEPENDENT VARIABLES	CODE
Topographical Variables	
Elevation	E
Aspect*	A
Slope angle	SA
Slope position**	SP
Slope category†	SC
Windward vs. leeward‡	WL
Soil physical variables	
Bulk density (g cm^{-3})	BD
Coarse fragments (%)	CF
Texture - sand (%)	TS
Texture - silt (%)	TI
Electrical conductivity (dS m^{-1})	EC
Soil Chemical Variables	
pH	PH
Organic matter (%)	OM
Extractable NH_4-N (mg g^{-1})	NH
Extractable NO_3-N (mg g^{-1})	NO
Available P (mg g^{-1})	P
Exchangeable K (meq. 100 g^{-1})	K
Exchangeable Ca (meq. 100 g^{-1})	CA
Exchangeable Mg (meq. 100 g^{-1})	MG
Exchangeable Al (meq. 100 g^{-1})	AL
Extractable Na (meq. 100 g^{-1})	NA
Available Mn (meq. 100 g^{-1})	MN
Available Fe (meq. 100 g^{-1})	FE
Cation Exchange Capacity (meq. 100g^{-1})	CEC
Litter Nutrient Variables	
Nitrogen (mg g^{-1})	L-N
Phosphorus(mg g^{-1})	L-P
Potassium(mg g^{-1})	L-K
Calcium (mg g^{-1})	L-CA
Magnesium (mg g^{-1})	L-MG
Sodium (mg g^{-1})	L-NA
Aluminum (mg g^{-1})	L-AL
Iron (mg g^{-1})	L-FE
Manganese (mg g^{-1})	L-MN
DEPENDENT VARIABLES	**CODE**
Height (m)	HT
Mean annual height increment (m yr^{-1})	MAHI
Diameter at breast height (cm)	DBH
Mean annual diameter increment (cm yr^{-1})	MADI
Age (yrs.)	AGE
Volume (m^3 ha^{-1})	VOL
Basal area(m^2 ha^{-1})	BA

* Aspect was coded from one to eight beginning with N45E and continuing in a clockwise direction using 45° increments to the North.; ** Slope position was coded as 0= upper, 1= middle, and 2= lower. † Slope category: 0= <15° and 1= >15°; ‡ 0= windward side of the island and 1= leeward side of the island.

alternative hypothesis suggests that the samples have come from populations with different distributions, so that differences between the samples reflect real differences between the populations.

In order to apply the H test the data must first be ranked from lowest to highest. The sums of the ranks are then found for each compared group. The appropriate degrees of freedom for significance testing are determined by the number of compared groups minus one. At the 0.05 significance level, it can be determined whether the calculated value of H is larger or smaller than the critical value. If the calculated H value is larger than the critical value, the null hypothesis is rejected. Therefore it can be assumed that the differences between the populations are significant.

In order to determine which sample is significantly different from the others, a non-parametric version of the Scheffé test can be applied. Using the following formula presented by Miller (1966, p.166), a range comparison can be derived:

$$|\bar{R}_i - \bar{R}_{i'}| \leq (\text{SQRT Chi-square}_{(k-1)}) * [\text{SQRT } (N(N+1)/12] * [\text{SQRT}(1/n + 1/n)]$$

where, Chi-square for k-1 or 2 is equal to 5.991 at the P=0.05 level, with k representing the number of groups in the data set (i.e., three reserves being compared), N equals the total number of replicates (i.e., 6+6+6=18), and n equals the number of replicates in each reserve (i.e., 6).

To be significantly different, the difference between the mean rank (i.e., $|\bar{R}_i - \bar{R}_{i'}|$) of the compared group (i.e., group 1 vs 2, 1 vs 3, and group 2 vs 3) must exceed the calculated value (7.54).

CHAPTER FIVE: RESULTS

5.1 SITE CHARACTERISTICS

The slope gradients were extremely variable between sites because of the diverse and steep topography that was characteristic of the island. Much of the landscape was influenced by the relatively steep gradient of the rivers that originated from the upper confines of the watershed and where most blue mahoe plantations were located. The site characteristics of the eighteen blue mahoe plantations are presented in Table 5.1.

The Hermitage plots (H-1 to H-6) were located between 350 and 372 m elevations on the leeward side of the island. Plantation sizes ranged from 0.32 to 1.25 ha. Hermitage is a major water catchment area where flow is in a classic radial drainage pattern over coarse grained, highly permeable pyroclastic materials. The topography varied from lower slope positions along valley bottoms (H-4) to steeply sloped ridges (H-3). Slope gradients ranged from 11° to 32° for the Hermitage plots.

The Montreal plots (M-1 to M-6) were located on the windward side of the island between 455 and 467 m elevations, which was significantly higher than the other reserves (Table 5.1). Plantation sizes ranged from 0.49 to 3.24 ha. Montreal had more land area with slopes <15° than Hermitage or Vermont, and many of the plantations were established in these more gently sloped areas. The Montreal reserve was located at the toe of Petite Bohnomme and Grand Bohnomme mountains where these concave slopes resembled an extinct volcanic crater. Slope gradients ranged from 5° to 27° with three of six sites having slopes <15°.

The Vermont plots (V-1 to V-6) were located on the leeward side of the island between 254 and 396 m elevations, on the opposite side of the central mountain core from the Montreal reserve. The Vermont plantations ranged from 0.08 to 2.75 ha in size. The slope gradients ranged from 3° to 30° with four of six sites having slopes >20°.

Table 5.1. Site characteristics for 18 blue mahoe plots in the Hermitage, Montreal, and Vermont reserves were evaluated by Kruskal-Wallis H Test. Means in columns followed by the same letter were not significantly different at the P<0.05 level based on non-parametric Scheffé tests.

RESERVE	**SITE CHARACTERISITICS**					
Hermitage	**Elevation (m)**	**Area (ha)**	**Slope (°)**	**Aspect**	**Slope Position**	**Age (yrs)**
H-1	350	0.48	27	NW	middle	29
H-2	350	0.32	11	NW	lower	33
H-3	372	0.73	32	S	upper	36
H-4	360	1.25	26	SE	lower	36
H-5	355	1.25	21	SE	middle	36
H-6	353	0.48	22	SW	upper	33
Mean	**357[a]**	**0.75**	**23.2[a]**	–	–	**33.8[a]**
Montreal	**Elevation (m)**	**Area (ha)**	**Slope (°)**	**Aspect**	**Slope Position**	**Age (yrs)**
H-1	457	1.09	5	SW	lower	33
H-2	465	3.24	18	NE	middle	34
H-3	465	0.69	21	E	upper	34
H-4	467	0.49	27	E	upper	34
H-5	455	3.24	14	NE	middle	34
H-6	462	1.09	8	NE	lower	34
Mean	**462[b]**	**1.64**	**15.5[a]**	–	–	**33.8[a]**
Vermont	**Elevation (m)**	**Area (ha)**	**Slope (°)**	**Aspect**	**Slope Position**	**Age (yrs)**
H-1	396	2.67	15	NW	upper	33
H-2	381	2.75	21	E	middle	29
H-3	274	0.08	19	NE	middle	27
H-4	292	1.21	15	NE	lower	29
H-5	301	1.21	3	SE	upper	29
H-6	254	2.63	30	NE	lower	29
Mean	**316[a]**	**1.76**	**17.2[a]**	–	–	**29.3[b]**
H	**9.22**	–	**3.13**	–	–	**11.79**
p	**0.01**	–	**0.21**	–	–	**0.003**

5.2 VEGETATION CHARACTERISTICS

The selected blue mahoe plantations occurred within the Secondary Rainforest between the Primary Rainforest and the upper limits of permanent cultivation. Since these were areas of natural regeneration, the most common pioneer species were spanish ash (*Inga vera*), trumpet tree (*Cecropia peltata L.*), palm (*Palmae* sp.), penny piece (*Pouteria grandis*), and candle wood (*Miconia guianensis*). Other indicators of secondary forest that were associated with human occupation in these areas were the presence of tree stumps and fruit tree species, such as breadfruit (*Artocarpus communi*) and mango (*Mangifera indica*).

The blue mahoe plantations were characterized by a dense overstory canopy, with only a few native species >3 m, and a shrub layer that ranged from sparse (0-5%) to densely covered (>50%). In total, 22 species were identified and considered to be commonly associated with these selected blue mahoe plantations (Table 5.2).

Species composition varied considerably among the three plantation reserves. Shrub species tended to have a clustered distribution that enhanced the site variability and uniqueness. Vermont plantations had large clusters of heliconia on slopes >20° with the occasional pioneer species in the understory. Ferns were common in all plantations but the Montreal reserve had a higher density of small ground ferns on the plantation floor. Also, a symbiotic relationship appeared to exist between epiphytes and veri vines, and blue mahoe. Half of the blue mahoe in the Montreal plots had veri vine covering the bole of the tree. Approximately, one-third of the blue mahoe measured in Hermitage plantations have epiphytes, while only 20% of the blue mahoe in Montreal and Vermont plots had epiphytes on their boles.

The most common understory vegetation species in Hermitage blue mahoe plantations were boardwood, red manjack, penny piece, tree fern, spanish ash, and shoemaker bark. The

Table 5.2. Plant species commonly associated with blue mahoe plantations in the Hermitage, Montreal, and Vermont reserves.

St. Vincent Common Name	Scientific Name
angeline	*Andira inermis*
blue mahoe	*Hibiscus elatus*
boardwood	*Simaruba amara*
candle wood	*Miconia guianensis*
epiphytes	*Bromelia sp.*
gommier	*Dacryodes excelsa*
ground fern	*Cyathea sp.*
gru gru palm	*Palmae acrocomia*
gunstock	*Freziera hirsuta*
heliconia	*Heliconia sp.*
red manjack	*Cordia alliodora*
palm	*Palmae sp.*
penny piece	*Pouteria grandis*
royal palm	*Palmae bactris*
shoemaker bark	*Hibiscus rosa-sinensis*
spanish ash	*Inga vera*
sword fern	*Cyathea sp.*
tree fern	*Cyathea arborea*
trumpet tree	*Cecropia peltata L.*
veri vine	*Stachytarpheta sp.*
wild coco	*Meliosma herbertii*
wild ginger	*Hedychium sp.*

canopy cover was fairly dense with an average of 78% (Table 5.3). Candle wood made up 66% of the shrub layer and the remaining percentage comprised of blue mahoe seedlings, spanish ash, and angeline (Plate 5.1). The average ground cover was approximately 15% with ground fern being the most abundant species.

Trees <3 m tall in the Montreal reserve were mainly comprised of penny piece, spanish ash, tree fern, and royal palm. The average canopy cover for the six plots was 63%. Royal palm comprised about 35% of the shrub layer followed by heliconia (30%) and candle wood (30%) (Plate 5.2). The average amount of ground cover was 17% with ferns comprising

Table 5.3. Summary of vegetation cover in blue mahoe plots. Differences among reserves were evaluated by Kruskal-Wallis H Test.

RESERVE PLOT	PLANTATION COMMUNITY	GROUND COVER (%)	SHRUB COVER (%)	UNDERSTORY COVER (%)	CANOPY COVER (%)
HERMITAGE					
H-1	blue mahoe/candle wood	25	15	5	80
H-2	blue mahoe/fern	40	70	50	75
H-3	blue mahoe/candle wood	10	20	40	50
H-4	blue mahoe/fern	5	45	5	85
H-5	blue mahoe/penny piece	5	20	40	85
H-6	blue mahoe/candle wood	5	50	10	90
Mean		**15.0**	**36.7**	**25.0**	**77.5**
MONTREAL					
M-1	blue mahoe/fern	5	70	10	75
M-2	blue mahoe/royal palm	20	30	5	70
M-3	blue mahoe/candlewood	5	15	5	55
M-4	blue mahoe/fern	5	<5	70	60
M-5	blue mahoe/royal palm	5	5	50	40
M-6	blue mahoe/fern	60	5	10	80
Mean		**16.7**	**21.7**	**25.0**	**63.3**
VERMONT					
V-1	blue mahoe/haliconia	5	40	20	55
V-2	blue mahoe/spanish ash	2	10	10	65
V-3	blue mahoe/fern	5	35	10	75
V-4	blue mahoe/fern	5	5	5	75
V-5	blue mahoe/haleconia	5	20	20	65
V-6	blue mahoe/wild ginger	25	20	5	70
Mean		**7.8**	**21.7**	**11.7**	**67.5**
H		**1.94**	**2.94**	**0.47**	**4.36**
P		**0.38**	**0.23**	**0.79**	**0.11**

approximately 64% of the stratum, while candle wood, royal palm, wild cocoa, and wild ginger also were common (Plate 5.3).

Vermont blue mahoe plantations were most commonly associated with heliconia, candle wood, and wild cocoa as well as tree fern, gru gru palm, trumpet tree, and spanish ash (Plate 5.4). Heliconia were known to be associated with areas of disturbance and were most abundant on sites with slopes >20°. The average ground cover was 8% with candle wood, joint bush, fern, and wild cocoa being the most common species.

Plate 5.1. Blue mahoe / penny piece stand in Hermitage plantation reserve (H-5).

Plate 5.2. Blue mahoe / fern stand in the Montreal plantation reserve (M-4).

Plate 5.3. Blue mahoe / royal fern stand in the Montreal plantation reserve (M-5).

