THE UNIVERSITY OF CALGARY

Soil Erosion and Nutrient Dynamics in Tropical Mahogany (*Swietenia macrophylla*) and Acacia (*Acacia mangium*) Forest Plantations of the Caratal Watershed, St.Vincent, West Indies

by

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ABSTRACT

A soil erosion/nutrient dynamics study was conducted in the Perseverance sub-basin of the Caratel Watershed, located on St.Vincent, West Indies. The goal of the study was to quantify the amount of runoff, sediment and nutrients lost in a mahogany and acacia plantation (both eight years of age). From this, conclusions regarding the effectiveness of the plantations at stabilizing former agricultural land can be drawn. Farmers are relocated The effect of under story clearing on runoff, sediment loss and nutrient loss also was determined.

Erosion plots and modified Gerlach Troughs were used to demonstrate that sediment loss was 2.8 greater in the acacia plantation and runoff was 0.66 times greater in the mahogany plantation. Nutrient loss with sediment was greater in the acacia plantation while nutrient loss as runoff was greater in the mahogany plantation. It also was determined that the nutrient balance of both plantations may be in a degrading state. Understory clearing resulted in a 6.1 times increase in runoff, a 3.7 times increase in sediment loss and an increase in nutrient loss of 60%.

Rainsplash erosion was the dominant erosive force in the acacia plantation and overland flow erosion in the mahogany plantation. Controlling the types of erosion were the differences in vegetation, namely tree heights and grasses and the soils aggregate stability.

DEDICATION

This thesis is dedicated to my family: Mom, Dad, Donna, Diana, Kevin, Zachary and Zoe for supporting me in so many ways. Thank You.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The forests of small islands are vital for protecting both the soil and water resources. However, economic pressures have caused expansion of agriculture into unsuitable areas leading to soil erosion, decreased soil productivity through nutrient loss, sedimentation of rivers, lakes and reservoirs and the degradation of coral reefs. The use of agrochemicals has also risen, leading to contamination of streams that are used for drinking water.

Since the time of colonization St. Vincent has developed an economy strongly dependent on monocrop agriculture. This has included sugarcane, arrowroot, cotton and now bananas, which are the most prized export on St.Vincent. Expansion of banana cultivation soared in the 1980's with parts of one watershed going from zero cultivation in 1981 to 55% by 1992 (Reid Collins, 1994). Bananas cover more arable land than any other crop and employ upwards of 60% of the agricultural work force, they also account for 50% of all merchandise exports (World Almanac, 1998). In 1988, 90% of all exports were agricultural in nature, however this has changed; in 1993 tourism surpassed bananas as the chief source of foreign exchange (Europa, 1988 ; World Almanac, 1998).

The growth of the banana industry has resulted in expansion of cultivation into unsuitable areas, namely on steep mountain slopes and adjacent to streams. This is cause of several problems, including soil erosion, stream siltation and pollution. In 1912 the government evoked a proclamation which established a 1000 foot crown land line. The purpose of this line was to ensure no agriculture threatened water resources, which are vital to the small island. However, expansion of bananas to higher elevations has resulted in areas of primary and secondary rain forest being cleared. Thereby threatening biodiversity and pushing some species on to endangered species lists. The banana has been responsible for bringing a certain degree of prosperity to St. Vincent but the future may not hold such good fortune.

In the past the banana market has been protected through an agreement (The Lome Convention) which ensures all bananas produced In St. Vincent and the Windward Islands will be exclusively exported to Britain. However, this is changing with the actions of the WTO (World Trade Organization) who deemed the agreement with Britain, as undemocratic. Plans to completely open the market in the year 2002 to other banana exporting countries able to produce a cheaper product will leave St.Vincent in a economically dangerous situation. The initial results of these plans currently are being seen on St.Vincent. Banana prices have dropped and it is speculated that if this trend continues more farmers will abandon land used for banana cultivation or expand cultivation in order to compensate for the drop in prices. Either situation leaves St.Vincent's Department of Forestry with the task of maintaining the 1000 foot crown land line. The potential for large scale banana land abandonment leaves the St. Vincent forestry department faced with the problem of deciding what should be done with this land.

With aid of CIDA (Canadian International Development Agency) through 1989-1994, St. Vincent was able to invest in and develop their forestry department. Considerable effort was placed on establishing a workable National Forestry Management Plan that was specifically suited for the situation on St. Vincent. Included in this plan is the function of plantation forests in the islands management plans. The application of plantation forests is multipurpose, depending on such factors as site conditions and species. However, the prominent use is environmental, not economical. Considerable effort has been made to maintain the plantation program, with a local nursery producing seedling and a continuous maintenance program for existing plantations. It has been concluded that the use of plantations will continue and expand, they are seen as a valuable and intricate part of St.Vincent's future. Personal observation indicate a sincere dedication by forestry staff to the protection of the island's forests and maintaining a high degree of professionalism.

1.2 STATEMENT OF PROBLEM AND RATIONALE

The St.Vincent goverment proclamation of 1912 was meant to protect all land above 1000 feet; unfortunately, due to the lack of enforcement, agriculture has encroached into primary and secondary rain forests and extended "branches" above 1000 feet. (Anderson, 1992). These expansions occur with the farmers' desire to maximize earnings through banana cultivation while the prices are favorable. Furthermore, farmers who once grew other crops switched to bananas, thereby requiring additional land. The impact of expansion has been constant and increasing soil erosion on St.Vincent caused by the removal of natural vegetation and cultivation of crops on steep slopes. This extended agriculture also is taking place in direct proximity to streams, which are used as a source of drinking water.

The steep nature of St.Vincent's topography combined with the replacement of natural forest with crops, namely bananas, has led to several soil and water quality related problems. These include the erosion of topsoil, loss of soil nutrients (i.e.: soil fertility), sedimentation of streams and water supply contamination by agrochemicals, silts, and clays (CCA, 1991).

For several decades, but more so recently, the quality of water on St.Vincent has come under increasing pressure from stream encroachment by agriculture and the use of agrochemicals. A lack of government control and regulations regarding the application of these agrochemicals poses a serious threat to St.Vincent's water supply. Expansion of agriculture directly adjacent to streams with no riparian buffer zones has resulted in agrochemicals entering streams with runoff and contaminating drinking water. Agrochemicals including chromium, copper, phosphates, nitrates and cyanide enter streams where they become down stream pollutants endangering human health. In a continuous cycle, farmers add more agrochemicals in order to regain productivity lost by soil erosion. An area where this has occurred is in the Perseverance catchment area, located in the Caratal watershed.

One response to this dilemma has been the relocation of farmers by the St.Vincent Department of Forestry in conjunction with the Central Water and Sewage Authority (CWSA) to more suitable areas. However, this solution gives rise to another problem; land left in an unstable condition on steep slopes, combined with the erodible nature of the soil results in abandoned land being susceptible to degradation. This degradation has been countered through the establishment of forest plantations which are thought to stabilize the slopes and decrease erosion. The Department of Forestry currently maintains test plots in an attempt to assess several species biological performances but little attention has been given to their ability to reclaim degraded lands.

Two tree species currently being used for reclamation are mahogany (*Sweitenia macrophylla*) and acacia (*Acacia mangium*). It is around these two species that this thesis is focused, since little is known about their performances in reclamation and conservation on St. Vincent.

The plantations established to reclaim agricultural lands also have been questioned as to nutrient sustainability. Once the natural forest cover is removed for agriculture, the existing nutrient cycles are severely disrupted and the growing and removal of crops further increases nutrients lost. By establishing plantations it is hoped that a "natural" or near natural cycle be achieved. However, it should be kept in mind that nutrient loss is a natural phenomena and "losses" may be off set by input from other sources. Therefore, nutrient loss is only relative when compared to these inputs. The concern is that if nutrient output is not being off set by input, then the plantation may be degrading and therefore unstable.

Further concerns include the plantation management techniques used in the mahogany plantation. Once established, mahogany plantations have their under story cut annually to reduce competition from grasses and shrubs for soil nutrients, water and light. This practice benefits seedlings which are easily overtaken by faster growing grasses. However, under story clearing continues even after the mahogany trees are well established and appears to result in higher amounts of runoff and soil erosion due to the removal of the protective under story grasses and the litter the grasses produces.

1.3 STUDY OBJECTIVES

This research study is focused upon the use of forest plantations as a means of soil reclamation, erosion protection and nutrient conservation on the island nation of St.Vincent and the Grenadines. Specific objectives of the study include:

1) To numerically quantify and compare the effectiveness of *Swietenia macrophylla* and *Acacia mangium* at controlling runoff , soil erosion, and nutrient loss.

2) To evaluate the management technique of clearing the understory in the mahogany plantation on runoff, soil erosion, and nutrient loss.

3) To gain insight into the nutrient dynamics of *Swietenia macrophylla* and *Acacia mangium* plantations.

4) To assess each species overall performance regarding soil reclamation and to make recommendations to the St.Vincent Forestry Department based on the study's conclusions.

1.4 PREVIOUS RESEARCH

The use of tropical forest plantations for reclamation purposes has been studied by several researchers. Gonzalez and Fisher (1994) showed that *Acacia mangium* had the highest growth rates on abandoned pasture in Costa Rica. Parrotta (1992) had a more biological approach and showed that plantations accelerated biomass and nutrient accretions at greater rates then natural forest control sites. From a more physical aspect, Brandt (1988) was able to demonstrate that soils under forests were susceptible to erosion due to the presence of high tree canopies affecting raindrop size. Wiersum, (1983) worked in a *Acacia auriculiforis* plantation, in Indonesia, attempting to quantify soil erosion and to determine what component of the vegetation structure was responsible for minimizing soil erosion. He resolved that the most important factors in protecting the soil were the presence of a direct soil cover and an overall proper functioning of the forest ecosystem and not the trees themselves.

The problem of soil erosion on St.Vincent has been noted and studied by several researchers (Watson, 1958; Ahmad, 1981 and Limbird, 1992). However, only two studies exist in which the subject has been approached quantitatively. Ciccaglione (1998) studied soil erosion in banana plantations on different slopes. Strand (1996) compared rates of erosion under blue mahoe plantations and secondary forests, and concluded secondary forests and blue mahoe plantations had very similar total runoff, but a greater amount of sediment loss occurred in the blue mahoe plantations. Total nutrient loss as C.E.C. also was shown to be higher in the blue mahoe plantations. However, even though secondary forests may be better at controlling erosion than blue mahoe plantations there are arguments for and against using them.

Natural regeneration of secondary forest is considerably cheaper than establishing plantations. No seedling nurseries, planting or maintenance costs exist with natural regeneration. Secondary forests also increase the land base available to wildlife and act as a buffer between primary forest and agriculture. Alternatively, plantations when properly managed, initially have higher rates of productivity and can be harvested, producing timber for local consumption (Lugo, 1988). Lugo also demonstrated that natural forests had more roots, greater root biomass in micro sites and quicker nutrient turnover than small unmanaged mahogany and Caribbean pine plantations, both of which are used extensively on St.Vincent. Of consideration is the reason plantations are established; if the sole purpose is soil and water conservation, then there will few direct economic returns and the costs of planting and maintenance will not be recovered (Jordan et al., 1982). Since St. Vincent's primary concern is soil and water conservation they can expect little economic return unless the plantations are harvested. Nonetheless, if degraded natural resources lead to a decreased standard of living, then not only does soil erosion become an issue of economics, but a negative influence to all aspects of life. Other drawbacks of natural regeneration include the perception of forests held by farmers. Forested land is seen as unproductive land and farmers have little problem with clearing it when agricultural land is needed. In contrast, plantations are respected by farmers; this respect may be due to fear of prosecution by the authorities or the realization that there are potentially beneficial uses for them. If plantations are chosen for reclamation, the question is which species should be used.

It has been demonstrated (Lugo et al., 1990) that not all species are efficient at improving the nutrient status of degraded soils. Nutrient cycling strategies of individual species can make a significant difference to nutrient accumulation and availability. Therefore, selection criteria should include research into how the existing environmental conditions will enhance the performance of species.

It is the intent of this thesis to contribute information regarding soil erosion and nutrient loss from plantations of mahogany and acacia, not only to the existing body of knowledge gained from the two previous studies done on St.Vincent, but also to apply the information to other tropical regions which are using the same tree species in plantations.

1.4.1 MAHOGANY AND ACACIA (History and Ecology)

The choice of the St.Vincent Department of Forestry to use mahogany and acacia is influenced for differing reasons since they are two strikingly different species. Firstly, the mahogany is a species that originated in Central America, northern South America and the Caribbean. It resides in the family Meliaceae and within the genus Swietenia, of which there are seven or eight species (Morton, 1987). Two of these species, *Swietenia mahagoni* and *Swietenia macrophylla* are located on St.Vincent, of which macrophylla is the more widely used. *Sweitenia macrophylla* can exceed 30m. in height and 1.5m. in diameter when grown under the optimal conditions of the tropical dry forest, based on Holdridge's system (Holdridge, 1967). These conditions include a mean annual temperature of 24°C and yearly precipitation between 1000 mm and 2000 mm with a marked dry season (Lamb, 1966). However, optimal conditions can vary depending on where in its range mahogany is found and this may explain the high degree of phenotypic "plasticity" found within the species.

Suitable soil conditions vary from deep poorly drained acid clays to well drained alkaline limestone soils, but the optimal soil is deep well drained fertile soils that maintain a abundant supply of moisture year around. It is classified as a pioneer species that is shade intolerant; therefore, it is often found on disturbed sites in full sunlight. The tree can be identified easily at a distance by its dark green, glossy, leathery leaves, these characteristics were used to locate the tree by mahogany hunters in the early part of this century (Lamb, 1966). In general, the wood is reddish to yellowish, with a deep brown luster growing as it ages. The texture can vary greatly from fine to coarse with an array of grain patterns, resulting in an attractive wood. These desired qualities initiated the mahogany trade, which began as early as 1514 with the Spaniards and spread to the English and North America. Mahogany is recognized by many craftsmen to be the most workable of woods. Unfortunately, due to intensive logging of the past, future stocks of mahogany are threatened. The genetic diversity has decreased substantially, leading to a biological bottleneck or a low degree of genetic variability (Lamb, 1966).

In contrast to the mahogany, *Acacia mangium* is considerably different in both biology and history. The origins of *Acacia mangium* are in northeastern Australia, Papua New Guinea and eastern Indonesia and *mangium* is only one of approximately 1100 species in the genus *Acacia,* family Mimosoidae (Salvator, 1997). Most of these species are small trees or shrubs adapted to arid regions, but some can be found in cooler moister areas at higher elevation and a few are distributed on the lowland wet tropics. *Mangium* is a straight growing tree that reaches heights of 30m and diameters up to 90 cm. Up to half the bore can be free of branches, the result of a "self pruning" mechanism (Ruskin, 1984). The height of the plantations on St.Vincent are low in comparison to other locations, such as sites in Bangladesh where heights of 8m were obtained in 2 years.

Naturally *Acacia mangium* is found at elevations below 100m but some stands are located at 450m. It is not found in mature rain forest as mahogany is, but instead on the fringes of mangroves and riverine forests grading into grasslands (Salvator, 1997). They normally do not exist in large stands and are considered a pioneer species since they are found along train tracks, road sides and other disturbed sites where there is high sunlight. The tree does best in temperatures with maximums around 31°-34° and minimums of 12°-16°; it prefers wetter climates with precipitation as high 4400 mm annually (Ruskin, 1984). It does not do well with extended dry periods, which should be considered since some areas of lower elevation on St.Vincent have a long dry period.

Mangium can grow on a wide range of soil types including alluvial, rocky eroded, deeply weathered or thin mineral soils. Taxonomically speaking, it is found on ultisols, entisols, oxisols and andosols. A characteristic that enhances *mangium's* already impressive qualities is its ability to fix atmospheric nitrogen. In symbiosis with the bacterial genus *Rhizobium*, *mangium* provides itself with sufficient nitrogen as not to need fertilizer. In some areas it also has been shown to be in symbiosis with the fungi *Thelephora ramariodes* which increases its ability to take up micro and macro nutrients, especially phosphorus (Ruskin, 1984). It is unknown if this fungus is present in Vincention soils, but based on the fact that andosols are notoriously low in phosphorus and the impressive performance of the trees, it might be surmised that this fungus or one that performs the equivalent role exists on St.Vincent. The wood properties of *mangium* include a specific gravity as high as 0.56 (weight/volume), in comparison to *Swietenia macrophylla* between 0.43 to 0.61 (Ruskin 1984 ; Lamb, 1966). It has a medium brown coloured, hard, strong and durable heartwood, that is useful as furniture, light-duty construction material, particle board and fuel wood. It also is seen as a species good at battling deforestation due to its fast growth and decreasing soil erosion because of its high foliage output (Salvator, 1997). Overall, the choice of species by the Department of Forestry in regards to site suitability, appears to be sound except for the differences in the two species annual rain distribution requirements. The acacia preferring a short dry season with more rain and the mahogany preferring less rain with a distinct dry season.

1.4.2 ANDOSOLS AND FORESTRY

Soils of the ando group are distributed around the world, at high and low latitudes and under a wide range of climatic conditions. Most commonly though they are found in the vicinity of volcanoes; this association is based on the volcanic parent material. A wide array of various plant communities can be found on andosols, including forest communities. The conditions that forested andosols develop under vary greatly and therefore there is diversity in the properties of the soils. In general though, soils of the andosolic group are believed to have suitable properties for forestry. Considerable research has been done on forestry and the andosols of U.S Pacific

Northwest. Site/soil productivity for tree plantations in this area have proven to be acceptable for regeneration, due to several key characteristics of andosols.

Soil water holding capacity and the availability of this water to vegetation is a limiting factor to tree growth. Some general physical properties of andosols are high porosity and water holding capacity. These soils may have only a third to a half the volume of solids but twice the volume of water/100cm^3 compared to soils derived from clay minerals. This unique quality is determined by the size distribution of voids, not by the amount of surface area (Maeda et al., 1977) and their macrostructure which is commonly granular with aggregate sizes in the area of 0.25 mm (Shoji et al., 1978). High water holding capacity would be particularly beneficial in wet tropical areas where there is high air temperature and large leaf area, which combined induce high evapotransporation rates. Andosols that are freely drained are also able to supply more water to plants than other soils. Soil that loses water through evaporation or plant uptake will have this water replaced quicker in an andosol than in other soils. Overall, they have a higher available water capacity; the limits of hydroscopic water are not reached as readily as in other soils (Maeda et al., 1977)

Organic matter accumulation is a characteristic that has positive effects on plant growth; it is composed of numerous plant nutrients and has a positive relationship with total C.E.C. Andosols in Japan have been shown to have 7.6% to as high as 40.3% organic matter, with A horizons in excess of 100 cm depth. Organic matter accumulation in andosols is related to the degree that the soil has weathered as evidenced by the change to finer texture, the amount of above ground biomass, increases in sesquioxides and intensification in the allophanic character of the clay (Egawa, 1977). These levels are initially high as a result of the early weathering of parent material which releases high amounts of plant nutrients (Egawa, 1977). Grasses are the first form of vegetation that colonize areas of recent ash deposits and they promote high organic matter contents. It also is believed the allophane and the sequioxides present in andosols have a catalytic reaction which stabilizes organic matter against further decomposition, at which point it could be lost from the soil (Meuriss, 1976). The transition of land from grasses to trees, whether it be natural or not, may result in decreases in soil productivity. Once the input from grasses decreases and trees become dominant, their uptake of organic matter may not be off set by inputs. This could be an important variable in the long term management of andosols.

Furthering their suitability for forestry is andosol's capacity at retaining high amounts of cations, anions and other plant nutrients. This suitability is primarily related to the high organic matter content but also to the presence of allophane and its weathering products. Allophane has a large surface area with a negative or positive charge which is dependent on pH. When under favorable pH conditions andosols are capable of absorbing high amounts of anions and cations (Tan, 1984) A draw back to an andosols productivity is the potential for phorphorus fixation. This element is commonly the limiting element when growing crops or trees on andosols (Visser, 1989) Even when fertilized, only approximately 10% of the phosphorus is able to be utilized by the vegetation. There has also been some concern over the leaching of nutrients from andosols after harvesting due to their coarse texture. Several studies have indicated nutrient loss, but most show andosols can retain nutrients owing to the vesicular nature of their pore spaces which causes a retention of soil solution (Meurisse, 1976).

In general, most studies and researchers state that andosols are a soil of medium to high fertility (Egawa 1977 ; Tan 1965 ; Frie, 1978 and Shoji and Ono, 1978). On St.Vincent this may be expressed through the growth rate of the acacia which are only slightly slower than some of the fastest grown acacias.

1.4.3 BIOCIDE/AGROCHEMICAL USE ON ST.VINCENT

Biocides are used over most of St.Vincent to increase crop productivity, but mostly in bananas (Grossman, 1992). However, there is little quantitative data on the effects of pesticides and herbicides on the aquatic and terrestrial life on St.Vincent. There is also little effective control over the use of these chemicals and minimal efforts are made by industry or government to educate farmers regarding application rates, storage or disposal. Biocides listed as restricted or cancelled in other countries because of the detrimental effects to humans are still in use on St.Vincent. The extent of biocide use on St.Vincent is not known since only half the importers of the chemicals, responded to a 1989 survey attempting to measure amounts imported (Reid Collins, 1994).

Biocides normally are stored in small sheds and are applied with spray applicators carried on the backs of farm workers who wear no protective clothing or breathing apparatus. Commonly, the disposal of containers involves simply leaving them on the ground, burying them or throwing them in streams. These practices which are a result of a lack of knowledge, are dangerous to soil and water resources and potentially to entire ecosystems.

The application of biocides at uncontrolled rates, directly adjacent to streams and on steep lands draining directly into water intakes, is a serious threat to human health, as many are known carcinogens. These applications occur throughout the wet season when runoff is highest, therefore transporting a greater portion of the applied chemicals (CCA, 1991). Fertilizers, such as nitrates and phosphates also are applied; these enter streams where they cause algae bloom and general eutrophication.

Commonly used biocides include Gramozone, Mocap, Furadan, Vydate and Calyxin. Farmers and government workers have noted the effects of these chemicals through decreases in fish and crustacean populations downstream from cultivated land. There is also evidence suggesting the direct application of biocides into streams in order to collect fish at certain times of the year when aquatic populations increase (Reid Collins, 1994).

The major effects of the indiscriminate application of biocides include:

- Contamination of surface and ground water used for drinking and the consequent effects on human health
- Pollution of surface waters and the resulting toxicity to aquatic and terrestrial biomes, including the marine environment
- Potential contamination of crops and effects on marketability due to consumer perception

- Increased soil erosion and sedimentation due to the removal of ground cover (Reid Collins, 1994).

This problem can be controlled in part through education. Agricultural extension agents need to train farmers regarding the safe use of biocides and the Forestry Division must continue to relocate or stop farmers from encroaching next to streams. However, the use of biocides is a very complex problem with numerous political and social factors at both the local and international level affecting it (Grossman, 1992).

CHAPTER 2

STUDY AREA

2.1 INTRODUCTION

St.Vincent and the Grenadines is an island group located in the Windward Islands which make up the southern reach of the Lesser Antilles in the southeastern Caribbean. The country is composed of over 30 small cays and islets, which extend for 70km in a south- southwest direction from the main island of St.Vincent (Figure 2.1). The island chain covers approximately 389 sq. km with the main island of St.Vincent making up 344 square km. St. Vincent proper lies between 13°10′ N and 13°20′ N and 61°15′ W and 61°05′ W (Figure 2.1). The Atlantic Ocean bounds it to the east and the Caribbean Sea to the west. St. Vincent, at its longest axis points, is roughly 29 km in length and 18 km in width. Surrounding nations include St. Lucia 40 km to the north, Grenada 110 km to the south and Barbados 160 km to the east.

St. Vincent and the Grenadines is a relatively young nation, in that it attained complete political autonomy from the British West Indies in 1979, up until which point it had associate statehood status (World Almanac, 1998). It has a parliamentary democracy and is an independent state within the Commonwealth. Despite its young political age, St. Vincent is rich in history, dating back thousands of years to the Arawak Indians and then more recently to the Carib Indians.

The introduction of Africans by Europeans for slave labour on agricultural plantations dramatically changed the ethnicity of St. Vincent. This can be seen today with the

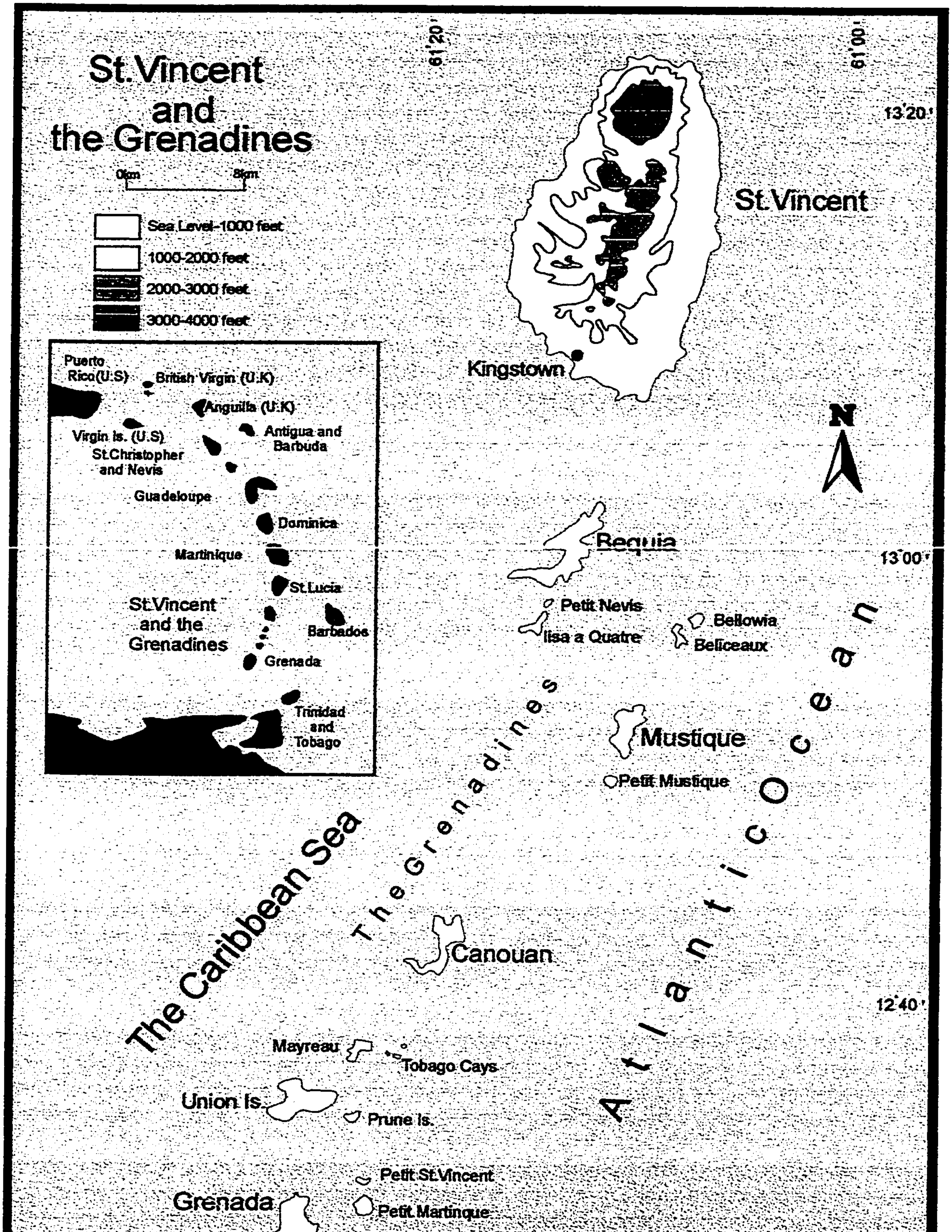

Figure 2.1 St. Vincent and the Grenadines (Modified from Ciccaglione, 1998).

greatest portion of the population being of African descent (66%) with smaller portions of mixed (19%), East Indian (6%), Carib Indian (2%) and a few descendents of white English colonists. (World Almanac, 1998) The total 1990 population was recorded at 113,000 with 104,000 Vincentians residing on St. Vincent proper. The majority of the population is concentrated near coastal areas and on the southwestern end of the island near the capital of Kingstown. The age distribution is heavily skewed with a large portion of the population below the age of 15 (CCA, 1991). The average life expectancy is 68 for males and 72 for females. Infant mortality currently stands at 17/1000. Religion is dominated by Anglican (47%), Methodist (28%) and Roman Catholic (13%), with small portions of Seventh Day Adventist and Hindu. The literacy level is somewhere between 85% and 98%, depending on which source is cited (C.C.A., 1991; World Almanac, 1998)

Sixty percent of the economy of St. Vincent is dependent on agriculture, with the major export markets in both European and other CARICOM (Caribbean Community) countries. Agriculture was the most productive sector of the economy and was the primary generator of foreign exchange until 1993, when tourism surpassed it. However, most tourism is in the Grenadines, where a market for wealthy foreign yachters has developed. The GNP was $275 million in 1987 (CCA, 1991) and it was unchanged for 1995 (World Almanac, 1998). It is unlikely this figure is correct for both dates, but with the recent decline in agriculture any growth has likely slowed. Outside of agriculture and tourism, plastic products, food processing, furniture, clothing, starch and cement all contribute to the economy.

A variety of root crops are grown including tannias, dasheens, yams, sweet potatoes and eddoes (CCA, 1991). At one time these crops contributed significantly to St. Vincent's exports, but with the decline in the economy of Trinidad, which was the main importer, there has been large decreases in exports. Now these crops are produced primarily for local consumption. Arrowroot once played an important role in St Vincent's economy but has been declining in importance since the 1950's. A factor limiting agriculture in St.Vincent is the lack of arable land. Due to the rugged topography of the island, agriculture is only possible on 40% of the land and much of this may not be sustainable under current land use practices. In the past, most agriculture existed on the gentler rolling coastal plains, but with the growth of the banana industry more land was needed. Therefore, crops were planted in steep narrow valleys on slopes inherently unstable for agriculture. The repercussions of this have been the loss of rain forest and accelerated soil erosion (CCA, 1991).

2.2 CLIMATE

The climate of St. Vincent is classified as humid tropical marine with little temperature variation either seasonally or diurnally. Major influences are the subtropical anticyclone belt and the inter-tropical convergence zone (ITCZ) or inter-tropical front (ITF). St. Vincent has a distinctive dry and wet season, which is the result of latitudinal movements of the ITCZ. From mid-December to early May there is a dry season at lower elevations and near the coast 70% of the 2000mm of precipitation falling during the remainder of the year (Watson, 1958). At higher elevations rainfall can vary between 3800mm and 6000mm with no pronounced dry season. Spatially, the windward side of the island receives roughly 10% more annual rainfall than the leeward (Reid Collins, 1994). The topography of St.Vincent is largely responsible for the local climate, with a high mountain range extending the length of its axis, thus forcing the moisture-laden trade winds of the Atlantic to rise. These winds blow predominantly from the east-northeast or east-southeast, shifting with movement of the ITCZ. The precipitation that occurs is orographic, with 500mm increases per 100m rise in elevation on the windward side and 700mm per 100m rise in elevation on the leeward (Reid Collins, 1994). This results in a concentric spatial distribution of rainfall (Fig.2.2). Mean temperature at sea level is 26.7^0C with very little variation seasonally or diurnally. Decreases in temperature occur as elevation increases with the potential of 12^0C decreases at the highest peaks. St.Vincent lies in the hurricane belt and has suffered several major storms, but these do not occur on a regular basis.

2.3 GEOLOGY/GEOMORPHOLOGY

St.Vincent is a relatively young island as is the entire Lesser Antillian arc of islands which extends 400 miles. The Lesser Antilles is separated into the Leeward Islands in the north and the Windward Islands in the south. The Lesser Antilles can also be divided on the age of the islands. The Limestone Caribbes are ancient low lying volcanic islands topped with limestone; the Volcanic Caribbes are younger in origin and higher in elevation. The formation of this arc occurred when the North American tectonic plate subducted under the Caribbean tectonic plate, causing magma to rise to the surface forming the Lesser Antilles, including St.Vincent (Tomblin, 1970).