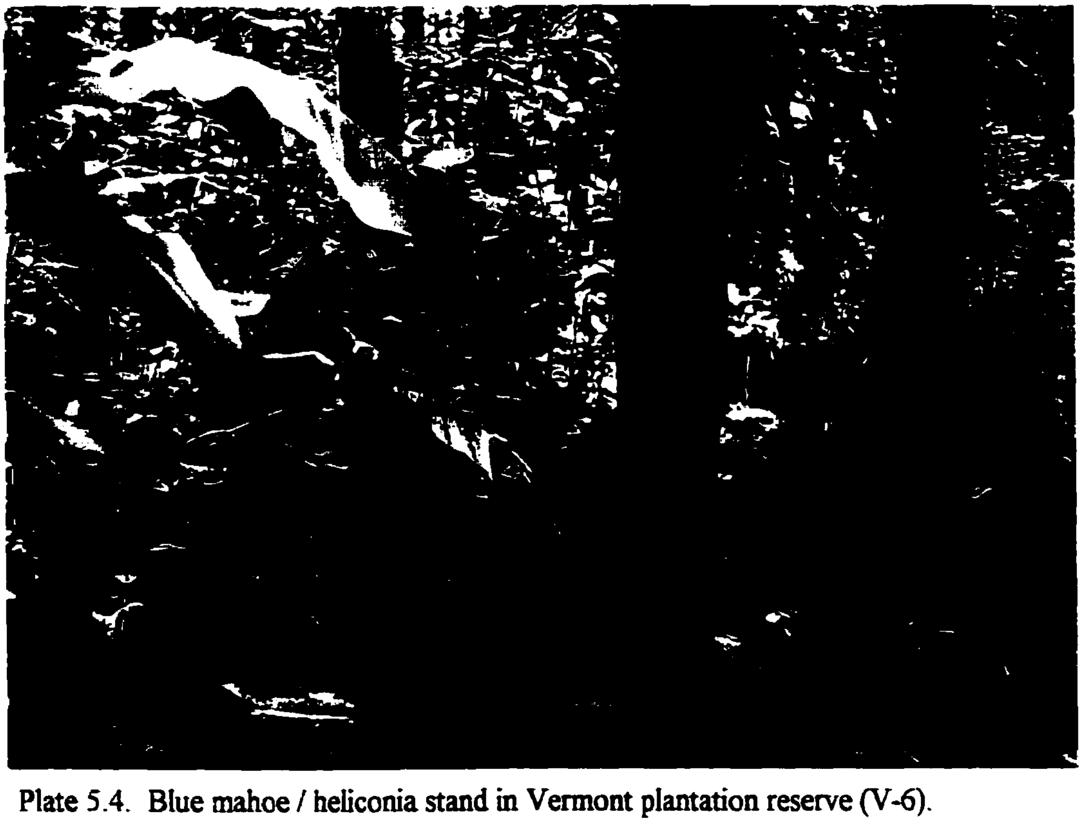

Plate 5.4. Blue mahoe / heliconia stand in Vermont plantation reserve (V-6).

5.3 BLUE MAHOE GROWTH PARAMETERS AND PLANTATION CHARACTERISTICS

5.3.1 Hermitage Plots

The Hermitage blue mahoe plantations were between 33 and 36 years old. Stand density ranged from 494 to 909 stems ha^{-1} after a pre-commercial thinning in 1975 and removal of suppressed trees in 1985. The average tree spacing was 3.60 m for the six plots. Basal area for blue mahoe stems ranged from 28 to 111 m^2 ha^{-1} and volume of blue mahoe ranged from 220 to 1,344 m^3 ha^{-1} (Table 5.4). Diameter growth ranged between 0.64 to 1.16 cm yr^{-1} and height growth between 0.55 to 0.81 m yr^{-1} for blue mahoe. Blue mahoe showed poor form on most sites. Epicormic[1] branching was a common defect that occurred on every plot. One of every three blue mahoe in the Hermitage plots had sweep[2], epicormic branching, or a crooked stem.

5.3.2 Montreal Plots

Montreal blue mahoe plantations were between 33 and 34 years old. Stand density ranged from 334 to 818 stems ha^{-1} after selective harvesting of 72% of the trees in 1989. The average tree spacing in Montreal plots was 2.62 m. Basal area for blue mahoe stems ranged from 53 to 91 m^2 ha^{-1} with diameter growth rates between 0.88 to 1.14 cm yr^{-1} and height growth between 0.62 and 0.77 m yr^{-1}. Volume ranged from 493 to 1,057 m^3 ha^{-1}. Tree defects were less common in Montreal plots than in Hermitage and Vermont plots. Epicomic branching occurred in 50% of the plots. Half of the trees in M-4 had sweep which were typically associated with steep slopes.

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[1] Epicormic branches are shoots that arise from an adventitious or dormant bud on the tree stem. Sometimes referred to as secondary growth.

[2] Sweep is a curve in the tree stem generally induced from solifluction and/or strong prevailing winds.

Table 5.4. Blue mahoe growth characteristics for 18 plots in the Hermitage, Montreal, and Vermont reserves. Differences among reserves evaluated by Kruskal-Wallis H Test. Parenthesis () enclose one standard error of the mean, while [] enclose the basal area and volume corrected to 30 years.

RESERVE PLOT	DIAMETER		HEIGHT		BASAL AREA	TOTAL VOLUME
	cm	cm yr^{-1}	m	m yr^{-1}	m^2 ha^{-1}	m^3 ha^{-1}
HERMITAGE						
H-1	34.4 (3.4)	1.04 (0.20)	23.61 (1.1)	0.81 (0.06)	74.3 [76.9]	766.2 [792.6]
H-2	27.5 (1.3)	0.83 (0.09)	20.34 (0.4)	0.61 (0.02)	47.5 [43.2]	411.9 [374.5]
H-3	26.6 (1.0)	0.73 (0.07)	20.02 (0.3)	0.55 (0.02)	44.4 [37.0]	378.3 [315.2]
H-4	42.1 (2.9)	1.16 (0.20)	27.14 (0.9)	0.75 (0.05)	111.3 [92.8]	1344.1 [1120.1]
H-5	31.2 (1.2)	0.86 (0.08)	21.54 (0.4)	0.59 (0.02)	61.1 [50.9]	566.9 [472.4]
H-6	21.4 (1.6)	0.64 (0.11)	18.31(0.5)	0.55 (0.03)	28.7 [26.1]	220.2 [200.2]
Mean	**30.5 (1.9)**	**0.88 (0.13)**	**21.8 (0.6)**	**0.64 (0.03)**	**61.2 [54.5]**	**614.6 [545.8]**
MONTREAL						
M-1	37.8 (2.9)	1.14 (0.20)	25.52 (1.2)	0.77 (0.06)	89.7 [81.5]	1010.8 [918.9]
M-2	33.8 (3.9)	1.04 (0.27)	24.64 (1.7)	0.72 (0.09)	79.9 [70.3]	865.0 [763.2]
M-3	31.4 (2.7)	0.92 (0.18)	22.34 (1.1)	0.65 (0.06)	61.8 [54.4]	598.2 [527.8]
M-4	36.6 (2.6)	1.07 (0.18)	25.05 (1.1)	0.73 (0.06)	84.1 [74.0]	927.9 [818.7]
M-5	38.1 (3.1)	1.12 (0.21)	26.17 (1.3)	0.76 (0.07)	91.2 [80.3]	1056.6 [932.3]
M-6	29.2 (2.2)	0.88 (0.15)	21.41(0.9)	0.62 (0.05)	53.5 [47.1]	493.1 [435.1]
Mean	**34.5 (2.9)**	**1.03 (0.19)**	**24.2 (1.2)**	**0.71 (0.07)**	**76.7 [67.9]**	**825.3 [732.7]**
VERMONT						
V-1	33.0 (2.0)	1.13 (0.14)	22.76 (0.8)	0.68 (0.04)	68.4 [62.2]	676.0 [614.5]
V-2	26.5 (2.3)	0.97 (0.16)	20.26 (0.9)	0.69 (0.05)	43.9 [45.4]	379.3 [392.4]
V-3	30.1(2.2)	1.03 (0.15)	22.37 (0.8)	0.82 (0.04)	56.9 [63.2]	551.3 [612.6]
V-4	21.5 (1.9)	0.74 (0.13)	18.39 (0.7)	0.63 (0.04)	29.0 [30.0]	223.4 [231.1]
V-5	31.1(2.9)	1.07 (0.20)	22.03 (1.1)	0.75 (0.06)	60.7 [62.8]	578.2 [598.1]
V-6	20.6 (1.5)	0.71 (0.10)	18.04 (0.6)	0.62 (0.03)	26.6 [27.5]	200.5 [207.4]
Mean	**27.1 (2.1)**	**0.94 (0.15)**	**20.6 (0.8)**	**0.70 (0.04)**	**47.6 [48.5]**	**434.8 [442.7]**

H	**5.19**	**2.27**	**4.54**	**2.45**	**5.33 [3.31]**	**5.13 [3.61]**
P	**0.07**	**0.32**	**0.10**	**0.29**	**0.07 [0.19]**	**0.08 [0.16]**

5.3.3 Vermont Plots

The blue mahoe in the Vermont plots were slightly younger than the Hermitage and Montreal plots ranging between 27 and 33 years old (Table 5.1). Approximately 720 stems ha^{-1} occurred in five of the six plantations, while V-2 had 1,250 stems ha^{-1}. Historical records did not indicate dates of selective thinning but stumps in the area suggested thinning had recently occurred in V-1 and V-3. The average tree spacing in Vermont plots is 2.83 m. Basal area for blue mahoe stems ranged from 27 to 68 m^2 ha^{-1} with diameter growth rates between 0.71 to 1.13 cm yr^{-1} and height growth between 0.62 and 0.82 m yr^{-1}. Volumes of blue mahoe ranged from 200 to 676 m^3 ha^{-1}. Forty percent of the blue mahoe had signs of epicormic branching, sweep, or forked branching. Sweep was most prevalent on plots V-1 and V-3 which were located on 27° and 32° slopes, respectively.

5.3.4 Kruskal-Wallis H Test

The Kruskal-Wallis H test indicated no significant differences ($P<0.05$ level) in tree size characteristics or growth rates. On average, blue mahoe in Montreal plots were 2 to 3 m taller than blue mahoe in Vermont. In addition, the basal areas and volumes in the Montreal reserve were almost twice as great as Vermont. The standardized measurements of growth (mean annual diameter increment and mean annual height increment) did not have significant differences among reserves. Basal area and volume were also not significantly different among reserves.

5.3.5 Vegetation Cover and Blue Mahoe Growth

No significant relationship ($P<0.05$) was found between ground, shrub, understory, and canopy cover and blue mahoe mean annual diameter increment (MADI), mean annual height increment (MAHI), basal area, or volume. The data did show a general decrease in understory vegetation cover as tree canopy coverage increased (Figure 5.1).

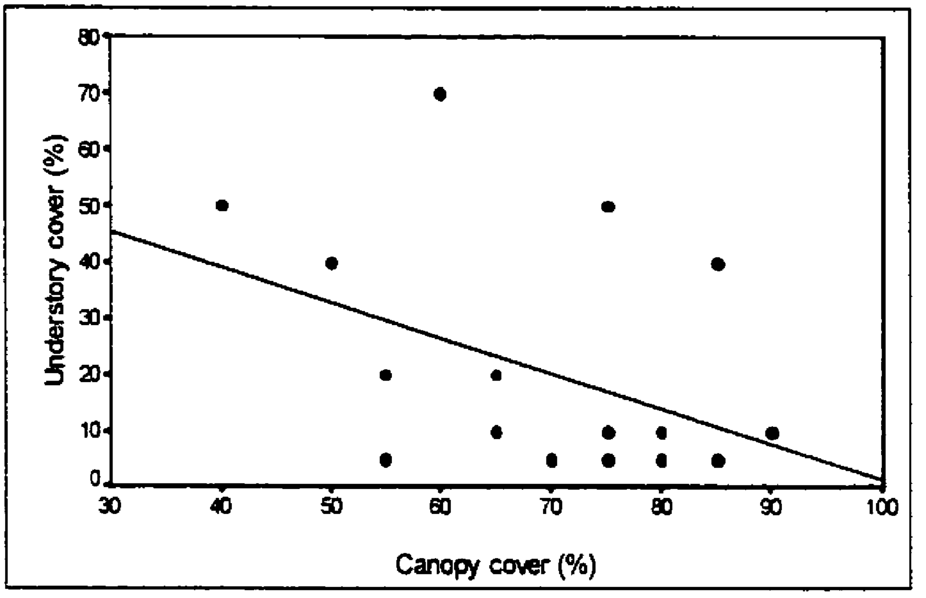

Figure 5.1. Relationship of percent understory cover (plants 1.5 to 3.0 m) and canopy cover (plants >3.0 m) in blue mahoe plots. % understory cover = -0.63 + 64.34 (% canopy cover) +/- 18.93, n=18, r^2=0.12, P=0.09.

More than half of the blue mahoe sites had <10% understory vegetation cover. Canopy cover ranged from 40 to 90%. In general, some of the older blue mahoe stands in the Hermitage and Montreal reserves had more understory cover than those in the Vermont reserve.

5.4 PHYSICAL PROPERTIES OF SOIL ORGANIC HORIZONS

5.4.1 Litter Accumulation

The organic horizons consisted of an L and F layer that ranged from 2.0 to 8.0 cm in thickness (Plate 5.5). The distribution of litter over the plantations and relative thickness of the layer depended on the micro-topography of the site. The litter accumulations were greatest at the toe of the slope, near the base of large trees, in small depressions, and on small terraces that were once used for erosion control during cultivation of these areas (Plate 5.6).

Plate 5.5. Litterfall beneath candle wood, fern, and blue mahoe (H-6).

Plate 5.6. Surface profile of the soil organic layer with stems of ground fern (M-1).

The average litter mass accumulations in Hermitage, Montreal, and Vermont sites were 814 g m^{-2}, 856 g m^{-2}, and 907 g m^{-2}, respectively (Figure 5.2). The Hermitage reserve recorded both, the lowest (426 g m^{-2}) and highest (1,162 g m^{-2}) accumulations. Overall, there were no statistical differences (Kruskal-Wallis H Test, P=0.77) in the quality of litter by fraction or in the amount of total litter among reserves.

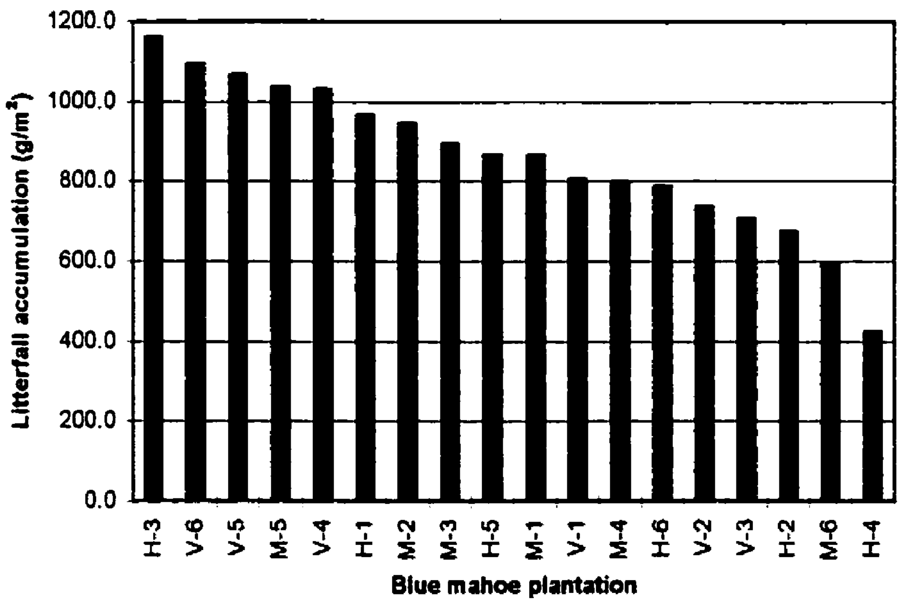

Figure 5.2. Accumulated litter mass for 18 blue mahoe plots in the Hermitage, Montreal, and Vermont reserves. Plantations are arranged from highest to lowest litter mass accumulation.

The amount of litter (i.e., blue mahoe leaves, miscellaneous fragments, fine wood, and other species leaves) varied considerably among the four components (Table 5.5). In 11 of 18 plots, miscellaneous fragments were the dominant component and the remainder had blue mahoe leaves. Leaf fragments and pieces of bark were commonly found beneath a layer of large intact blue mahoe leaves. These leaves were considered to have fallen most recently, while the miscellaneous fragments were considered to be the older of the two components.

Table 5.5. Summary of total mass and mass of individual litter components in blue mahoe plantation plots. Differences among reserves were evaluated by Kruskal-Wallis H Test. There were no significant differences among reserves.

RESERVE PLOT	LITTER MASS (g m^{-2})	BLUE MAHOE LEAVES (g m^{-2})	MISCELLANEOUS FRAGMENTS (g m^{-2})	OTHER SPECIES LEAVES (g m^{-2})	FINE WOOD (g m^{-2})
HERMITAGE					
H-1	967	198	434	9	326
H-2	675	88	319	52	217
H-3	1162	143	548	18	453
H-4	426	139	157	78	52
H-5	865	347	368	14	137
H-6	788	414	190	51	132
Mean	**814**	**221**	**336**	**37**	**219**
MONTREAL					
M-1	865	223	387	70	186
M-2	945	362	359	9	216
M-3	894	209	462	19	204
M-4	799	413	337	30	19
M-5	1038	224	694	19	100
M-6	593	287	202	12	92
Mean	**856**	**286**	**407**	**26**	**136**
VERMONT					
V-1	805	274	356	92	83
V-2	737	383	284	27	42
V-3	707	289	257	58	103
V-4	1031	388	479	32	132
V-5	1068	367	387	72	242
V-6	1094	477	290	53	274
Mean	**907**	**363**	**342**	**56**	**146**
H	**0.54**	**4.71**	**0.79**	**4.49**	**1.66**
P	**0.77**	**0.09**	**0.67**	**0.11**	**0.44**

Most of the fine wood fraction was composed of small twigs and stems of the blue mahoe leaves. The Hermitage plantations had on average 25% of its total litter mass as fine wood, and three of six plots had fine wood as the second most dominant litter component (Table 5.5). Montreal and Vermont had 15.8 and 15.2% of their total litter mass as fine wood, respectively. Although, fine wood did not cover a large portion of the plantation floor, it substantially influenced the total mass of the litter due to its density and size.

The other species leaf component ranged from 0.9 to 18.3% of the total litter mass. The Kruskal-Wallis H Test did not indicate a significant difference among the three reserves, however, Montreal plantations had almost half the amount of other species leaves in the litter compared to Vermont and Hermitage (Table 5.5). Hermitage and Vermont had two extreme values (H-4 and V-1) that substantially increased the arithmetic mean.

5.5 CHEMICAL PROPERTIES OF SOIL ORGANIC HORIZONS

5.5.1 Nutrient Concentrations in Litter

Concentrations of N, P, and K in the blue mahoe leaf litter were statistically similar among reserves. N concentrations in the miscellaneous fragments were highest in Montreal and Hermitage reserves (Table 5.6). P in the miscellaneous fragments was significantly higher in Montreal than Hermitage or Vermont reserves. Ca and Mg concentrations of blue mahoe leaves were highest in Hermitage and Montreal reserves.

Nitrogen was the only macronutrient that was significantly different in other species leaves. The concentration of N in Hermitage was almost twice that of Montreal and Vermont reserves. Concentrations of P, K, Ca, and Mg in other species leaves were very similar among reserves. Vermont plantations had the highest concentrations of Al, Fe, and Mn in other species leaves (Table 5.6).

Table 5.6. Nutrient concentrations of four litter components in the Hermitage, Montreal, and Vermont blue mahoe reserves. Differences among reserves were evaluated by Kruskal-Wallis H Test and non-parametric Scheffé range test P<0.05.

LITTER NUTRIENT (mg g^{-1})	RESERVES				
	HERMITAGE	MONTREAL	VERMONT	H	P
BLUE MAHOE LEAVES					
N	0.32^{a}	0.30^{a}	0.21^{a}	0.99	0.61
P	0.11^{a}	0.16^{a}	0.14^{a}	3.24	0.20
K	0.28^{a}	0.47^{a}	0.30^{a}	4.04	0.13
Ca	25.75^{b}	24.69^{b}	17.27^{a}	9.22	0.01
Mg	2.65^{b}	3.25^{b}	1.92^{a}	8.56	0.01
Na	1.38^{a}	2.20^{a}	1.63^{a}	3.22	0.20
Al	1.23^{a}	1.24^{a}	1.48^{a}	1.38	0.50
Fe	0.51^{a}	0.56^{a}	0.57^{a}	0.46	0.79
Mn	0.05^{a}	0.03^{a}	0.04^{a}	3.49	0.17
MISCELLANEOUS FRAGMENTS					
N	0.23^{b}	0.28^{b}	0.15^{a}	6.80	0.03
P	0.10^{a}	0.16^{b}	0.12^{a}	7.69	0.02
K	0.25^{a}	0.30^{a}	0.37^{a}	5.43	0.07
Ca	16.75^{a}	18.95^{a}	14.24^{a}	2.82	0.24
Mg	2.15^{a}	2.66^{a}	1.98^{a}	4.99	0.08
Na	2.11^{a}	1.42^{a}	1.24^{a}	1.41	0.49
Al	2.47^{b}	1.47^{a}	2.60^{b}	6.00	0.05
Fe	0.71^{a}	0.60^{a}	0.84^{a}	4.40	0.11
Mn	0.06^{b}	0.04^{a}	0.06^{b}	6.39	0.04
OTHER SPECIES LEAVES					
N	0.36^{b}	0.19^{a}	0.15^{a}	6.07	0.04
P	0.14^{a}	0.15^{a}	0.14^{a}	2.80	0.25
K	0.25^{a}	0.30^{a}	0.29^{a}	1.50	0.47
Ca	14.12^{a}	15.62^{a}	12.24^{a}	1.31	0.52
Mg	1.44^{a}	1.71^{a}	1.77^{a}	1.42	0.49
Na	2.05^{a}	1.23^{a}	2.07^{a}	2.92	0.23
Al	1.15^{b}	0.63^{a}	2.53^{c}	12.78	0.002
Fe	0.48^{b}	0.29^{a}	0.83^{c}	12.80	0.002
Mn	0.03^{a}	0.02^{a}	0.06^{b}	12.20	0.002
FINE WOOD					
N	0.16^{a}	0.27^{a}	0.17^{a}	4.10	0.13
P	0.09^{a}	0.13^{a}	0.16^{b}	7.42	0.02
K	0.25^{a}	0.33^{a}	0.29^{a}	2.72	0.26
Ca	21.38^{a}	16.91^{a}	17.62^{a}	0.74	0.69
Mg	2.08^{a}	1.39^{a}	1.71^{a}	0.89	0.64
Na	1.71^{a}	1.07^{a}	3.56^{a}	2.54	0.28
Al	0.20^{a}	0.27^{b}	0.33^{b}	6.24	0.04
Fe	0.08^{a}	0.09^{a}	0.10^{a}	2.61	0.27
Mn	0.01^{a}	0.01^{a}	0.01^{a}	2.42	0.30

Al and P concentrations in the fine wood were statistically different among reserves (Table 5.6). The highest concentrations of P were found in Vermont plantations, while Al values were lowest in the Hermitage plots.

There were no significant differences in nutrient concentrations among the four litter types, except for Al and Fe (Table 5.7). Overall, miscellaneous fragments had the highest concentrations of Al, while very low concentrations of Fe occurred in other species leaves. There was considerably more Ca in blue mahoe leaves and fine wood than in other species leaves and miscellaneous fragments.

Table 5.7. Average nutrient concentrations in different litter types based on 18 blue mahoe plots. Differences evaluated by Kruskal-Wallis H Test and non-parametric Scheffé range test ($P<0.05$).

NUTRIENT ($mg\ g^{-1}$)	BLUE MAHOE LEAVES	MISC. FRAG.	OTHER SPECIES LEAVES	FINE WOOD	H	P
N	0.28^{a}	0.22^{a}	0.23^{a}	0.20^{a}	0.95	0.56
P	0.14^{a}	0.13^{a}	0.14^{a}	0.13^{a}	0.66	0.62
K	0.35^{a}	0.31^{a}	0.28^{a}	0.29^{a}	1.46	0.33
Ca	22.57^{a}	16.65^{a}	13.99^{a}	18.64^{a}	2.02	0.12
Mg	2.61^{a}	2.26^{a}	1.64^{a}	1.72^{a}	1.35	0.28
Na	1.74^{a}	1.59^{a}	1.78^{a}	2.11^{a}	1.28	0.31
Al	1.32^{a}	2.18^{b}	1.44^{b}	0.27^{a}	4.57	0.03
Fe	0.55^{b}	0.72^{b}	0.53^{b}	0.09^{a}	5.01	0.02
Mn	0.04^{a}	0.05^{a}	0.04^{a}	0.01^{a}	1.18	0.42

By examining the nutrient concentrations in each of the litter types, very few patterns emerged in relation to the amount of litterfall accumulation. The only significant relationships ($P<0.05$) were between blue mahoe leaves and N concentration and total litterfall mass and P concentration in the litter (Figures 5.3 and 5.4).

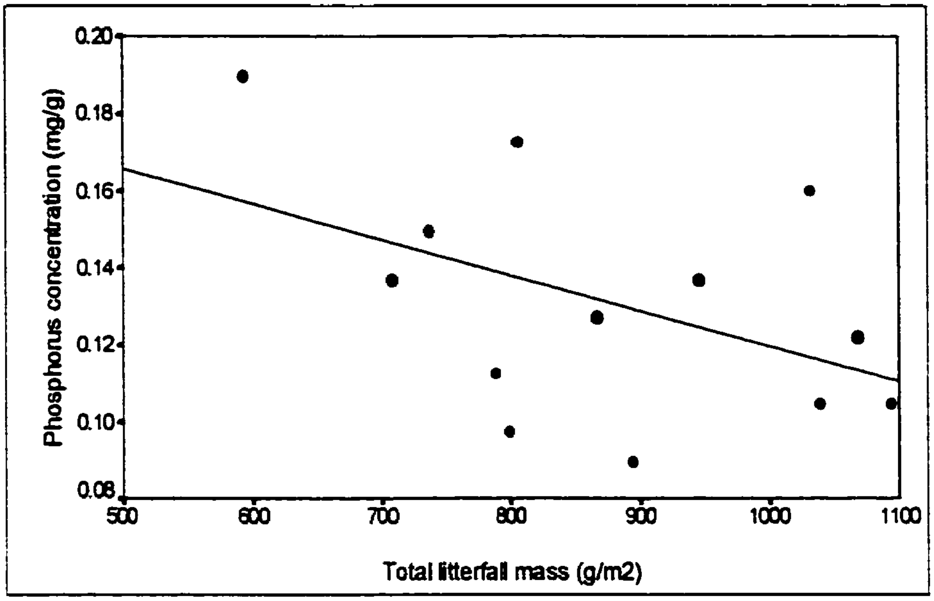

Figure 5.3. The relationship of total litterfall and P concentration in litter. P concentration mg g^{-1} = 0.21- 9.23 (total litterfall mass g m^{-2}) +/- 0.03, n=18, r^2=0.15, P=0.04.

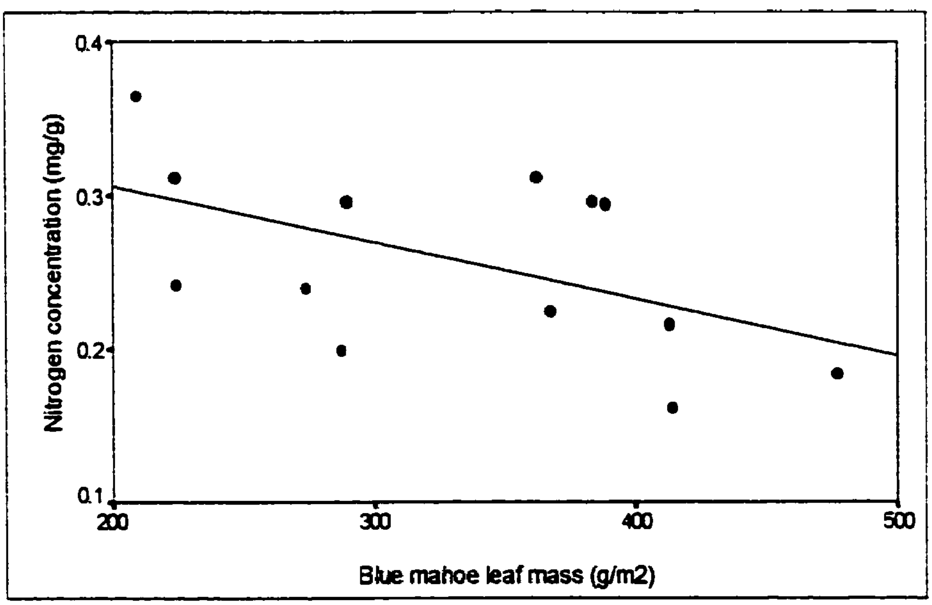

Figure 5.4. The relationship of blue mahoe leaves and N concentration in litter. N concentration mg g^{-1} = 0.38 - 3.70 (blue mahoe leaf mass g m^{-2}), n=18, r^2=0.22, P=0.04.

5.5.2 Nutrient Variations Between Plantation Reserves

The concentrations of N, P, Al, and Mn in the litter were statistically different between plantation reserves (Table 5.8). The Kruskal-Wallis H Test and non-parametric Scheffé range test showed that litter N concentrations were significantly lower in Vermont plantations, whereas Hermitage plantations had the lowest P concentrations. Montreal plantations had significantly lower concentrations of Al and Mn in the litter than the other reserves. The Vermont reserve had twice the concentration of Al in the litter compared to Montreal. Often an increase in one of Al, Fe, or Mn was associated with an increase in the other two elements.