Most studies place St.Vincent's formation in the Pleistocene, with the oldest rock dating back to

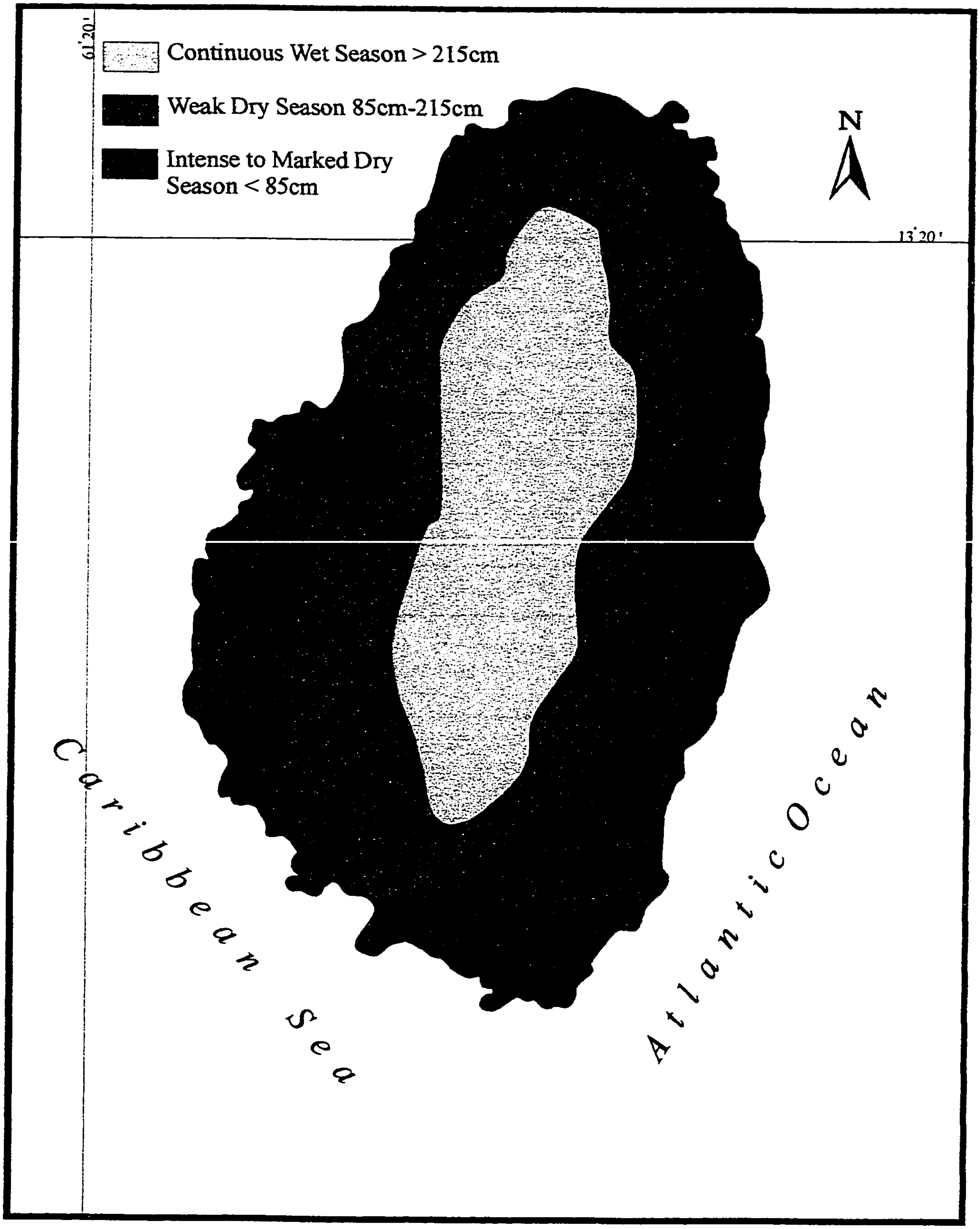

Figure 2.2 Major Precipitation Zones of St.Vincent (Modified from Watson, 1958).

the Eocene or Miocene (Maury, et al., 1990). The island has a relatively high proportion of lava flows to pyroclastic rock, with a predominance of basalt over andesite. St. Vincent is unique in the Lesser Antilles in that basalt is the pre-dominant rock. Other common rock types include a coarse agglomerate of basaltic to andesitic composition (Maury et al., 1990 ; Watson, 1958).

The physiographic structure of St. Vincent is centered around a rugged central mountain range running on a north-south axis. Heading in a northerly direction, the mountains of St. Vincent increase in elevation, with the highest peak being La Soufriere, a dormant conical shaped strato-volcano extending 1224m (4014ft). The volcano's crater is 1.6 km in diameter with a large lava dome at the center of the crater (Robson, 1965) (Figure 2.3). La Soufriere has experienced numerous periods of intense volcanic activity with witnessed and recorded episodes in 1718, 1812, 1902, 1971, and 1979. The result has been a blanket of pyroclastic material that covers 55% of the island, ranging in depth from an average of 6.0m to 12.0m on the south end of the island and increasing to a maximum of 36.0m on the north end of the island (Hay, 1959) (figure, 2.4). The 1902 eruption cost the lives of 1500 people on the north end of the island when hot ash (*nuee ardent*) poured down the windward side. La Soufriere also is responsible for the displacement of thousands of people who must be evacuated to the south end of the island whenever an eruption is looming. During the last eruption in 1979, no lives were lost, but 17 000 people were evacuated and agriculture crops was severely damaged. The central mountains decrease in age to the north, with older more highly eroded peaks such

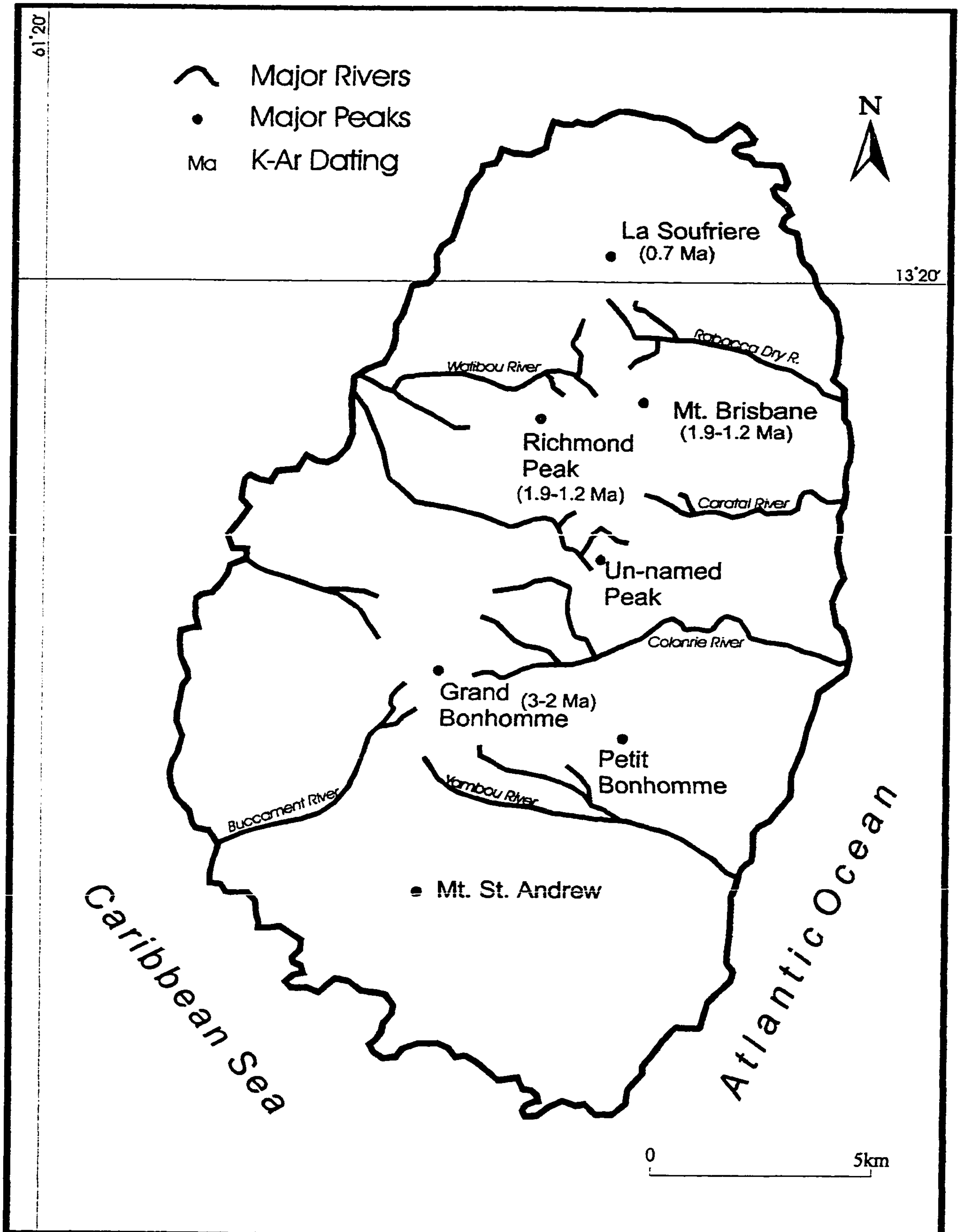

Figure 2.3: Major Peaks and Rivers of St.Vincent (modified from Ciccaglione, 1998).

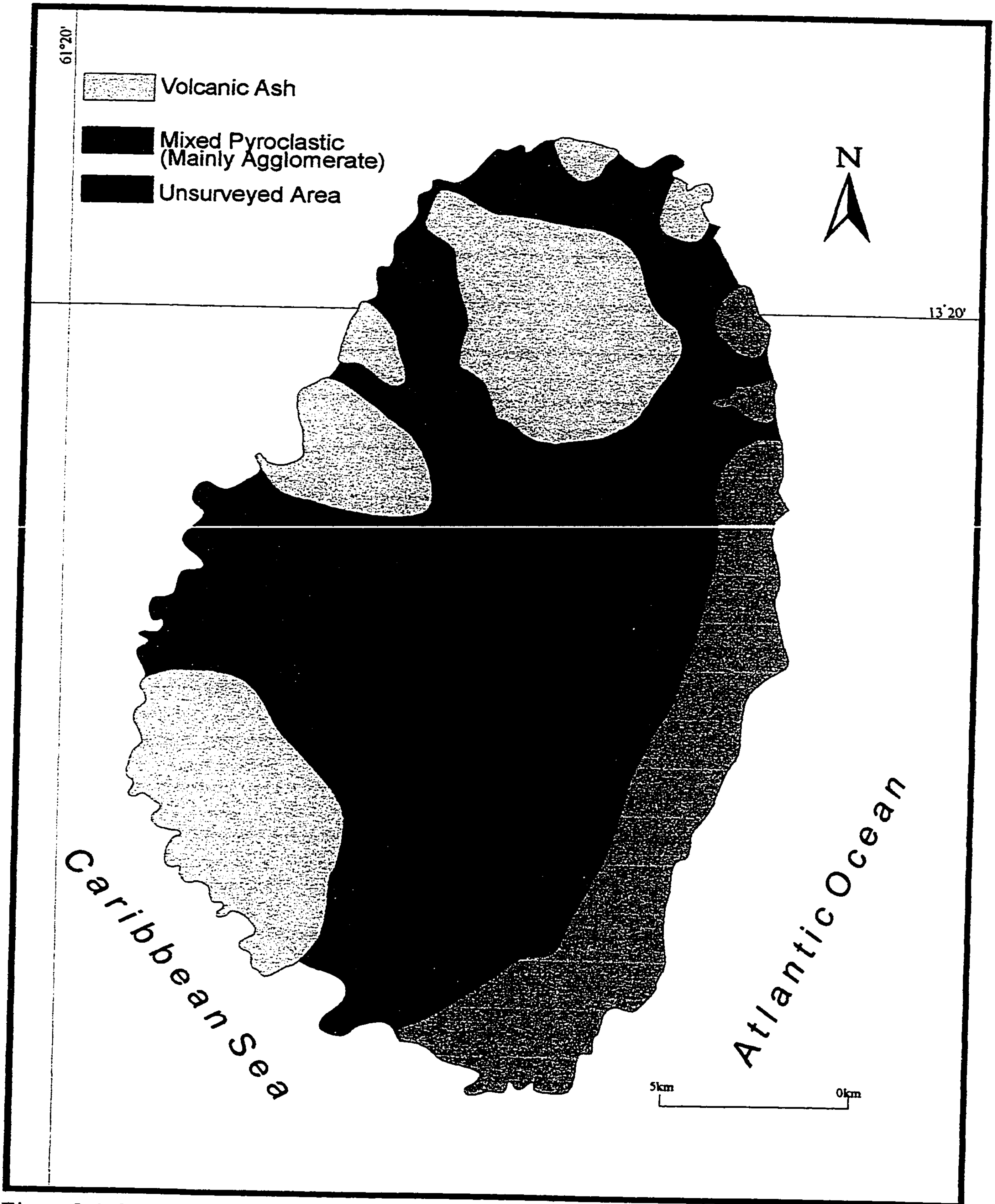

Figure 2.4: Surficial Material of St.Vincent (modified from C.C.A., 1991).

as Mt. St. Andrews (735m), Richmond Peak (1026m) and Grand Bonhomme (970m) located in the south (figure 2.3) All are of volcanic origin but few prominent craters exist. One crater that can be identified is the Mesopotamia Valley on the southeastern corner of the island, which has a high crater rim encircling it. Extending outward from the central mountain chain are long sharp ridges which reach down to the coastal plains on the windward side and drop off into the Caribbean sea on the leeward side. Between these ridges are steep valleys where numerous streams channel water out of the mountains to the ocean.

Stream gradient is high leaving the central mountain chain and therefore has cut down through the unconsolidated pyroclastic debris and agglomerates. Large boulders are left behind, strewn in and next to stream channels. Channel morphology is characteristically short, straight, steep and narrow, with no meanders at higher elevations. At lower elevations wider channels and slight meandering occur (Reid Collins, 1994). Drainage patterns are commonly radial, especially in the north where numerous streams flow down the flanks of La Soufriere. On the windward side alluvial fans are not formed by these streams because of the presence of strong ocean currents, high wave energy, low sediment load (during the dry season) and steep coastal shelves (Maury, 1990). A portion of St. Vincent's innumerable small streams are ephemeral, which is in part the result of coarse streambeds having a high infiltration capacity thereby requiring large quantities of water to saturate them. Hence the term "dry river" is used to describe the Rabacca Dry River, a major stream on the southeast flank of La Soufriere. Other prominent rivers include the Colonarie and Yambou on the windward side and the Cumberland, Wallilabou and Richmond on the leeward side (Fig.2.3).

The topography of the island is extremely rugged with steep slopes being the norm. Fifty percent of St.Vincent's land area is sloped greater than 30^0 and only 20% is less than 20^0 (Barker, 1981). Exposed on the eastern side of the island are a series of marine terraces, the result of tectonic tilting of the island. The leeward side has submerged and the windward side has emerged, with the last terrace coinciding with the melting of ice caps in the late Pleistocene (Ahmad, 1984). On the east side of the island these terraces have left a significant area of relatively flat to rolling land which appears to be the largest tract on the island. A further difference between the two sides of the island is the jagged peaks and ridges of the leeward in comparison to the more rounded features of the windward. The windward side has been subjected to the erosive forces of the northeasterly Trade winds causing a "smoother" topography.

2.4 VEGETATION/FOREST RESOURCES

Similar to the distribution of precipitation, vegetation is distributed in a concentric manner (Fig.2.5). Vegetation zones correspond to changes in precipitation and temperature, which are dependent on elevation. These zones are quite discernible upon ascent of the central mountain range. Beard (1949) thoroughly described the vegetation of the entire Lesser Antilles including St.Vincent; he originally described 6 vegetation zones on St. Vincent. It has been estimated that 67 percent of the forested land is covered with a combination of secondary forest, dry scrub and plantations, 21 percent by palm brake and elfin woodland, and 13 percent with primary forest (Birdsey et al., 1986).

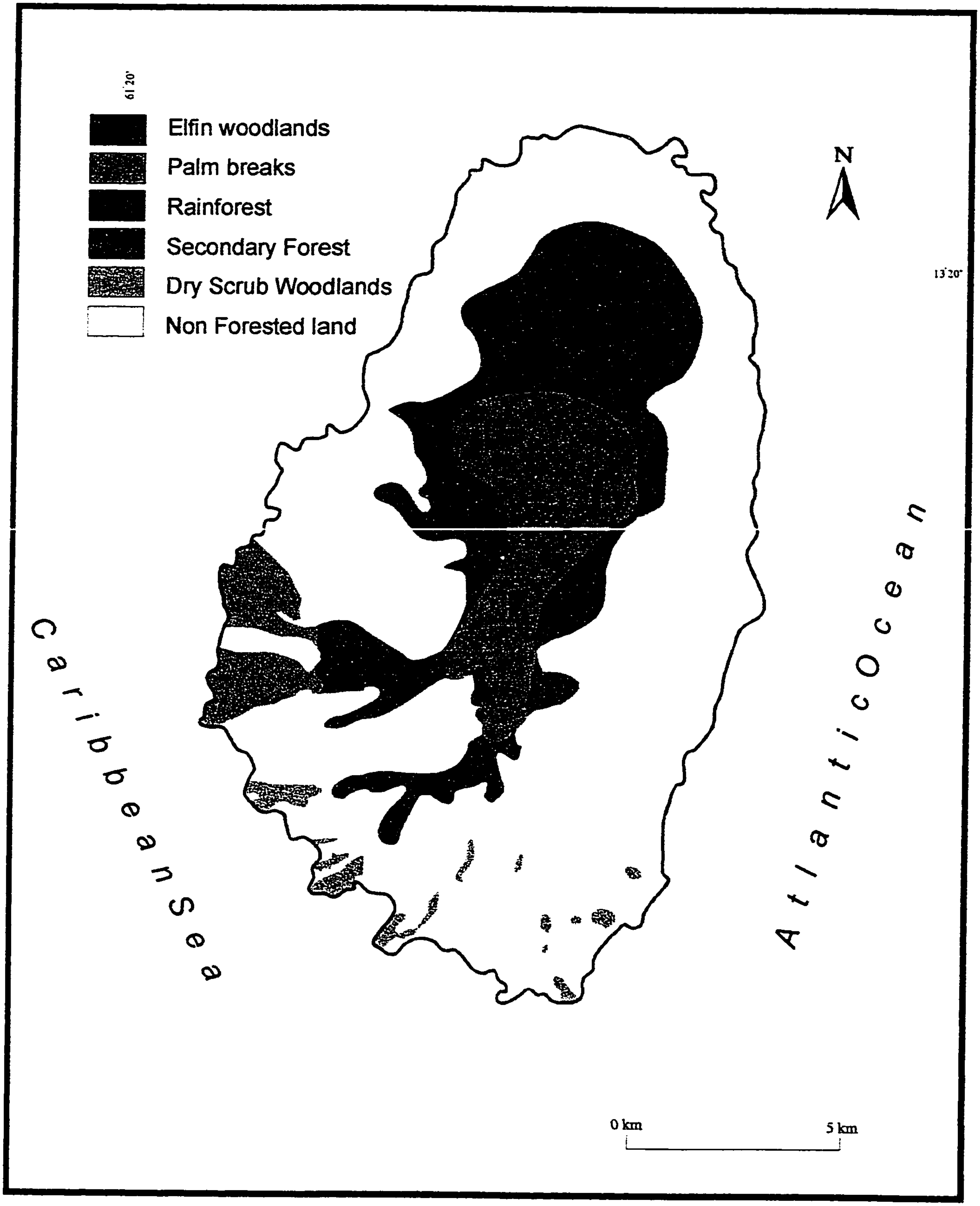

Figure 2.5: Vegetation Zones of St.Vincent (Modified from Ciccaglione, 1998).

Today, areas of primary rain forest exist only where cultivation has been impossible due to steep slopes. A belt of rain forest is located between 300m and 500m; below is either cultivation or secondary forest, and above is palm brake. The primary rain forest is on steep slopes and ridges, which are subject to slope failure and high wind speeds. The forest is similar to those found on Dominica and St. Kitts with dominant emergent species being Mountain cabbage (*Euterpe* spp.), Gommier (*Dacryodes excelsa*), Sweet wood (*Lauraaceae* spp.), and Wild cocoa (*Meliosma herbertii*) (Beard, 1949). The lower shrub and under story layers are sparse and relatively open. Above 500m and on exposed ridges the rain forest quickly grades into palm brake, which covers large areas of the central mountain system. The ecotone between palm brake and rain forest is patchy, with rain forest species clumped in amongst palms. The trees in the palm brake are covered in mosses, climbers and epiphytes. Higher on the windward side, the palm *Euterpe globosa* is dominant with twice the abundance than all other species combined. The next most common species is also a *Euterpe* spp. (Beard, 1949). However, this species is practically non-existent on the leeward side. On exposed ridges above 500m, set in a matrix of palm brake and at the highest elevations, areas of elfin woodland can be found. This forest consists of gnarled trees, generally not exceeding 4m in height, and is the result of lower temperatures and higher wind speeds.

On St.Vincent the term secondary rain forest applies to land disturbed by human activities or natural occurrences such as volcanic eruptions, hurricanes or landslides. This forest type can be found throughout the island whereever land was once used for agriculture, but usually between rain forest and cultivated land (Reid Collins, 1994). The greatest area of secondary forest is found on the flanks of La Soufriere where repetitive volcanic eruptions have halted and restarted succession. Species composition of secondary forest depends on the stage of succession of the plant community. Pioneer species such as tree ferns, *Heliconia* sp., Spanish ash and trumpet trees can be found here (Rodney, 1992). Species that indicate human occupation are mango (*Mangifera indica*) and breadfruit (*Artocarpus communis*) (Boag and Strand, 1993). In general, as they age, secondary forests species' compositions tend to shift to that found in primary rain forest.

The final prominent vegetation zone on St.Vincent is dry scrub woodlands/cactus scrub. This zone is found mainly in coastal patches on the leeward side and was heavily used as a wood source in the past. One reasonably preserved area is King's Hill Reserve in the southeast section of the island. Species include *Tabebuia pallida, Swietenia mahogoni, Brusera simarumba*, and *Hymenaea courbarril*. Ground vegetation is dense in parts and also commom are cacti scrub and bushes (Beard, 1949).

The terms primary and secondary forests on St.Vincent are somewhat ambiguous. It is unlikely that there are any forests on the island that have not been affected by hurricanes, volcanic eruptions or cultivation. Therefore, there actually are no true primary forests left. It is then a question of when does secondary forests qualify as primary forest? For classification purposes it is common to state any forest that has reached a "climax" stage is no longer secondary forest. This is not to say there are not differences in forest types; structural differences are notable. These differences include a decreased density of the under story and only 86stems/ha in the primary forest compared to 92stems/ha in the secondary forest. The average d.b.h is 39 cm in the secondary forest and 98 cm in the primary forest (Rodney, 1992). This variation is the result of the length of time since the last disturbance.

2.5 WATER RESOURCES

Surface water (i.e., streams and springs) constitutes the largest source of fresh water for human consumption and agricultural use on St.Vincent (CCA, 1991). Therefore, protecting and sustaining these resources are a vital matter. The agency responsible for collecting and coordinating all hydrological data on St.Vincent is the Central Water and Sewage Authority (CWSA). A new act has given the CWSA greater authority to enforce and protect water resources and, in conjunction with other government agencies such as the Forestry Division, this authority as been implemented.

Potable water supplies vary greatly, with approximately 6.2 million imperial gallons per day during the rainy season to 3.5 million during the driest period. Demands are met during the rainy season but during the dry season shortfalls of up to 50 percent can occur. Particularly in April and during extreme conditions, rations are necessary. There are 16 public potable water supply systems across St.Vincent, six are spring fed and the remaining 10 are derived from rivers. In addition, there are 7 emergency springs available. Combined, the Dalaway, Cumberland, Montreal and Majorca water catchments comprise 90 percent of the fresh water supply gathered from rivers (Fig.2.3). They collect 10,987, 6,359, 1,764 and 1,909 liters/min. respectively. Estimates of water loss through leakage are as high as 40 percent for water collected and piped from rivers. This is observable, as there are many visible leaks along water pipelines. Sixty percent of Vincentians have water piped directly to their homes, 25 percent obtain water from public standing pipes while the remainder collect water directly from streams and runoff mechanisms. Household chores such as laundry are also done directly in rivers and although few Vincentions admit to dumping garbage into rivers the visible evidence suggests otherwise (Anderson, 1992).

2.6 Soils

St.Vincent has soils which are dominated by the Andosolic Great Group. The agglomerate parent material is relatively constant across the island; therefore it is the time factor that has a great influence on soil development. Hardy (1938) separated the volcanic rock of St.Vincent into two groups: old accumulations at the southern part of the island and new accumulations at the northern part. This can be expected to have an influence on soil development; soils in the south are older, more highly weathered and compacted and contain more clay, while the opposite occurs in the north. Several soil surveys have been conducted on the island: Hardy in 1934, Watson in 1958 and Limbird in 1992. Hardy was the first to separate the islands soil into the 4 groups which are still used today: Yellow Earth soils, Recent Volcanic Ash soils, Shoal soil and Alluvial soils.

Yellow Earth soils are distinguished by their yellow brown color and good physical properties. Hardy (1938) further subdivided Yellow Earth soils into High Level Sedentary soils and Low Level Transported soils. The former are formed in situ at the top of slopes at high altitudes (>

600ft) and are the most acidic and deeply weathered soils on the island. The Low Level soil consists of erosional material transported to lower levels (<600ft) on gentler slopes (Hardy 1938). These soils are darker brown in color than yellowish High Level soils and are common on the southeastern portion of the island (Fig.2.6). The factors responsible for the color differences are the uplifting/tilting of the island and the concentric zonation of rainfall, each of which has caused and causes different water regimes (CCA, 1991).

Recent Volcanic Ash soils are young in age, with the pyroclastic parent material dating back to recent eruptions of La Soufriere. They are coarse in texture, highly permeable and grayish in color. The study site consists of these soils which are prolific on the northern half of the island where the greatest amount of volcanic fallout occurs (Fig. 2.6). Site (slope) and texture subdivide the soils. Soufriere Cindery Gravely Loamy Sand soil and its variants are located on gently sloping land, while the remainder of the soils are in more mountainous terrain. Due to their friable nature and loose consistency, they are especially prone to erosion on steeper slopes.

Shoal soils make up a relatively small portion of the land base, existing mainly on the coastal areas of the south and west portion of the island. The parent material is cemented agglomerate and lava. This leads to a shallow soil with a bouldery subsurface and a fine textured surface horizon. The surface, due to its high clay content, results in cracking during the dry season and extreme stickiness during the wet season. Cultivation on this soil is limited but it is still useful as pasture (CCA, 1991; Watson, 1958)

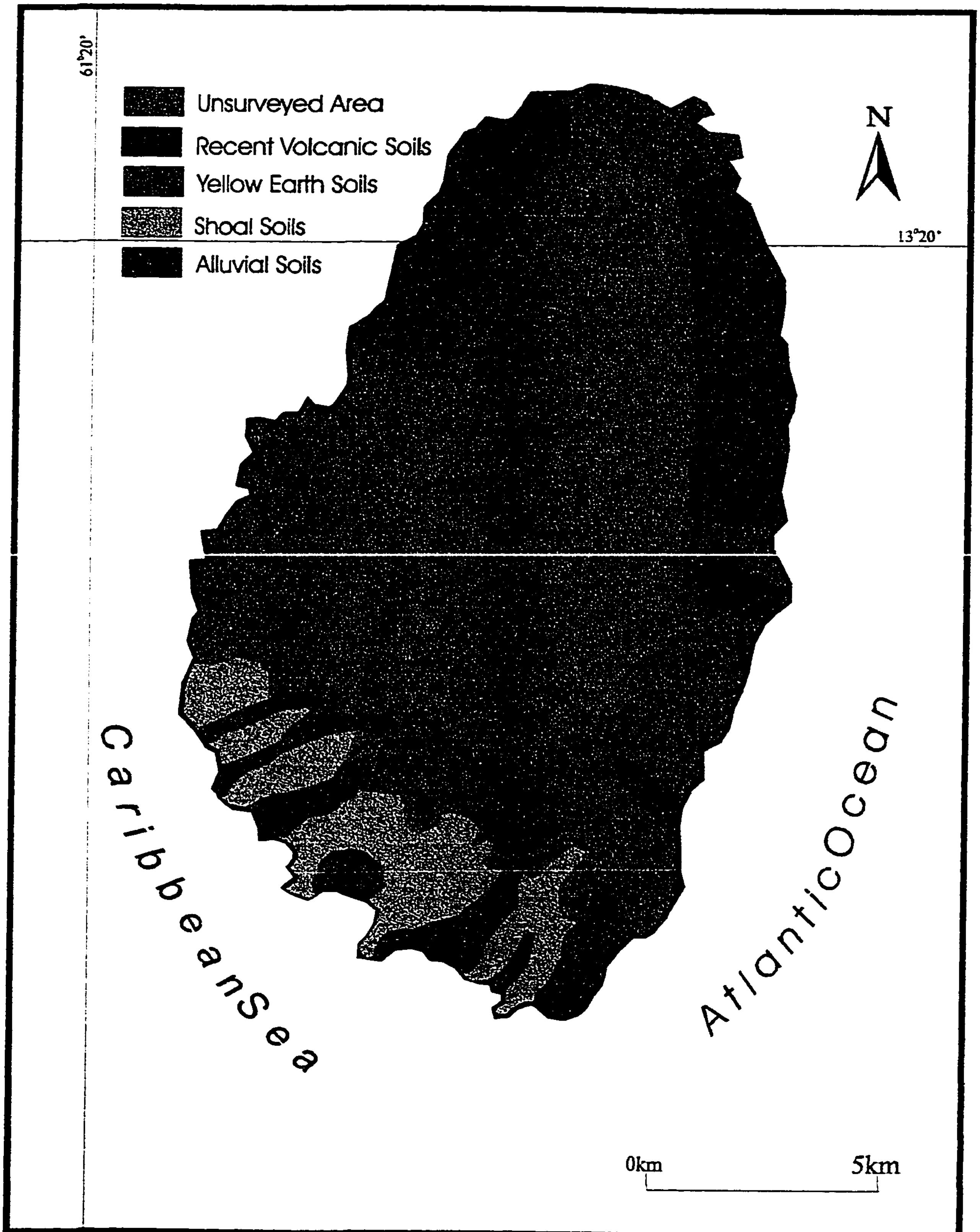

Figure 2.6: Soils of St. Vincent (Modified from Ciccaglione, 1998).

Alluvial soils are found mainly in the southeastern corner of St.Vincent on wide alluvial flat lands. Parent material is brought down by fluvial action or by mass wasting of hillslopes. These soils have a wide range of characteristics and are considered the most productive on St.Vincent (Watson, 1958).

2.6.1 Erodibility of Vincentian Soils

The problem of soil erosion is not a recent occurrence on St.Vincent. In the 1950s the Ministry of Agriculture was aware of the extent and importance of soil erosion and took an active role in controlling it. The soil conservation measures being used were simple and effective. These included growing annual crops, temporary drains, mixed and strip cropping, growing of ground cover, planting of grass barriers and contour planting (Watson, 1958). By comparing Watson's description to current practices it would appear that erosion control was more prevalent than it is today. This maybe related to the greater diversity of crops grown earlier compared to the monocrop agriculture present today. In Watson's 1958 survey the soils of St.Vincent were classified according to the descriptions in section 2.6. He also gave all the soils an erosion potential ranking. 1= none to slight erosion, 2= slight to moderate erosion and 3= moderate to severe erosion. Watson stated in a general observation that the least erodible soils on St.Vincent were the Alluvial soils and the most erodible were the Recent Volcanic Ash soils. The soils that makes up the study area are the Recent Volcanic Ash soils and Watson comments on their land use: " Severe erosion hazard, only tree crops, pasture and forest permissible". Watson's classification and statements are extremely general (justifiably on a regional scale) and the potential for soil erosion on St.Vincent has much greater variability than he noted. More recently (Ahmad, 1984) it has been stated that under natural conditions the soils of St.Vincent are considered to be relatively stable. However, it is agreed that the prominent cause of erosion on St.Vincent is the removal of natural vegetation for the planting of crops and the improper management of the land (Ahmad, 1984; Watson, 1958; Limbird, 1992).

In the initial stages after clearing, erosion is greatest before any plant growth (natural or anthropogenic) has returned. In areas where natural forest was cleared, splash erosion and rill formation was witnessed. The first of these were noted through differential erosion. Small stones or other resistant material were left perched on a pediment while the finer material was eroded (Figure 2.7). Rills were noted on the same site but on greater slope angles. Other areas of obvious erosion were footpaths leading through forest plantations and banana plantations and areas of open construction and roads that were not fully paved, thereby allowing their undermining. It also was noted that there were areas in the Colonarie Watershed where forests were cleared for marijana cultivation. If these areas are large enough and under the right soil conditions, the potential for landslides exist (Limbird, 1992). Even on naturally forested slopes that were extremely steep, several small landslides were noted in the Colonarie Watershed. It appears under given topographic and climate conditions of St.Vincent, some degree of soil erosion is a natural phenomenon, but even minor disturbances are enough to induce and increase soil erosion.

Figure 2.7: After clearing of forest cover the newly exposed soil is poorly protected by the young crops. The result is differential erosion and stone covered pediments. The above features formed after only several rainfall events.