The variability in nutrient concentrations was most evident between individual plantations rather than reserves. Perhaps the best example was illustrated in H-4 which had the smallest litter accumulation (Table 5.5) but the highest concentration of N in the litter. The lowest concentrations of N in the litter were found in V-2 and V-3 which had the smallest amount of litter in the Vermont plots.

The concentration of Al in the litter was extremely variable between blue mahoe plantations. Although H-3 had the greatest amount of litter mass (Table 5.5), it did not have the greatest concentration of Al (Table 5.8). V-4 had the highest concentration of Al in the litter.

5.5.3 Total Nutrient Content In Litter

Nutrient concentrations in the litter, as expressed on an ovendry basis (mg g^{-1}), were multiplied by the corresponding mass (g) to obtain the total nutrient content in the measured litter. Since the value represented 900 g cm^{-2}, the nutrient content values were prorated to a standard unit of measure (g m^{-2}). Because of differences in nutrient concentrations among the different types of litter, the total nutrient content did not always follow the pattern established by litter mass (Tables 5.8 and 5.9). For example, H-3 had the highest litter accumulation which corresponded with

Table 5.8. Litter nutrient concentrations for 18 blue mahoe plots in the Hermitage, Montreal, and Vermont blue mahoe plantation reserves. Means in rows followed by the same letter are not significantly different as analyzed by the Kruskal-Wallis H Test and non-parametric Scheffé range test (P<0.05).

RESERVE PLOT	LITTER NUTRIENT CONCENTRATIONS (mg g^{-1})								
	N	P	K	Ca	Mg	Al	Fe	Mn	Na
HERMITAGE									
H-1	0.16	0.11	0.26	14.93	2.06	2.29	0.63	0.04	2.33
H-2	0.31	0.13	0.26	18.71	1.38	1.26	0.50	0.04	1.35
H-3	0.31	0.14	0.23	20.17	1.96	1.04	0.39	0.04	1.75
H-4	0.37	0.09	0.27	22.61	2.10	0.87	0.35	0.03	1.31
H-5	0.22	0.10	0.23	23.69	2.09	0.58	0.24	0.03	0.80
H-6	0.24	0.11	0.31	16.89	2.90	1.53	0.57	0.03	3.32
Mean	**0.27^b**	**0.11^a**	**0.26^a**	**19.50^a**	**2.08^a**	**1.26^b**	**0.45^a**	**0.04^b**	**1.81^a**
MONTREAL									
M-1	0.20	0.19	0.48	18.53	2.37	1.27	0.57	0.03	1.51
M-2	0.24	0.17	0.29	15.73	2.04	1.10	0.47	0.03	1.34
M-3	0.30	0.15	0.24	21.27	2.88	0.94	0.45	0.03	1.15
M-4	0.30	0.14	0.33	20.80	2.49	0.60	0.25	0.02	2.08
M-5	0.30	0.16	0.23	16.29	1.63	0.68	0.29	0.02	1.35
M-6	0.23	0.12	0.52	21.64	2.10	0.83	0.28	0.02	1.43
Mean	**0.26^b**	**0.16^b**	**0.35^a**	**19.04^a**	**2.25^a**	**0.90^a**	**0.39^a**	**0.03^a**	**1.48^a**
VERMONT									
V-1	0.19	0.11	0.26	19.32	1.72	1.36	0.54	0.05	1.40
V-2	0.13	0.13	0.34	10.38	1.56	1.72	0.62	0.04	2.80
V-3	0.15	0.13	0.33	16.31	2.06	1.44	0.53	0.04	1.01
V-4	0.17	0.14	0.34	14.65	1.85	2.37	0.71	0.05	1.08
V-5	0.21	0.13	0.27	16.78	1.95	1.79	0.56	0.04	2.62
V-6	0.17	0.14	0.34	14.63	1.93	1.74	0.56	0.04	3.81
Mean	**0.17^a**	**0.13^b**	**0.31^a**	**15.35^a**	**1.85^a**	**1.74^b**	**0.59^a**	**0.04^b**	**2.12^a**

H	**8.52**	**8.13**	**4.49**	**5.16**	**4.77**	**8.43**	**5.22**	**12.30**	**0.42**
P	**0.01**	**0.02**	**0.11**	**0.08**	**0.09**	**0.01**	**0.07**	**0.002**	**0.81**

the highest N, P, and Ca values. But this was not the case for the remaining nutrients because of their lower concentrations in the litter. The stand with the smallest litter mass, H-4, had the highest N concentration which resulted in one of the lowest totals for N in the litter. However, there were no significant differences in total nutrient content among reserves (Table 5.9).

The greatest amounts of N, P, K, Ca, and Mg were consistently stored in the blue mahoe leaves and miscellaneous fragments followed by fine wood and other species leaves (Table 5.10). These leaf components accounted for 79% of the total accumulated nutrients on the plantation floor. The nutrient content in other species leaves were significantly less than the amount of nutrients stored in the other components. This litter component accounted for a small percentage of the total accumulated litter but contained concentrations of N, P, K, Ca, and Mg that were equal or greater to those found in blue mahoe tissues. The other species leaves and fine wood litter showed significant differences in Al concentrations among reserves but Vermont blue mahoe plantations had three times the amount of Al in other species leaf fractions in comparison to Montreal.

On average, the fine wood component accounted for 17% of the total litter mass and approximately 14% of the total nutrient content in the plantation litter (Table 5.10). Total amounts of K, Ca, and Mg in the fine wood component showed the greatest variability among plantations, whereas N and P followed a similar distribution to their litter mass. The total N, P, K, Ca, and Mg in fine wood were significantly higher than those found in the other species leaves but significantly less than the amounts found in blue mahoe leaves and miscellaneous fragments.

Table 5.9. Total nutrient content of 18 blue mahoe plantations in the Hermitage, Montreal, and Vermont reserves. Evaluated by Kruskal-Wallis H Test P<0.05, n=3. Nutrient concentrations for each litter component were multiplied by their corresponding weight and then summed to obtain the total nutrient content for 1 m^2 in each plot, two replicates.

RESERVE PLOT	LITTER MASS ($g\ m^{-2}$)	TOTAL LITTER NUTRIENT CONTENT ($g\ m^{-2}$)								
		N	P	K	Ca	Mg	Al	Fe	Mn	Na
HERMITAGE										
H-1	967.0	0.15	0.11	0.25	15.67	0.45	3.00	0.66	0.05	3.36
H-2	675.0	0.28	0.09	0.16	12.43	0.18	0.84	0.31	0.03	1.06
H-3	1162.0	0.40	0.19	0.29	23.35	0.48	1.34	0.47	0.05	2.39
H-4	426.0	0.18	0.04	0.11	9.08	0.18	0.43	0.17	0.01	0.64
H-5	865.0	0.24	0.09	0.19	20.47	0.39	0.70	0.29	0.03	0.76
H-6	788.0	0.21	0.09	0.23	14.16	0.41	1.28	0.46	0.03	1.46
Mean	**814.0**	**0.24**	**0.10**	**0.21**	**15.86**	**0.61**	**1.26**	**0.39**	**0.03**	**1.61**
MONTREAL										
M-1	865.0	0.16	0.16	0.42	18.19	0.46	1.24	0.54	0.03	1.39
M-2	945.0	0.18	0.16	0.30	15.69	0.48	1.38	0.60	0.03	1.60
M-3	894.0	0.22	0.13	0.20	16.81	0.50	1.09	0.50	0.03	0.93
M-4	799.0	0.32	0.12	0.27	18.31	0.48	0.63	0.26	0.02	2.24
M-5	1038.0	0.20	0.14	0.25	19.48	0.42	0.89	0.39	0.02	1.30
M-6	593.0	0.15	0.08	0.39	14.44	0.32	0.66	0.23	0.02	0.79
Mean	**856.0**	**0.21**	**0.13**	**0.31**	**17.14**	**0.45**	**0.98**	**0.42**	**0.03**	**1.37**
VERMONT										
V-1	805.0	0.19	0.09	0.20	13.29	0.26	1.35	0.52	0.05	0.96
V-2	737.0	0.07	0.09	0.26	8.78	0.24	1.44	0.53	0.03	1.95
V-3	707.0	0.11	0.09	0.22	12.24	0.30	1.01	0.38	0.03	0.81
V-4	1031.0	0.14	0.13	0.30	15.86	0.39	2.52	0.82	0.06	1.07
V-5	1068.0	0.23	0.14	0.27	18.48	0.41	1.77	0.58	0.04	2.00
V-6	1094.0	0.22	0.16	0.38	18.76	0.47	1.72	0.55	0.05	4.22
Mean	**907.0**	**0.16**	**0.12**	**0.27**	**14.57**	**0.34**	**1.63**	**0.56**	**0.04**	**1.83**
H	**0.33**	**2.07**	**1.34**	**3.00**	**0.86**	**2.52**	**1.61**	**2.07**	**3.51**	**0.31**
P	**0.72**	**0.16**	**0.29**	**0.08**	**0.44**	**0.11**	**0.23**	**0.16**	**0.06**	**0.74**

Table 5.10. Average nutrient content in individual litter components. Calculations were based on 18 plots. Means in rows followed by the same letter were not significantly different at $P<0.05$ analyzed by the Kruskal-Wallis H Test and non-parametric Scheffé range test, n=4.

NUTRIENT ($g\ m^{-2}$)	BLUE MAHOE LEAVES	MISC. FRAG.	OTHER SPECIES LEAVES	FINE WOOD	H	P
N	0.08^b	0.08^b	0.008^a	0.03^b	11.89	0.001
P	0.04^b	0.05^b	0.005^a	0.02^b	23.52	0.001
K	0.10^b	0.10^b	0.013^a	0.05^b	20.63	0.001
Ca	6.25^c	6.17^c	0.564^a	2.87^b	28.69	0.001
Mg	0.15^c	0.17^c	0.014^a	0.05^b	35.46	0.001
Na	0.51^b	0.59^b	0.085^a	0.42^b	9.82	0.001
Al	0.39^b	0.79^c	0.067^a	0.04^a	32.04	0.001
Fe	0.16^b	0.26^b	0.025^a	0.02^a	15.21	0.001
Mn	0.01^b	0.02^b	0.002^a	0.002^a	3.58	0.001

Different stages of leaf litter fragmentation were represented by the blue mahoe leaves and miscellaneous fragments. The miscellaneous fragments were blue mahoe leaf litter (F layer) that had reached a later stage of decomposition (L layer). Regression analysis did not indicate any relationships between N, P, K, Ca, and Mg and the two different litter components. Alternatively, Al, Fe, and Mn concentrations in the litter did indicate a positive relationship between blue mahoe leaves and miscellaneous fragments (Table 5.11). In addition, concentrations of Al, Fe, and Mn in the litter were strongly correlated among each other; an increase in one of Al, Fe, or Mn generally resulted in an increase in the other two elements.

Table 5.11. Regression equations for different stages of litter decomposition (miscellaneous fragments and blue mahoe leaves), $P<0.10$, n=18.

REGRESSION EQUATIONS, ADJUSTED r^2, AND P-VALUE
Al concentration in blue mahoe mg g^{-1} = 1.04+0.80 (Al concentration in miscellaneous fragments mg g^{-1}) r^2=0.16, P=0.10
Fe concentration in blue mahoe mg g^{-1} = 0.58+0.40 (Fe concentration in miscellaneous fragments mg g^{-1}) r^2=0.21, P=0.03

5.6 SOIL PROFILE AND MINERAL HORIZON CHARACTERISTICS

5.6.1 Physical Properties of Soil Mineral Horizons

Soil profiles in all three reserves were representative of the High Level Yellow Earth group. Field observations and laboratory analysis confirmed that Hermitage and Montreal soils were Montreal Loam and Clay Loam soil series, and Vermont plantations were Greggs Clay Loam and Clay soil series. The main difference between these two soil series are Montreal Loam and Clay Loam develop from fine pyroclastic rocks and Greggs Clay Loam and Clay are formed from cemented agglomerate and lava parent rock. Soils in Vermont were bouldery, moderately deep, well-drained, and medium to coarse-textured. The Montreal series differed from the Greggs series by their deeper profile composed of layers of sharply contrasting texture and consistence.

Both soil types were generally well-drained with moderate to high permeability and were characterized by Ah horizons that ranged from 8.0 to 17.0 cm in thickness (Table 5.12). The Ah horizons were sandy loam with friable, moderate, fine granular structure. On average, the percentage of coarse fragments in the surface horizon was highest in Hermitage (47%) followed by Vermont (38%), and Montreal (31%) plantation reserves. The Ah horizon in Montreal and Hermitage soil profiles ranged from 14.0 to 17.0 cm in thickness. Vermont Ah horizons were less developed ranging from 8.0 to 14.0 cm.

A transitional AB horizon was prominent in all soil profiles (Plate 5.7 and 5.8) The soil color is slightly brighter and lighter (10YR 2/1 to 10YR3/3) with a clear gradual boundary between 15 and 30 cm in depth. The AB horizons were characterized by a sandy loam to silt loam texture with friable, moderate, fine, sub-angular blocky structure. Soil bulk densities ranged from 0.49 to 0.80 g cm^{-3} in the Ah horizon, increasing slightly to an average of 0.91 g cm^{-3} in the AB horizon. There were significant increases in bulk density between the Ah and AB horizons (Kruskal-Wallis H Test, H=6.59, P=0.01) but no significant

Table 5.12. Soil physical and chemical profile descriptions for Hermitage (H), Montreal (M) and Vermont (V) reserves.

PROFILE	HORIZON	DEPTH (cm)	COLOR	TEXTURE	% CF	% OM	pH	EC (dmS $^{-1}$)	BD (g cm $^{-3}$)	ALLOPHANE
H-1	LF	2-0								
	Ah	0-14	10 YR 3/2	SL	43	4.8	6.05	0.94	0.80	Yes
	AB	14-26	10YR 3/6	LS	33	4.2	6.08	0.60	1.09	Yes
	B1	26-40	10 YR 3/3	SL	39	4.3	5.92	0.50	-	Yes
	B2	40+	10 YR 3/6	S	12	1.6	5.75	0.56	-	No
H-2	LF	5-0								
	Ah	0-16	10 YR 2/2	SL	49	4.0	5.95	0.75	0.49	Yes
	AB	16-45	10 YR 4/6	LS	22	2.4	6.01	0.42	0.79	Yes
	B1	45-89	10 YR 5/8	LS	23	0.3	5.90	0.34	-	No
	B2	89+	10 YR 5/8	LS	15	0.4	6.09	0.56	-	No
M-3	LF	8-0								
	Ah	0-17	10 YR 3/2	SL	23	4.6	5.82	1.14	0.75	Yes
	AB	17-34	10 YR 3/3	SL	17	4.6	5.88	0.74	1.01	Yes
	B1	34-66	10 YR 3/4	LS	13	4.3	5.62	0.55	-	Yes
	B2	66+	10 YR 3/6	S	8	3.2	5.70	0.51	-	Yes
M-4	LF	5-0								
	Ah	0-8	10 YR 2/1	SL	18	2.2	6.06	0.38	0.63	Yes
	AB	8–26	10 YR 3/3	LS	19	3.5	5.66	0.37	0.95	Yes
	B1	26-75	10 YR 3/4	LS	7	4.3	5.60	1.17	-	No
	B2	75+	10 YR 3/6	S	13	1.3	5.90	0.81	-	Yes
V-2	LF	5-0								
	Ah	0-8	10 YR 3/3	SL	18	4.4	5.97	0.54	0.67	No
	AB	8–24	10 YR 3/4	SL	18	3.4	5.79	0.53	0.99	No
	B1	24-60	10 YR 4/6	LS	20	0.5	5.86	0.30	-	No
	B2	60+	10 YR 4/6	LS	12	0.6	5.87	0.26	-	No
V-3	LF	4-0								
	Ah	0-14	10 YR 3/3	SL	34	4.3	6.11	47.20	0.55	Yes
	AB	14-25	10 YR 3/6	SL	19	4.2	6.24	72.10	0.79	Yes
	B1	25-57	10 YR 3/6	S	30	1.9	6.10	56.30	-	Yes
	B2	57+	10 YR 4/6	SiL	50	2.6	5.90	37.80	-	No

Note: OM - soil organic matter, CF - coarse fragments, EC - electrical conductivity, BD - bulk density.

Table 5.12. Concluded.

			CATIONS (meq. 100 g^{-1})										
PROFILE	HORIZON	DEPTH (cm)	NH_4-N	NO_3-N	PO_4-P	K	Ca	Mg	Na	Al	Fe	Mn	CEC
H-1	LF	2-0											
	Ah	0-14	1.34	0.33	0.23	0.23	19.61	1.92	0.73	0.12	0.004	0.003	22.61
	AB	14-26	0.38	0.08	0.30	0.10	6.08	0.62	0.86	0.14	0.005	0.003	7.81
	B1	26-40	0.74	0.18	0.38	0.06	6.86	0.56	0.35	0.27	0.004	0.006	8.11
	B2	40 +	0.28	0.06	0.27	0.05	2.45	0.14	0.26	0.18	0.005	0.003	3.09
H-2	LF	5-0											
	Ah	0-16	1.97	0.23	0.43	0.26	17.52	1.85	0.88	0.12	0.005	0.003	20.64
	AB	16-45	0.35	0.02	0.39	0.07	5.95	0.74	0.82	0.10	0.004	0.003	7.69
	B1	45-89	0.27	0.01	0.26	0.06	7.37	2.12	3.66	0.31	0.006	0.012	13.54
	B2	89+	0.27	0.02	0.31	0.07	9.23	1.67	4.43	0.14	0.003	0.005	15.54
M-3	LF	8-0											
	Ah	0-17	2.16	0.08	0.42	0.33	32.42	3.89	0.91	0.12	0.007	0.128	37.81
	AB	17-34	2.08	0.05	0.25	0.09	6.05	0.80	0.91	0.21	0.006	0.007	8.07
	B1	34-66	0.56	0.02	0.31	0.08	3.34	0.13	0.34	0.18	0.005	0.006	4.08
	B2	66+	0.30	0.01	0.50	0.05	1.15	0.09	0.25	0.17	0.005	0.004	1.72
M-4	LF	5-0											
	Ah	0-8	1.42	0.38	0.31	0.31	29.92	2.85	0.85	0.12	0.002	0.005	34.06
	AB	8--26	0.27	0.01	0.42	0.03	5.40	0.18	1.97	0.25	0.006	0.002	7.83
	B1	26-75	0.27	0.04	0.38	0.10	10.29	1.04	0.44	0.13	0.004	0.004	12.01
	B2	75+	0.27	0.01	0.27	0.07	6.51	0.59	0.36	0.11	0.006	0.004	7.65
V-2	LF	5-0											
	Ah	0-8	0.56	0.06	0.19	0.43	27.81	3.90	0.87	0.15	0.007	0.017	33.18
	AB	8--24	0.31	0.03	0.36	0.10	8.05	1.07	0.68	0.37	0.006	0.015	10.29
	B1	24-60	0.27	0.02	0.14	0.04	1.71	1.09	0.27	0.16	0.006	0.004	3.28
	B2	60+	0.27	0.01	0.29	0.08	6.47	0.27	0.59	0.28	0.007	0.009	7.71
V-3	LF	4-0											
	Ah	0-14	0.94	0.05	0.19	0.36	17.22	2.29	1.55	0.14	0.008	0.010	21.58
	AB	14-25	0.27	0.04	0.14	0.11	9.84	1.68	1.96	0.08	0.003	0.008	13.68
	B1	25-57	0.27	0.16	0.13	0.04	13.33	2.13	2.68	0.11	0.004	0.024	18.32
	B2	57+	0.27	0.04	0.13	0.06	10.60	3.68	3.11	0.18	0.004	0.029	17.66

Note: CEC - cation exchange capacity = K + Ca + Mg + Na + Al + Fe + Mn

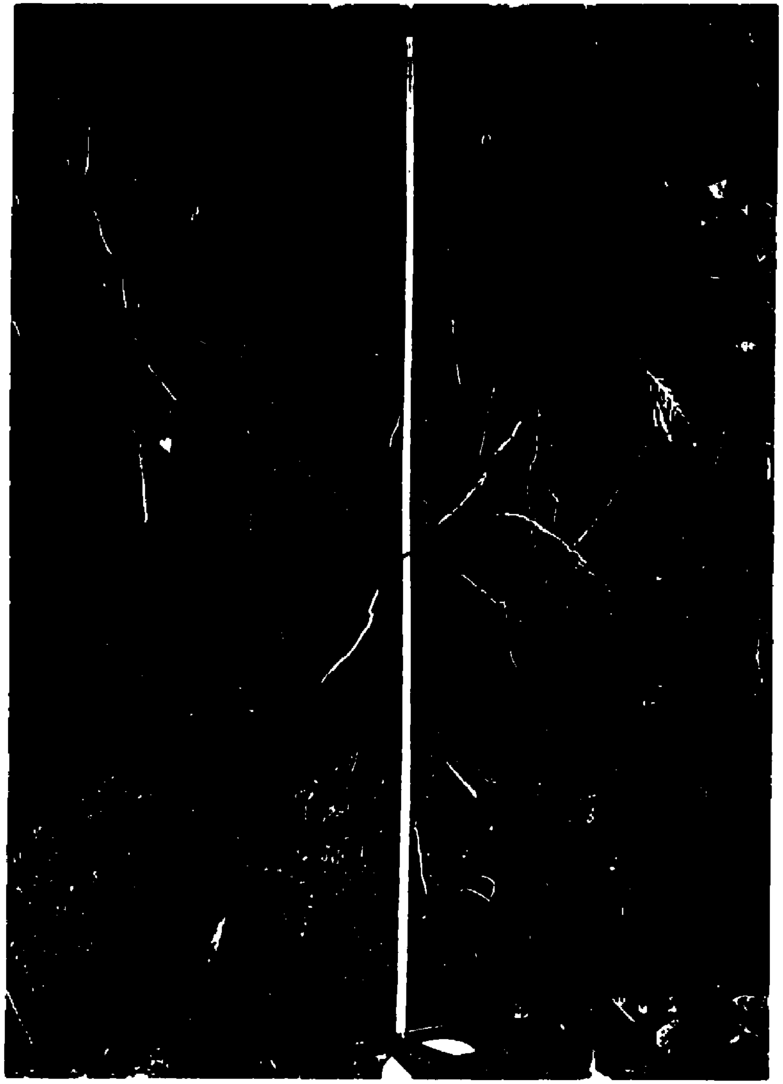

Plate 5.7. Soil profile in the Vermont forest reserve (Greggs Loam and Clay Loam).

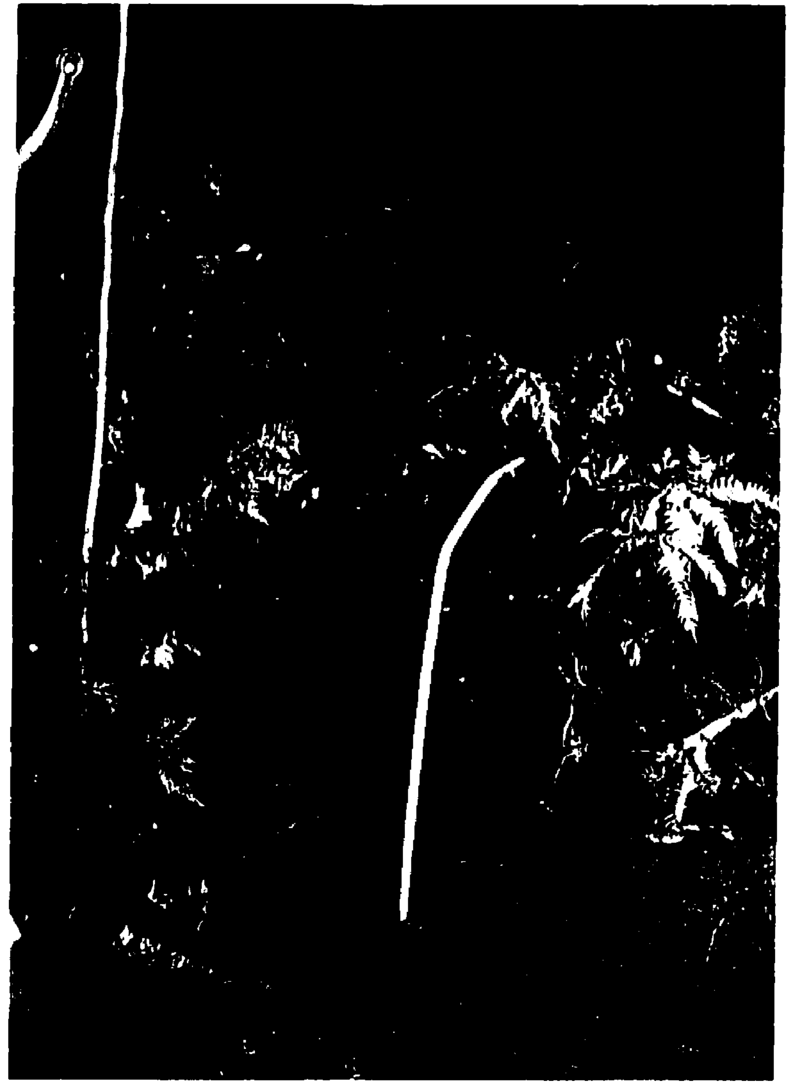

Plate 5.8. Soil profile found in the Hermitage and Montreal forest reserves (Montreal Loam and Clay Loam).

differences were found between individual reserves. Generally, bulk density appeared to increase slightly with depth in soil profiles for all reserves.

Allophane was present in most Ah and AB horizons except for two sites in Vermont (V-4 and V-6). These sites were located on the oldest part of the island where soils had been exposed to prolonged weathering and over time allophane may have changed to gibbsite and kaolinite. At least one horizon in every soil profile did not have allophane present. Typically, these horizons occurred at a depth of >60 cm and had a thickness of 35 to 70 cm. Plantation V-2 had no detectable allophane throughout its soil profile.

5.6.2 Chemical Properties of Mineral Soil Horizons

The average soil pH in the Ah horizons for Hermitage, Montreal, and Vermont plantations were 6.02, 5.81, and 6.14, respectively (Table 5.13). The Kruskal-Wallis H Test and range test showed a significantly higher pH for the Ah horizons in Vermont compared to Hermitage and Montreal (H=14.46, P=0.001). The same regional variation occurred for soil pH in the AB horizons. In the AB horizon, Montreal had significantly lower pH values than Vermont and Hermitage (Table 5.14). The soil pH in the AB horizon in relation to the Ah horizon in the Hermitage, Montreal and Vermont reserves, increased and decreased, respectively. The distribution of organic matter ranged from 3.8 to 5.6% in the upper 15 cm of the soil mineral layer for all blue mahoe plantations. The Kruskal-Wallis H Test showed a significantly higher soil organic matter content on Vermont sites compared to sites in Hermitage (Table 5.13). The average soil organic matter content changed from 4.5% in the Ah horizons to 3.0% in the AB horizons. There was a significant difference in soil organic matter between the Ah and AB horizons (H=6.64, P=0.02).

In general, the salt level in the soil, as indicated by electrical conductivity decreases with an increase in soil profile depth (Table 5.12). The Kruskal-Wallis H Test showed that surface

Table 5.13. Surface soil (Ah horizon) characteristics for three blue mahoe plantation reserves. Values are the average of four replicates. Evaluated by Kruskal-Wallis H Test. Means in rows followed by the same letter are not significantly different at P=0.05 based on non-parametric Scheffé range test (n=6).