2.7 CARATAL WATERSHED/PERSEVERANCE SUB-BASIN

2.7.1 Location and Physical Description

The Carartal Watershed (CWS) is the third largest watershed on St.Vincent and is located on the windward side of the island just north of the central east west axis (Fig.2.8). The ocean bound end of the watershed encompasses 8 km. of coast line with the upper boundary extending approximately 4 km through the central mountain chain, giving the watershed a blunt triangular shape. The greatest distance from the central mountain chain to the coast is 6.28 km. The largest town in the CWS is Georgetown located on the coast, the main access route is the Windward Highway.

West from Georgetown, access to the upper watershed and the Perseverance sub-basin (PSB) is along a road passing through Chili Village and then along the Caratal River. Scattered housing extends over gentle to moderate slopes for about 1 km. mixed with banana fields after which housing gives way to continuous banana fields. The road gradually increases in gradient for about 3 km while crossing the Caratal River several times. In the latter sections, the road gradient increases noticeably and terminates at the boundary of the PSB. The road to the study site originally extended directly to the plantations but has been dangerously undermined by erosion. The stream leading out of the PSB is a small tributary which joins the Caratal River just prior to the CWSA Perseverance catchment dam. The catchment dam is passed on the 300m hike along the footpath to the plantations. The PSB in nestled into the southwest corner of the CWS with its upper boundary coinciding with the island's central divide. Watersheds adjoining to the Perseverance include the Colonaire and Rabacca on the windward side and the Richmond

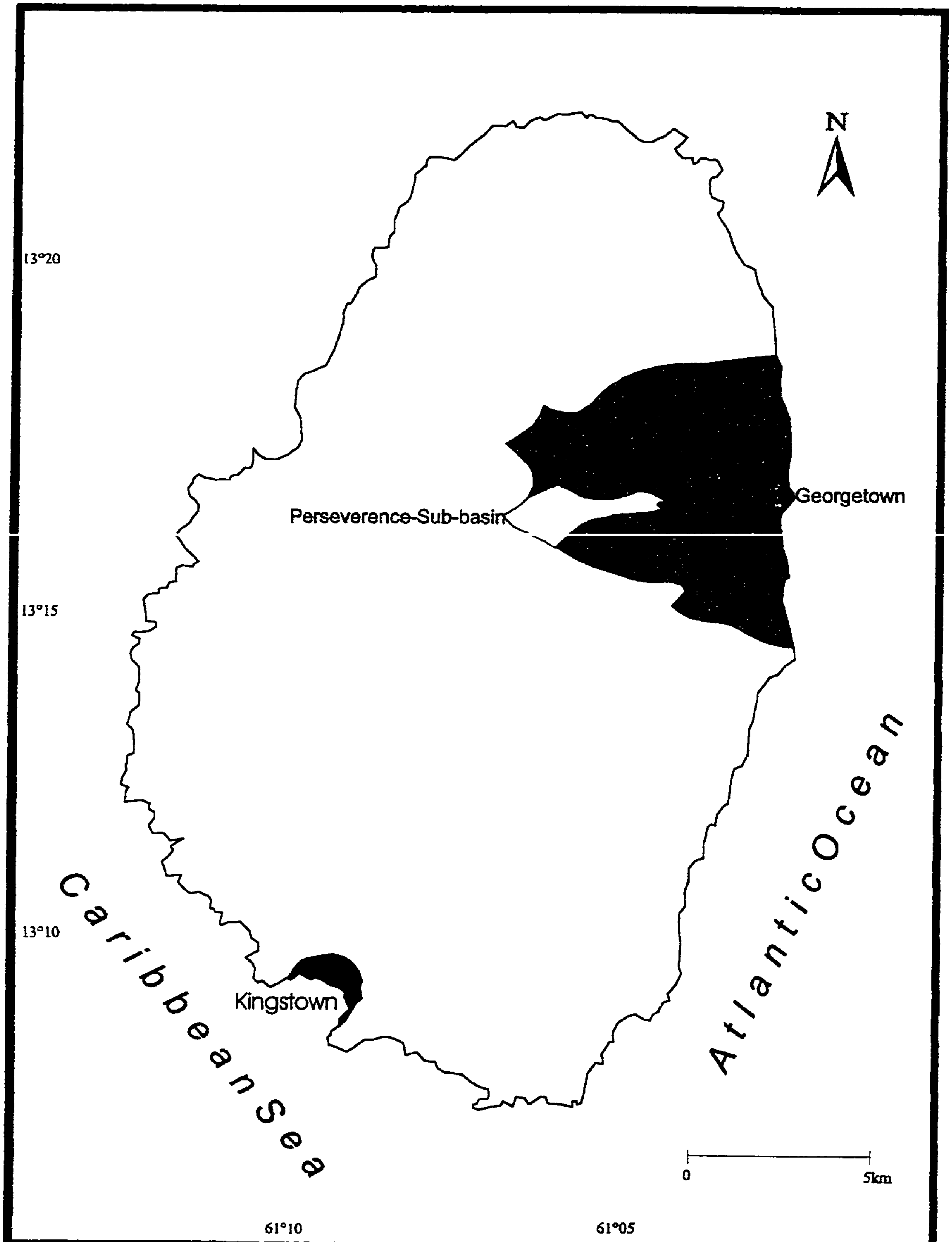

Figure 2.8: Location of the Caratal Watershed, Perseverence Sub-Basin, Study Area and Georgetown.

on the leeward side. This elongated and narrow sub-basin is approximately 2.8 km in length and 0.6 km in width (figure 2.8). The upper reaches of the basin have extremely steep slopes, and although the lower portion levels off, it still has steep slopes on either side. These steep slopes have resulted in translational landslides in the mahogany plantation. One of these extended across the entire width of an erosion plot; it is probable that this occurred when the land was being cultivated or while waiting for the plantation to be established. The trees have suffered no damage.

2.7.2 Vegetation of the Caratal Watershed

The lower portion of the CWS is completely void of all primary forest. Small patches of secondary forest exist along the river, but bananas and fruit trees are the major vegetation types. As one moves further into the watershed greater areas are forested, but extensive areas of forest are observed only in the upper basin. The distribution of vegetation and species composition is essentially the same as described by Beard (1949), with changes related to altitude. The natural vegetation of the PSB consists of secondary forests around the numerous plantations. At higher elevations, primary forests grow, and higher yet, primary forest grades into palm brake.

2.7.3 Plantation Forests (PF)

The majority of St.Vincent's plantation forests (PF) have been planted in deforested areas of upper watersheds. The purpose of these PF is soil and water conservation with minimal emphasis on poles, posts, fuel wood or timber production (CCA, 1991). Three species make up most of the PF on St.Vincent: the blue mahoe (*Hibiscus elatus*) makes up 70%, while mahogany

(*Swietenia macrophylla*) combined with Caribbean pine (*Pinus caribbean*) contribute 18%. Other species, including galba (*Calophyllum antillanum*), cedar (*Cedrela ordata*), acacia (*Acacia mangium*), and cype (*Cordia allidom*), are actively used, but make up a small portion of the plantations (CCA, 1991). The Forestry Division is responsible for establishment and management of plantations, predominantly on illegally cleared agricultural land. Recently, 85% of the PF established have been on crown lands with only 15% on private lands (Trevin, 1993 as cited in Strand). In part, these figures reveal the expansion of banana cultivation onto crown land. There have been several periods of intense PF expansions: one from 1968-1969 when one third of the existing plantations were established, another from 1980-1984 when an additional 40% was planted and presently. It is expected that the last series of expansions will cover 56.0 ha and continue until 2002 (Trevin, 1993). Of all the PF, 60-70% have had no silviculture treatments (thinning); therefore, they are well below their growing potential (CCA, 1991). The Forestry Division, through the work of forestry guards, monitors PF and conducts maintenance such as under story clearing. The forest guards also act as a liaison between landowners and the government, relaying information, settling disputes and apprehending offenders.

The PSB is an area where several species of trees are being evaluated for their potential as forest plantation species. Due to the need to protect its water resources, the PSB has become an opportune area to test new species and to actually use them in "real" reclamation situations. Unfortunately, back ground documentation of the plantations in the PSB is minimal and a pre-planting physical description of the plantations is not possible.

Several test plots are passed on the footpath to the study area. These include blue mahoe (*Hibiscus elatus*), acacia (*Acacia mangium*) and cype (*Cordia alliodora*). The plots are approximately 15m x 5m with a tree density of 9 to 12/plot. Across the Caratal River are plantations of small leaf mahogany (*Swietenia mahogoni*) and hybrids of King mahogany (*Swietenia macrophylla*) and small leaf mahogany. Cype has shown the most rapid growth, reaching heights of 17m in 7 years. The slowest growing species is King mahogany (*Swietenia macrophylla*) with heights as low as 2m in unfavorable sites in seven years. The difference may be due in part to variations in site conditions; such as water and nutrient regimes.

The studied acacia plantation covers 4.5 ha and has a south-southeastern aspect. The mahogany plantation is slightly larger with a north-northeast aspect. Both plantations are at 300 m (984ft.) above sea level and are less than 50m apart. Separating the two plantations is a small stand of blue mahoe and the unnamed tributary to the Caratal River (for convenience, the tributary separating the plantations has been named the Macacia, a combination of the species bordering it). Upslope from both plantations are areas of primary and secondary rain forest.

2.7.4 Land Use

The CWS, similar to the Colonarie Watershed, can be divided into three regions based on elevation: the lower, the middle and the upper basins (Reid Collins, 1994). Lower portions are those lands below 152 m, middle are between 152-305 m, and upper is any land above 305 m. Table 2.1 provides some basic statistics for each elevational designation of the CWS.

Table 2.1 Caratal Watershed Basis Characteristics

Descriptor	Upper Basin	Middle Basin	Lower Basin
Elevation range (m)	> 305 m	152-305 m	<152 m
Area (in % of total)	65	20	15
Dominant Land Use	Forest	Cultivation	Cultivation
Level of Settlement	None	Sporadic	High

Land use in the CWS is most intense in the lower basin with practically all land under banana cultivation. Areas of tannias, dasheens and other root crops exist among bananas but only use minimal land. The lower basin is also the area of greatest urban settlement. Georgetown is at the centre of the urban community, with housing extending north and south along the coast wherever possible. Housing becomes more scarce as elevation increases into the middle basin and a point is eventually reached where only small banana shacks exist. A corresponding population density decrease also occurs in the middle basin with residents becoming widely scattered. Bananas are still the main crop in the middle basin but decrease as greater areas of secondary forest are present. Cultivation extends right up to the 304 m (1000 ft) crown landline, which coincides with the lower boundary of the PSB.

Law restricts land use in the PSB, no activities are permitted except for PF and water collection, and all other access is considered unlawful. This is to ensure a safe water supply for Georgetown. Prior to construction of the CWSA catchment area in the PSB, one family had been farming the area for a period of three generations. The land's occupants were moved a short distance away to the next sub-basin. The farmer stated that the CSWA told him he would be compensated for their relocation, but still had not been six years after the move. Counter to this, a government employee stated that the farmers had been illegally squatting for decades and no compensation was to be given for land that should never have been farmed. It was the perception of the farmer that such a long residency implied ownership.

At higher elevations than the study area there is no cultivation except for the possibility of marijuana; this is strongly suggested by the well-worn paths leading through the plantations to the upper basin. Another illegal land use in the PSB is fishing. Offenders dam the Macacia and then collect the fish isolated in the pools. This method of fishing has repercussions on the stream flow and water quality of the Macacia. The breaking of the dam by forestry workers increased the suspended sediment load of the Macacia, which was then carried into the Caratal River and the water catchment.

Various other land uses can be seen in the CWS but they are minimal in comparison to agriculture. In the middle basin two water catchment areas exist, one in use the other not. An abandoned banana packing plant is also in the middle basin. This structure now is used to mix and pour cement blocks used in house construction. Often the cleared areas adjacent to agricultural fields are used for grazing goats or other animals.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Preliminary investigations for a suitable methodology were carried out at the University of Calgary. This included considering what direction the on going land management studies on St.Vincent should follow. Two previous soil erosion studies on St.Vincent have been conducted; therefore, the most desirable type of study to complement these had to be determined. Some key decisions were not made until meetings with the Chief Agricultural Officer for St.Vincent and the Director of Forestry for St.Vincent. Further investigation regarding site selection and species characteristics was done at the Forestry Division's Library.

Field methods needed to be flexible enough to the meet the unforeseen, but somewhat expected difficulties of working in a different cultural setting. Thankfully, experience by previous students was able to benefit the study greatly. The complete methodology consists of five components: selection of study parameters, site selection, data collection, laboratory methods and statistical analysis.

3.2 STUDY PARAMETERS

Prior to implementation of any study it must be specifically decided what one is attempting to achieve and then if these study parameters are feasible. The rationale of this study was to add to the existing knowledge regarding the continuing problem of soil erosion, land use and reclamation on St.Vincent. This study is centered on soil erosion; therefore, measuring eroded soil and runoff water was included. However, soil fertility also is of interest; therefore, quantifying nutrient loss required additional study parameters, since nutrient loss occurs not only with soil loss but also with runoff and leachate water. The loss of nutrients is only relative to the input of nutrients, thus, for a greater understanding, nutrient input as atmospheric deposition was measured.

3.3 SITE SELECTION

Site selection was done prior to arriving on St.Vincent through the use of previously compiled reports, but after viewing the intended study plantations they were deemed not suitable for a comparative study. Through meetings with the Forestry Division and Ministry of Agriculture officials the most beneficial alternative plantations were chosen. Further assistance was provided through the aid of a Forestry Officer who participated in field reconnaissance of the suggested areas. Several factors were important for a comparative soil erosion study: soil type, slope angle, vegetation type, precipitation characteristics and site access all must be considered.

Important factors in choosing the PSB included the proximity of acacia and mahogany plantations to each other. The plantations were within 60m of one another, minimizing variations in soil type and precipitation. Both plantations were also on similar slopes and had trees of similar age. The presence of the acacia stand, the largest on St.Vincent, was pivotal in site selection. Little is known about the performance of the highly praised acacia in the Caribbean or on volcanic ash soils. This study provided a unique opportunity not only to compare these two species, but also to investigate the acacia under the given conditions.

Mahogany was included in the study because it is second only to the blue mahoe as the most commonly used plantation species on St.Vincent. As well, the growth of the mahogany plantations has been poor due to the presence of the shoot borer (*Hypsipyla grandella*) which attacks the apical bud of young mahogany. The result can be death but more often it is severe stunting of the tree. Very large difference in tree size (i.e.: height) can be seen between those individuals that were attacked and those that were not. So, even with the mahogany and acacia plantations being the same age there is a considerable difference in tree height. Comparing trees of different height will result in variations in the amount of soil erosion under the different trees; however, the shoot borer has attacked practically all the mahogany on St.Vincent. Therefore, it is taken that this condition is a constant for all existing mahogany plantations. Knowing this, the comparison of the mahogany and acacia plantations is also based on age and not tree stature. Furthermore, the mahogany plantations are below their growing potential and deserve attention as to their use as a reclamation species.

Determination of plot location within the plantations was based primarily on finding slopes as similar in angle as possible. The most comparable slope angles were 26.0^0, 31.0^0 and 33.0^0 for mahogany and, 32.0^0, 33.00 and 35.0^0 for acacia.

3.4 DATA COLLECTION

Erosion plots with the following dimensions were measured and established; 5m x 15m, three were set up in each plantation, A, B and C in the mahogany and D, E and F in the acacia. At the top of all the plots a 15cm x 6m piece of metal flashing was sunk approximately 7 cm into the soil to prevent any up slope runoff from entering the plots, except on one acacia plot (plot F) where its upper boundary was a ridge top. The use of lateral boundaries was not necessary as slope morphology prevented runoff from flowing into the plots. Within each plot, sediment traps were buried flush to the ground and set at right angles to the slope. The sediment traps were a modified version of the Gerlach Trough as designed by Strand (1996) and had the following dimensions: 100.0 cm length x 12.7 cm width and x 7.7 cm depth. The troughs all had a 5 cm. metal lip on the slope side which was inserted 2-4 cm under the soil surface, to ensure the trough were not undermined by water. Troughs were spaced at 1m giving 60 percent coverage of the plots. Wooden stakes or re-bar were pounded into the ground on the backside/upslope of the troughs, which also helped stabilize them. Each trough had a 5cm. hole at one end, under which a 20.0 L pail was placed to collect runoff. Troughs were covered by plywood cut to fit and the pails were covered with polyethylene plastic to ensure no incident rainfall was collected.

The troughs were slightly tilted in the direction of the pail in order to ensure water did not sit in the trough and evaporate and to keep as much sediment in the trough as possible making collection easier. Sediment was collected mainly from the troughs but the water was filtered to ensure any sediment in the pails was also collected.

Troughs were left for one week before collection began in order for the disturbance caused by installation to dissipate. A longer time period would have been more desirable but due to time constraints this was not possible. Each trough was sampled weekly for a period of 13 weeks. Sediment (g) was air dried and kept in plastic zip lock bags and water (ml) was measured using a graduated cylinder. Water samples were collected in 25ml plastic bottles and kept refrigerated. The water samples to be analyzed for nitrates, ammonium and phosphates were treated with 10% sulphuric acid.

Precipitation was measured using a Belfort Universal Dual Traverse Weighing Bucket Recording Rain Gauge and two Weathertronics Tipping Bucket Rain Gauge & Event Recorders. Gauges were placed in a clearing in the upper portion of the mahogany plantation. The Traversing rain gauge recorded intensity, duration and total rainfall, the Weathertronics rain gauges recorded only total rainfall, but were useful in ensuring total precipitation was measured accurately. Data for both gauges were collected weekly. The data used in the analysis was from the Traversing Rain Gauge. Precipitation for the analysis of nutrient content was collected using a glass bottle with a funnel inserted in the top. The funnel had a nylon mesh cover to ensure no debris entered the sample. Samples were collected weekly and were not treated with acid but were kept refrigerated.

Leachate was collected using 6 (one for each plot) self designed lysimeters. Two pieces of flashing 30 cm x 15 cm were taped together with two 1 cm. pieces of wood on the outer edge. The top piece of flashing was perforated with numerous small holes to allow water but not soil to pass through to the second piece of flashing. The entire apparatus was inserted into a hole dug under the soil at a depth of 10 cm. The leachate plates were at a slight angle so water would run down into a collection cup. The collection cup was covered with nylon mesh and a piece of flashing was inserted into the soil above the cup to keep runoff water out of the collection cup. The cup was covered with polyethylene plastic. The collection sites were directly adjacent to all 6 erosion plots. Samples were transferred to 25ml plastic bottles, treated with 10% sulphuric acid and refrigerated. Unfortunately, leachate collection was not decided upon until after the study was two thirds of the way complete. The outcome has been a sample size too small to test statistically. As well, due to contamination and technical problems, the metals (Fe, Al and Mg) were not analyzed in the leachate.

Vegetation analysis was performed at the conclusion of the study as not to disturb the sites, it involved measuring d.b.h. (diameter at breast height) and estimating the tree height of every tree in all plots. Percent coverage was estimated for the litter layer (0.0m, i.e.: ground level), shrub/grass (under story) layer (0.0m-2.5m) and over story (canopy) (2.5m->). Species identification, frequency and distribution for each plot were recorded on data sheets.

Slope morphology/shape was described, as this can influence the movement and speed of runoff. Characteristics such as gullies, slumps, mounds and dead fall were recorded to assist in explaining variation in the amount of sediment and runoff.

After the fifth week of collection the Forestry Division management practice of clearing the ground cover was done in the mahogany plantation, to reduce the competition between grasses and the trees. Several forestry workers armed with cutlasses (machetes) walked through the plantation and cut the ground cover to approximately 10 cm height. The vegetative matter was left where it fell. They were asked not to perform their task with any extra caution so as to ensure as "realistic" a situation as possible. This meant the workers walked through the erosion plots. Whether this practice is useful or if it increases erosion is discussed in Chapter 5.

One soil pedon was dug in each plantation with the following approximate dimensions: mahogany 1m in width x 1.5m in depth and acacia 1.5m in width x 2.4m in depth. Horizons were distinguished based on color and texture changes. Each horizon was sampled and stored in a ziplock bag to minimize moisture change. Samples were refrigerated and returned to Canada within 24 hours of their collection. Detailed profile descriptions were done for both pedons (see Appendix A).

3.5 LABORATORY METHODS

Before any analysis was performed all samples were mixed, then ground with a mortar and pestle, ensuring the break up of any larger aggregates; then they were passed through a 2mm sieve (this was done for all sample analysis). Large enough sample sizes were collected for all analysis except for the C.E.C of eroded sediment. The sample size of eroded soil was small and weekly samples had to be combined and averaged in order to obtain enough for analysis.

Soil texture was determined using two methods: the feel/ribbon method in the field and the hydrometer method in the laboratory. The A horizon of each pedon was passed through a series of sieves, sizes 74μ, 88μ, 106μ, 180μ, 210μ, 300μ and 495μ. This was done to obtain a particle size distribution of the A horizon, which is the horizon that is the interface with rainfall and primarily determines the erodibility of the soil. The texture can be estimated in the field depending on the length of the ribbon to which the soil can be stretched. The higher the clay content the greater the length of the ribbon, the higher the sand content the less stable and more friable the sample will be. The hydrometer method followed was the "modified hydrometer method for soil particles less then 2.0 mm" (Mckeague, 1978). First samples were treated with 20 ml of hydrogen peroxide to ignite any organic matter. This treatment was done to keep the clay from flocculating with the organic matter, which can be interpreted as sand by the hydrometer. Following this treatment forty grams of each soil horizon were soaked for 12 hours in a solution of 300 ml of distilled water and 100 ml of 5% calgon. Each sample was then thoroughly mixed for 20 minutes on an electronic mixer. The slurry was transferred to 1.0L cylinders and readings were taken with a hydrometer at 30 sec., 1 min., 3 min., 10 min., 30 min., 90 min., 280 min. and 1080 min.

A Unicam 939 Atomic Adsorption Spectrophotometer was used to analyze both soil and water samples for the following elements: Al, Ca, Fe, K, Mg, Mn and Na. One gram of dry weight equivalent of soil was weighed and mixed with 40 ml of 0.025 M of $BaCl_2$ and shaken for 2 hours. Then the slurry was passed through Whatman Quantitative Filter Paper # 42 and analyzed.

Soil pH and conductivity were analyzed using a modified version of the Fixed-Ratio Extract method (Rhoades, 1982). Ten grams of oven dry weight soil were added to 20 ml of dH2O and left to stand for 1 hour with periodic shaking. The samples were centrifuged for 20 min. and a Fisher Scientific Accumet pH meter 50 was used to determine pH and conductivity.

Organic matter was measured using a Perkin-Elmer Lambda 3 UV/VIS Spectrophotometer, following a modified version of the Walkely-Black wet oxidation method (Sims and Haley, 1971). One gram of soil was added to a 10ml of potassium dichromate ($K_2Cr_2O_7$), 20 ml of concentrated sulfuric acid (H_2SO_4) and 70 ml of dH20 (distilled water) and left to cool for 20 min. This extract was filtered through Whatman # 2 filter paper and analyzed.

Extractions for exchangeable inorganic nitrate (NO_3-N) and ammonium (NH_4-N) were done by sieving 5g dry weight equivalent field moist soil and mixing with 40 ml 2M KCl for 1 hour. The extract was filtered with Whatman # 42 filter paper and passed through a Technicon autoanalyzer. The Cadmium Reduction Method and Technicon Industrial method No. 100-70W/B were used in the analysis.

Extractable inorganic phosphorous was done using the Modified Medium Bray extract. The extract consists of 1.108g of 0.03N NH_4, 1,54g of 0.03N $H2SO_4$ and 1L of distilled water. Twenty ml of extract is mixed with 5g dry weight equivalent soil and swirled for 2 minutes before being filtered through # 42 Whatman filter paper. The extract was passed through the

Technicon Autoanalyzer using the Technicon Industrial method No. 94-70 W/B. Calculations of ug/g PO4-P to mg/g were done using the following equation:

$$(\text{conc. sample} - \text{Conc. blk}) \times \text{volume (L)} \times \frac{1}{\text{wt.(g)}} \times 1000\text{ug/mg} \times 0.3261 \times \text{dilution factor}$$

3.6 STATISTICAL ANALYSIS

The prime objective of the statistical analysis was to determine if any significant differences existed between the data collected at the two sites. Statistics include descriptive statistics to show trends in the data, multiple regression to assess what variables had the greatest influence on sediment loss, runoff and nutrient loss. Independent sample t-tests were performed to show any significant difference in data collected between sites. All statistical test were run at 95% confidence interval on the statistical package SPSS.

3.6.1 Descriptive Statistics

Descriptive statistics are useful in showing trends in data sets that may otherwise go unnoticed. They also provide a foundation upon which more complex statistical methods are based (Tabachnick and Fidell, 1996). Weekly arithmetic means were calculated for runoff, sediment loss and nutrient loss.

3.6.2 Students' t-test

The students' t-test is a powerful test when working with small data sets; it tests difference between sample and population means. Several forms of this test exist, with the "difference between independent sample means" being the method used on this data. This choice was based on the small sample size and the assumption that the two sites are from the same population in regards to their variances (Earickson and Harlin, 1994).

3.6.3 Stepwise Multiple Regression

Before regression analysis was applied to the data, scatter plots were done to observe any outliers and determine what type relationships existed between the dependent and independent variables (ie: linearity). In addition, correlation matrixes were completed to reveal the correlation independent variables had with one another. Too great of correlation results in multicollinearity which can corrupt the regression equation and decrease its predictive power. Only variables that had linear relationship and were not to highly correlated were included in the regression equations.

In regression analysis a mathematical model is estimated that explains the relationship between a dependent variable (Y) and one or more independent variables (X) (Kenkel, 1989). It attempts to provide a simplified or idealized view of the real world. Regression analysis is capable of several useful insights. It allows one to quantify a theory about how the variables X and Y are related and it enables one to test a theory about the relationship of a variable X to a variable Y. It also allows the strength of a relationship between variables to be tested and it enables the value of Y to be predicted based on values of X (Kenkel, 1989).

Stepwise multiple regression, a form of regression, operates on the basis of the removal of independent variables from the regression equation that do not contribute significantly to the explanatory power of the equation or increase the R^2 value. Stepwise regressions were run on the dependent variables sediment loss, runoff and nutrient loss. The vegetation variable was not included in the analysis of the acacia plantation since this vegetation was static and did not change during the study period. However, in the mahogany plantation when the under story was intact a "0" was assigned to the data, after clearing a "1" was used in the regression equations. This form of variable is referred to as a dummy variable and indicates the presence or absence of some characteristic (Kinkel, 1989). The regression equations used in the analysis are of the standard form:

$$y_i + b_0 + b_1 x_{i1} + b_2 x_{i2} + \ldots e_I \qquad (3.1)\ (\text{Kinkel, 1989}).$$

In the above equation y_i is the predicted value of y, b_0 is the value of y_i when all x's equal 0, b_1 and b_2... represent regression coefficients and x_1 and x_2... represent independent variables (Tabachnick and Fidell, 1989).

Variables used in the above equation for the mahogany plantation include the following:

Dependent Variables	Independent Variables
Sediment Loss	Runoff Vegetation Total Precipitation A.A.E (above average number of above average intensity events/weeks)
Runoff	A.A.E. Total Precipitation Vegetation

Nutrient Loss	Runoff Total Precipitation Sediment Loss

Independent Variables used in the acacia regression were as follows:

Dependent Variable	**Independent Variable**
Sediment Loss	All Variables Rejected
Runoff	(A.A.E.) Total Precipitation (mm) Maximum Intensity (mm/hr)
Nutrient Loss	Number. of Weekly Events Total Precipitation (mm) A.A.E.

Performing the regression involved entering all the independent variables and then letting the stepwise regression determine which variables were rejected, this always correlated with independent variables that were to highly correlated to each other. Scatter plots and discussions were reserved for the three variables with the highest correlations (Appendixe C&D). The generated correlation coefficients (R) were squared to arrive at the coefficient of determination (R^2). This figure describes the proportion of the total variation in the data that is accounted for by the independent variable.

3.6.4 Analysis of Variance (ANOVA)

ANOVAs were performed (by SPSS) on the results of the multiple regressions to test the null hypothesis "no linear relationship exists between X and Y". The regression sum of squares and the residual sum of squares are used to estimate the variance about the regression line (F ratio).

Rejection will occur if the observations are to variable or if the regression model is incorrect (if the computed test value exceeds the F value) (Earickson and Harlin, 1994). Also included were the P values which indicate the probability of making a type two error (i.e., rejecting the null hypothesis when it is in fact true).

CHAPTER 4.0

RESULTS

4.1 Introduction

The purpose of this chapter is to present the field and laboratory results of the study. Results for the statistical tests also are presented. Precipitation, runoff, soil erosion, nutrient loss and vegetation descriptions are given. Soil properties and slope morphology also are included. The discussion addressing the dynamics of these variables is presented in chapter 5. The details of the soil chemistry are given in appendix B.

4.2 Precipitation

Soil erosion is influenced strongly by precipitation characteristics, including the number of events, duration, average and maximum intensity and total amount. Runoff occurs when rainfall intensity exceeds the infiltration capacity of the soil or when the soil profile becomes saturated (Moron, 1996). Due to their proximity to each other, only one rain gauge was used to study the two plantations. Therefore, the rainfall characteristics between the two plantations can be considered identical. The records from this gauge are given in table 4.1. The weekly rainfall also is presented as an overlay with the runoff and sediment loss results in figure 4.4 and 4.6. Based on the total amount of rainfall up until the end of the study period, the total yearly annual rainfall was posed to meet if not exceed the expected amount, which is in excess of 3000mm. This amount of rainfall and the intensities recorded have been associated with landslide activation on other humid tropical Caribbean islands, further exasperating land management problems (Larsen et al., 1993).

Table 4.1: Precipitation Characteristics of the Acacia and Mahogany Plantations

	Total	Weekly Average
Precipitation (mm)	1023	78.69
Number of events	156	12
Average intensity (mm/hr)	10.92	N/A
Max. intensity (mm/hr)	92	N/A
Duration (hr.)	144.17	11.09
Average duration (min.)	55.45	N/A

4.3 Site Characteristics

The site characteristics for both the acacia and mahogany plantations include vegetation descriptions, soil descriptions, and slope characteristics. The properties of the surface (A) horizon are emphasized due to its importance to soil erosion.

4.3.1 Vegetation Characteristics

The nature of vegetation can greatly influence the capacity of precipitation to cause soil erosion, runoff and nutrient transport (Bui, 1992). The physical characteristics, spatial arrangements and frequency of both the acacia and mahogany trees are presented; the various characteristics of other vegetation present in the plantations also are given. The vegetation characteristics are used in Chapter 5 to discuss the runoff, nutrient and sediment transport trends. The changes in the vegetation of the mahogany plantation after clearing are shown.

4.3.1.1 Mahogany Plantation

The vegetation in the mahogany plantation varied greatly in size and diversity. Beside the mahogany trees, trumpet trees (*Cecropia peltata*) were scattered throughout, these trees were not cleared with plantation maintenance because it is believed they assist in controlling erosion.

These trees have severely outgrown the mahogany with heights reaching 10 m. Architecturally, they have a single layer canopy with no lower branches; leaf shape is oblate and extends up to 75cm in length and 75cm in width. They have a stilt like root system which can elevate the trunk 20-30cm above the soil surface.

Observations indicated the trumpet tree contributed little to erosion control and may actually enhance erosion. It was noted during rainfall events, water coalesced on the large leaves until very large drops were released. These large drops combined with the high canopy of the tree result in canopy drip with a high kinetic energy, thereby increasing the erosion potential (Shainberg et al., 1996). Another tree species present in the mahogany plantation is orange trees, and although there are only two of these, they are large with multi-layered canopies extending approximately 9.1-10.6m in diameter. One of these canopies extended into and covered 15% of plot B. These trees are remnants from when the area was under cultivation; but they are being overcome by a high density of epiphytes and appear to be dying. These trees had a thick canopy with the lower branches 2m above ground level; leaf size was small, resulting in canopy drip that was less erosive than incident rainfall. Under and near the orange tree canopies the growth of grasses was suppressed because of shading. The mahogany trees adjacent to the orange tree were also smaller then trees further away. This stunted growth may be attributed to competition for water and nutrients and by the partial interception of sunlight by the larger orange tree canopies. The only other tree present in the mahogany plantation was a 4.6m avocado.

The litter layer (LFH) in the mahogany plantation was continuous and varied in depth between 3 and 5 cm, the L was 1 cm, the F 2-3 cm and the H only 0.5 cm. It consisted of litter originating from the grasses and shrubs, and to lesser extent from mahogany leaves. The litter layer was not in a loose form, but was bound with interwoven roots from the grass. The ground cover consisted mainly of corn, guinea and elephant grass which averaged heights of 1.0m and widths of 5cm. In depressions where nutrient accumulations occur, the grasses reached 1.5m. These grasses formed a continuous cover in the lower areas of the plantation, especially in plot B. The grass types have been used for decades on St.Vincent for erosion control as barriers, largely because they possess a deep and dense rooting system extending to depths of 1-2 m (Watson, 1958). The most common ground cover after the grasses (0-1 m) consisted of *Verbenacea spp.* and until clearing it provided continuous ground cover under and around the citrus trees where the grasses were less populous. *Verbenacea* averaged 60 cm in height and was the most common ground cover species in plot C. In total 27 different species were recognized of which 81% were identifiable. Table 4.2 gives a list of all the species in the mahogany plantation. This is followed by a picture of the mahogany plantation; worth noting is the high contribution grasses make to the plantations biomass.