SOIL CHARACTERISTICS		RESERVE			
PLANTATIONS	HERMITAGE	MONTREAL	VERMONT	H	P
pH	6.01^{b}	5.80^{a}	6.13^{b}	14.46	0.001
Organic matter (%)	3.95^{a}	4.22^{ab}	5.18^{b}	23.17	0.001
Electrical conductivity (dS m^{-1})	1.61^{a}	3.06^{b}	1.57^{a}	10.08	0.010
Extractable NH_4-N and NO_3-N (mg g^{-1})	0.12^{a}	0.10^{a}	0.11^{a}	0.28	0.870
Available PO_4-P(mg g^{-1})	0.02^{a}	0.03^{a}	0.04^{b}	9.47	0.001
Exchangeable K (meq. 100 g^{-1})	0.21^{a}	0.33^{ab}	0.43^{b}	12.11	0.002
Exchangeable Ca (meq. 100 g^{-1})	19.61^{a}	32.42^{b}	27.82^{b}	6.60	0.040
Exchangeable Mg (meq. 100 g^{-1})	1.92^{a}	3.88^{b}	3.90^{b}	10.47	0.005
Exchangeable Al (meq. 100 g^{-1})	0.12^{a}	0.12^{a}	0.15^{a}	1.96	0.380
Extractable Na (meq. 100 g^{-1})	0.73^{a}	0.91^{a}	0.87^{a}	3.44	0.180
Available Mn (meq. 100 g^{-1})	0.003^{a}	0.013^{b}	0.017^{b}	23.35	0.001
Available Fe^{3+} (meq. 100 g^{-1})	0.004^{a}	0.007^{b}	0.007^{b}	9.34	0.001
Cation Exchange Capacity (meq. 100 g^{-1})	22.58^{a}	37.69^{b}	33.19^{b}	7.96	0.020

Table 5.14. Subsurface soil (AB horizon) characteristics for three blue mahoe plantation reserves. Values are the mean of four replicates in each plot. Evaluated by Kruskal-Wallis H test. Means in rows followed by the same letter are not significantly different at P=0.05 based on non-parametric Scheffé range test (n=6).

SOIL CHARACTERISTICS		RESERVE			
PLANTATIONS	HERMITAGE	MONTREAL	VERMONT	H	P
pH	6.11^{a}	5.66^{b}	5.95^{a}	14.80	0.001
Organic matter (%)	3.01^{a}	2.73^{a}	3.26^{a}	2.62	0.270
Electrical conductivity (dS m^{-1})	0.73^{b}	0.90^{b}	0.47^{a}	9.47	0.010
Extractable NH_4-N and NO_3-N (mg g^{-1})	0.03^{a}	0.02^{a}	0.03^{a}	2.52	0.280
Available PO_4-P (mg g^{-1})	0.06^{a}	0.07^{a}	0.08^{a}	1.28	0.530
Exchangeable K (meq. 100 g^{-1})	0.10^{a}	0.09^{a}	0.10^{a}	1.30	0.520
Exchangeable Ca (meq. 100 g^{-1})	6.08^{a}	6.05^{a}	8.05^{a}	2.08	0.350
Exchangeable Mg (meq. 100 g^{-1})	0.62^{a}	0.80^{a}	1.07^{a}	1.81	0.410
Exchangeable Al (meq. 100 g^{-1})	0.14^{a}	0.21^{a}	0.37^{a}	6.69	0.030
Extractable Na (meq. 100 g^{-1})	0.86^{a}	0.91^{a}	0.68^{a}	0.34	0.840
Available Mn (meq. 100 g^{-1})	0.002^{a}	0.008^{ab}	0.017^{b}	14.31	0.001
Available Fe^{3+}(meq. 100 g^{-1})	0.008^{a}	0.008^{a}	0.008^{a}	3.58	0.160
Cation Exchange Capacity (meq. 100 g^{-1})	7.82^{a}	8.07^{a}	10.30^{a}	1.25	0.540

horizons in Montreal have significantly higher electrical conductivities than Hermitage and Vermont (Table 5.13). The Montreal reserve had the the highest electrical conductivity in the subsurface horizon (Table 5.14).

The cation exchange capacities (CEC) range from 14.95 to 90.95 meq. 100 g^{-1} for all Ah horizons. Hermitage reserve had the lowest CEC among the three reserves (Table 5.12). Although, the CEC values for subsurface horizons were statistically similar among reserves, there was a 70% decrease in CEC values between the Ah and AB horizons in most blue mahoe plantations. As depth increased in the soil profiles (i.e., B1 and B2) the CEC began to decrease because of a reduction in organic matter (Table 5.12).

Statistical differences in available P, Fe, Mn, and exchangeable K, Ca, and Mg were found in the Ah horizons of the sampled blue mahoe plantations (Table 5.13). Available P was significantly higher in Vermont soils compared to Hermitage or Montreal reserves, however, the concentrations only ranged from 0.02 mg g^{-1} to 0.04 mg g^{-1} among the reserves. The same statistical result was found for exchangeable K with a doubling of the concentration in Vermont as compared to Hermitage soils. Although Fe and Mn occurred in small quantities, there was a 1.5 and 5-fold respective increase in soil concentrations from Hermitage to Vermont soils. Extractable N, Al, and Na concentrations were not significantly different in soils between reserves. Exchangeable Al and Mn were the only soil nutrients in the AB horizon that were significantly different among plantation reserves (Table 5.13).

Overall, the soil chemistry was variable in terms of CEC, soil organic matter, total extractable N, exchangeable concentrations of K, Al, Ca, Mg, and K and available concentrations of P, Mn and Fe. Differences between the minimum and maximum concentrations for each of the measured soil characteristics ranged widely. Extractable Ca and Mg in the Ah horizon of M-4 was significantly larger than all other sites.

5.7 CHANGES IN SOIL CHEMISTRY AND LITTER NUTRIENT CONCENTRATION AS A FUNCTION OF BLUE MAHOE AGE

Differences in soil organic matter of blue mahoe plantations were related to variations in stand age (Figure 5.6).

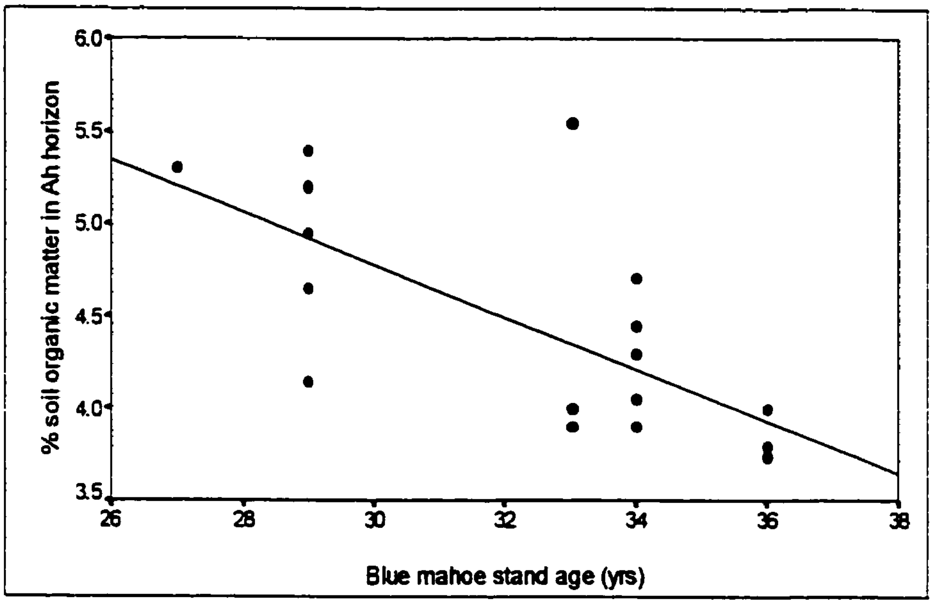

Figure 5.6. Relationship between blue mahoe age and percentage of soil organic matter in the Ah horizon. % organic matter = -0.14 + 9.02 (stand age) +/-0.46, n=18, r^2=0.45, P=0.002.

In addition, there were three significant litter nutrient variables that were related to blue mahoe age. Blue mahoe stand age explained 58% of the variation in N concentrations in the litter with a standard error of the estimate of 0.04 mg g^{-1} of N (Figure 5.7). The second litter nutrient was Ca whereby stand age explained 56% of the variation in Ca concentration in the litter with a standard error of the estimate of 2.42 mg g^{-1} (Figure 5.8). Thirdly, blue mahoe stand age explained 63% of the variability in Al concentrations in the litter with a standard error of the estimate of 0.32 mg g^{-1} (Figure 5.9).

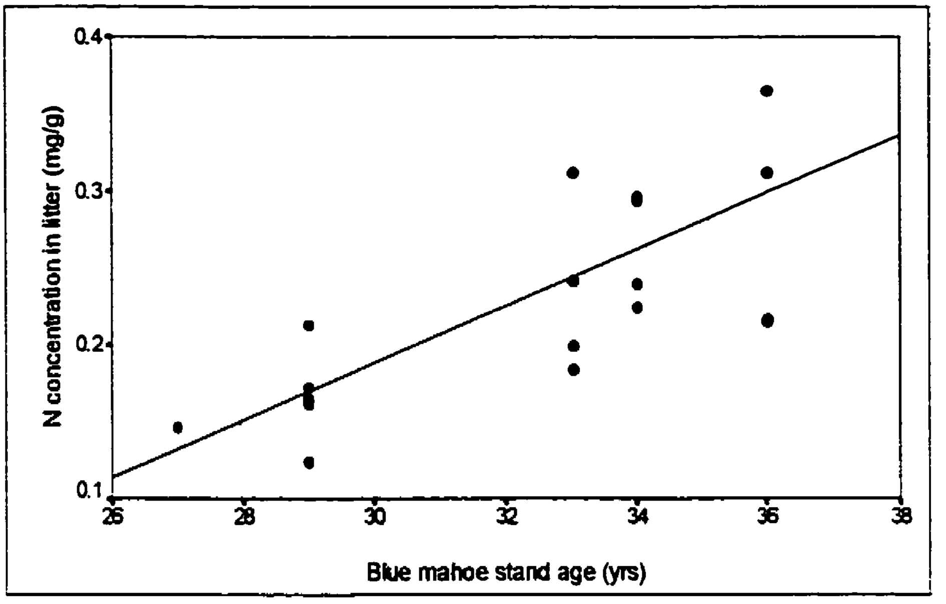

Figure 5.7. Relationship between blue mahoe age and N concentration in the litter. N concentration in litter (mg g^{-1}) = -0.37 + 0.02 (stand age) +/- 0.04, n=18, r^2=0.58, P=0.001.

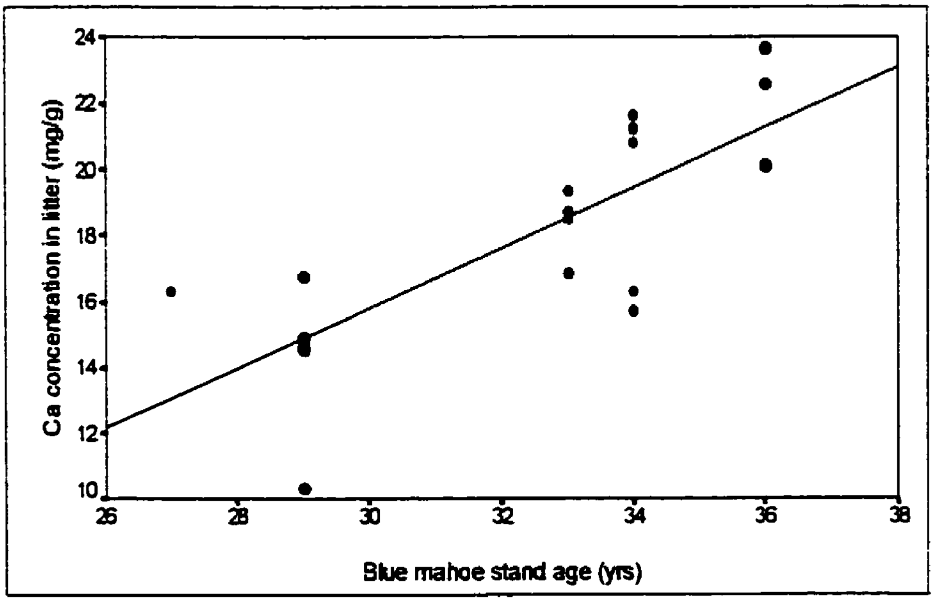

Figure 5.8. Relationship between blue mahoe age and Ca concentration in the litter. Ca concentration in litter (mg g^{-1}) = -11.45 + 0.91 (stand age) +/- 2.42, n=18, r^2=0.56, P=0.001.

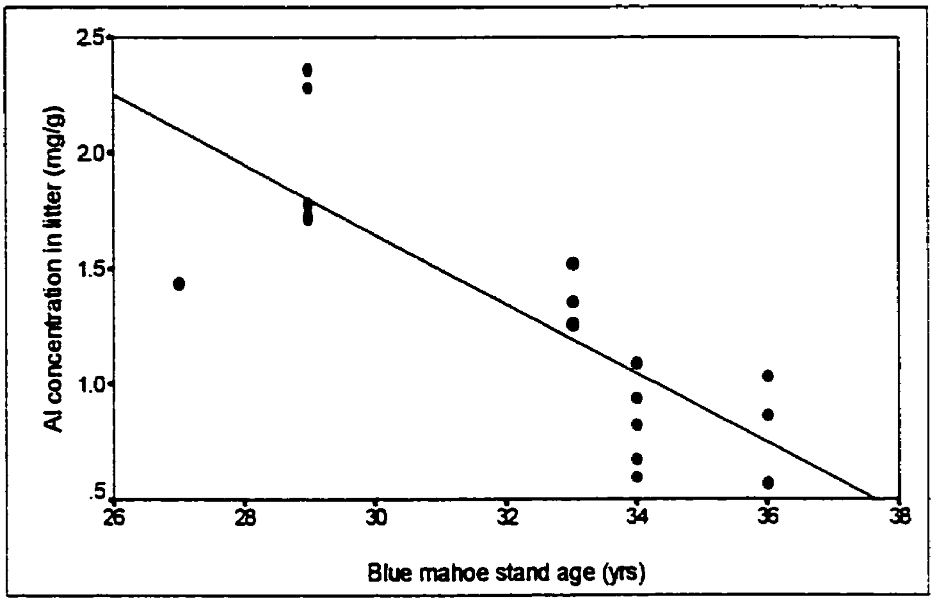

Figure 5.9. Relationship between blue mahoe age and Al concentration in the litter.
Al concentration in litter (mg g^{-1}) = -0.15 + 6.16 (stand age) +/- 0.32, n=18, r^2=0.63, P=0.001.

5.8 PREDICTING BLUE MAHOE GROWTH FROM SOIL, LITTER, AND TOPOGRAPHIC FACTORS

Stepwise multiple regression was used to relate mean annual height increment, mean annual diameter increment, basal area, and volume (dependent variables) to topographic factors, soil physical and chemical properties, and litter nutrients (independent variables). In addition, vegetation cover including ground, shrub, understory, and canopy were considered in the equations. A total of 61 independent variables were used in an attempt to predict blue mahoe growth. Basal area and volume were standardized to 30 year old blue mahoe. The dependent and independent variables used in the regression analysis were listed in Table 4.1. No significant equations were derived for mean annual height increment and mean annual diameter increment.

5.8.1 Basal Area and Volume

Total Mn in the litter explained 20% of the variability in blue mahoe basal area with a standard error of the estimate of 17.9 m^2 ha^{-1} (Figure 5.10).

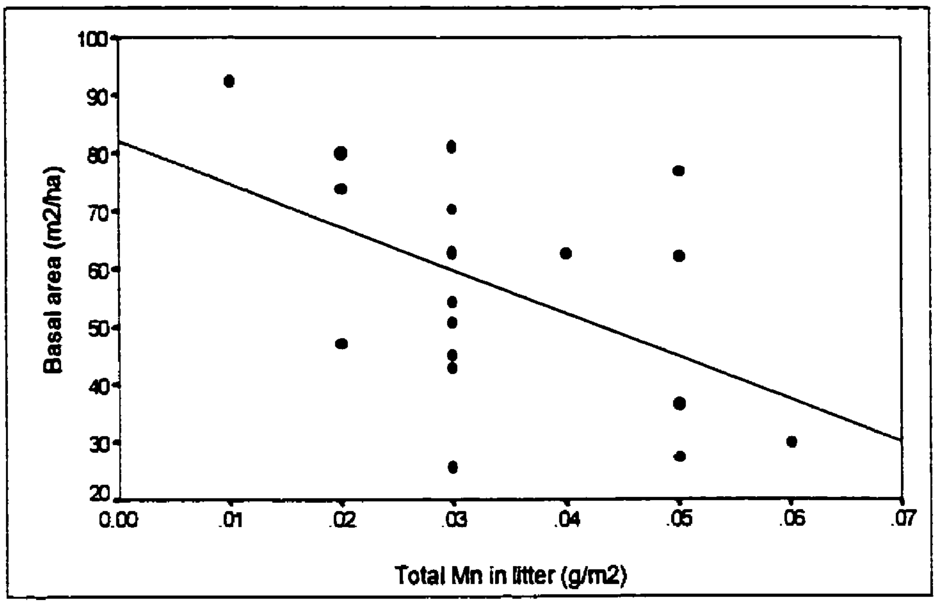

Figure 5.10. Relationship between basal area and total Mn in the litter. Basal area (m^2 ha^{-1}) = -745.91 + 82.25 (Total Mn in litter g m^{-2})+/-17.9, n=18, r^2=0.20, P=0.04.

The relationship (0.5 x basal area x height) was used to calculate stem volumes for blue mahoe (Newbound, 1967; Francis and Weaver, 1988). Total Mn in the litter explained 24% of the variability in blue mahoe volume with a standard error of the estimate of 236 m^3 ha^{-1} (Figure 5.11).

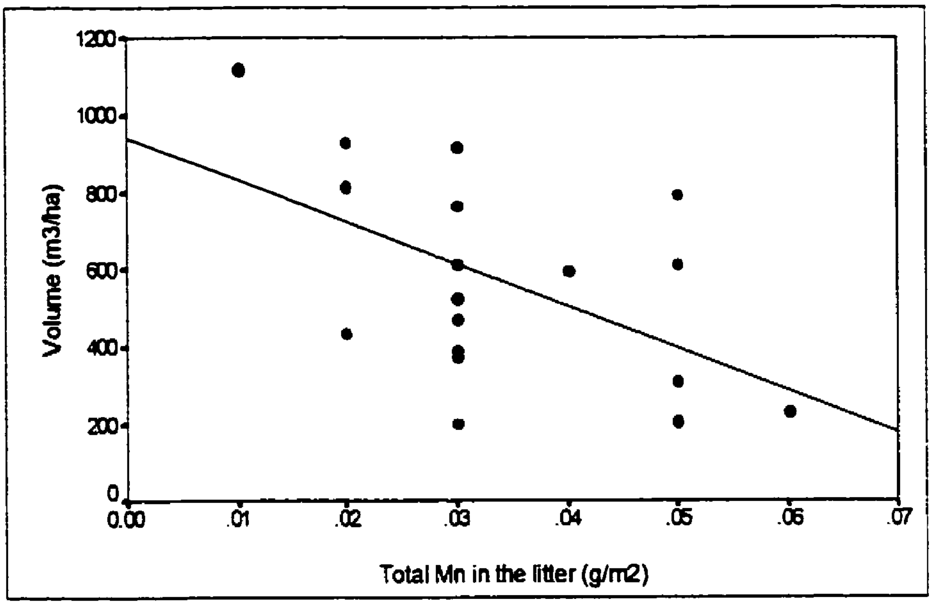

Figure 5.11. Relationship between volume and total Mn in the litter. r^2=0.24, Volume (m^3 ha^{-1}) = -10871.32 + 942.14 (Total Mn in litter g m^{-2}) +/- 236.92, n=18, P=0.04

CHAPTER SIX: DISCUSSION

6.1 GROWTH PREDICTION

Blue mahoe plantations were originally recommended for sandy, well drained granitic upland sites, with rainfall between 1,650 and 2,500 mm yr^{-1} (Geary and Briscoe, 1972), but were acceptable of areas receiving >1,000 mm yr^{-1}. In Jamaica, blue mahoe grows on moist limestone soils at 150 m above sea level, and on shales and residual volcanic soils over 1,200 m above sea level (Swabey, 1940). Sites that were known to be least favorable for blue mahoe were droughty (i.e., shallow soils over bedrock), very poorly drained soils and severely eroded or nutrient depleted sites (Francis and Weaver, 1988). In Cuba, blue mahoe have survived on extremely dry sites but it is comparably a smaller tree. Soil-site conditions on St. Vincent are favorable for blue mahoe growth with rainfall between 2,850 and 3,100 mm yr^{-1} and young Andisolic soils that are more fertile than most tropical soils.

There was natural variation in the growth of blue mahoe among the studied stands. The growth characteristics presented in Table 5.4 did suggest that the Montreal reserve had trees with greater volumes, but overall there were no significant differences among reserves. Stands of similar age in Puerto Rico had comparable height, diameter at breast height, basal area, volumes, and growth rates (Francis and Weaver, 1988). Other published sources on blue mahoe growth suggested that plantations in Hawaii, Jamaica, Puerto Rico, and St. Lucia also had similar growth but silvicultural management was a key factor in determining the success of these plantations.

Regression analyses showed that no single soil-site factor adequately predicted blue mahoe mean annual height increment or mean annual diameter increment. However, one variable was related to basal area and volume. Total Mn in the litter explained 20% and 24% of the variability, respectively. No topographic factors were significant for predicting growth. Of similar studies that were reviewed, soil physical and chemical factors accounted for a large percentage of the variation in growth. In mixed conifer stands of Douglas-fir (*Pseudotsuga* *menziesii*) and white spruce (*Picea glauca*) in Idaho; the depth to volcanic ash, bulk density, P content, and elevation were key variables (Brown and Loewenstein, 1978). For white pine (*Pinus strobus*), soil properties such as coarse fragments, pH, CEC, organic C, and moisture characteristics were most consistently correlated with volume (Mader, 1976). Norway spruce (*Picea abies*) growth in New York also was related to soil textural components, soil pH, and CEC; but topographic properties made little or no independent contribution to the predictive model. Overall, basal area was not predicted well (Mader, 1976).

The multiple regression procedure has been applied to red pine (*Pinus resinosa*) in Massachusetts with some success, and it was concluded that height growth was related to foliar Ca content, and basal area to foliar K content (Hoyle and Mader, 1964). Although there were significant differences in N, P, and Al among reserves, Mn was the only litter nutrient successfully related to blue mahoe growth (i.e., basal area and volume). As a result, there are a number of environmental factors which allow Mn to be a key factor in influencing the soil-site conditions beneath blue mahoe plantations and perhaps even, minor differences in blue mahoe growth among forest reserves.

The concentration of Mn in the litter is not likely a major factor in determining blue mahoe growth since it is rarely limiting and fertilization with micronutrients is not normally required. The rate of Mn uptake differs considerably between plant species and the requirements of blue mahoe is not known. In plant tissue, Mn is tightly bound with proteins adding structural stability to the molecules and plays a role in photosynthesis. Mn is preferentially translocated to meristematic tissues, thus young plant tissues are generally rich in Mn (Binkley, 1986). Mn content of blue mahoe litter ranged from 0.02 to 0.05 mg g^{-1} whereas the critical deficiency level for most plant species is in the range of 0.02 to 0.03 mg g^{-1} in the dry matter of upper plant parts (Mengal and Kirkby, 1979). Perhaps, the closest to blue mahoe leaves were citrus tree leaves which showed deficiency symptoms with <0.02 mg g^{-1} of Mn. Typically litter concentrations should be lower than foliage due to nutrient retranslocation prior to leaf senesce. In addition, the litter layer is generally comprised of older leaves which would contain the lowest concentrations of Mn in the tree. Although blue mahoe litter was within the critical deficiency range for most plant foliage, it does not provide a sufficient comparison due to the chemical and microbial changes of litter as well as leaching of Mn, once it reaches the forest floor. Other soil-site factors may be attributed to the significant contribution of Mn in the litter to the growth of blue mahoe on St. Vincent.

It is suggested that there is a formation of Mn complexes with organic matter which may account for a relationship between Mn and soil pH (Tisdale and Nelson, 1967). An increase in soil pH usually increases the chemical and microbial oxidation of Mn. Some plant species on soils with near-neutral pH and high soil organic matter have exhibited varying degrees of Mn deficiency. A high organic matter content may result in the appearance of deficiency symptoms at lower pH values than on soils with lower humus content which suggests that certain types of organic matter form insoluble complexes with Mn making it unavailable to plants.

The key factor here seems to be that oxidation, which would likely occur under well drained soil conditions and moderately high soil porosity such as those on St. Vincent, may contribute to a reduction of Mn to plants. This oxidation deficiency is associated with a soil pH which is magnified when higher amounts of organic matter are present (i.e., lower pH levels can have deficiencies if there is enough organic matter). The level of available Mn in the soil has been previously related to the distribution of parent materials on St. Vincent (Watson et al., 1958). The most recently derived parent materials generally were found on the northern half of the island, while the older, more weathered parent materials occurred on the southern half (Limbird, 1987). The Greggs Loam and Clay Loam soil series identified in the Vermont reserve are theoretically underlain by the oldest parent materials and these soils do in fact have the highest concentrations of available Mn in the soils among the three reserves. Healthy soils are reported to contain at least 0.02 to 0.05 mg g^{-1} of extractable Mn. The Hermitage, Montreal, and Vermont reserves reported levels of 0.02 mg g^{-1}, 0.03 mg g^{-1}, and 0.05 mg g^{-1} of extractable Mn, respectively.

6.2 SOIL AND LITTER NUTRIENT CHARACTERISTICS OF BLUE MAHOE

P levels in blue mahoe plantations were inversely related to the amount of litterfall on the forest floor (r^2=0.15) (Figure 5.3). As the total litterfall increased, it appeared that P levels were neither decreasing or increasing but instead the concentrations were being diluted by increasing litter accumulation. There appears to be a finite available P-PO_4 pool which is cycled as organic P; in which case, some would be lost through mineralization and P fixation, but the remainder would continue to be cycled.

The decomposed soluble organic P are often an important factor in supplying P to plants in tropical soils (Brady and Weil, 1996). Decomposing leaves in blue mahoe plantations may involve the early immobilization of P, followed by net release. In some cases if P is extremely limiting, it could place litter decomposers in competition with blue mahoe. Nevertheless, immobilization, vegetation competition, and the soils ability to fix P into unavailable forms may further reduce P availability (Vitousek, 1984; Grubb, 1989).

The results suggested that N concentration in the litter increases (r^2=0.22) as blue mahoe leaf mass decreases, which potentially facilitates faster decomposition (i.e., less forest floor accumulations, higher decomposition and mineralization rates, and lower nutrient immobilization) (Figure 5.4). In addition, blue mahoe leaves had the highest N levels out of the four litter components. The rate of litter decomposition may be faster on nutrient rich sites but there was no indication that blue mahoe on St. Vincent had differences in site productivity (assuming that growth was an indication of site productivity). Similar to P levels in the litter, there may be a N concentration threshold in the blue mahoe leaf compartment beyond which decomposition accelerates (Lugo et al. 1990; Gosz, 1994). Vitousek (1982) also argued that N concentration in the litter was a reliable indicator of N availability on a site. The recently fallen litter (intact leaves) could provide a better indication of N availability in blue mahoe because it is more representative of what nutrients are in the foliage, whereas fragmented leaves have already undergone mineralization and humus formation. The results did suggest a slight decrease in N concentration from the blue mahoe leaves to miscellaneous fragments possibly due to the rapid consumption and recycling of this nutrient (Table 5.6).

The Kruskal-Wallis H Test indicated no significant differences in litter K, Ca, and Mg levels between plantations or individual litter components (Table 5.8). The consistency in these levels between reserves may suggest that adequate amounts of K, Ca, and Mg are available to the trees. Generally, the lack of response to K fertilizers in Andisols can be explained by the parent ashes which are high in K and K feldspars (Limbird, 1992).

According to Lugo et al. (1990), blue mahoe generally store a large amount of nutrients in their litter, but have relatively low litter accumulations in comparison to other tropical tree species. St. Vincent blue mahoe plantations had on average 8.6 Mg ha^{-1} of litterfall whereas Puerto Rico blue mahoe plantations had approximately 10.1 Mg ha^{-1}. Other species such as *Pinus caribaea* and *Pinus elliottii* had accumulations of litter ranging from 24.3 to 27. 8 Mg ha^{-1}. Most of the N, P, and Mg in the litter of St. Vincent and Puerto blue mahoe stands were stored in the blue mahoe leaves, while Lugo et al. (1990) found more nutrients stored in the fine wood fraction. The differences in litterfall mass on the forest floor and the associated nutrient concentrations are likely due to the age of the foliage and time of year.

Little is known about the nutrient cycling of Al, Fe, and Mn in blue mahoe plantations, but clearly, the miscellaneous fragments component had the greatest concentrations of Al and Fe (Table 5.7). The greater accumulations of Al and Fe compared to other macronutrients (i.e., N, P, and Mg) were reflective of the non-volatility of these elements (Table 5.6). Divalent and trivalent cations, such as Fe^{2+} and Al^{3+} are transferred primarily by leaf fall because they are bound more strongly and are least likely to be leached through the soil (Jordan, 1985). Mn^{2+} was an exception since it can be leached easily from the crowns of the trees (Miller, 1984). The high concentrations of Al and Fe in the L and F layers indicated that it may take longer for the related compounds to be broken down and are typically less desirable to microorganisms. An excess storage or availability of Al in the soil could potentially lead to Al toxicity if it is not cycled through the system effectively or the soil pH drops below 5.5.