Table 4.2 List of species identified in the mahogany plantation

Common Name	Latin Name
mahogany	*Sweitenia macrophylla*
bud grass	*Desmodium triflorum*
khus-khus	*Vetiveria zizanoides*
button weed	*Borreria laevis*
wedealina	*Wedealina sp.*
joint bush	*Piper amalago*
verbenacea	*Bouchea prismatica*
seed on the leaf	unknown
french weed	*Commelina diffusa*
cow heal	*Lepianthes peltata*
rabbit bush	*Emelia tosbergii*
ipomean	*Ipomea sp.*
edge teat bush	unknown
orange tree	*Citrus sp.*
pepercomia	*Peperomia rotundifolia*
buddy eye	*Lantana camara*
lance mahot	*Aegiphila martinicensis*
fontonia	*Iihonia sp.*
banana	*Musa sp.*
guinea grass	*Panicum maximum*
veri vine	*Stachytarpheta jamaicensis*
elephant grass	*Pennisetum purpureum*
trumpet tree	*Cecropia peltata*
corn grass	Unknown
unknown	
unknown	
unknown	

The physical structure of the mahogany plantation is characterized as having an open canopy, with only 30% coverage by the mahogany trees themselves. This open canopy allowed a high amount of direct sunlight onto the plantation floor and resulted in the dense understory of light demanding grasses. The mahogany trees had an average height of approximately 3.2 m and an average d.b.h (diameter at breast height) of 23.24 cm. Average plot density (mahogany stems/plot) was 12.0 and stem spacing was 2.4m, giving canopy coverage of 30 % (Figure 4.1). The canopy of each individual tree was not in contact with other trees; there were approximately 1.2m spaces between individual tree canopies. The shrub/grass layer (0.0 m-2.5 m) coverage varied from plot to plot but overall had 80% coverage. There were no woody species in this size class, only grasses. Average litter layer coverage was 65%. Due to the abundance and density of the vegetation there was 95% soil coverage; only very small areas of exposed soil existed.

After the fourth week the vegetation of the mahogany plantation was severely altered with the clearing of the under story and ground cover. The plant debris was left on site and formed a continuous cover but over the next few weeks as decomposition and litter transport occurred, areas of bare soil were observed. Litter transport was noted by the increase of plant matter collected in the sediment traps. Within several weeks vegetation began to grow back, but in the next 9 weeks it did not fully recover to the pre-clearing condition. Table 4.3 shows the changes in vegetation after clearing in comparison to pre-clearing vegetation.

Table 4.3: Changes in vegetation characteristics following treatment

	Litter (%)	Shrub/Grass (%)	Canopy Coverage (%)
Pre-clearing	65	82	30
Post-clearing	95	5	30

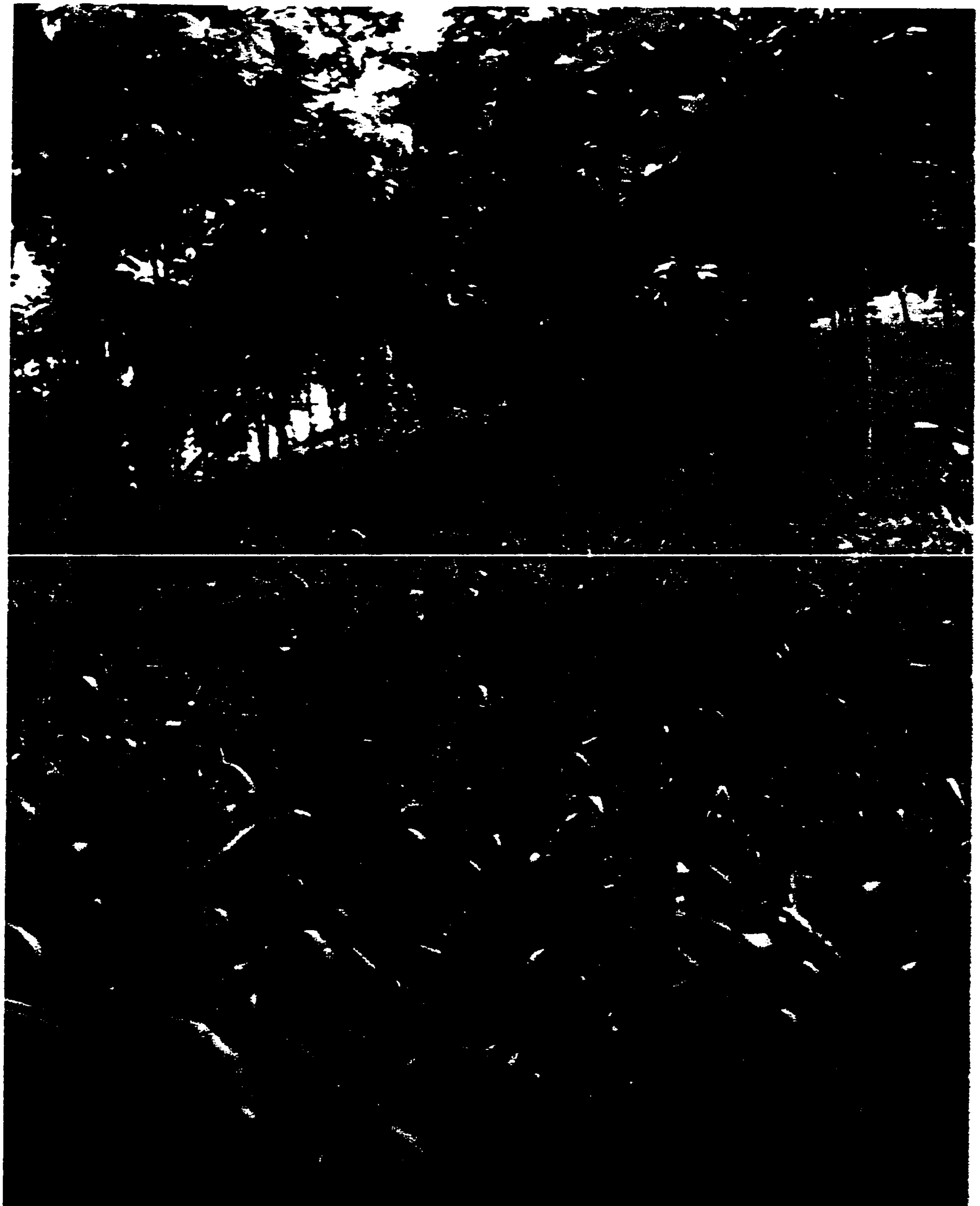

Figure 4.1: Note the high biomass accumulation of the understory and the open canopy of the mahogany plantation. Tree height averaged 3.2m; much taller trumpet trees can be seen intermixed in the background. Split bores can also be seen; the result of shoot borer attack.

4.3.1.2 Acacia Plantation

In comparison to the mahogany plantation, the acacia plantation resembled more of a forest environment, largely due to the greater structural complexity of the shrub layer, but also the result of the larger stature of the acacia trees. The over story had an average tree height of 8.9 m and an average d.b.h of 47.6 cm. Average stem density and spacing were equal to that of mahogany at 12 stems/plot and 2.4m . These facts combined with the globular shape of the acacia's canopy resulted in 60% canopy coverage, with multi-layering in the top sections of the trees. Trumpet trees also were present in the acacia plantation but did not extend above the acacia as they had the mahogany, instead they were intermixed with the acacia canopy (Figure 4.2). Also present in the acacia plantation were a greater number of banana plants.

The shrub/grass (under story) layer (0.0m-2.5m) of the acacia had coverage of 55% and had a variety of species with different leaf size and shapes. Most under story species had a simple leaf shape and varied in leaf area from 15cm squared up to over a 100 cm squared. No shrub species exceeded 2.5m (except for banana plants, none of which were in the study plots) and most ranged between 1.5m and 2.0m. The distance between the bottom of the acacia canopy and the top of the under story was 7m, resulting in a canopy of little horizontal stratification. Table 4.4 gives a complete species list for the acacia plantation.

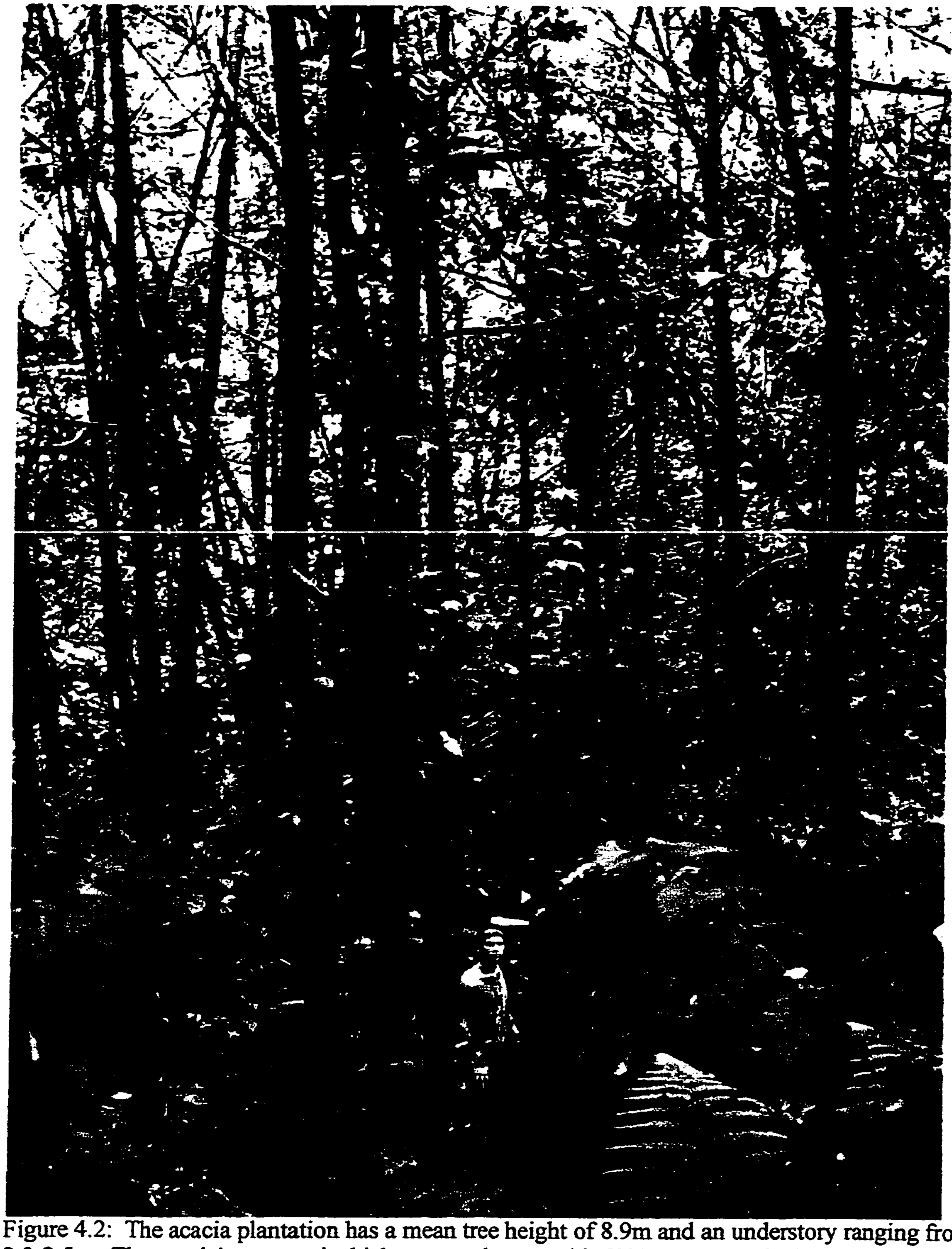

Figure 4.2: The acacia plantation has a mean tree height of 8.9m and an understory ranging from 2.0-2.5m. The acacia's canopy is thickest near the top with 60% coverage, the lower branches are not heavily foliated.

Table 4.4: List of Species Identified in the Acacia Plantation.

Common Name	Latin Name
joint bush	*Piper amalago*
fontonia	*Iihonia*
banana	*Musa spp.*
cow heal	*Lepianthes peltata*
bamboo grass	*Arthrostylidium excelsum*
odontoemanema	*Odontonema nitidum*
tannia	*Xanthosoma sagittifolium*
button weed	*Borreria laevis*
plain jane	*Gonzalagunia spicata*
wild yam	*Dioscorea alata*
acacia	*Acacia mangium*
trumpet tree	*Cecropia peltata*
unknown fern	

The litter layer coverage proved to be surprising low at only 40%. With all the above biomass it was expected that a shallow L layer would accumulate. However, this did not occur due to the high slope angle, which induced a high degree of litter transport. This transport was observed by the high amount of litter caught in and around the sediment traps, particularly during high intensity rainfall events. High litter transport also was detected by the amassing of litter at the lower slope of the plantation, adjacent to the Macacia stream.

4.3.1.3 Vegetation Comparison

The growth rate of the mahogany was lower than the acacia and it will be decades before the mahogany attain and surpass the height of the acacia. However, when they do the canopy will be thicker and have greater complexity, but be narrow in relation to the height of the tree (Lamb, 1964). In part the cause of this canopy difference is the acacia's self pruning mechanism

(Ruskin, 1983). All the lower branches of the acacia trees were devoid of any foliage, with only the upper portion of the canopy having leaves. The mahogany trees were different as even the smaller trees were demonstrating a canopy with multiple layers. The undergrowth of the plantations is very different; the acacia has shrubs and other leafy plants and the mahogany is dominated by grasses. *Acacia mangium* is well known as a species efficient at suppressing pioneer grass species that make any type of reclamation or restoration difficult, if not impossible in some cases. The canopy of the acacia intercepts a large portion of incoming light, thereby suppressing grasses which are light demanding and encouraging more woody species (Kuusipalo et al., 1995). This grass suppression was seen on St. Vincent as only a small portion of the acacia under story consisted of grasses; most species were woody in nature. *Acacia mangium* is also a nitrogen fixing legume; the nitrogen rich litter increases the biological activity of the soil (Kuusipalo et al., 1995). A summary of differences and similarities between the mahogany and acacia plantation is shown in table 4.5.

Table 4.5: Comparison and Contrast of Similarities and Differences in Vegetation Characteristics in the Acacia and Mahogany Plantations.

	Mahogany Plantation	Acacia Plantation
Canopy	-open canopy -starting to multi-layer -average coverage 30%	-partially closed canopy -multi-layering at upper reaches -average coverage 60%
Over Story	-8 foot spacing -average12 stems/site -average height 3.2m -average d.b.h 23.24cm -predominantly mahogany with scattered trumpet and citrus trees	-8 foot spacing -average 12 stems/site -average height 8.9m -average d.b.h 47.60 -primarily acacia with scattered trumpet tree of equal height
Shrub Layer/	-95% coverage, primarily grasses with small portion of leafy species -no woody species	-60% coverage, mainly woody species with large leaf area -few grasses
Litter Layer	-average 2.2cm thick with 65% coverage -dense and fibrous	-no accumulation of litter -40% litter coverage -sparse, areas of exposed soil
Other	-direct sunlight reaching the plantation floor, very open canopy - greater species diversity	-sun flecks reaching forest floor -long distance between vegetation layers

4.4 Soils

The soils under both the mahogany and acacia plantations were classified as Recent Volcanic Ash soils of the Soufriere cindery gravelly sandy loam variety, based on the regional soil survey of St.Vincent done by Watson (1958). Research on the Recent Volcanic Ash soils is limited to work by Watson. Therefore, to this researcher's knowledge, the present study is the most detailed done to date. Greater emphasis is given to the surface horizons due to their importance to soil erosion. Complete profile descriptions are contained in Appendix A. Parent material for this soil consists of volcanic ash from numerous volcanic eruptions, most probably from the Holocene. Records from the 1902 eruption show up to 30 cm of ash being deposited in one morning (Tomblin, 1971). It is therefore possible to hypothesize the present soil originated from ash deposited recently. These "mountain soils", as Watson referred to them, are generally coarse textured and deep grayish-brown in colour. They are well drained, of loose consistence and readily erodible (Watson, 1958).

The soils of the study area have been relatively undisturbed since the establishment of the plantations 8 years ago and no soil related evidence indicates any past cultivation. Evidence of erosion in the mahogany plantation was almost undetectable since the soil surface was nearly completely covered in vegetation. The only areas where erosion was visible was around the roots of the trumpet tree, which elevated the trunk slightly above the soil, and on the footpaths. In contrast, the acacia plantation showed several indicators of erosion. Small pediments with coarse material on top were left after the finer material had been eroded. Also, in areas of concave slopes, rills had formed where sediment and litter were being transported. Lastly, during intense rainfall, sediment was noted in the Macacia stream through slight changes in water colour, indicating the presence of sediment from up slope. Runoff at the base of the acacia plantation may have been enhanced because the base of slopes adjacent to streams generate runoff more readily. This runoff occurs since these are areas of higher water tables and saturated soils (Bonell et al., 1978).

Another visible difference between the two soil profiles and a possible indicator of erosion was the presence of an extremely coarse discontinuous gravel horizon. In the acacia plantation this horizon was 12 cm closer to the surface than in the mahogany plantation. One explanation for this difference may be that more erosion has taken place in the acacia, bringing this horizon closer to the surface. This explanation is plausible, assuming the gravel layers were deposited during the same volcanic event.

The soils shared similarities in structure, aggregate size and consistence; these were granular or platy, fine or medium and friable respectively. Both profiles were moderately well drained and had a high permeability. Through collection in pails and direct work in the soil, it was noted that the macro-invertebrate populations were higher in the mahogany plantation, likely the result of the greater accumulation of litter. Boundary changes between horizons were all abrupt, with little or no gradation. Roots were at greater depth in the acacia than the mahogany and were coarser. In the mahogany plantation, tree roots were shallower and grass roots were abundant in the upper A horizon. Soil colour was similar in the A horizons but was different in the lower horizons, with the acacia's soil being red in colour or higher in chroma. The mahogany soil generally had low chromas and values, and was more brownish to slightly gray in colour.

The soil texture of both sites was very coarse, with variations between sandy loam to sand. This can be attributed to the coarse texture and young age of the parent material. In the mahogany soil, the subsurface horizons were classified as sand and the upper two horizons were sandy loam and loamy sand. Overall the acacia soil was finer in texture, but again there was very little variation with increased depth. The coarse texture of these soils has several important influences on trends in other soil characteristics, namely organic matter and nutrients. Organic matter follows the expected trend of decreasing with depth, but through the gravel horizons, it drops a greater magnitude then in previous horizons. From the mahogany B1 to the gravel, the organic matter decreases from 4.6% to 2.0% and in the acacia it decreases from 3.6% to 2.2%. As organic matter is a source of nutrients the gravel layer acted as a "nutrient funnel", transporting nutrients to lower horizons. This phenomenon is detectable through the increase in organic matter in the horizons below the gravel layer (2.0% in the gravel to 5.1% in the C horizon).

Surface Horizon Properties 4.4.1

The physical and chemical properties of the A horizon are of paramount importance to the erosion process, this horizon is the one that interacts directly with rainfall and is the medium to the underlying soil. Removal of vegetation thereby exposes this soil horizon to water drops which initiates erosion. The surface or A horizons of the two profiles are comparable in regards to texture, an important variable in the erodibility of a soil. Figures 4.1 and 4.2 compare the particle size distribution of the eroded sediment to the in situ soil of the A horizon. This size distribution was determined for material smaller than 495μ, partly because this material is highly susceptible to erosion since it is more easily dislodged and transported than coarser particles (Hill, 1997). Also since the smaller particles attract and retain the essential plant nutrients, their loss is important to soil fertility.

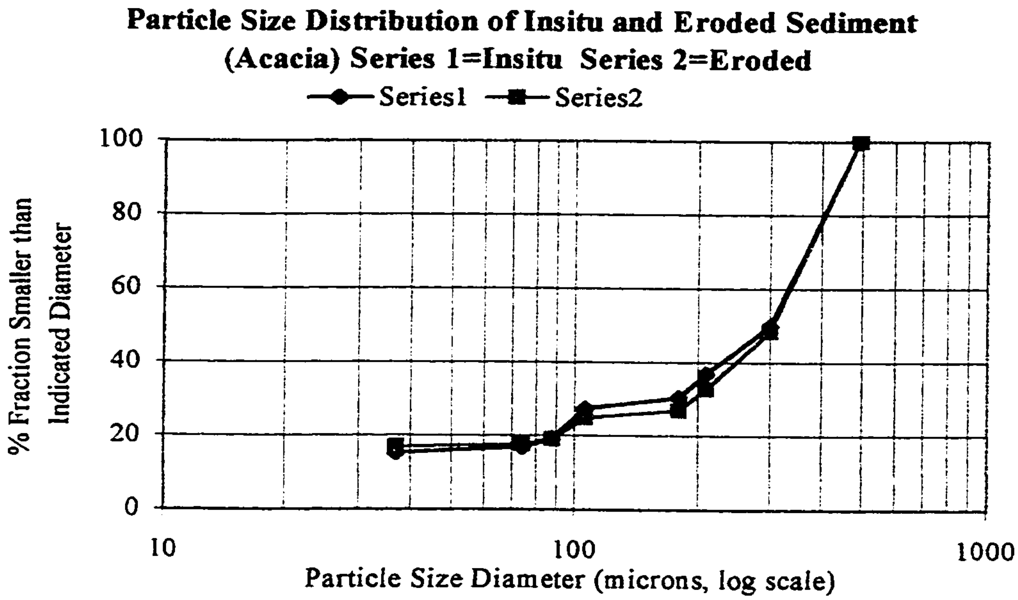

Figure 4.1: Particle Size Distribution for Eroded and In Situ Sediment (Acacia). The particle size distribution for the two sediment curves is nearly identical, revealing that no differential erosion was occurring.

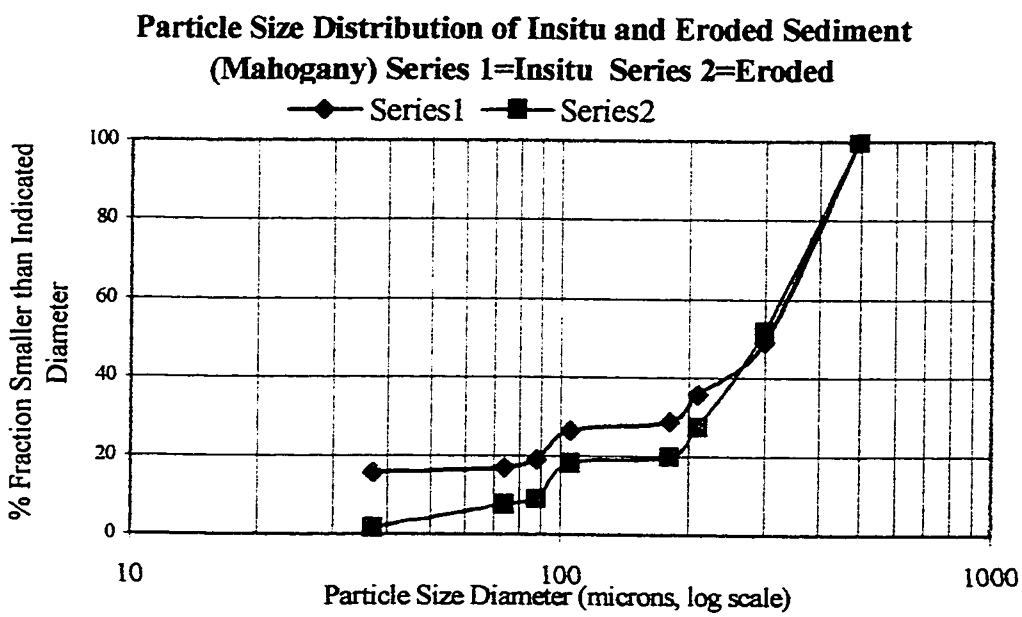

Figure 4.2: Particle Size Distribution for Eroded and Insitu Sediment (Mahogany). The eroded sediment had lower portions of fine sediment, which is opposite of what would be expected.

Coarser textured soils are generally less susceptible to erosion because they have a high infiltration rate and therefore do not generate runoff. Both A horizons were a sandy loam with a low stone to soil ratio. The mahogany's A horizon, by weight, consisted of 38.5% material over 2 mm in diameter, the acacia was minimally different at 37.4%. Organic matter content of the A horizon was 6.2% in the mahogany and 4.9% in the acacia. Variations in organic matter can be attributed to the vegetation. The grasses have a higher biomass in the A horizon and a shorter life span, thereby adding more dead plant material than the deep rooted trees and shrubs of the acacia plantation. Organic matter influences erosion through the aggregation of fine particles into larger ones, which then increase the infiltration rate of a horizon (Bissonnais, 1996). The structure of both A horizons was fine to medium granular and the infiltration rate would be similar for both.

4.5 Slope Characteristics

Slope morphology includes several variables: length, angle, shape and aspect. All of these influence the amount of runoff and soil erosion. Once precipitation is on the soil surface, the length, shape and angle of a slope will determine the velocity runoff water achieves and thereby the potential for erosion (Torri, 1996). Also of importance, are the micro-topographic variations found on the soil surface, such as depressions, small slumps and surface roughness; these micro-variations and the slope morphology variables will be considered in this segment.

In this study the slope lengths (15 m) were held constant by the flashing which bound the upper portion of the erosion plots. The same can be said for slope angles, which were similar. The slope roughness or micro-topographic variations of the two plantations were different; the acacia had less vegetative stems entering the soil. The mahogany however, had a high density of grass stems interfacing with the soil surface. The mahogany also had the remnants of a translational landslide in plot C, an indication of the area's prior instability.

The erosion plots varied in their position on the slopes. The mahogany plots were all at the toe of the slopes, while two acacia were at upper positions and one was at mid-slope. The average slope angle of the mahogany was 29.3° and 33.3°for the acacia, a difference of 4.03°. This variation is small, but the recorded slope angle runs counter to the results, which had the lower sloped mahogany with greater runoff than the steeper sloped acacia.

4.6 RESULTS AND T-TESTS

Statistical analysis is a vital part of data interpretation. In this section statistics are applied to runoff, sediment loss and nutrient loss results. Statistical tests include t-tests and Z-tests to indicate differences in means and multiple regressions to test what variables had the greatest influence on runoff, sediment loss and nutrient loss. Graphs are used to reveal the various trends in the data and to compare trends between plantations. The runoff and sediment and nutrient loss data are displayed and analyzed in two manners. First, the entire data set is considered, including the under story removal in the mahogany. Then, mahogany plantation results are displayed separately to determine the effects of the treatment. The details of the multiple regression follow once all the data are presented.

4.6.1Runoff and Sediment loss

The runoff in the mahogany plantation was greater than in the acacia plantation but it was not statistically different through the use of Z-tests. The acacia had greater sediment loss than the mahogany and this difference was statistically significant. Table 4.6 shows the total and weekly averages for runoff and sediment loss for both plantations. It should be emphasized that only 60% of the 75m^2 erosion plots were covered, therefore results can be extrapolated to the entire plantation, but the accuracy of the results will inevitably be less applicable.

Table 4.6: Total and Average Weekly Values for Runoff and Sediment Loss for the Mahogany and Acacia Plantations.

	Mahogany Plantation Total	Mahogany Plantation Weekly	Acacia Plantation Total	Acacia Plantation Weekly	Statistical Difference
Sediment (g)	238.25	18.33	670.44	55.95	Yes
Runoff (l)	142.38	10.95	94.95	7.30	No
Sediment tons/ha	0.019	N/A	0.055	N/A	Yes
Sediment kg/ha	17.61	N/A	49.58	N/A	Yes
Sediment g/m^3	5.29	N/A	14.90	N/A	Yes

The total runoff in the mahogany was 34% greater than in the acacia and seen as not statistically different, the sediment loss was 2.8 times greater in the acacia and was statistically different. It could be inferred that these differences would even be higher if the sampling had occurred throughout the rainy season; unfortunately due to time constraints the last third of the season was not sampled. Figure 4.3 shows the trend in runoff for the plantations.

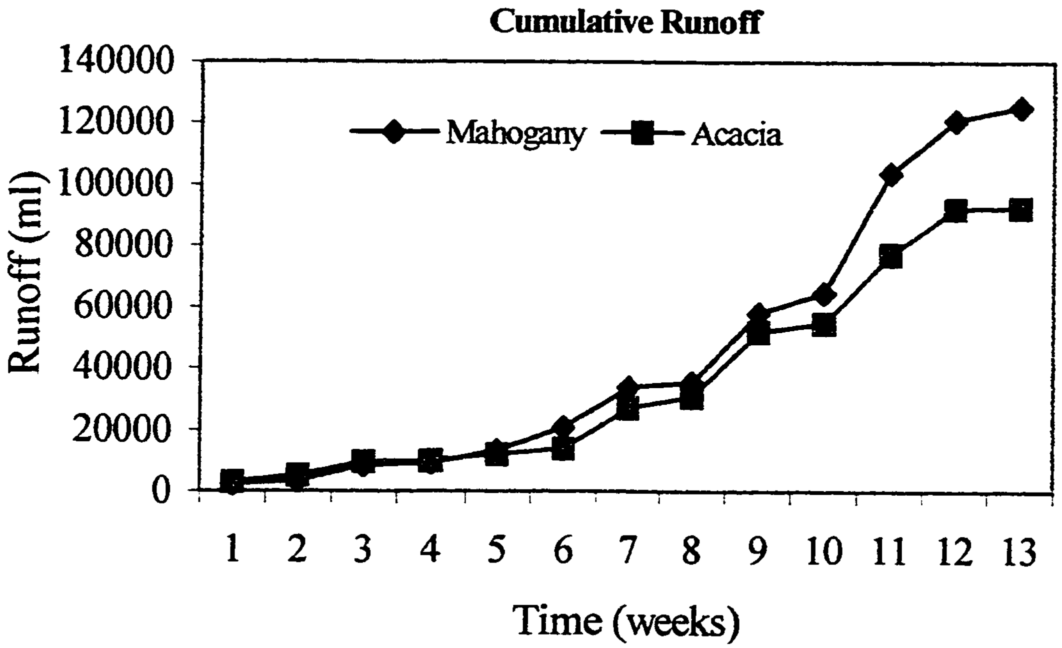

Figure 4.3: Cumulative Runoff for the Mahogany and Acacia Plantations.

Runoff is similar until the 10^{th} week (Fig. 4.3) when the slope of the mahogany line increases substantially. An increase can also be seen at week 5 in the mahogany plantation following the treatment.

Unfortunately, due to a design flaw, the possibility of leakage into the collecting pails at week 10 of the mahogany may have occurred. If this occurred direct rainfall would skew the results. This may in part explain the high runoff in the mahogany plantation. Runoff in the mahogany plantation showed a greater sensitivity to weekly rainfall changes (Figure 4.4), and continued to increase after clearing in week 4, despite decreases in rainfall; this response demonstrates the control the under story has on runoff.

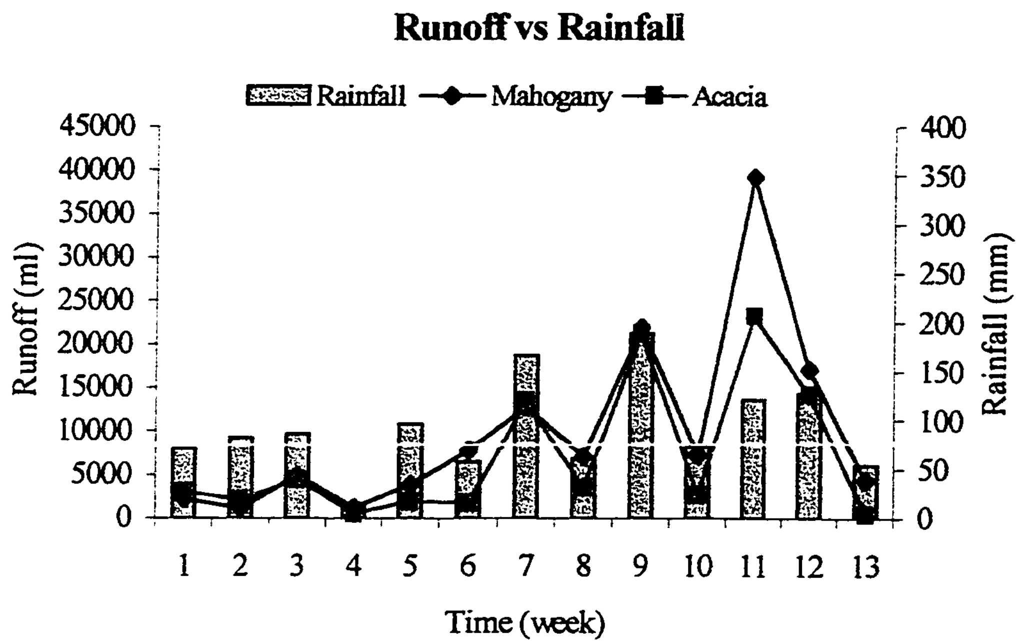

Figure 4.4: Mahogany and Acacia Runoff vs. Weekly Rainfall

In contrast to runoff, the cumulative sediment loss was higher in the acacia plantation than in the mahogany. Figure 4.5 shows the cumulative sediment loss for both plantations. Worth noting is the constant slope of both lines in relation to the slopes of the runoff lines in Figure 4.3. Sediment loss does not show the sensitivity to variation in precipitation characteristics, particularly intensity. Figure 4.6 presents the response of runoff to changes in weekly precipitation.

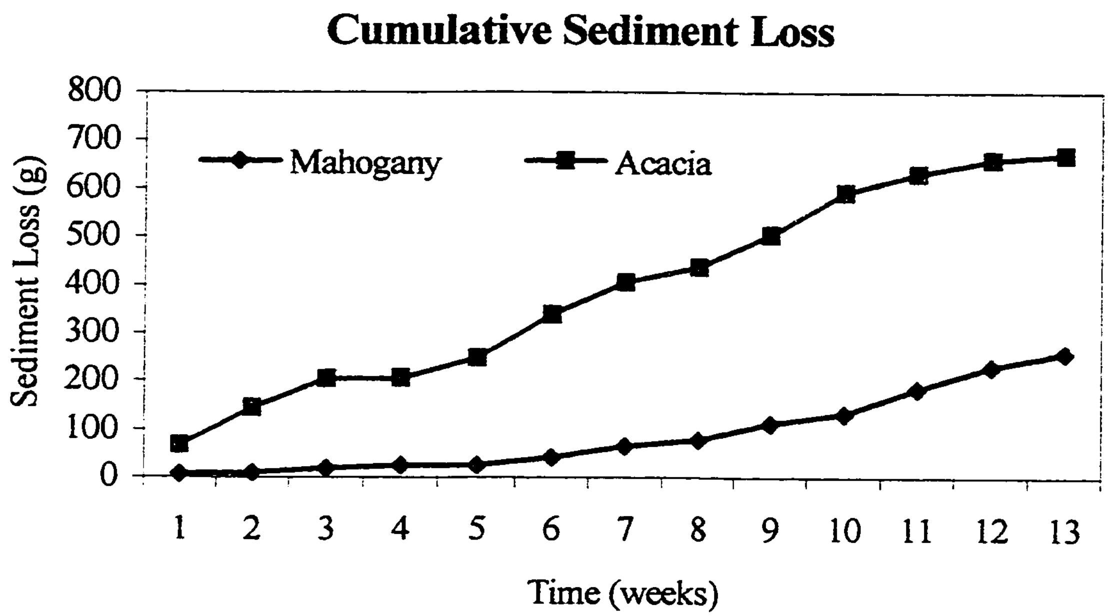

Figure 4.5: Cumulative Sediment Loss for the Mahogany and Acacia Plantation.

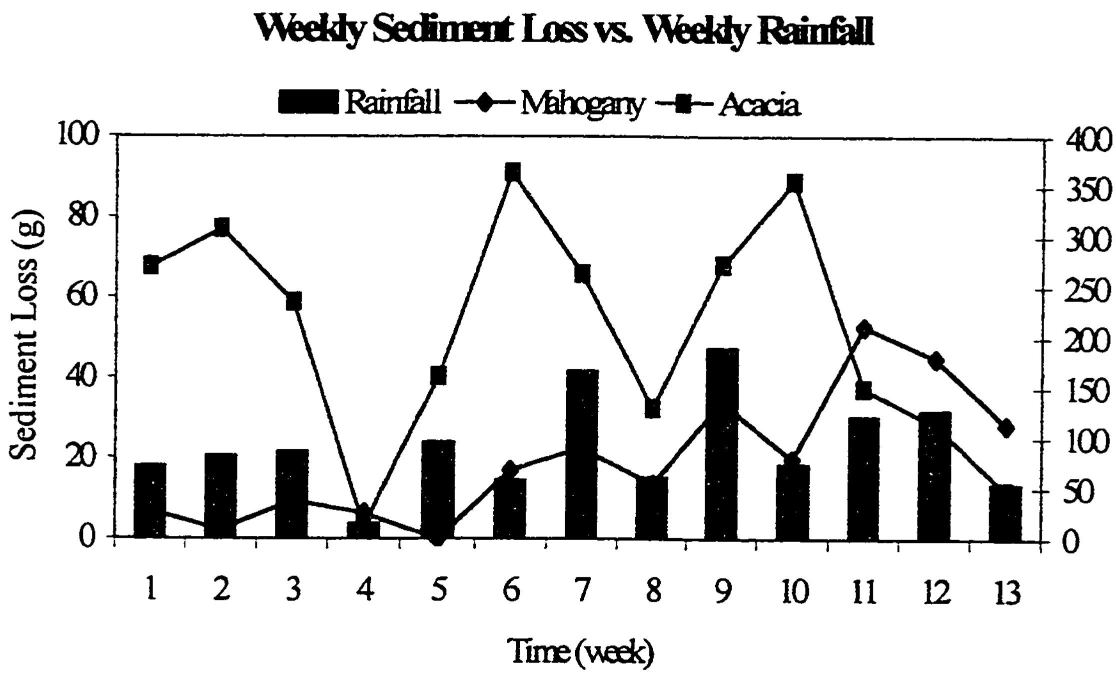

Figure 4.6: Mahogany and Acacia Sediment Loss vs. Total Weekly Rainfall.

Sediment loss in the mahogany plantation follows the rainfall patterns more closely than the acacia, suggesting a more complex relationship in the acacia. Nine of 13 changes in sediment loss in the mahogany are in accordance with the changes in rainfall, while only 6 of 13 correspond in the acacia. The magnitude of weekly change in the acacia is significantly greater than in the mahogany. The slope of the acacia line is considerably steeper than the mahogany's. Indicating that the acacia has a greater response to variations in total rainfall.

Table 4.7 shows the changes in runoff and sediment loss following the clearing of the under story. Of consideration is that rainfall events with greater totals and higher intensity occurred after the treatment making it difficult to determine if changes in runoff and sediment loss are the result of the treatment or variations in rainfall characteristics. However, when analyzing the results as a whole it is best to interpret them as a complete data set. Essentially, the changes in rainfall should be viewed as part of the treatment since it is an annual occurrence.

Table 4.7: Changes in Runoff and Sediment loss After Under Story Clearing in the Mahogany Plantation

	Pre-clearing Weekly Averages	Post-Clearing Weekly Averages	Statistical Difference
Sediment Loss (g)	6.802	25.833	Yes
Runoff (l)	2.350	14.395	Yes
Sediment ton/ha	0.001	0.010	Yes

The treatment resulted in statistically significant changes in sediment loss and in runoff. These changes are a consequence of the changes in vegetation and rainfall. Unfortunately, the affect of these two variables can not be separated. Changes in runoff and sediment loss after the treatment in the fourth week of the study can be seen in both figures 4.3 and 4.5. In the fifth week, immediately after the treatment, the runoff begins to increase at a rate greater than that of the acacia. If the grasses had been left, it would be logical to assume that runoff would be less than in acacia, due to grasses ability to decrease runoff. Figure 4.3 shows the runoff in the mahogany increasing in relation to the acacia and this difference widened as the study period continued. The effects of these variables on runoff and sediment loss are discussed in their respective sections.

4.6.2 Nutrient Losses

In a forest environment nutrient loss can occur through numerous vectors, including biomass removal, runoff, eroded sediment, volatilization, litter transport and leaching (Vitousek, 1984). These losses are important to a forest plantation and if not offset by inputs they can lead to an unsustainable system (Bowen and Nambiar, 1984). In the present study loss of nutrients was measured in eroded sediments, runoff and leaching. A nutrient budget has been constructed for the two plantations to determine if they are in an aggrading, degrading or equilibrium state. However, caution must be taken since some of the sample sizes were too small to permit any statistical analysis; these samples will be acknowledged and discussed in a descriptive manner only. The measured nutrients are all macro-nutrients, but the nutrient requirements of each tree species is not known. Therefore the impact of a loss of a specific nutrient on the tree species is not known. Table 4.8 presents the results of nutrients lost in runoff water and indicates whether there is a statistical difference between plantation types.

Table 4.8: Weekly Average Nutrient Concentration in Mahogany and Acacia Runoff Water.

Nutrients (mg/l)	Mahogany Plantation Weekly Average	Acacia Plantation Weekly Average	Statistical Difference
Al	9.200	4.873	No
Ca	5.832	9.500	Yes
Fe	1.467	0.657	Yes
K	10.367	10.369	No
Mg	0.597	1.287	Yes
Mn	0.209	0.075	No
Na	8.812	8.741	No
Total Dissolved Solids	36.484	36.085	No

There appears to be no trend in the nutrients found in the runoff water, with the exception that metals are all higher in the mahogany water. Large differences exist in Ca, Mg, Al, Fe and Mn, however only Ca, Mg and Fe are seen as statistically different and K and Na are very similar. The differences offset each other and sum to very similar total disolved solids. Since the total dissolved solids are not statistically different, these plantations are losing nutrients with runoff concentrations in equal quantities. However, the proportion contributed by each nutrient is not equal, and this will be addressed later. Table 4.9 shows the nitrate, ammonium and phosphate concentrations. While the mahogany has greater concentrations of ammonium and phosphate, statistically the only difference is the higher nitrate concentrations in the acacia plantation.

Table 4.9: Ammonium, Nitrate and Phosphate Concentrations in Runoff Water

Nutrients (mg/l)	Mahogany Plantation Weekly Average	Acacia Plantation Weekly Average	Statistical Difference
NH_3-N	2.790	1.869	No
NO_3-N	2.519	6.761	Yes
PO_4-P	1.403	1.260	No

Table 4.10 shows the nutrient concentrations in the eroded sediment of the acacia and mahogany plantations. As with the runoff water, the eroded sediment has no obvious trends, and only the Mn and Na are significantly higher in the acacia. The nutrients show variation in what vector had higher losses, runoff or sediment, but the totals (C.E.C and Total Dissolved Solids) are highly similar.

Table 4.10: Nutrient Concentrations of Eroded Sediment from the Mahogany and Acacia Plantations

Nutrients (m/eq/100g)	Mahogany Plantation Weekly Average	Acacia Plantation Weekly Averages	Statistical Difference
Al	2.985	3.251	No
Ca	29.932	28.555	No
Fe	0.004	0.004	No
K	1.218	1.535	No
Mg	3.031	3.597	No
Mn	0.028	0.037	Yes
Na	1.148	1.359	Yes
C.E.C	38.346	38.338	No

Levels of ammonia and phosphate in eroded sediment were higher in the mahogany, and nitrate was greater in the acacia, only nitrate was significantly different (Table 4.11). This was unexpected since the acacia is a nitrogen fixer and would be expected to have high concentrations of nitrogen compounds. The low phosphate concentrations are a result of phosphate fixation, a noted characteristic of volcanic ash soils (Visser, 1989).

Table 4.11: Nitrate, Ammonium and Phosphate Concentrations in Eroded Sediment

Nutrient Concentrations (mg/g)	Mahogany Plantation Weekly Average	Acacia Plantation Weekly Average	Statistical Difference
NO_3-N	0.038	0.087	Yes
NH_3-N	0.088	0.053	No
PO_4-P	0.0028	0.0022	No

Nutrients analyzed in leachate included Ca, K, Mg, Na, NO_3-N, NH_3-N and PO_4-P. However, the sample sizes for all the elements are below the acceptable size for statistical analysis. Therefore, the results only are discussed in a descriptive manner

Table 4.12: Nutrient Concentration Losses through Leachate

Nutrient Concentrations (mg/l)	Mahogany Plantation Weekly Average	Acacia Plantation Weekly Average
Ca	5.696	9.860
K	4.442	3.856
Mg	0.296	0.808
Na	9.141	8.800
NO_3-N	0.67	9.288
NH_3-N	0.43	0.560
PO_4-P	0.925	0.925

Nutrient loss through leachate (Table 4.12) was in general, marginally less than through runoff (Table 4.5). Ca, K, and Mg were all greater in runoff, with only Na being higher in leachate. Ammonia and phosphate are both considerably higher in runoff. However, nitrate was higher in leachate than in runoff in the acacia plantation.

Nutrient loss in eroded sediment is commonly greater than that of the nutrient levels of the original soil due to the differential erosion of clays and organic particles which are enriched with plant nutrients (Gachene et al., 1997). Enrichment occurred in this study and the results are given in Table 4.13, where a comparison of the nutrient concentration in eroded sediment and the original surface soil of the mahogany plantation is given.

Table 4.13: Comparison of Surface Horizon (A) Nutrient Concentrations to Average Nutrient Concentrations of Eroded Sediment of the Mahogany Plantation, Note* Indicate Increases.

Nutrients (meq/100g)	Surface Horizon	Eroded Sediments Weekly Averages	Difference (%)
Al	2.409	2.985	23.9*
Ca	9.980	29.932	300*
Fe	0.006	0.004	15
K	0.227	1.218	536*
Mg	1.526	3.031	198*
Mn	0.010	0.028	28*
Na	1.803	1.148	157
C.E.C	15.961	38.346	240*

Greater accumulations were found in all the eroded sediments of the mahogany plantation except for Fe and Na. The largest increase was for K, which was over 500% and the smallest was for Mn, which was only 28%. The metals all showed the lowest increases, a result of their insolubility. The remaining salts showed the largest increases, largely due to their abundance and solubility (Gachene et al, 1997). The C.E.C. doubled largely a repercussion of the increase in eroded Ca. Table 4.14 shows the enrichment of nutrient attached to sediment over that of in situ soil of the acacia plantation.

Table 4.14: Nutrient Concentration of Surface Horizon in Comparison to Eroded Sediment of the Acacia Plantation, Note: * Indicate an Increase.

Nutrient (meq/100g)	Surface Horizon	Eroded Sediment Weekly Average	Difference (%)
Al	2.890	3.251	12*
Ca	11.132	28.550	256*
Fe	0.007	0.004	17.5
K	0.223	1.536	688*
Mg	1.231	3.597	292*
Mn	0.005	0.037	7.4*
Na	0.353	1.359	384*
C.E.C	15.841	38.334	241*

Increases in the nutrient concentration of the acacia's eroded sediment occurred in all elements except Fe, one of the two that decreased in the mahogany sediment. Of the 7 elements composing the C.E.C., 5 were removed at greater rates in the acacia plantation than the mahogany plantation, as well as the total C.E.C. itself. The greatest increase was seen in K, which was also the highest in the mahogany plantation. K is highly soluble and this may increase its mobility. As in the mahogany plantation, the acacia plantation shows the metals as being the least mobile and the remaining salts having the greatest changes. The validity of the above comparisons should be tempered by the fact the surface horizon nutrient concentrations are based on only one representative sample. However, a trend is still obvious in that out of 14 opportunities (seven elements for each plantation) the sediment nutrient concentration increased 11 times. In this study a selective removal of nutrients occurred indicating a decline in soil fertility. The two surface horizons are very similar in their nutrient status (not statistically tested) and the nutrient losses are similar in terms of the C.E.C., which indicates both plantations are losing nutrients at equal rates. However, some nutrients are being lost in different amounts.

The above tables expressed nutrient losses in small imperial units, however more practical and understandable units include losses expressed in mass or area. Losses expressed in mass also are preferred so the results are comparable to Ciccaglione's (1998) and other researcher's results. Table 4.15 compares results in the present study to Ciccaglione's, which were collected under bananas on steep and moderately slopes.

Table 4.15: Mahogany and Acacia Plantation Nutrient Loss in Eroded Sediment Compared to Ciccaglione (1998). Statistics refer only to this study

Nutrients (g/kg)	Mahogany Plantation	Acacia Plantation	Statistical Difference	Moderately Sloped	Steeply Sloped
Al	0.265	0.297	No	0.020	0.040
Ca	5.811	5.736	No	1.200	2.700
Fe	0.001	0.001	No	0.006	0.004
K	0.477	0.644	No	0.250	0.400
Mg	0.368	0.450	No	0.080	0.280
Mn	0.014	0.010	Yes	0.020	0.100
Na	0.264	0.336	Yes	0.070	0.080

Only Mn and Na are statistically different, the same as when expressed in meq/100g. Both plantations resemble the steeply sloped site most closely and have higher nutrient loss for all nutrients except Mn.

The above tables all present nutrient losses; the following table (Table 4.16) present a nutrient input, in the form of precipitation and also some of the previously mentioned nutrient losses to give nutrient balances for both plantations. Metals were not included in the budget and once again the sample sizes for some of the data in the budget were not adequate for the results to be statistically validated.

Table 4.16: Mahogany and Acacia Plantation Nutrient Budget. Note: all data is in (mg/l) < D.L = Below Detection Limit; Bold Lettering Indicates Net Nutrient Status. (R= Runoff, L= Leachate and P= Precipitation)

	Mahogany			**Acacia**		
Nutrient (C.E.C)	Combined Average R + L	Precipitation (mg/l)	P-(R+L)	Combined Average R + L	Precipitation (mg/l)	P-(R+L)
Ca	11.528	1.900	**- 9.628**	15.692	1.900	**- 13.792**
K	14.809	0.479	**- 14.33**	14.223	0.497	**- 13.736**
Mg	0.893	0.142	**- 0.751**	1.405	0.142	**- 1.263**
Na	17.953	6.657	**-11.296**	17.612	6.657	**- 10.955**
NO_3-N	3.46	0.700	**- 2.76**	11.157	0.700	**- 10.457**
NH_3-N	2.949	< D.L	**- 2.949**	7.321	< D.L	**- 7.321**
PO_4-P	2.328	0.767	**- 1.561**	2.185	0.767	**- 1.418**

Table 4.16 shows all 7 elements in both plantations are being lost at a rate greater than they are being replaced by inputs from precipitation. This data suggests that both these plantations are degrading in their nutrient status. Table 4.16 does not include nutrient loss through sediment, however, based on the negative balance shown in the above table, the inclusion of nutrient loss by sediment would further increase the negative balance. Even without leaching, runoff alone exceeded inputs.

The vector resulting in the greatest nutrient loss is important to know, since a high mass or volume loss vector in relation to a low concentration may falsely lead one to believe that a high nutrient loss is occurring or the exact opposite. Table 4.17 is a comparison between nutrient loss in sediments and runoff. It shows which vector was responsible for the majority of the losses and combines runoff and sediment loss for a total loss.

Table 4.17: Comparison of Nutrient Loss in Runoff and Sediment. (R= Runoff and S= Sediment Loss (g/ha).

Nutrients (g/ha)	Mahogany (R)	Mahogany (S)	Acacia (R)	Acacia (S)	Total Mahogany	Total Acacia
Al	96.8	4.7	34.3	14.5	**101.5**	**48.8**
Ca	63	102.3	66.8	283.2	**165.3**	**350**
Fe	10.5	0.017	4.6	0.055	**10.5**	**4.65**
K	109.1	8.4	72.9	29.8	**117.5**	**102.7**
Mg	6.2	6.5	9.0	21.7	**12.7**	**30.7**
Mn	2.2	0.247	0.527	0.504	**2.4**	**1.0**
Na	92.7	4.6	61.4	15.5	**138.7**	**76.9**
NO_3-N	29.3	1.5	13.1	47.6	**30.8**	**59.8**
NH_3-N	26.5	0.669	47.5	6.0	**27.2**	**53.5**
PO_4-P	14.8	0.049	8.9	2.3	**14.8**	**11.2**

Table 4.17 reveals that in the mahogany plantation, runoff was the main cause of nutrient loss except for Mg and Ca. In the acacia plantation Ca, Mg and nitrate were more abundant in sediment than runoff; the remaining nutrients were higher in runoff. Of the 10 above nutrients analyzed, mahogany lost six in amounts greater than the acacia.

The last nutrient data to be presented are the effects of under story clearing. Considerable changes in soil nutrients occurred after under story clearing, which was expected with the mineralization of nutrients through decomposition of the cut vegetative matter.

Table 4.18: Changes in Soil Nutrients Following Under Story Clearing

Nutrients (meq/100g)	Pre-clearing Weekly Average	Post-clearing Weekly Average	Statistical Difference
Al	2.701	3.033	Yes
Ca	18.920	35.599	Yes
Fe	0.004	0.005	No
K	1.191	1.232	No
Mg	2.404	3.551	Yes
Mn	0.024	0.029	Yes
Na	1.142	1.218	No
C.E.C	26.386	44.637	Yes

Unfortunately, the sample size for testing changes in nutrient concentrations in runoff water after under story clearing was too small to be statistically valid. Table 4.18 shows that all seven elements making up the C.E.C. increased after under story clearing. Statistically, Mn, Mg, Ca, Al and the C.E.C. were all different.

4.7 STEPWISE REGRESSION ANALYSIS

The following section presents the results and equations of six separate stepwise regressions. Regressions were performed on runoff, sediment loss and nutrient loss for both mahogany and acacia plantations. The variables all were acceptable for regressions, in that they did not violate any laws of normality or correlation based on matrices and scatter plots. Outliers were not detected by Mahalanobis analysis (Davis, 1986).

4.7.1 Mahogany Plantation

The first regression conducted was on sediment loss, with four independent variables: above average number of precipitation events/week that exceeded above average weekly intensity (A.A.E.), total precipitation, runoff and vegetation change (as a dummy variable). The units applied to the sediment loss figures are grams of soil. Their addition was based on their correlation coefficients (R) with the dependent variable, which were as follows: runoff 0.875, (A.A.E.) 0.528, vegetation change 0.577 and total precipitation 0.428. However, after examining the correlation matrixes it was determined that the correlation between three of four of the independent variables was too high to be included in the regression equations. (These variables also were rejected automatically by the stepwise regression, which found their contribution to the descriptive power of the equation to be insignificant.). Total precipitation and A.A.E. correlated at 0.876, total precipitation and vegetation at 0.480 and vegetation and A.A.E. at 0.380. Therefore, only runoff entered the regression and produced an R-value of 0.828 and a R^2 of 0.685. By squaring the runoff correlation coefficient (0.828), a percentage of the variability in the sediment loss explained by runoff was 68.5%. The calculated regression equation was

$$\textbf{\textit{Sediment Loss}} = \mathbf{7.486 + 0.0013(x_{Ri}) + \ldots \pm 3.656} \qquad (4.1).$$

Equation 4.1 states that mahogany sediment loss is equal to the constant 7.486, plus the value for runoff (regression coefficient {0.0013}) multiplied by the observed value for runoff plus or minus the standard error of estimate (+ or – 3.190). The best fit line in scatter plot 1 of appendix C supports the results of the above regression equation, it has a positive slope, showing that as runoff increases sediment loss increases. There were no outliers detected by the Mahalanobis analysis, but the scatter plot does show a data point that is considerably higher than the others. This point occurred on a date (July 31) that coincides with the highest intensity event of the study period, 100mm/hr. As has been noted by Ciccaglione (1998) who recorded an event of 240mm/hr, events of these magnitudes are not outliers. They occur during the rainy season, but since only a portion of the season was measured only three of these events were recorded. The two earlier events of 92mm/hr and 88mm/hr, did not generate high amounts of runoff and sediment loss since the litter from the under story was still intact and protected the soil. These two events also were followed by high amounts of litter collection in the troughs. If the study had been longer, more of these events may have occurred. Overall, runoff was the independent variable that explained the greatest portion of the variability (68.52%) in the sediment data. The ANOVA for the above equation revealed an F value of 23.939 and a critical value of 4.84. Therefore, the null hypothesis (there is no significant relationship between X and Y) was rejected. A P value of 0.0005 was also generated.

Although not in the regression equation, the scatter plots of vegetation and total weekly precipitation vs. sediment loss are included in appendix C. Both these had a positive linear relationship with sediment loss. The increase in sediment loss after clearing does pose a statistical problem, because it is difficult to determine if increases in the measured variables are a result of changes in precipitation or the applied treatment. However, events of equally high magnitude as described earlier and with similar total weekly rainfall, that occurred before the under story clearing did not have as high as sediment loss as those after. The 0.00 point on the scatter plots corresponds to a low runoff week, but also to the week when the under story was cleared. The abundance of fresh litter would have acted as an excellent soil protector, resulting in infiltration of most of the runoff or surface detention, which would be evaporated later, in turn decreasing sediment loss.

The second mahogany regression involved runoff (units as ml of water) as the dependent variable and as with sediment loss, A.A.E., total weekly precipitation (TWP) and vegetation as independent variables. Once again, through stepwise regression two of these were excluded: total precipitation and vegetation, leaving A.A.E. as the sole independent variable. The TWP correlation coefficient was 0.621, vegetation's was 0.488 and A.A.E. was 0.641. The correlation between the rejected variables was 0.850 between A.A.E. and total precipitation, 0.416 between total precipitation and vegetation and 0.219 between A.A.E. and vegetation. The following equation was generated using only A.A.E.

$$\boldsymbol{Runoff = 690.266 + 2214.961(\chi_{AAEi})\ldots \pm 4138.864} \qquad (4.2)$$

Equation 4.2 states that the mahogany runoff is equal to the constant 690.266, plus the value for A.A.E. (the regression coefficient β_1 {2214.961}) multiplied by the observed value for A.A.E. plus or minus the standard error of estimate ($\pm$ 4138.864). The above equation resulted in an R-value of 0.641 and a R^2 of 0.411which accounted for 41.0% of the variability in runoff. The ANOVA revealed a F value of 8.307, again rejecting the null hypothesis (critical value = 4.84). A P value of 0.015 was also included.

The scatter plots (5&6) for the two excluded variables both displayed a positive linear relationship with runoff and again, the high intensity event of July 31 is distinguished by the high runoff point just under 40,000 ml. Also, of interest is the alignment and distribution of points on equal values of A.A.E. on scatter plot 4. Weeks with an equal number of A.A.E. generated different amounts of runoff, suggesting a variable outside of A.A.E. (possibly total precipitation) affecting runoff. The higher runoff events of equal A.A.E. occurred after under story clearing. Furthermore, the vegetation had an R value of 0.498; this value is evidence to suggest that changes in vegetation are influencing runoff even though the variable was rejected from the regression equation.

The third and final regression for the mahogany plantation allotted nutrient loss (units in C.E.C) as the independent variable. Nutrient loss is related to the movement of sediment and runoff water, which are controlled by rainfall characteristics (Bernhard-Reversat, 1987). Initially, the nutrient loss regression included total rainfall and runoff, but the correlation matrix revealed that these two independent variables had a coefficient of 0.572. Based on the large size of this number, rainfall was removed since it had the lower R-value with nutrient loss. The relationship between runoff and nutrient loss is expressed as follows:

$$\textit{\textbf{Nutrient Loss}} = \mathbf{21.376 + 0.0017(\chi_{Ri}) + \ldots \pm 3.126} \qquad (4.3)$$

Equation 4.3 states nutrient loss is equal to the constant (21.376) plus the value for runoff (0.0017) multiplied by the observed value for runoff (χ_{ri}), plus or minus the standard error of estimate.

This equation generated a Pearsons Coefficient (R) of 0.922, a R^2 of 0.851 and explained 85.10% of the variability found in the nutrient loss data. This is a strong relationship, stating that as runoff increased, nutrient loss increased. Although, it should be realized that increases in nutrient loss are not directly related to the amount of soil lost, as it is a measurement of the concentration of a fixed weight of soil. However increased runoff has been shown to have greater amounts of nutrients (Kang and Lal, 1981). Therefore, increases represent changes in the nutrient regime of the soil and these may be related to under story clearing. Scatter plot 7 shows the relationship between nutrient loss and runoff. It is highly linear, with high runoff having high losses of nutrients. In scatter plot 8, sediment loss can be seen to have a positive and highly linear relationship with nutrient loss. The distribution of total precipitation against nutrient loss (scatter plot 9) is similar to runoff since, it is in part controlled by precipitation. A F value of 57.356 rejected the null hypothesis and a P value of 0.0 was included.

The three independent variables used in each of the separate stepwise regressions, showed positive correlation's and explained 68% (runoff) of the variation in sediment loss, 41% (A.A.E.) of the runoff and 85 % (runoff) of the nutrient loss. All of the rejected variables also showed positive linear correlation's as seen in appendix C. One unexpected result was the lack of influence the weekly average rainfall intensity had on the dependent variable; it appeared this variable controlled the dependent variables through runoff. The inclusion of A.A.E. as an independent variable in a regression equation and its high correlation coefficient, suggests the time periods with a high number of events with exceptionally high intensities have large losses. Not simply those with a high weekly average intensity and total amount of precipitation.

4.7.2 Acacia Plantation

Three regressions also were performed on the dependent variables sediment loss, runoff and nutrient loss to determine what explained the variation of these variables in the acacia plantation. The screening procedure followed was the same as the one described in the mahogany plantation. Correlation matrices were checked for extreme coefficients and scatter plots were done for the variables (Appendix C & D). The correlation matrices revealed that the acacia had different variables with higher coefficients; therefore, several new independent variables were used in the regression equations. However, this change in independent variables confounded any comparisons between the two plantations, but also revealed that different processes are at work in the acacia plantation. The first regression was done on sediment loss, but none of the entered variables were accepted into the equation. The highest correlation was with total weekly rainfall (0.347), followed by duration (0.338) and the number of events (0.300).

The second attempted regression was for runoff water (units in ml water) and again different variables were entered into the equation. A.A.E. (0.824), total weekly rainfall 0.791) and maximum weekly intensity (0.512) all had reasonably high R values, but total rainfall and maximum intensity were too highly correlated and were excluded based on the rules of multicollinearity. This exclusion resulted in the following equation being generated.

$$\boldsymbol{Runoff = -1869.303 + 2126.581(\chi_{AAE}) \ldots \pm 2284.330} \quad (4.4)$$

The above equation states that runoff is equal to the constant (-1869.303) plus the value for A.A.E. (the regression coefficient, 2126.581) multiplied by the observed value for rainfall, plus or minus the standard error of estimate (2284.330). A R^2 of 0.679, an adjusted R^2 of 0.650 and a 68% explanation of variation in the runoff data were the outcome. A F value of 23.266 rejected the null hypothesis and a P value of 0.001 was generated.

The third and final regression was for nutrient loss (units in C.E.C) in the acacia. Entered independent variables included number of weekly events (0.609), A.A.E. (0.537) and total weekly precipitation (0.514). Of these the stepwise method only permitted number of events to remain in the following equation.

$$\textit{Nutrient Loss} = 29.020 + 0.710(\chi_{NE})\ldots \pm 3.755 \quad (4.5)$$

This equation shows that nutrient loss is equal to the constant (29.020) plus the value for number of events, multiplied by the observed value for number of events (χ_{NE}), plus or minus the standard error of estimate (3.755). This equation resulted in a R^2 value of 0.371, and adjusted R^2 of 0.313 and shows that number of weekly rainfall events explained 37% of the variability in the nutrient loss data. The ANOVA showed a F value of 6.475, thereby rejecting the null hypothesis and generated a P value of 0.027.

4.4 Chapter Summary

The above sections have presented all the results of runoff, sediment loss and nutrient dynamics. These results have been discussed and statistics have been applied whenever possible. General trends have been noted and shown in graphic form. Runoff has been shown to be higher in the mahogany, although not statistically significant by t-tests. Sediment loss was 3 times greater in the acacia and was significantly different. This counter-intuitive phenomenon is attributed to the differences in the vegetation of the two plantations and the effects on precipitation. Also, the presence of a compacted subsurface in the mahogany may be responsible. Although not tested statistically, runoff had more nutrients with a greater amount of nutrients than that of leachate, making it the main liquid vector. Only Ca, Fe and Mg were significantly different in the runoff and total dissolved solids were extremely similar. Nutrient loss caused by soil erosion also proved to be similar. The nutrients in the eroded sediment in both plantations were considerably higher than in the soil profiles. Consistent with the tendency for differential erosion of clays, organic matter or both. There was little difference in the nutrient loss between the two plantations. However, the loss of sediments which hold the nutrients was three times higher in the acacia, meaning that overall there was greater loss in the acacia plantation through sediment loss. From the above data it also can be stated with a certain degree of confidence that the plantations are losing more nutrients than are being replaced in precipitation. The factor off setting this must be the weathering of parent material.

The regression analysis was able to reveal that the dominant variables controlling sediment loss were runoff in the mahogany and an undetermined variable in the acacia. Runoff was best explained by A.A.E. in both plantations and nutrient loss by runoff in the mahogany and the number of weekly events in the acacia.

CHAPTER 5.0

DISCUSSION

5.1 Introduction

This chapter discusses the results presented in chapter 4. Trends in the data are noted and explained, in addition to the recognition and discussion of apparent anomalies. The discussion considers variations in the soil profiles and then runoff and sediment and then nutrient losses. For runoff and sediment loss, the discussion for both plantations is done simultaneously so as to allow for a direct comparison.