Soils with a pH <5.5 are more susceptible to Al toxicity since its solubility increases drastically when more than half the cation exchange sites become occupied by Al. The lowest measured soil pH was 5.6 in the Montreal reserve. According to Mengal and Kirkby (1979), higher plants usually contain in order of about 30 mg g^{-1} of Al in the foliage. The highest concentration of Al in the blue mahoe dry litter was 5.3 mg g^{-1}.

There were no significant trends in the nutrient concentrations of litter at different stages of decomposition, except for Al, Fe, and Mn (Figure 5.5). These elements increased in concentration with stand age which suggested an advancement of Al, Fe, and Mn from the L to F layer. Lugo et al. (1990) found that the same trend occurred for N and Ca which had significant impacts on nutrient mineralization and humus formation. The highest accumulation of Al was found in the Vermont reserve which were the oldest soils.

6.3 SOIL AND LITTER CONCENTRATIONS - AGE RELATIONSHIPS

As blue mahoe stands aged, there were changes in the way its total nutrient content in the litter was distributed. This was related primarily to changes in biomass distribution that occurred with age and the differences in concentration of nutrients in each component with age. The regression analyses suggested that N (r^2=0.58) and Ca (r^2=0.56) were positively correlated and soil Ah organic matter content (r^2=0.45) and Al in litter (r^2=0.63) were negatively correlated with blue mahoe age (Figures 5.6 through 5.9).

Overall, N concentrations in the litter should increase with age as more N is absorbed into roots due to an increased symbiotic relationship between N-fixing bacteria and blue mahoe root systems over time. In addition, there also may be some N-fixing understory species which develop on older sites. Blue mahoe stands in Hermitage showed higher concentrations of N in the litter than the Vermont reserve but the productivity of these plantations were similar among reserves (Figure 5.7).

The high concentration of Ca in the litter and the low concentration of extractable Ca found in the Hermitage soils suggested that blue mahoe accumulate Ca with age (Figure 5.8). Several reports have documented that Ca concentration in litter increased with age in higher plants (Heilberg and White, 1951; Beaton et al., 1965; Van den Driessche, 1974). Also, the Ca concentrations increased in the litterfall since blue mahoe recycled Ca efficiently to sustain annual cyclic needs and to retain as much Ca before it is lost due to leaching. This high nutrient use efficiency is relatively common among tropical species where rainfall and chemical solution tend to remove bases such as Ca, via percolation of water through the soil profile.

The distribution of plantations in the regression plot suggested that younger blue mahoe stands have more soil organic matter in the Ah horizon than the older stands (Figure 5.6). Soils in the Vermont reserve contained significantly more soil organic matter than the Hermitage reserve possibly due to the previous land use, site is slightly drier, and with an increase in age there is more leaching (Table 5.11). The accumulation of litter mass was also the largest in Vermont but there was no association between the amount of litter on the plantation floor and the percentage of soil organic matter in the Ah horizon. Miller (1984) described the life of a plantation as having a sinuous cycle of litter accumulation, declining rapidly from clear-felling until the new crop closes canopy, and then increasing to reach a maximum about a half to two thirds of the way through the rotation. The rotation age of blue mahoe is approximately 25 to 35 years which corresponded with the ages of the studied blue mahoe stands in St. Vincent (Francis and Weaver, 1988). Although, there is no clear reason as to why Vermont reserves had a significantly higher soil organic matter content, the larger accumulations of litter mass and lower nutrient concentrations in the litter may suggest that nutrient use may be more efficient in this reserve than the others. If environmental factors such as soil nutrient availability or rainfall distribution are limiting in the Vermont reserve, more biomass may be produced at lower nutrient concentrations, especially for N and Ca which are primarily transferred through litter (Vitousek, 1984; Medina, 1989). These conclusions need further examination on annual litter mass accumulations and litter concentrations within blue mahoe. Typically, blue mahoe are a high nutrient demanding species that require sites of high nutrient fertility and are less efficient at the use and recycling of nutrients in comparison with several other tropical tree plantation species (Lugo et al., 1990).

The strong relationship between the age of blue mahoe stands and Al accumulations was more likely due to the age of the associated parent material. The solubility of Al-phosphate depends on the age and surface area of the minerals. Typically, the Al-phosphate are insoluble which would naturally take the Al "out of action" with an aging site (Figure 5.9). Al concentrations in the litter decreased in older sites (i.e., Hermitage and Montreal) as the Al became part of clay structures and were less likely to be taken up by roots, cycled though the tree, and returned as litterfall. Al has no known physiological importance in most plant species and its role in blue mahoe is not well understood.

6.4 OTHER FACTORS TO CONSIDER IN BLUE MAHOE GROWTH

The elevational changes on St. Vincent were an important contributor to orographic uplift and hence, the increase in precipitation (Limbird, 1987). Associated with the change in elevation was a slight reduction in air and soil temperature. Although elevations were significantly different among reserves, it was not found to be a key factor in determining the growth of blue mahoe (Table 5.1). Blue mahoe plantations between 254 and 467 m above sea level should have similar growth rates if precipitation, temperature, and soil nutrient availability are similar.

The Vermont reserve is located on the southern half of St. Vincent where there is typically a four to six month dry season and where some of the driest areas on St. Vincent occur. There has been reports that vegetation in the Vermont reserve had more symptoms of moisture stress during the dry season than the other reserves (McLeod, 1999; Limbird, 2000). However, the adaptability of blue mahoe to a wide range of soil-site conditions and its tolerance of dry conditions for a short period of time should not substantially affect growth.

Slope aspect was not a significant variable in growth of blue mahoe. In higher latitudes slope aspect may be separated into north and south in areas where sunshine and shade are important. However, in the tropics separation into windward and leeward slopes is more appropriate (Lugo et al., 1989; Limbird, 1987). The Montreal reserve is located on the windward side which receives the moisture laden air from the northeast trade winds as well as from tropical fronts. There was evidence at the sites that prevailing winds may have contributed to a higher occurrence of "sweep" in Montreal blue mahoe. Alternatively, these winds could be beneficial, such that non-senesced leaves are broken off and fall to the forest floor providing the ecosystem with a higher quality of litter material (Lugo et al., 1990). The results of the litterfall accumulations in the Montreal reserve did not suggest that this had occurred, but perhaps annual litterfall measurements may provide a better indication of nutrient recycling in blue mahoe on different aspects of the island.

Often differences in soil chemical properties are enhanced by site factors related to landscape position. Slope gradient did not provide a valuable explanation for blue mahoe growth (Table 5.1). Even when the slope gradients were separated into two groupings (>15° and <15°) there were no differences in growth. Slopes <15° are considered to be more stable for tree establishment because soil erosion is minimal, water infiltration is increased, and deeper soils form under more stable conditions.

Epicormic branching was a common defect that occurred throughout the blue mahoe plantations, even with spacings that ranged between 2.6 m and 3.6 m which is considerably greater than their known tolerance (1.8 m). In Jamaica, epicormic branching also was found to be a problem. However, this was overcome by maintaining wider spacings and regular pruning (Swabey, 1940). It also was found that epicormic sprouting was more common in wet areas, but this problem was not well enough understood to be avoided in site selection (Francis and Weaver, 1988). In St. Vincent, there were no indications that epicormic branching was more prevalent on wet sites but the soils beneath St. Vincent blue mahoe were well drained. It recently has been found that epicormic branching is inherited, so genetic selection may be the only solution in some cases (Zobel et al., 1984).

Blue mahoe is relatively free of plant pests and diseases but recently the pink mealy bug has invaded several plantations on St. Vincent. Typically, the dieback is in the canopy of the tree which made it difficult to identify plantations that may or may not have been attacked. In Grenada, the pink mealy bug devastated several hectares of blue mahoe forcing the Forestry Division to look for alternative tree plantation species (Johnson, 1999). To date, no data could be found on the effects of the pink mealy bug on the growth of blue mahoe.

The vegetation structure in blue mahoe plantations was very similar for all reserves but there were variations in the dominance of certain native species. Clearly, the understory was not as developed in these blue mahoe plantations as it should have been after 30 years, even with minimal silvicultural management. The variation in understory growth was unique to individual sites but each reserve was commonly associated with a specific type of plant community. The shrub understory typically had a clustered distribution that enhanced the regional variability and reinforced the clustered distribution commonly found among tropical species. The differences in understory strata did not affect the growth rate of blue mahoe - but the "functions" of these understory species may affect the growth rate. Other studies have found that nutrient concentrations in the litter of native understory species were sometimes higher than the planted species litter which reflected the productivity of a site (Lugo, 1992). It is also believed by many that exotics such as the blue mahoe, may poison the soil so that understory vegetation does not grow well (Zobel et al., 1987; Strand, 1996). It could also be a result of overdensity and shading out of understory growth especially in Vermont plantations where densities are higher than others. Proper management of stand density may allow for understory to grow which in turn may help reduce erosion as well as increase the size of the timber yield (Zobel et al., 1987).

In St. Vincent, the effects of silvicultural management on the growth of blue mahoe is not well documented. Stand density was not consistent throughout the study area ranging from 334 to 1,250 stems ha^{-1}. These stand densities were similar to those found in Puerto Rico which ranged from 400 and 1,200 stems ha^{-1} (Francis and Weaver, 1988). There were no significant differences in tree growth among St. Vincent reserves despite the range in stand density. However, it is suspected that silvicultural management may have influenced the relationship between soil-site conditions and growth characteristics of the studied blue mahoe plantations. Other studies have found that spacing and thinning practices in exotic tree stands affected height, diameter at breast height, form, current annual increment, and mean tree volume (Zobel et al., 1984).

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Despite the lack of significant differences in blue mahoe growth among the reserves there appeared to be a complex association of "positive" and "negative" variables that allowed the growth to remain consistent on St. Vincent. Consequently to accurately use soil and litter nutrients to predict growth, factors such as moisture stress, year to year variation in nutrient uptake, competition effects, genetic variation among planted seedlings, and silvicultural management must be taken into account. Although not all of these factors could be controlled during the study, efforts were made to control as many as possible. As a result, there were several conclusions that could be made about the characteristics of blue mahoe plantations on St. Vincent.

- There were no differences in tree size characteristics or growth rates of blue mahoe among the Hermitage, Montreal, and Vermont reserves;

- The growth rates of blue mahoe were similar to other blue mahoe plantations in the Caribbean and Hawaii;

- No single soil-site factor was related to mean annual diameter increment and mean annual height increment based on multiple regression analyses, but basal area and volume were associated with the Mn content of the litter layer.

- The average litter mass accumulations for Hermitage, Montreal, and Vermont reserves were 8.1 Mg ha^{-1}, 8.6 Mg ha^{-1}, and 9.1 Mg ha^{-1}, respectively. The litter mass was dominated by the miscellaneous fragments followed by blue mahoe leaves, fine wood, and other species leaves;

- N, P, K, Mg, and Ca concentrations were similar for all four litter components.

- Soil (Ah) variables that were significantly different among the reserves included: pH, soil organic matter content, electrical conductivity, extractable P, K, Ca, Mg, Fe, Mn, and CEC . The four significantly different soil variables in the AB horizon included: pH, electrical conductivity, Al, and Mn.

There were no indications of nutrient deficiencies (except possibly Mn at some sites) or excesses in St. Vincent blue mahoe plantations nor were there any signs of allelopathic effects. The concept that blue mahoe are an especially high nutrient demanding tree is likely true due to its rapid growth rate. However, Andisols are well suited for blue mahoe forest plantations because they are generally well drained, provide ample rooting depth, and have an adequate water holding capacity. The natural fertility is high and is maintained by the release of bases and other nutrients during weathering of volcanic ashes.

7.2 MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

The findings of this research may have management implications if blue mahoe are harvested from plantations. While this study provides some baseline information on soil-site conditions, individual plantations should be reviewed prior to intensive harvesting or implementation of management techniques. In addition, these are some recommendations that may be considered:

- The nutrients in the litter and the accumulated litter on the forest floor were considered to be large in comparison to the available and extractable nutrients in the mineral soil. The litter is an important nutrient reservoir and should be conserved during implementation of silvicultural practices. The litter also reduces soil erosion and may provide essential nutrients for a second tree crop.

- Blue mahoe on slopes >15° and within 50 m of water catchment facilities, streams or rivers should not be thinned or harvested to prevent soil erosion and siltation of water supplies.

- The Forestry Division needs to maintain their efforts in proper thinning of blue mahoe stands to provide quality timber, if they wish to market this product.

- As stands age productivity declines, trees become vulnerable to attack from pests and pathogens. With the recent invasion of the pink mealy bug, the Forestry Division should watch for any indications that older stands of blue mahoe could be more susceptible to infestation. If this is the case, more intensive silvicultural management may be needed in these areas.

- The Forestry Division should continue to experiment with different species and varieties as well as native species to maximize efficient use of soil resources.

Harvesting is the most expensive component of all the forestry operations and careful planning and management is required if it is to be cost effective. Since transportation forms a major component of harvesting cost, it is clear that plantations should be as close as possible to the processing site. Since the main purpose of the plantations were for soil and water conservation, many are inaccessible and would not be feasible to harvest. In some blue mahoe plantations, it would be more practical to encourage secondary succession and focus intensive management on more accessible sites that are productive and manageable.

7.3 FUTURE RESEARCH

Additional studies are needed in St. Vincent to determine the long-term effects of various tree species on soil characteristics. Given the same environmental conditions and management history, the nutrient recycling characteristics of a species could be an important selection criteria. Certain species may be more suitable for soil and water conservation, reclamation of agricultural lands, or the production of timber. The Caribbean pine appeared to grow quite successfully in St. Vincent and should be evaluated more closely. The soil characteristics beneath the Caribbean pine stands were considerably different than those found under blue mahoe stands.

The understory composition and "function" should be evaluated in blue mahoe stands because of such factors as N-fixing nodules (legumes) or Ca "pumps" which may have significant implications on the success or failure of a tree crop. In addition, studies on St. Vincent blue mahoe should carefully evaluate the importance of Mn in is growth cycle, perhaps through fertilization trials (manganese sulfate or manganese oxide mixed with fertilizer).

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