5.2 Soil Profile Characterizations and Discussions

5.2.1 Mahogany Soil Profile Characterization.

The mahogany soil profile was topped with a moderately thick LFH layer (2cm-5cm), although this did vary with changes in the under story. Following clearing, areas of bare soil were noted, likely where workers had struck the mineral surface with their cutlasses. These areas expanded as decomposition proceeded, it appears the expansion rate was greater than the rate at which the vegetation was recovering. This layer had a positive influence on all the measured variables as it would have encouraged greater infiltration rates and surface detention (Temple, 1972). Also contributing to the expected high infiltration rate is the coarse texture of the A horizon (Sandy Loam) and its structure (fine-medium granular). In fact, the entire profile had a texture (coarse) and structure (granular) conducive to high percolation, which explains why runoff was highest during the weeks of greatest rainfall and high A.A.E. It would take a substantial amount of water to saturate the profile or exceed the infiltration rate of the A horizon. The possibility of saturation may be increased by the presence of the discontinuous sand/gravel layer present between B2 and IC. The downward movement of water may be repelled into lateral movement by the macropores of the sand which have less attraction for water than the finer textured soil above (Strand, 1996). Moreover, the finer textured soil below the gravel layer would cause lateral flow once the profile was saturated (Brady, 1990). This phenomena also was noted by Strand (1996) in blue mahoe plantations and secondary rain forest sites where it is thought to be the cause of landslides. The possibility exists that the gravel layer may also be responsible for the old landslide in plot C. Sub-surface lateral flow and runoff may also be affected by the presence of a platy B horizon of a firm consistence at 23cm depth in the mahogany plantation. This layer would have impeded percolation and generated runoff quicker by saturating the soil between the B horizon and the surface. During high intensity events, the upper 23cm absorbed rainfall and it is possible the water moved laterally over the horizon down to the toe of the slope where it reemerged near the troughs. This lateral movement would occur because the water table near the toe of a slope is closer to the surface and soil here would be more saturated (Singh, 1992). Water resurfacing here would be at a low velocity due to a shorter slope length and unable to detach soil particles because of the shortened slope length. All three mahogany plots were located at the toe of the slope.

Organic matter trends were as expected, with the highest levels occurring in the A horizon, where the death of grass roots added organic matter (Judd, 1979). The organic matter of this horizon also has the beneficial effect of controlling erosion. The polysaccharides produced by soil fauna act as a bonding agent and promote aggregation of smaller soil particles into larger ones; giving the aggregates greater stability than individual soil particles (Hausenbuiller, 1987).

Organic matter drops substantially in the mahogany gravel layer and then increases downward in the lower profile. These moderately high levels of organic matter act as a reservoir for plant nutrients (Primavesi, 1968), which explains the moderately high C.E.C. in the surface horizon. The recorded C.E.C. values are similar, although slightly lower than those reported by Ciccaglione (1998) and Strand (1996). The lower nutrient status might be related to the high biomass of the grasses that efficiently retain and absorb mineralized nutrients with their shallow rooting system. Low C.E.C. may also be attributed to the high sand and low clay content, which would reduce the number of exchange sites. The trend in the C.E.C. correlates directly with the changes of organic matter changes (see appendix B).

The pH decreases with depth, resulting in an inverse relationship with organic matter, a result of the organic humic acids released from weathering (Hausenbullier, 1987)(see appendix B). One possible explanation for this may be related to the chemical composition of the parent material; variations during a volcanic eruption may result in a profile with such inverse relationships (Martin-Kaye, 1969). Electrical conductivity showed a general decreasing trend with slight increases in the C horizons. These trends follow organic matter and are likely related to leaching of salts from the horizons above. Of the discussed soil characteristics, all except pH show increases below the coarse sand layer (see appendix B). The layer appears to be acting as a funnel for the solution component of the soil. This also occurred in Strand's (1996) study area, and may suggest that the lateral movement of water at this contact is not as prevalent as considered earlier because of a higher hydraulic conductivity.

The platy structure of the B horizon in the mahogany also could influence the horizon development. The structure of this horizon (B) would have decreased the amount of water entering deep into the profile, thereby limiting the weathering of the parent material.

5.2.2 Acacia Soil Profile Characterization

The acacia profile was more than two times the depth of the mahogany; this depth was a result of continued variations in the acacia profile as the pedon was dug. The mahogany profile had greater homogeneity and further digging was unnecessary. The difference in the complexity and depth of the two profiles could have several explanations, which may be attributed to the manner of deposition of the volcanic parent material. The mahogany is north facing, therefore, ash and pyroclastic deposition would have accumulated at a greater rate than on the south facing slope. This is a result of the angle of the northern slope in relation to the trajectory of the incoming tephra from La Soufriere. Essentially, the exposed material of the pedon on the north facing slope was never deposited on the south facing slope. Had the north facing pedon been excavated further, there was a possibility of exposing a buried south facing pedon. However, this hypothesis only can apply if the coarse sand layers are not equal in age. To understand the sequence of events that occurred dating methods would be required which are beyond the scope of this study. However if the coarse sand layers are equal in age, their distance from the surface could be a marker indicating the degree of erosion. The acacia's coarse sand layer was 11cm closer to the surface, suggesting greater erosion, which the results confirm.

The discontinuous nature of the acacia litter layer and, its almost total lack of a H and F layers, likely are associated with the steep nature of the slopes. Runoff water transported the litter to progressively lower areas of the plantation until it accumulated at the lower reaches or on smaller flatter areas on the steeper slope. The areas where litter did accumulate would have provided soil protection, but overall the litter layer was not highly conspicuous.

Although there was no evidence of landslides in the acacia plantation, the upper horizons were highly unstable due to the lack of grasses and their dense root network, and also due to of the soil structure, which caused a rolling of aggregates when disturbed. At the conclusion of the study, several mini-landslides had been initiated by the trails formed by our movements.

The lower organic matter content of the acacia plantation is related to the lack of grasses and their organic inputs. Levels generally decreased with depth, but the slight increase at 105cm is not explainable (see appendix B). Although, it is possible that the increase in organic matter could be the result of a buried A horizon. The lower organic matter content may have also resulted in a less stable structure of the A horizon compared to that of the mahogany. This structure could have made the horizon more susceptible to erosion. The organic matter drops sharply through the sand/gravel layer as in the mahogany, reinforcing the horizon's role as a "funnel".

As with mahogany, the acacia's pH increases with depth as the organic matter decreases, until passing through the sand layer, whereabouts the pH increases. This trend is again reversed as to what is expected, and might be attributed to variations in the parent material. The pH of the lower horizons is more basic, and is likely associated with the high levels of bases at lower depths. Of particular interest, is the trend in C.E.C. of the acacia profile. The surface horizon of the acacia is very similar to the mahogany, however, it shows decreases with depth and then increases four fold at 65cm with these values continuing until the bottom of the profile. The increases are the result of increases in the bases not the metals of the soil. The cause of this is also likely to be of a variation of the parent material, which may be from different volcanic eruptions.

5.3 Runoff and Sediment Loss in the Mahogany and Acacia Plantations

Section 4.6 of chapter 4 showed the results of the runoff and sediment loss in the mahogany plantation. The runoff was higher in the mahogany plantation, although not statistically different. This was unexpected since the roots and stems of grasses are known to decrease runoff, these results are therefore an anomaly. Different types of vegetation affect soil properties and microenvironments around the plants. Vegetation differences cause variation in organic matter input, aggregate stability, soil shear strength and other erosion parameters. Differences in these soil properties likely are related to architecture, growth, biomass production, and incorporation of organic matter into the soil matrix (Andreu et al., 1998).

There is substantial contrast in the physical and biological structure of the two plantations. Even though the plantations are equal in age, they have each developed a very different physical structure. One of the most obvious differences is the partially closed canopy of the acacia. Although this canopy does not have a great deal of multi-layering, it is a robust and mature plantation. In contrast, the growth of the mahogany is well behind the acacia which is not unexpected, for it is well known that acacia is one of the quickest growing tree species in existence (Ruskin, 1983). The differences in vegetation affect the behavior of water once it is intercepted, and it also influences various soil properties (Andreu et al., 1998).

The differences in runoff and sediment loss may have been even greater if the sampling period had extended further into the rainy season. This prediction is based on the fact that the mahogany shows greater magnitudes of change in runoff than the acacia with increases in total weekly rainfall (Figure 4.4). A similar phenomena also was revealed by Strand (1996) when he noted that a blue mahoe plantation on St.Vincent generated a greater magnitude of runoff than a secondary rainforest when higher intensity storms occurred. Figure 4.3 shows the cumulative runoff for both plantations. The changes in the slope of the line indicate the response of the two plantations to weeks of varying rainfall. The mahogany shows greater changes, which suggests that it is more sensitive to changes in rainfall, especially during the last several weeks of the study.

Runoff, as mentioned earlier, may also be affected by the occurrence of the B horizon, which is at a depth of 23 cm and platy in structure. This horizon may be impeding percolation due to high moisture levels at this depth, thereby generating runoff due to saturation of the above horizons. Nortcliff et al., (1990) demonstrated the following; that 6% of the total precipitation occurred as runoff under forested and partially cleared plots and 16% under cleared plots. However, upon closer examination it was discovered that runoff outputs as great as 22.6% were occurring, depending where on the slope measurements were taken. A lateritic layer at 38cm was causing increased runoff by impeding percolation due to the higher moisture levels at this depth.

Nortcliff's results support the earlier presented argument on the effects of the finer and platy structured B horizon in the mahogany generating greater runoff.

The patterns of runoff did not correspond exactly to total weekly rainfall and several factors might account for the variation, the first being the amount of canopy coverage. The mahogany had a lower degree of canopy coverage (30%). In contrast, the acacia's canopy, which provides greater coverage (60%), would intercept and evaporate more rainfall. This means that twice the amount of rainfall was intercepted by the acacia canopy (the leaf area was similar for both species). Runoff in the mahogany may also be generated quicker, since the open canopy would allow incident rainfall to collect on the grasses, and be funneled to the soil surface. Thereby saturating the soil quickly and generating runoff. In the acacia the canopy would have to first become saturated (Brandt, 1990) before throughfall and runoff could begin. The horizontal leaf structure of the acacia under story would also intercept and retain or alter through fall and decrease runoff. However, the influence of the canopy on affecting the forest water balance would be prominent only at the beginning of storms. Once a canopy is saturated its effects decrease substantially (Dorenwend, 1977).

Also affecting weekly variations in runoff were the antecedent soil moisture conditions, unfortunately there was no equipment available to perform this (Hausenbuillier, 1987). In 10 of the 13 weeks the acacia plantation had lower runoff than the mahogany. This may suggest different weekly soil moisture conditions, which would influence the following weeks conditions.

The presence of higher runoff in the mahogany plantation leads to the questions of why more sediment was not detached and transported by it. Temple (1972) showed that grasses ability to decrease erosion was due to their surface coverage and not their impedance to flowing water. Conflictingly, Unger (1996) states that the factor controlling runoff velocity and soil detachment is plant stem density, therefore there should be lower runoff in the mahogany plantation. Runoff may have been occurring in the mahogany plantation at a given velocity that was to low to detach soil particles. However, what is a more likely explanation, regardless of the runoff velocity, is the presence of grasses and their rooting systems. Grasses have a high density of fine surface roots, these roots physically bind soil and increase its resistance to detachment by runoff. The results also contribute to the soil organic matter and therefore increase its stability. Essentially, the soil in the mahogany plantation is not available to be eroded (Salleh, 1996).

In contrast to runoff, the cumulative sediment loss was higher in the acacia plantation than in the mahogany, as is shown in Figure 4.3. Similar to runoff, the slopes of the two lines of sediment loss are different, although relatively constant. The steeper line of the acacia indicates a greater sediment loss under equal rainfall than that of the mahogany. Neither line shows any sharp increases in slope angle, indicating little sensitivity to changes in rainfall, even when shifting from a low rainfall week to a high one. The slope also remains constant during weeks when there was an above average number of average intensity events. The greater sediment loss in the acacia suggests that the vegetation is altering the incident rainfall from its original form into one with a greater erosive power.

The alteration of the rainfall by the vegetation, which may have caused differences in runoff, also is hypothesized to be the cause of the large differences in sediment loss between the two plantations. The average height of the acacia canopy is 8.9m, only 1.1m short of the height at which most drops reach terminal velocity and have their greatest kinetic energy (Lal, 1990). Another source demonstrated that only 8m is needed for drops to reach 95% of their terminal velocity (Young, 1991). Rainfall collecting on the acacia's leaf surface coalesced into larger drops and then reached their terminal velocity upon falling; this resulted in water with greater erositivity or erosive power. A general observation put the canopy drip drops in the range of 3.00mm-4.00mm, and drops this size reach terminal velocity in 8.1m and 8.8m respectively and result in slash erosion (Lal, 1990). Drops of these sizes also have been shown to move fine soil particles as far as 1.06m and move 2mm fragments 18cm (Dorenwend, 1945). Therefore, the potential of a lower amount of water reaching the soil surface, but causing more erosion, is plausible. Although, to verify this, the kinetic energy of direct rainfall and canopy drip would need to be measured for both plantations.

The rain falling through and off the canopy would be intercepted by the under story, however, this layer may not necessarily decrease the kinetic energy of the water. The effectiveness of the under story is a factor of its height above the forest floor and the percent throughfall intercepted (Dorenwend, 1977). However, it is the lack of a litter layer (approximately 40%) which ultimately allows the kinetically enhanced canopy drip to strike the soil surface, resulting in splash erosion. The above statements are further supported by Salleh (1996), who found that changes in vegetation are enough to substantially alter (increase) the flow of energy and matter through the adjoining hill slope and soil subsystems. Vegetation functions as a regulator, controlling the magnitude and types of processes operating on erosion of the hill slope system. The steeper angle of the acacia, combined with the lack of litter, also can help explain the differences in the amount of sediment lost. It has been demonstrated (Ekern et al., 1950) that as slope angle increases, rain falling on a bare soil surface will eject soil particles asymmetrically, predominantly in a down slope direction. The grasses in the mahogany would have prevented symmetrical particle ejection since the rain would have been intercepted before it reached the soil surface, however such ejection could have occurred in the acacia because of its exposed surface. Splash erosion also is controlled by the trajectory of the water drops striking the surface. Incident rainfall normally does not fall perfectly vertical, which can cause a greater portion of the kinetic energy of the water drops to be transferred to up slope movement of the dislodged sediment. However, when falling in a vertical manner onto sloped land a greater amount of kinetic energy is delivered to down slope movement. This type of rainfall was common in the acacia plantation; the result of the canopy intercepting precipitation on an angle and then releasing it vertically as canopy drip (Torre et al., 1996).

It also is possible the effect of the difference in slope angle is being underestimated. Slope angle is the dominant factor in determining runoff and Temple (1972) demonstrated changes at low slope angles (1.5° to 3.5°) more than doubled sediment loss. The difference between the slope means of the mahogany and acacia plantations, 4°, is enough to cause an increase in sediment loss with comparable quantities of runoff. Temple states it is soil factors, such as slope and infiltration rate which control sediment loss, and not always necessarily the amount of water.

The litter layer is of paramount importance in controlling runoff and sediment loss in plantations and forests (Lowdermilk, 1930; Weirsum, 1983). It is this fact that does not coincide with the higher runoff in the mahogany plantation and which is largely unexplainable. In the acacia, the discontinuous litter layer left areas of soil exposed, and it is this spatial variation that affects rates of soil erosion (Spencer et al., 1990). The lower amount of water passing through the canopy in relation to that falling directly in the mahogany plantation generated runoff and rills were formed. However, the dominant form of erosion appeared to be splash erosion caused by canopy drip. The lack of a litter layer in the acacia allowed the water to move more freely and have a greater impact on the soil surface. This is not to say overland flow did not occur, surface sealing and decreases in infiltration resulted in small rills formed above plot E in the acacia plantation. Moreover, the low litter accumulation should not be misinterpreted. *Acacia mangium* has a very high rate of litter fall with annual rates as high as 9.7 t/ha (Bernhard-Reversat, 1993). However on the steep sloping land of the study area, little litter accumulates due to slope angle, and therefore never has the opportunity to act as a protective barrier.

Of particular interest is the results of the size distribution between the in situ and eroded sediment (Figures 4.1 and 4.2). The acacia showed only a slight decrease in eroded sediment size, but the mahogany had considerable differences. These results can in part be explained by the behavior of clay in the presence of a high organic matter. The organic matter increases the tilth, or aggregation of clays. These aggregates can be substantial in size and under low flow rates fine sands will be detached first. As overland flows increase over excellent tilth soils, an increase in eroded sands occurs and clay erosion decreases (Monke et al., 1977). An alternative explanation may be that the clay particles were being displaced into subsurface pore spaces, reducing infiltration and increasing runoff and detachment of the sands remaining on the surface (Rasiah and Kay, 1995).

Changes in the mahogany runoff after the under story clearing in the fourth week of the study can be seen in both Figures 4.1 and 4.3. In the fifth week, immediately after the clearing treatment, the runoff begins to increase at a rate greater than the runoff of the acacia. Sediment loss also increases, as indicated by the change of the slope in Figure 4.3. If the grasses had been left, it would be logical to assume runoff would be less than if they had not been cleared, a result of their ability to act as barrier to runoff. Figure 4.3 shows the runoff in the mahogany increasing relative to the acacia and this difference widened as the study period continued. The increased runoff seems to be the result of the cut vegetation decomposing and the eventual transport of the litter. After 5 weeks, decomposition had proceeded to the point where areas of bare soil were exposed; decomposition also broke the litter down to a size suitable for transport by runoff, thereby exposing even more soil. The exposed patches of soil are subject to rainfall without protection, resulting in runoff. Apparently, decomposition occurred quicker than re-growth of the under story; therefore, higher erosion would occur until the vegetation had re-established itself.

The results of the treatment were expected since it is known that a low lying vegetative layer is a pivotal factor in minimizing runoff and soil erosion (Wiersum, 1984). Weeding slash left as mulch also has been shown to reduce the rate of organic matter losses in young plantations as a result of the addition of organic matter and the reduction in surface temperature which decreases decomposition (Lundgren, 1980). The mahogany trees in this study also had numerous lianas, which may have decreased erosion by slowing stem flow and runoff at the base of the trees, but the lianas would have also been competition for the trees.

At present, the mahogany trees themselves appear to be contributing little to erosion control. The grasses are more likely responsible for the changes in water dynamics. If the mahogany trees were not present, the grasses would simply encompass the entire plantation. Regardless, the state of mahogany plantations on St.Vincent are similar to the study site and are representative of other plantations of similar age. One older mahogany plantation was observed which was in established in 1968/69. This plantation, the oldest on the island, gives the only insight into how a mature mahogany plantation on St.Vincent may appear in the future. The trees here were in excess of 30m with a dense narrow canopy and an under story containing no grasses, but made up of a low lying shrub layer with a well established litter layer. The site was on a 20° slope, but there appeared to be no signs of erosion in this plantation, although, this is not supported by quantifiable data. Alternatively, it has been suggested the need for maintenance is enough in itself not to use mahogany as a plantation species. The canopy of mahogany is too narrow, which results in an inability to suppress competition, making it a high maintenance tree. (Lamb, 1966) Conclusions based on these observations are discussed in chapter 6.

5.4 Nutrient Loss

Nutrient cycling is linked directly to ecosystem productivity, but depending on the purpose or state of a system (i.e: agriculture, plantation forest, natural forest) productivity may or may not be important. On St.Vincent, sustained, but not necessarily high productivity, is the current goal; that is, the protection of soil and water resources. However, productivity can be threatened by soil erosion. Soil erosion affects the chemical properties of a soil through the loss of organic matter and minerals, and by exposure of the acidic and infertile subsoil. If these losses are not being offset, then a system will decline in productivity. Moreover, it is not uncommon for plantations of middle age to experience declining growth associated with these losses, particularly nutrient deficiencies, thereby increasing the significance of nutrient losses (Goss, 1984). In general though, soils which have been under cultivation over long periods and are depleted of nutrients. In such cases reforestation has been shown to increase nutrients and organic matter content.

The vegetation of an ecosystem has a strong influence over the nutrient regime. Rooting systems, litter inputs, decomposition patterns, crown density and water and nutrient requirements are all involved in nutrient cycling (Jordan et al., 1979). The mahogany and acacia plantations were very different in their vegetative composition, and it would be expected these differences would influence nutrient dynamics and losses.

The C.E.C. of the eroded sediments contained amounts of nutrients that were extremely similar (mahogany C.E.C.=38.346 and acacia C.E.C.=38.338). The soil surface horizon of the plantations also proved to be very similar (mahogany C.E.C.=15.961 and acacia C.E.C.=15.841), which means that the similarities in eroded nutrients cannot be explained by differences in the in situ soil. The vegetation does not appear to be affecting the concentration of nutrients in the sediment, or if it is, the effect is equal from both vegetation types. Nevertheless, the total nutrient loss from the sites is related to the magnitude of the overland flow and sediment loss combined.

The higher runoff in the mahogany resulted in greater nutrient loss by this vector (7 of 10 nutrients) than in the acacia (not statistically). Alternatively, higher sediment loss in the acacia resulted in greater nutrient loss in the acacia, but again not statistically. The relation of runoff volume and sediment loss to total nutrient loss was also demonstrated by Pandy et al., (1983). Regardless of three times the sediment loss in the acacia, the nutrient concentrations and combined higher amounts of runoff in the mahogany resulted in greater total nutrient loss for 6 of 10 nutrients.

All nutrients in both plantations are lost at greater amounts in runoff except calcium and magnesium, suggesting an affinity of these nutrients for sediment. The loss of total nitrogen (NO_3-N and NH_3-N combined) was also higher in sediment, but only for the acacia. Reasons for this may be associated with nitrogen fixation and litter with high nitrogen content (Osman et al., 1995). While the higher nitrogen losses in the mahogany may have been proportionally related to the greater runoff. The results of the NH_3-N (ammonia) concentrations are as expected. Acacia, being a species that has a symbiotic relationship with nitrogen fixing bacteria, would lose more NH_3-N. Fixation occurs through the reduction of atmospheric nitrogen (N_2) to NH_3-N (Mengel, 1985); it occurs on root nodules, where carbon based compounds released by the tree are metabolized by bacteria in exchange for N-fixation. Nitrogen is then transferred throughout the tree including the foliage. Upon senescence and mineralization, the nitrogen is released on the surface and is then subject to erosion. The quality of the plant litter further affects nitrogen dynamics (Gosz, 1984). Acacia litter decomposes quickly due to its high N content, thereby exposing nitrogen to loss (Bernhard-Reversat, 1993). In the mahogany plantation, the nitrogen is in the biomass in lower amounts, less litter is produced and released at slower rates allowing absorption and lower losses.

Leaves in both plantations would likely play only a minor part in overall nutrient input. The mahogany leaves made up only a small portion of the litter, while the acacia leaves made up more, but had greater litter transport. What may be of importance here are the accumulation of biomass and the store of nutrients. Earlier studies (Maclean and Wein, 1977) have shown that in a *Pinus banksiana* plantation the under story contributed 6% of the biomass in older plantations and 88% in younger plantations. Under story species selectively store nutrients in their biomass influencing the nutrients exposed to losses. Based on the sheer biomass of the mahogany under story, a greater amount of nutrients are immobilized than in the acacia's under story, thereby affecting nutrient cycling losses (Gosz, 1977).

The acacia and mahogany had similar rooting systems, except the acacia's was of a greater magnitude. The acacia trees had deeper rooting, which would give the trees access to nutrients beyond the reach of the mahogany root system (Jordan and Herrera, 1981). In contrast, the mahogany's roots extended less than half the distance of the acacia's. However, due to their increased surface area, the denser root network of the grasses in the mahogany would be expected to decrease the amount of nutrients lost to erosion (Stark and Jordan., 1977). However, this was not the case since statistically, nutrients were lost from the plantations in equal amounts. Although, this is only when nutrient loss is considered on a sample bases. When the total mass of soil lost (which was greater in the acacia) is considered the acacia lost a great overall amount of nutrients with sediment. In contrast, although nutrient loss was equal in runoff water, the mahogany had greater runoff and therefore greater nutrient loss as runoff. However, to determine which plantation is loosing greater overall amounts of nutrients would require further study, including parent material analysis.

Clearing the under story resulted in an nutrient increase of 60%, this can be accounted for by the plant debris being left on site. This practice results in an increases in soil nutrients from the decomposition of the litter, similar to burning plant debris but not as rapid nutrient release (Ulh and Jordan, 1984). As the field season proceeded the cut plant litter decomposed, releasing nutrients the soil retained against leaching or runoff losses. Essentially a nutrient flush occurred, but these levels are not maintained. Once new under story starts to grow again it restores the nutrients back into biomass. If this study had been extended, it is expected decreases would appear.

In some cases there is concern that exotic species will sterilize the soil because of their heavy nutrient demands (Bowen and Nambiar, 1984). However, the high weathering rate of andosols, is related to the high surface area of volcanic ash and the high precipitation some andosols form under. These qualities result in the release of nutrients and soil sterilization does not seem to be a factor. Volcanic ash parent material also has a large amount of plant nutrients stored in it (higher than crystalline rock) that enables andosols to buffer nutrient losses (Shoji and Ono, 1977).

The relationship of runoff to nutrient loss in sediment is highly correlated as the regression equation in chapter 4 indicated. This correlation suggests the concentration of nutrients is increasing on the soil particles, or more exchange sites are occupied at higher runoff. The most obvious reason for increases would be the increases in the nutrient concentration of runoff, which is supported by some results. Kang and Lal, 1981 showed that as runoff increased K and Na also increased, but the opposite occurred for Ca and Mg. For this study, the week with lowest runoff shows nutrient concentrations higher than those of the week with the highest runoff. June 4th of the mahogany (lowest runoff) had higher nutrient concentrations for seven of seven recorded nutrients, while August 6 (highest runoff) had lower concentrations. Higher volumes of runoff may be diluting the nutrients, which are being taken up onto exchange sites. Dilution at high precipitation and concentration at low precipitation has been shown for leachate (Jordan, 1982) and this may be taking place with runoff quantities in this study.

The above circumstances do not appear to be occurring in the acacia plantation. Four of seven elements increased with higher runoff. One explanation for the acacia not concurring with the mahogany results might be the presence of different clays. The composition of the parent material or the rate of weathering can produce different clays (Maeda, 1977). It is possible there is a difference in clay composition of the two sites, which would in turn alter the charge potential and create scenarios other than the expected. There is a complex relationship between nutrients, water, sediments and the amounts they all are present. Overall the nutrient losses of the seven macro-nutrients making up the C.E.C in this study are similar to results reported from other tropical catchments (Kang and Lal 1981; 1973 ; Forti and).

The importance of nutrient dynamics on plantation management was demonstrated by Lugo et al., (1990) when they discovered that certain plantation species, including mahogany, store high amounts of certain nutrients in their litter. Given such storage ability, species selection can influence a proposed strategy to support nutrient accumulations and availability in litter and soil. Different species also affect the timing and rate in which nutrients are returned to the forest floor. Therefore, the nutrient cycling characteristics of a species are an important factor when selecting a species' suitability to a particular environment.

The above nutrient loss should be considered in light of each species nutrient requirements, through this losses become more relevant. The mahogany has a higher nutrient demand than the acacia (Ruskin, 1983). Therefore, losses are more detrimental to growth. The acacia is able to grow under harsh conditions such as very rocky or shallow soils. Overall mahogany is losing a greater amount of nutrients, while requiring greater amounts, therefore, these losses have greater impact than in the acacia plantation. However, these losses may still not be enough to have large impacts on growth.

Of consideration is the timing and duration of the study. It was performed during the beginning and middle of the rainy season; therefore the maximum amount of water was not moving through the system, which influences nutrient concentrations. The study was also only 13 weeks and an annual budget is impossible to determine since extrapolation would not be legitimate.

5.5 Effects of Precipitation

There appears to be a relationship between runoff, rainfall intensity and total weekly rainfall. The last variable influences the antecedent soil moisture conditions, which are also important in the initiation of runoff. Of the 13 changes in total weekly rainfall, the runoff in the mahogany changes accordingly 9 times and the acacia 7. In addition to this, weeks 6, 8, 9 and 10 exceed the average number of above average intensity events (A.A.E) although they do not correspond with all the weeks with the highest runoff. However, high runoff weeks do correspond with the above average intensity weeks when they coincide with high total weekly rainfall weeks (Figure 4.1). This relationship suggests that not only intensity, but also total rainfall, is related to runoff. Total weekly rainfall has implications in soil moisture; therefore, if high intensity events occur during low rainfall weeks, the soil is less saturated and has a higher infiltration capacity. In contrast, during high rainfall weeks, the soil is at a high degree of saturation and therefore generates runoff more readily when above average intensity events occur.

Also worth noting is the slope of the runoff line in Figure 4.1. During the weeks with an above average number of above average intensity events, the slope of the runoff line increases. Of the 4 weeks with an above average number of average intensity events, 2 have the slope of the mahogany line exceeding the acacia line, indicating that when there are an above average number of average intensity events the mahogany responds with greater runoff. It is reasonable to assume that this is related to the structure and percent coverage of the canopy, but this is somewhat counter intuitive to well understood processes. With a greater level of exposed soil in the acacia, surface sealing should occur and create runoff sooner than in the mahogany plantation (Agassi Levy, 1991). However, given the coarse texture of the surface horizon, sealing would become less important and soil saturation would become the main variable controlling runoff (Shainberg and Levy, 1992).

The effects of intensity and duration can have a significant influence on soil erosion. Storms of low intensity are thought to have little impact on erosion, but this impact can change with vegetative influences. In the acacia plantation, once the canopy was saturated, larger drops began to drip and initiate splash erosion, which could continue for hours under low intensity events (Dorenwend, 1977). While in the mahogany plantation this water would be infiltrating or flowing slowing, not exceeding the velocity to overcome the sheer strength of detachment. Therefore, low intensity events of long duration can exceed the kinetic energy of short high intensity events depending on the vegetation cover (Dorenwend, 1977).

The pattern of sediment loss corresponds with weekly changes in total rainfall more closely in the mahogany than in the acacia; 8 out of 13 and 6 out of 13 respectively. The correspondence of weekly sediment loss with the weeks with an above average number of average intensity events is not as similar as the runoff data. The slope of the acacia line in Figure 4.3 is considerably steeper than the mahogany with the exception of the final three weeks, when the acacia line levels off. The increases in the acacia's sediment loss correspond with the weeks with an above average number of above average intensity rainfall events. This implies sediment loss in the acacia plantation has a greater sensitivity to higher intensity rainfall events. Since the precipitation characteristics are equal for both plantations, the changes in runoff and sediment loss must be the result of variations in the soil, vegetation, or micro-topography.

The yearly distribution of rainfall will control the loss of nutrients by sediment loss, runoff and leachate since it is the primary vector of the nutrient movement (Ulh and Jordan et al., 1984). The sampling for this study was done with the largest portion in the rainy season, but also at the end of the dry season. Hence, the data represents nutrient loss neither at its greatest or at its lowest. Nutrient loss through soil erosion is highest during the rainy season, although this is not necessarily the case for runoff and leachate. During the rainy season the runoff and leachate are diluted and concentrations are not as high as during the dry season (Ulh and Jordan, 1984). This does not mean more nutrients are lost though; during the rainy season the water is less concentrated, but there is a greater abundance of nutrients available to off set the lower concentrations. The ionic concentrations of the precipitation collected on St.Vincent is similar to results collected in other tropical areas, but not for all elements. Table 5.1 presents these comparisons. Sodium has the largest differences but these figures can not be tested statistically due to a limited sample size.

Table 5.1: Rainwater Mean Ionic Values (mg/l).

Locale (references)	Na	K	Mg	Ca
Kampala	1.7	1.7	-	0.05
Turrialba	0.25	0.11	0.04	0.06
Panama	-	0.50	0.25	1.50
Ivory Coast	0.20	0.06	0.20	1.10
New Guinea	0.31	0.03	0.01	0
CentralAmazon	0.08	0.06	0.02	0.06
St.Vincent	**6.657**	**0.497**	**0.142**	**0.050**

5.6 Statistical Discussion

The following section reviews the results of the regression equations from chapter 4 and scatterplots in appendix C. The logic behind the inclusion and exclusion of independent variable will be considered, as well as cases where the regression could not be performed.

The reason for conducting multiple regression on this data was to determine what variables are responsible for controlling the independent variables: sediment loss, runoff and nutrient loss.

Negative constant values (i.e., negative y intercepts) indicate that a threshold value exists which must be exceeded before the dependent variable begins to rise above 0 (i.e., runoff does not begin until soil infiltration capacity is exceeded). Positive y-intercept values (constant) indicate a variable other than the independent causing the dependent to change. In the case of scatter plot 1, movement of forestry workers through the plot during the treatment could have caused sediment to fall into the traps. Additional possibilities include heaving due to wetting and drying and wind.

5.6.1 Mahogany Sediment Loss

From equation 4.2, it was determined that sediment loss in the mahogany plantation was (statistically) controlled wholly by the independent variable runoff (χ_{Ri}) with a $R^2 = 0.685$. The positive sign of the regression coefficient combined with the slope of the line from scatterplot 1 (see Appendix C) indicates that as runoff increased, sediment loss increased. Runoff was therefore able to account for 68.5% of the variability in the sediment loss data. The ANOVA showed that there is a significant relationship between X and Y and that the probability of committing a type two error was below 0.00.

The two variables, vegetation and A.A.E. were excluded because of their influence expressed in the runoff. This can be seen by the high correlation between A.A.E. and vegetation and runoff (see Appendix D). The slopes of the best fit lines of A.A.E. and vegetation show a positive linear relationship. They also indicate that increases in A.A.E. and changes in vegetation were reflected in sediment loss increases. Reinforcing the relationship between runoff and sediment loss is the extreme case in which runoff reached 40,000ml. This week also coincides with the week with the highest sediment loss (see scatterplot 1).

Scatter plot two also reveals an interesting fact. The week with the most above average highest intensity events did not generate the greatest sediment loss, the second highest did. Further examination of total weekly rainfall indicates that the week preceding the week with the lower sediment loss, had only 69mm of rain. The week with lower A.A.E. and greater sediment loss was preceded by a week with 121mm of rainfall. What high rainfall in preceding weeks demonstrates is the importance of the antecedent soil conditions in affecting the occurrence of runoff. As discovered by Ciccaglione (1998) (who suggests soil moisture as an independent variable), this study also shows the influence of soil moisture on sediment loss is substantial. This relationship also was stressed by Temple (1972), who found rainfall events occurring after higher intensity events produced as much as eight times the amount of runoff with only a 5% difference in intensity. Scatter plot 1 shows that at 0ml runoff a low amount of sediment loss is still occurring (y-intercept), this suggests that variables other than runoff are influencing erosion. Several possibilities include disturbance by forestry workers or other individuals, shrinking and swelling of the soil surface due to wetting and drying and wind.

5.6.2 Mahogany Runoff

The runoff in the mahogany plantation was best explained by equation 4.2 using the independent variable A.A.E, with a R^2=0.411. Scatterplot 4, and the positive value of the regression coefficient (b_1 = 2214.901), indicate that as A.A.E. increased, the runoff increased. A.A.E was able to explain 41% of the variability of the runoff data. The ANOVA revealed that there is a significant relationship between X and Y, all be it not as high as some of the other regressions. A P value of 0.015 showed that the probability of making a type two error was 1.5%.

The excluded variables, total weekly rainfall and vegetation, both had positive relationship with runoff. The correlation of rainfall intensity and rainfall quantity to runoff in forested watersheds has been shown by Pandy et al (1983) and Bren (1979). The relation of total rainfall to runoff can confidently be related back to soil moisture conditions, based on the sediment loss conclusions and the findings of soil moisture importance by Ciccaglione (1998) and Temple (1972). However, the effect of the independent variable, vegetation, on runoff is difficult to determine since increases in precipitation also occurred after the clearing treatment.

5.6.3 Mahogany Nutrient Loss

Nutrient loss in the mahogany plantation was best explained by the independent variable runoff. An R^2=0.851 was generated that explained 85% of the variation in the nutrient loss data. This highly correlated relationship is demonstrated by the positive value of the regression coefficient (b_2= 0.0017) and the slope of the best-fit line in scatter plot 7 (with a R^2 of 0.851), the slope of the line is nearing 1:1). This relationship intuitively makes sense since the nutrients are attached to the soil exchange sites and therefore runoff controls both sediment loss and nutrient loss. A F value of 57.356 indicated a significant relationship between X and Y, and a P value of 0.0 showed there was a 0% possibility of making a type two error.

The rejected independent variables, sediment and total weekly rainfall, both had high R-values. The slopes of both their lines indicate they are contributing to nutrient loss, but this is being expressed through runoff, sediment loss as explained above, and total rainfall by affecting runoff.

The clustering of points below 10,000ml on scatter plot 7 reveals the processes of differential erosion are taking place. At these low runoff volumes only finer materials (clays/allophane) would be dislodged and transported, but these particles retain the majority of nutrients. At higher runoff volumes both fine and coarse material would be eroded, but coarser material would make up a greater portion of the eroded and analyzed sediment, thereby repressing the losses if the sediment was all clays.

5.6.4 Acacia Sediment Loss

The complete rejection of all entered variables in the sediment loss regression equation was unexpected after a strong relationship was found in the mahogany plantation. It is believed the cause of this rejection is the complexity of the vegetation in the more forest like acacia plantation. The vegetation altered some of the precipitation characteristics, primarily intensity and total amount. Hence these were not as important controlling factors in the acacia sediment loss regressions. However, it is still perplexing that no independent variables, including runoff, were kept in the equation. The lack of independent variable acceptance suggests that rain splash erosion was the more dominant erosive force and runoff only a partial cause.

5.6.5 Acacia Runoff

From equation 4.4 the runoff in the acacia plantation was explained solely by the independent variable A.A.E (χ_{AAEi}) with an R^2=0.68. The positive value of the regression coefficient (b_1=2126.58) combined with the results from scatterplot 10 show that as A.A.E. increase, runoff increases. As the single independent variable, A.A.E was able to explain 68% of the variation in the acacia's runoff data. A F value (23.266) revealed a significant relationship between X and Y and the P value (0.001) indicates a low probability of making a type two error. The higher R^2 of the acacia in comparison to the mahogany (0.41) is odd; runoff presumably would be related more closely to precipitation in the mahogany because of the lack of a canopy to intercept and alter the precipitation.

The remaining two variables, total precipitation and maximum weekly intensity, were excluded from the equation as their contributions to sediment loss were expressed through A.A.E (see Appendix D). The scatterplots (11 and 12) of these omitted independent variables show they have a positive linear relationship with runoff volume, meaning that as they increased, runoff increased. These scatterplots suggest the vegetation may have been altering the rainfall, but these variables still have a direct relationship with runoff. The question then arises, why do these variables not have a relationship with sediment loss? Understandably, total precipitation's influence on runoff and sediment loss will be related to the distribution and intensity of the rainfall. However, the clustering on scatterplot 10 is at very low runoff volumes, possibly too low to cause erosion.

The four points on scatterplot 10 with the highest A.A.E. and runoff correspond to the four weeks with the greatest sediment loss. This correspondence leads to the possibility that a combination of rain splash and runoff are responsible for sediment loss. During high intensity events, runoff would be generated by a high amount of through fall, causing surface sealing and then erosion. But during lower intensity events, sealing does not occur and rain splash would be the dominant erosive mechanism.

5.6.6 Acacia Nutrient Loss

Equation 4.5 best explained nutrient loss in the acacia plantation. However, the only independent variable that remained in the regression equation was the number of weekly events and the correlation between them is intuitively weak. Nonetheless, an R^2=0.31 was obtained which explained only 37% of the variability in the nutrient loss data. The lower F value (6.475) still indicates a significant relationship between X and Y, but results in a larger P value 0.027. A positive linear relationship is apparent through the regression coefficient (χ_{NEi}) and scatter plot 13 (see Appendix C). Scatter plot 13 does show some heteroscedasticity in both variables. This suggests either non-normality in one of the variables, or that one variable is not related to the other directly, but rather through a transformation (Tabachnick and Fidell, 1989).

The relationship between the omitted independent variables, A.A.E. and total weekly precipitation, can be seen in scatter plots 14 and 15 (see Appendix C). Nutrient loss increases with increases in both of these variables. The number of events is directly related to total weekly precipitation, therefore its contribution to nutrient loss was expressed in the number of events.

5.7 Statistical Conclusions

The regressions for the mahogany plantation proved to have a greater predictive power than the ones generated for the acacia plantation. The major reason for the greater predictive power is hypothesized to be the extreme difference in the structure of the vegetation, which is altering several of the characteristics of the rainfall. The results of the mahogany were as expected, with runoff controlling sediment and nutrient loss, and the R^2 values ranging from medium (0.41) to high (0.84). The independent variable, above average number of above average intensity events/week, modeled runoff the most accurately. Since the weekly average intensity was omitted from all the equations, it is suggested that the number of high intensity events is more important than the intensity itself. However, this may be associated with the antecedent soil conditions.

6.0

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary andConclusions

The results of this study indicate that mahogany has a higher amount of runoff, but the acacia has three times the sediment loss. Although the results are counter intuitive, these differences are explained through variations in the vegetation, namely the rooting systems of the grasses in the mahogany plantation binding the soil. Greater erosion in the acacia plantation might in part be the result of the tree heights, which increase drop size and erosive power. The canopy may have also had minimal influences by retaining water in its dense canopy during short events or the beginning of longer ones.. The presence of a compacted B horizon may also be generating runoff in the mahogany. An anomaly that can not be fully explained is the higher runoff in the mahogany plantation in the presence of the grasses.

Nutrient concentrations in runoff and sediment were not significantly different, but since the acacia lost statistically significant greater amounts of soil, it lost more nutrients with sediment. The mahogany lost greater amounts of nutrients in water. The nutrient input from precipitation is not offsetting losses, which implies that neither plantation is agrading degrading. What must be considered though are inputs by the weathering of parent material and nitrogen fixation (acacia only). The growth of the plantations (especially the acacia) suggest that these inputs are great enough to compensate for the measured losses. Unfortunately, some of the sample sizes used in the nutrient work were below an acceptable limit; therefore some of the results were not statistically tested.

Statistical analysis by t-tests show that the differences in runoff were not significant but sediment loss was. The loss of some nutrients was significantly different, but the total C.E.C and the total dissolved solids were not. The clearing of the under story resulted in significant increases in runoff, sediment loss and nutrient loss.

Stepwise regression analysis was able to demonstrate that in the mahogany plantation runoff controlled sediment loss and nutrient loss and A.A.E. controlled runoff. Sediment loss in the acacia was not significantly correlated with any independent variable and no equation was generated. A.A.E. predicted nutrient loss most accurately and the number of weekly events was the most highly correlated with nutrient loss.

The results of the present study should assist the Division of Forestry in combating the on going problem of soil erosion on St.Vincent. The island is not only faced with the obvious problems associated with soil erosion, but also the numerous side effects that accompany it. Including siltation of rivers which destroys the habitat of aquatic life (both fresh water and marine), fills in water catchment areas resulting in a decrease in their effectiveness. In addition to sediment washing into streams, fertilizers and biocides/agrochemical (pesticides and herbicides) also enter with the sediment and runoff. These chemicals, although in smaller amounts, still pose a direct and immediate threat to humans and these carcinogenic substances also threaten animals that use the streams as a source of drinking water.

The initiating reason for the above problems is deforestation for the expansion of agricultural cultivation. For reasons that are often complex and economic in nature, Vincentian farmers expand cultivation into the secondary and remaining primary rain forests. In most cases these expansions are not the choice of the farmer based simply on the desire for growth, but are driven by external overseas policy the farmers have no control over.

St.Vincent has a limited land base for its flora and fauna have to retreat to when the forests are destroyed. Also, many species are adapted to a specific environment and do not display the necessary flexibility to move into new areas. In addition, the biodiversity of St.Vincent is being threatened and the effects of deforestation are seen through a decline in wildlife populations. One species that has been affected is the Vincention Parrot, which is battling to stabilize its population.

There exists on St.Vincent an inherent lack of forest protection. This is due to the lack of funding to adequately support a larger Division of Forestry and increased manpower. Forest patrolling is routine, but deforestation is occurring in areas that are extremely difficult to monitor. In some cases the clearing is not known about for some time since the deforestation is done in the upper watershed. There are laws in place protecting the forests, but these are not acknowledge.

The problems on St.Vincent seem overwhelming, but some farmers are sincerely dedicated to proper land management, and more encouraging is the dedication of the Forestry Division and its workers to a sustainable environment on St.Vincent. One action of the Forestry Division has been the removal of farmers from land illegally cleared, especially in areas used as a source of water. The lands that remain after a farmer is relocated are inherently unstable and must be managed to prevent serious deterioration. Land degradation is avoided by establishing forest plantations of exotic species or another alternative is to allow natural succession to proceed and use secondary forests in reclamation attempts. The problem with secondary forests is that many farmers do not hold them in high regard and have no problem with cutting them, forests are seen as unproductive land. Alternatively, plantations are associated with the Forestry Division and farmers are more aware of the penalties that can occur if cutting takes place.

However, through general observations and prior research, it has been demonstrated that some species of trees are not efficient at controlling erosion. Therefore, in order to keep using exotic trees, species that are better at reclamation are required. The objectives of the study were to access two species and to help solve the problems associated with stabilizing former agricultural land.

The current study dealt with the second most commonly used plantation species on St.Vincent, the mahogany (*Sweitenia macrophylla*) and a newer, less popular plantation species (at this time), the acacia (*Acacia mangium*). The ability of these species to minimize runoff, sediment loss and nutrient loss were compared through the use of erosion plots established in mono-culture forest plantations. Also studied was the management technique of clearing the under story of the mahogany plantation and the effects on the above variables. Clearing was done to minimize competition from grasses for light, water and nutrients.

6.2 Recommendations

It should be stressed that these recommendations are strictly the view of the author/researcher and are only guidelines. The results of this thesis will be used as a reference guide along with past research when attempting to make decision regarding species selection for erosion control.

Based on the results of this study several suggestions can be made regarding species selection for reclamation on St.Vincent. However, these results should not be extrapolated to other areas where conditions are highly dissimilar. Changes in site conditions can alter these results and it is dangerous to make assumptions. The results can be used for insight into areas where the same species will be used under similar conditions, but this needs to be done with caution and planning should not be based solely on these results.

First, the role of the of Forestry Division must be maintained, forestry personal are the main proponent in attempting to control the spread of deforestation. They also need to keep an open stream of communication with the farmers and possibly have out reach meetings that inform the farmers on their (forestry) activities. Instead of having a relationship where each party is trying to out maneuver the other, one of cooperation and trust would be beneficial to both farmers and the Forestry Division. Overseas education of forestry personal should be continued. Several forestry officers have been sent to study abroad in Canada, The United Stated and England and these are the individuals now making key decisions.

Secondly, based on this studies conclusions it is recommended that mahogany be used in combination with grasses to maintain the soil resource and slope stability on steep land.

Although, an alternative to a mono-culture may be intermixing other tree species with the mahogany trees. Finding a suitable species to mix with the mahogany would separate the trees and decrease the spread shoot borer attack (Newton et al., 1993).

This study's conclusions when compared to Strand's (1996), indicate regeneration of secondary forest is more efficient at controlling runoff and erosion than the blue mahoe, the mahogany or the acacia. In the case of St.Vincent, where the goal of plantations is soil water conservation and not timber production, there appears to be no benefits to plantation forests. They cost considerably more to establish and maintain and show no apparent advantage over secondary forests (Jordan, 1984). Furthermore, with the decrease in international aid, particularly CIDA, (largely due to a shift to assist former communist countries) and a potential failure of the banana industry, the situation is better suited for the use of secondary forests for reclamation. However, it is unlikely that plantations will be completely abandoned; therefore the ideal situation would see the use of plantations in areas of higher activity and on lower slope angles. While at higher elevations, which are less accessible and on steeper slopes, secondary forest would be more suitable.

The Forestry Division still maintains a nursery, which produces seedlings; this nursery should be kept in production and seedlings intermixed with secondary forests should be attempted. The nursery also ensures a stable seed source by not having to rely on oversea locations. St.Vincent relies heavily on only three species for reforestation; it is recommended that the nursery increase the diversity of species being grown and tested. It is better to have a measure of diversity in a reclamation program (Jordan et al., 1984).

The practice of clearing the understory in the mahogany plantation has to be seriously addressed, as it costs the Forestry Division a substantial amount of money and man power each year (Weekes, 1997: pers. comm.). Clearing/weeding is absolutely necessary during the early years of a plantation, often until the canopy closes and suppresses competing vegetation. But the mahogany plantations on St.Vincent have been so severely stunted by the Shoot Borer that even after 7 years the canopy is less than a third closed. The trees however, have grown above the grasses and are no longer competing for light. The question "how long does one invest in understory clearing and at what point is it no longer beneficial" should be asked. There exists a cost and benefit balance that needs to be established. The present study suggests that this balance is reached once the mahogany trees are growing sufficiently high above the grass, at this time clearing the understory of mahogany plantations should cease. When weeding is necessary during the first few years, it should be done during the dry season and not during the peak of the wet season when the potential for runoff and erosion are the greatest. Following planting, weeding of the acacia understory is also required, although only for 1-3 years (Ruskin, 1983), but as has been shown it does not protect the soil as well as the mahogany plantations.

The possibility of future thinning needs to be considered for the Perseverance mahogany stand. Stands at Heritage showed increased growth after thinning and attained heights exceeding 5m, which is required for a profitable return (Lamb, 1966). Much of the lack of growth and deformation of growth is caused by attacks from the Shoot Borer (*Hypsipyla grandella*) (Newton et al., 1993). Until a serious effort is made to control this insect, mahogany on St.Vincent will not produce to its full potential. The form of control that is becoming more recognized is integrated pest management. This style of management may include increasing spacing distances and interspersing fast growing species between the mahogany, intergrated pest management has been suggested on St.Vincent, but is not being practiced. The collection of seeds from pest resistant genotypes and their use as future seed pools combined with appropriate silvicultural system and natural biological control are example of integrated pest management. Complete elimination of the Shoot Borer is unlikely; more realistic is reducing populations to tolerable levels (Newton et al., 1993).

6.3 Study Limitations and Future Studies

This study attempted to explore the stated objectives as thoroughly as possible, however, limitations were still encountered some expected, some not. First, and of great importance to soil erosion studies is the length of the study. The longer the study the more representative and accurate the data. This study was only 13 weeks in total, and therefore the sampling period did not extend into the peak of the rainy season, when erosion would be the greatest. This leaves a gap in the data that can not be extrapolated from the collected data. Ideally, the study should have been at least one year, but due to time and financial restraints this was not possible.

A data set that would have been helpful in understanding the water dynamics of the plantations is antecedent soil moisture conditions. This variable could have assisted in explaining trends in runoff and sediment loss, but no equipment was available to determine this. Moreover, the lack of quantifiable vegetation data proved to be a draw back. The small sample size of the leachate and rainfall nutrient data is the result of a late decision to include this data, in the future, if nutrient cycling is an objective, this data should be collected from the beginning of the study.

For a complete understanding of nutrient loss, transported litter and parent material need to be collected and analyzed. Another data set which would have been useful, but initially was beyond the scope of the study, was measurements of the rainfall's and canopy drip's kinetic energy. It is suggested that future studies include this variable to assist in explaining differences in sediment loss.

Also causing potential problems is the effect of clearing on the measured variables, in relation to changes in other environmental factors such as rainfall. Increases in rainfall and the variables after clearing could lead one to believe that the clearing caused the increases when it did not. To over come this it would be necessary to use paired plots (as identical as possible) and calibrate both of the plots. The next step would be to apply the treatment to one plot, any variation caused by other environmental factors will affect both plots equally and any change after the application can only be the cause of the treatment.

Future studies should attempt to keep as much of the experimental design similar to the past three studies, as to allow for comparison of the data. The need for further erosion studies in the plantation forests of St.Vincent is questionable, but if they do occur the length of study must be extended. The only commonly used species that has not been studied is *Pinus caribbean*, and examination of these plantations showed no signs of erosion. Efforts might be better spent on determining if the plantations are achieving optimal growth. Although the main reason for plantations is conservation, interest in logging some of the older plantations on low slopes has been expressed (MacLeod, 1997: pers. comm.). If this continues land management will be vital, but so will productivity. It would also be a much needed input into the economy.

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APPENDIX A

SOIL PROFILE DESCRIPTIONS

Soil Classification: Thaptic Durustand

Parent Material: Volcanic Ash

Aspect: NNE

Elevation: 300m

Slope Angle: 26.0°/15% (Moderate)

Drainage: Well Drained

Vegetation: Mahogany Trees and Grasses

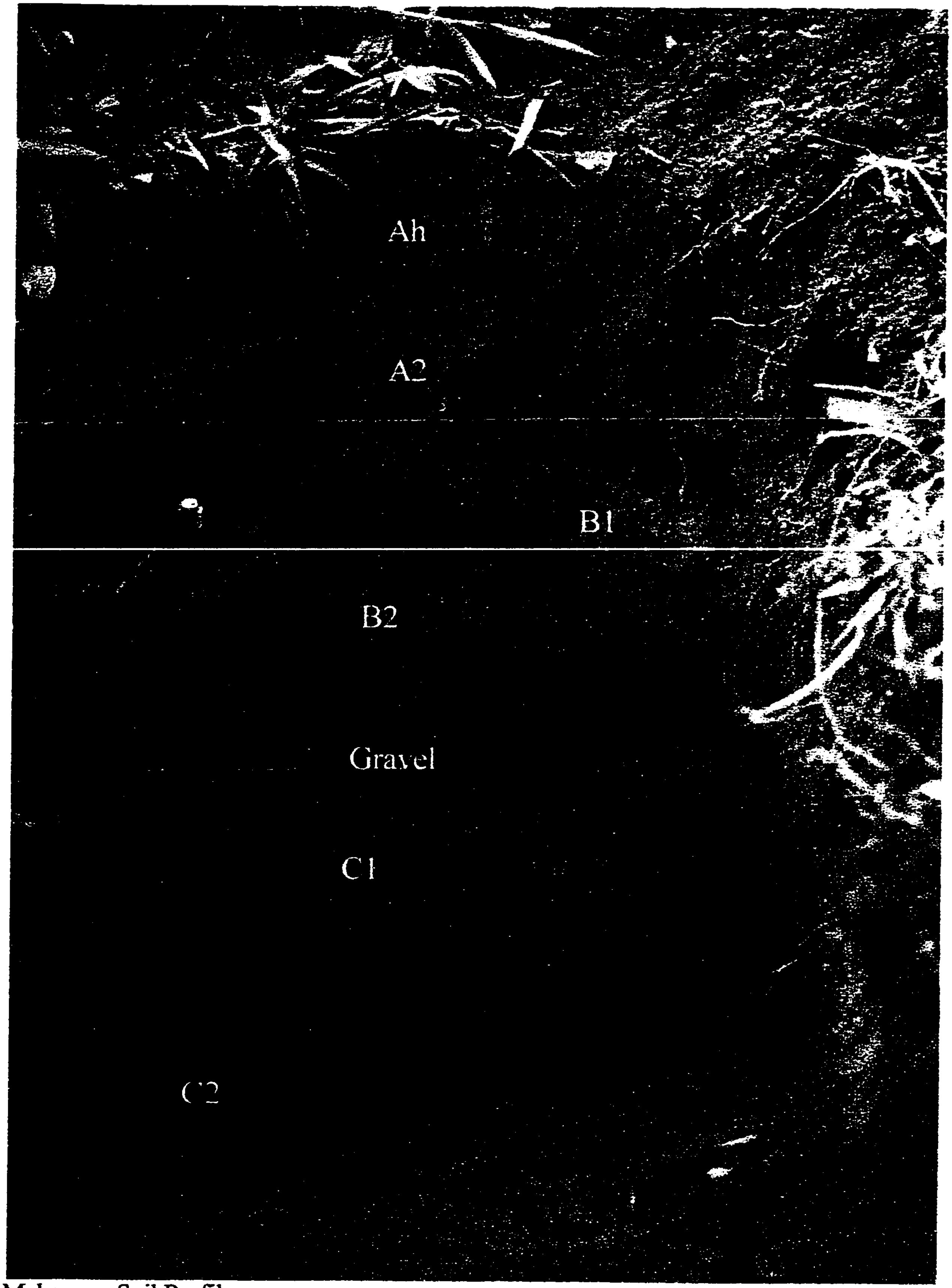
Erosion Hazard: Low

Note: horizons A1 and A2, B1and B2 and C1 and C2 were combined below.

Pedon dug adjacent to erosion plot B on August 19, 1997. Site was 8m from the toe of the slope, with high moisture conditions and widely scattered stones.

MAHOGANY PLANTATION SOIL PROFILE DESCRIPTION

Horizon	Depth (cm)	Colour	Remarks
Ah/Ap	0-23	10YR 3/2	Fine to medium moderate granular; very friable; clear, abrupt, wavy boundary; abundant fine roots; texture various with lateral boundary
B	23-59	7.5YR 3/3	Very coarse moderate platy; firm; abrupt irregular boundary; scattered mottling, roots; some vertical cleaving
Gravel	59-73	7.5YR 3/1	Structureless, loose, abrupt smooth to regular; discontinuous across profile
C	73-+	10YR 4/3	Very coarse slightly platy; firm ; vertical cleavages forming plates; roots



Mahogany Soil Profile

ACACIA PLANTATION SOIL PROFILE:
Soil Classification: Thaptic Durustand

Parent Material: Volcanic Ash

Aspect: SSE

Elevation: 310m

Slope Angle: 33.0°/19% (Moderately Steep)

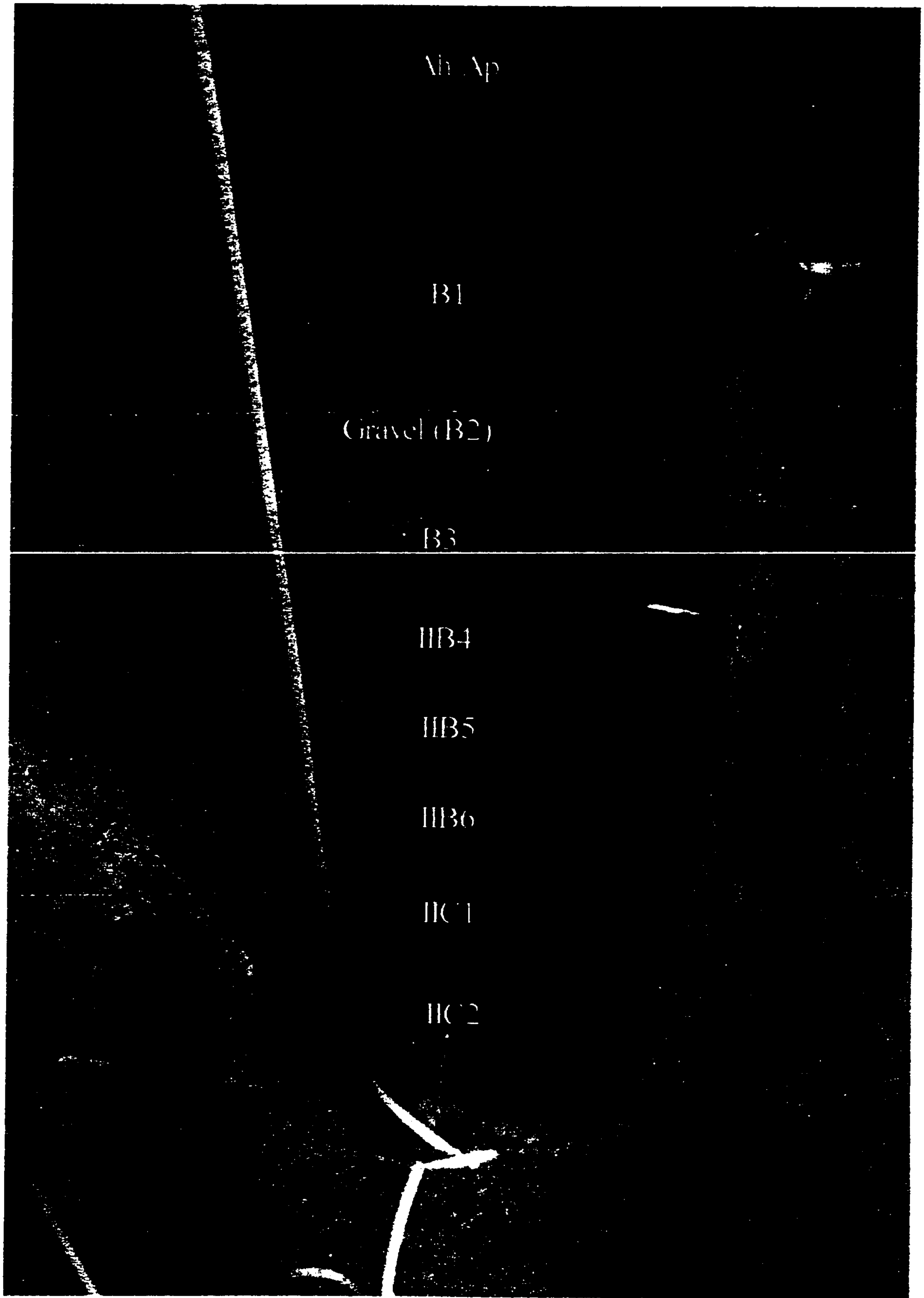
Drainage: Well Drained

Vegetation: Acacia Trees with Shrub Under Story

Erosion Hazard: Moderate

Profile Description

Horizon	Depth (cm)	Colour	Remarks
Ah/Ap	0-30	10YR 3/3	Clear smooth boundary, roots exposed, stones common on surface
B1	30-47	10YR 4/4	Abrupt smooth boundary
B2	47-65	10YR 3/3	Abrupt smooth irregular, stones and discontinuous gravel layer
IIB3	65-85	10YR 4/6	Abrupt Smooth, vertical cleavages, few roots
IIB4	85-105	7.5YR 4/8	Abrupt smooth, flecking of white nodules, stronger than 2B5
IIB5	105-150	7.5YR 4/6	Abrupt smooth, increase in stones, white flecking
IIC1	150-180	7.5YR 4/4	Abrupt smooth, decreased flecking, increase in clay, red mottling
IIC2	180+	5.5YR 4/6	Lighter colour, nodules and clay aggregates



Acacia Soil Profile

APPENDIX B

LABORATORY ANALYSIS
(Soil and Sediment Chemistry)

MAHOGANY SOIL CHEMISTRY (all elements expressed in meq/100g)

Horizon	Al	Ca	Fe	K	Mg	Mn	Na	C.E.C	pH	ECmS1	Texture	%OM
Ah	2.890	11.132	0.007	0.233	1.231	0.005	0.353	15.849	5.51	138	S.L	6.2
A2	2.801	7.841	0.007	0.118	1.373	0.006	0.375	12.521	5.57	61.3	L.S	5.7
B1	1.839	6.074	0.009	0.069	0.604	0.004	0.399	8.998	5.93	28.9	S	3.5
B2	2.191	5.612	0.009	0.102	0.347	0.003	0.444	8.708	6.03	28.8	S	4.6
Gravel	2.369	1.065	0.004	0.155	0.172	0.003	1.681	5.449	6.05	17.8	Gravel	2.0
C1	2.682	7.639	0.004	0.141	1.180	0.006	0.484	12.136	6.01	30.7	S	3.5
C2	2.904	7.948	0.004	0.110	0.467	0.005	0.403	11.841	6.12	34.1	S	5.1

ACACIA SOIL CHEMISTY (all elements expressed in meq/100g)

Horizon	Al	Ca	Fe	K	Mn	Mg	Na	C.E.C	pH	ECmS1	Texture	% O.M
Ah	2.409	9.980	0.006	0.227	1.526	0.010	1.803	15.961	5.56	81	S.L	4.9
B1	2.347	13.672	0.005	0.182	0.782	0.005	0.592	17.555	5.83	35.4	S.L	4.3
B2	2.486	6.206	0.007	0.138	0.554	0.006	0.571	9.968	5.82	49.8	L.S	3.6
Gravel	2.824	2.135	0.008	0.222	1.205	0.004	3.459	9.317	6.01	48.8	S	2.2
B3	3.068	36.537	0.003	0.313	2.977	0.009	2.062	44.969	6.00	38.9	S.L	2.2
B4	3.265	30.889	0.004	0.393	2.588	0.005	2.524	39.668	6.55	191	S.L	1.8
B5	2.748	33.947	0.005	0.142	3.846	0.005	3.290	43.983	6.69	38	S.L	S.L
2C1	2.264	42.291	0.005	0.081	4.912	0.004	3.691	53.248	6.62	55.7	S.L	S.L
2C2	2.575	34.774	0.006	0.108	4.250	0.004	2.895	44.612	6.68	44.2	S.L	S.L

MAHOGANY AVERAGE WEEKLY NUTRIENT LOSS (SOILS) (meq/100g)

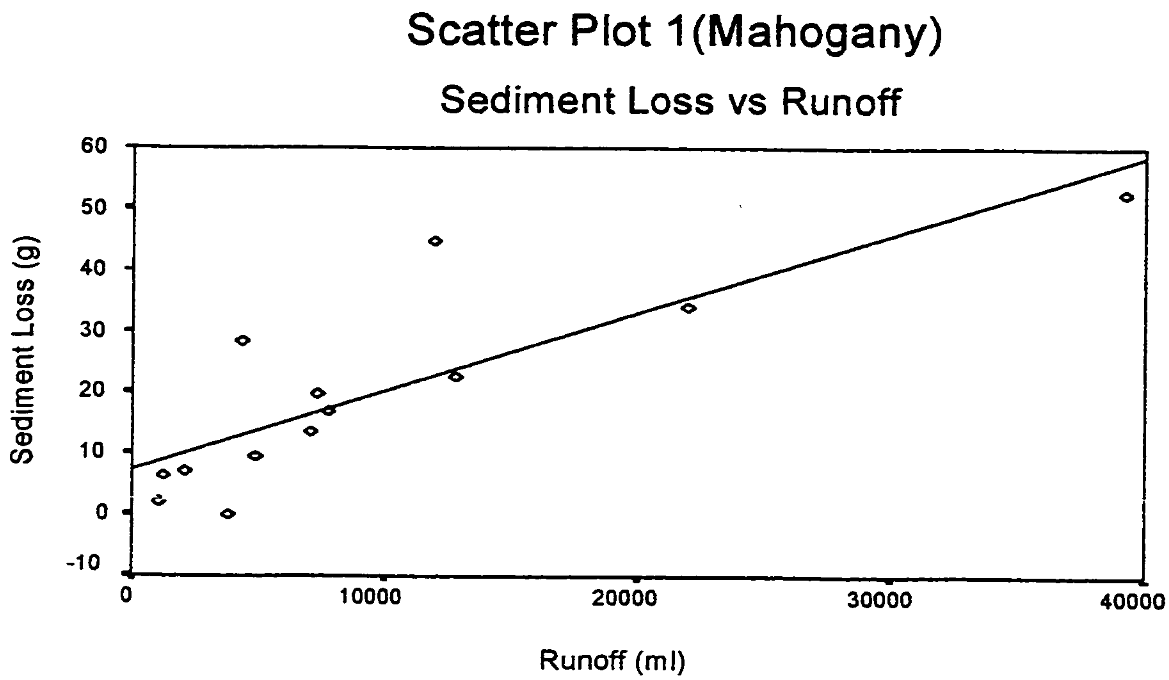
Week	Al	Ca	Fe	K	Mg	Mn	Na	C.E.C
1	2.764	17.552	0.002	0.825	1.269	0.370	0.926	23.678
2	2.578	14.222	0.004	1.696	1.840	0.016	1.274	21.630
3	2.688	23.107	0.005	1.444	2.347	0.023	1.495	31.109
4	2.997	20.798	0.006	0.797	1.986	0.021	0.871	27.476
5	2.310	17.834	0.003	1.241	2.264	0.045	1.681	25.378
6	3.250	17.825	0.004	1.100	2.304	0.024	1.076	26.318
7	3.169	24.925	0.006	0.908	4.282	0.026	1.133	34.449
8	3.987	23.328	0.004	0.999	2.950	0.044	1.194	32.506
9	2.806	74.823	0.007	1.045	5.801	0.049	1.164	85.695
10	3.472	23.935	0.007	1.232	3.030	0.017	1.174	32.867
11	2.747	67.614	0.006	0.966	4.830	0.035	1.173	77.371
12	3.01	31.492	0.009	2.891	3.978	0.013	0.966	42.359
13	2.548	19.612	0.006	0.710	2.520	0.012	0.797	26.205
Average	**2.948**	**29.005**	**0.005**	**1.220**	**3.03**	**0.530**	**1.148**	**37.465**

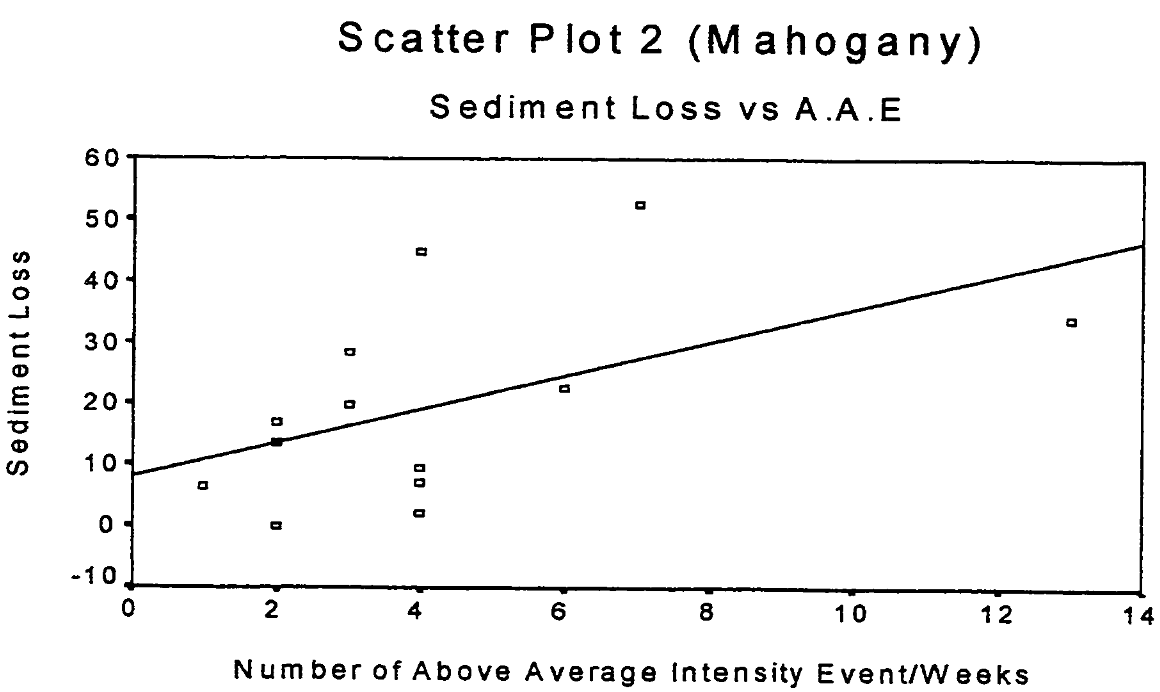
ACACIA AVERAGE WEEKLY NUTRIENT LOSS (SOILS) (meq/100g)

Week	Al	Ca	Fe	K	Mg	Mn	Na	C.E.C
1	13.979	35.359	0.002	2.12	3.308	0.045	1.446	57.259
2	3.309	41.088	0.004	2.386	4.134	0.045	1.353	52.724
3	3.633	18.277	0.005	2.220	2.392	0.035	1.340	27.902
4	3.698	20.006	0.007	1.1320	2.159	0.041	1.729	28.960
5	4.166	30.920	0.006	1.376	3.716	0.059	1.791	42.034
6	3.552	22.773	0.004	1.331	3.251	0.039	1.379	32.329
7	3.489	24.324	0.005	1.346	6.656	0.038	1.305	37.163
8	2.680	26.052	0.006	1.196	3.00	0.038	1.374	34.346
9	2.948	37.206	0.005	1.326	4.079	0.047	1.091	46.702
10	2.325	27.146	0.003	0.979	3.499	0.028	1.281	35.261
11	2.949	31.339	0.003	1.365	3.342	0.042	1.634	40.674
12	2.668	29.634	0.004	3.053	3.711	0.026	1.945	41.041
13	3.532	27.984	0.004	1.594	3.646	0.025	1.345	38.130
Average	**3.302**	**28.627**	**0.004**	**1.648**	**3.607**	**0.039**	**1.463**	**39.579**

APPENDIX C

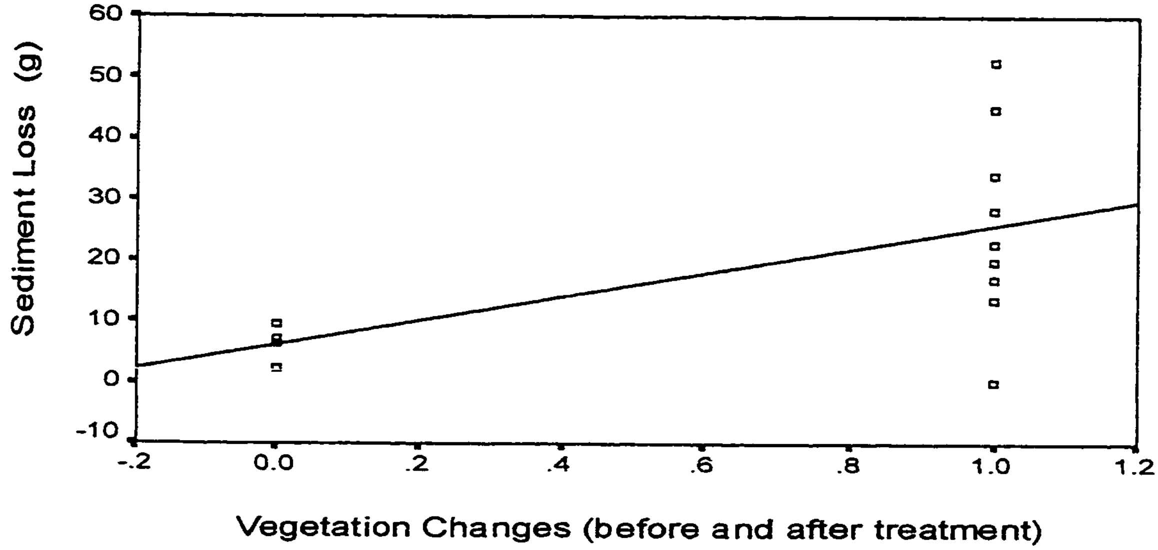
SCATTER PLOTS


Scatter Plot 1(Mahogany)
Sediment Loss vs Runoff
Sediment Loss (g)
60
50
40
30
20
10
0
-10
0
10000
20000
30000
40000
Runoff (ml)


Scatter Plot 2 (Mahogany)
Sediment Loss vs A.A.E
Sediment Loss
60
50
40
30
20
10
0
-10
0
2
4
6
8
10
12
14
Number of Above Average Intensity Event/Weeks

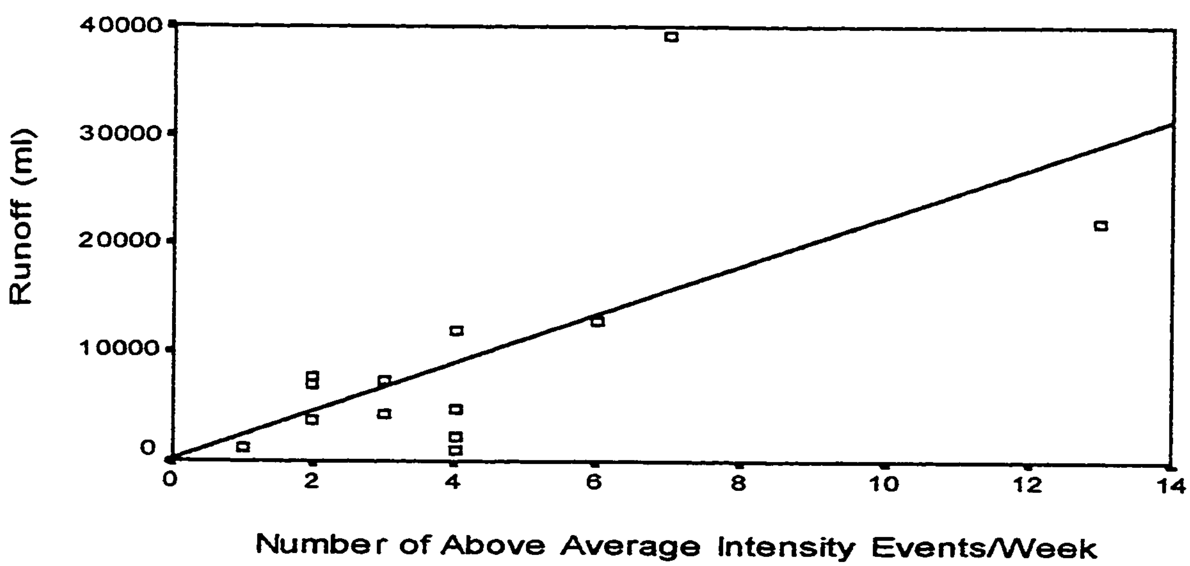
Scatter Plot 3 (Mahogany)

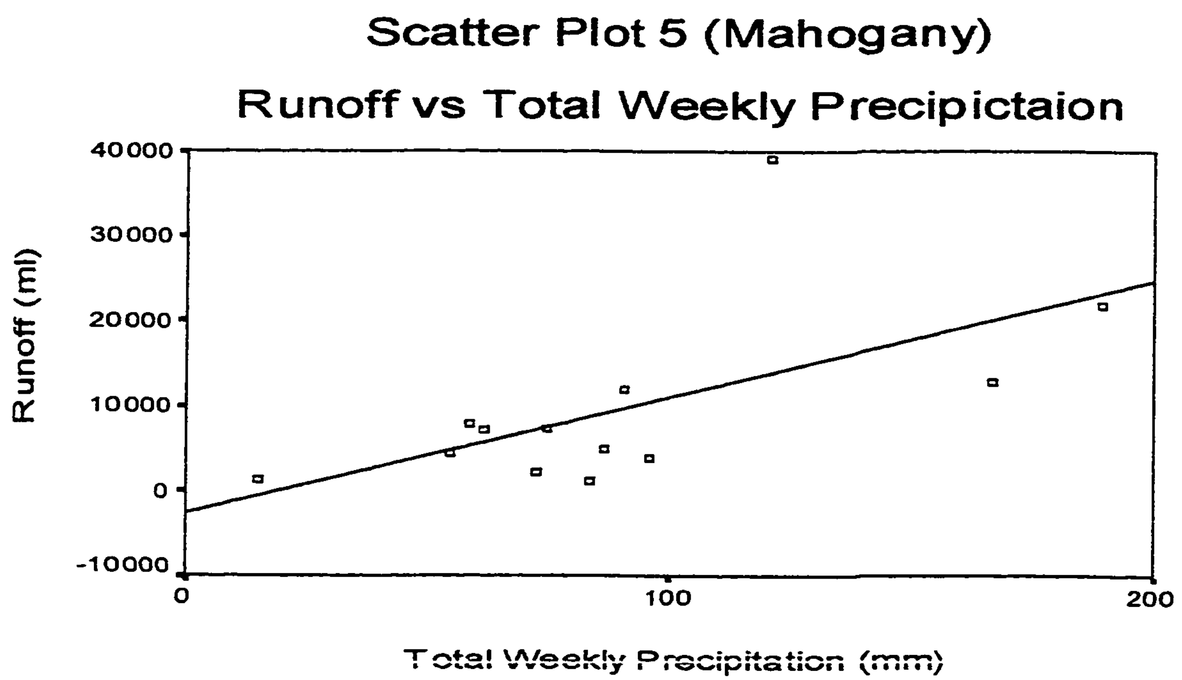
Sediment Loss vs Vegetation Changes

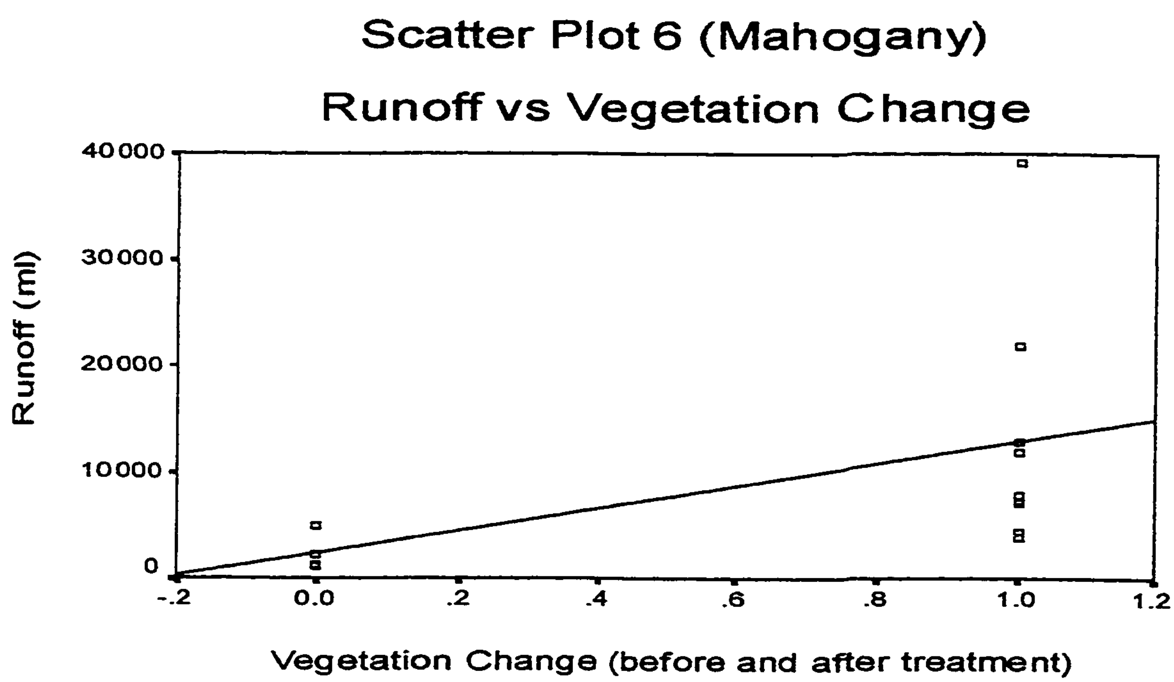


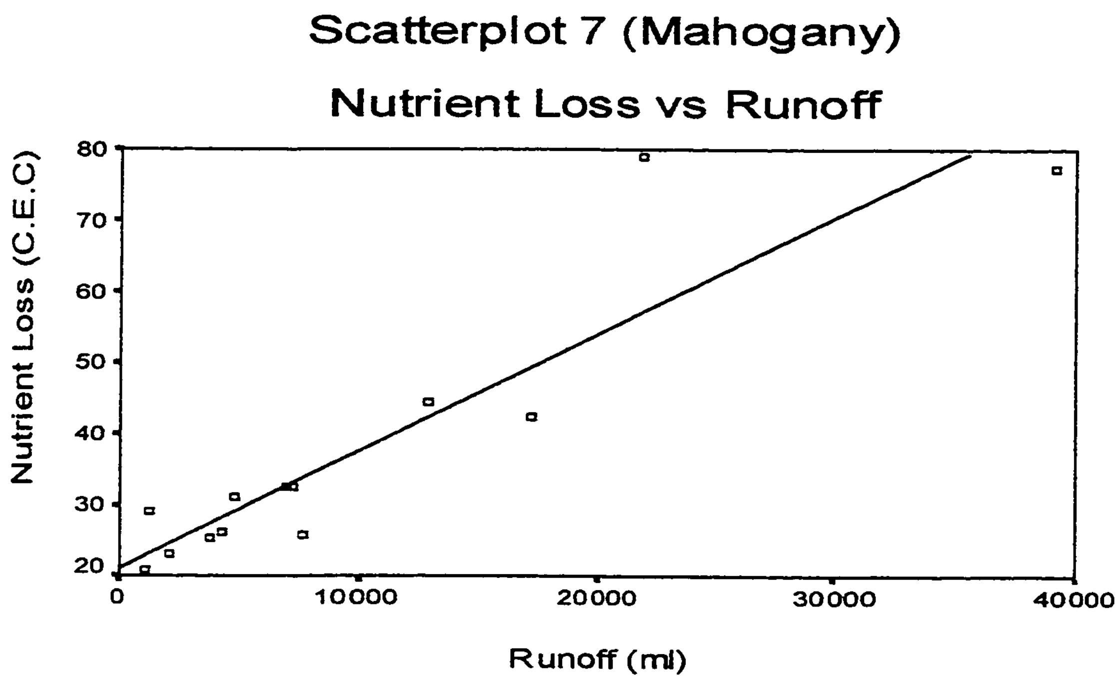
Scatterplot 4 (Mahogany)

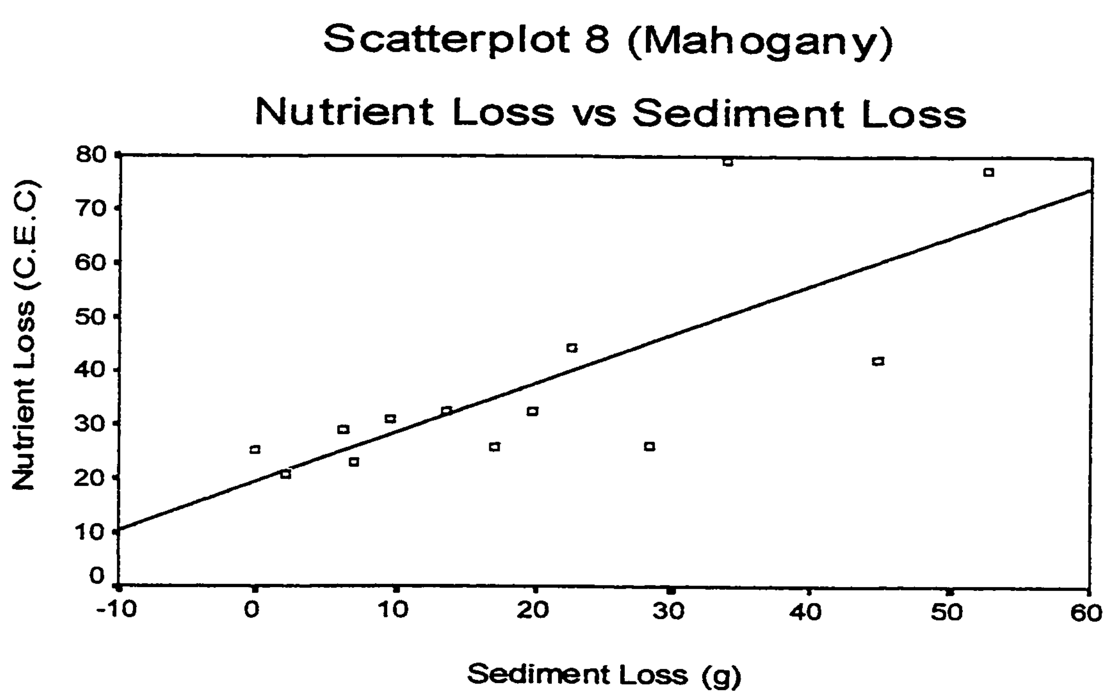
Runoff vs A.A.E

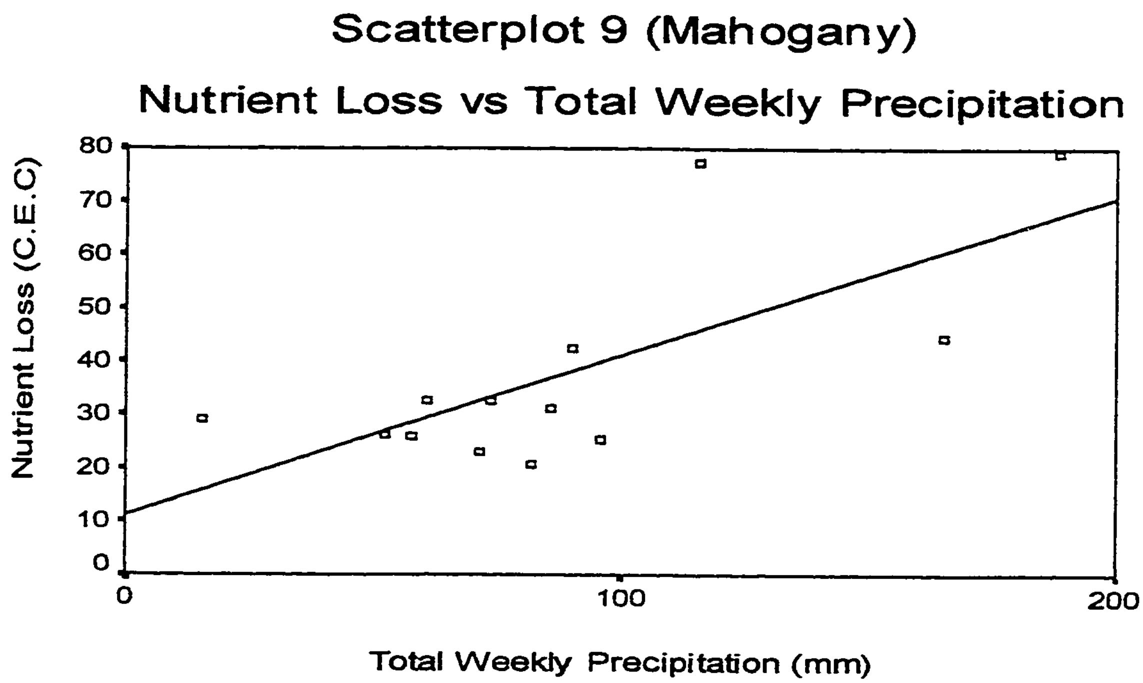


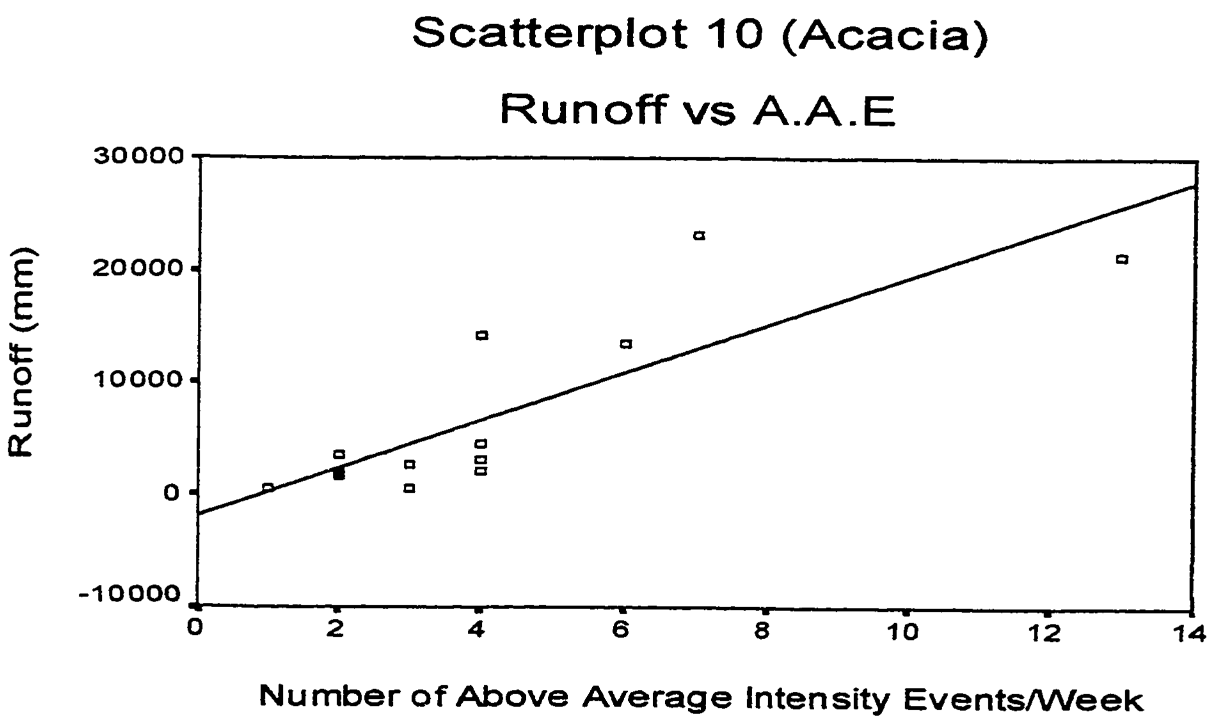

Scatter Plot 5 (Mahogany)
Runoff vs Total Weekly Precipictaion
40000
30000
20000
10000
0
-10000
Runoff (ml)
0
100
200
Total Weekly Precipitation (mm)

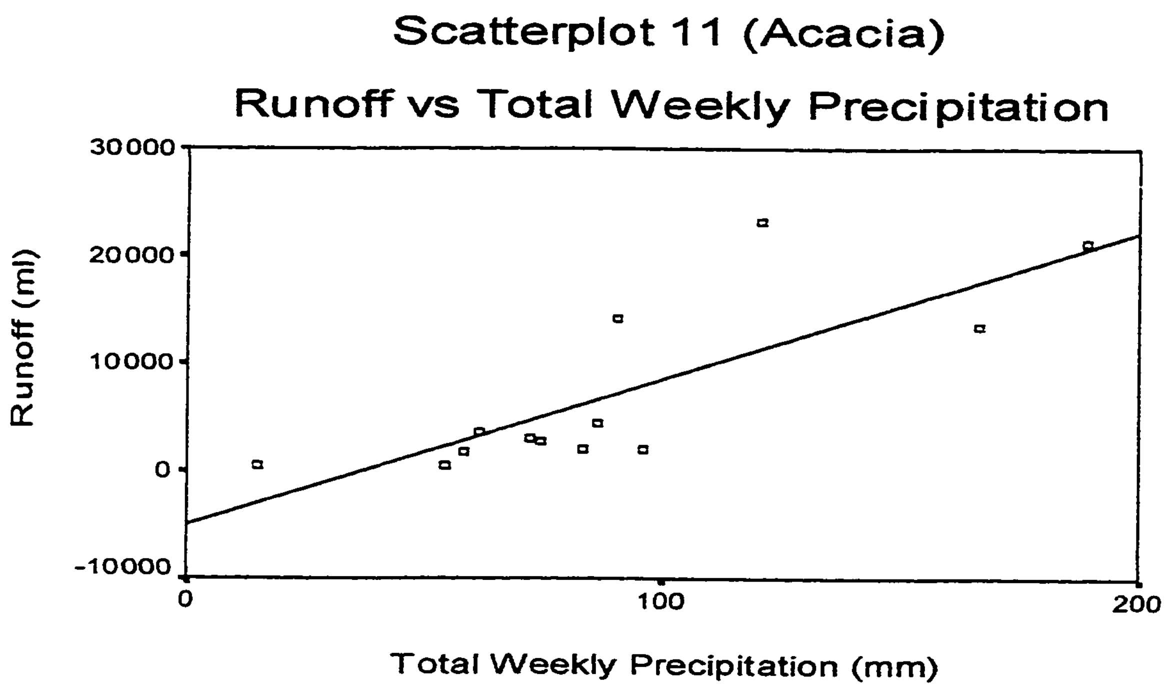

Scatter Plot 6 (Mahogany)
Runoff vs Vegetation Change
40000
30000
20000
10000
0
Runoff (ml)
-.2
0.0
.2
.4
.6
.8
1.0
1.2
Vegetation Change (before and after treatment)

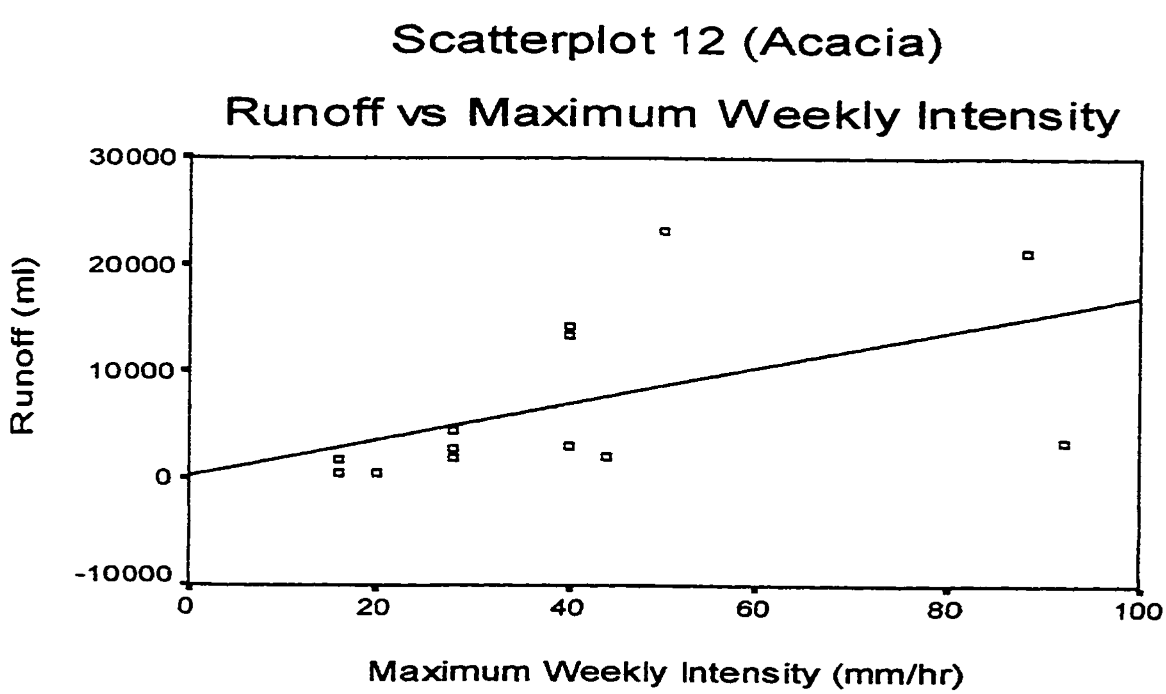

Scatterplot 7 (Mahogany)
Nutrient Loss vs Runoff
Nutrient Loss (C.E.C)
80
70
60
50
40
30
20
0
10000
20000
30000
40000
Runoff (ml)

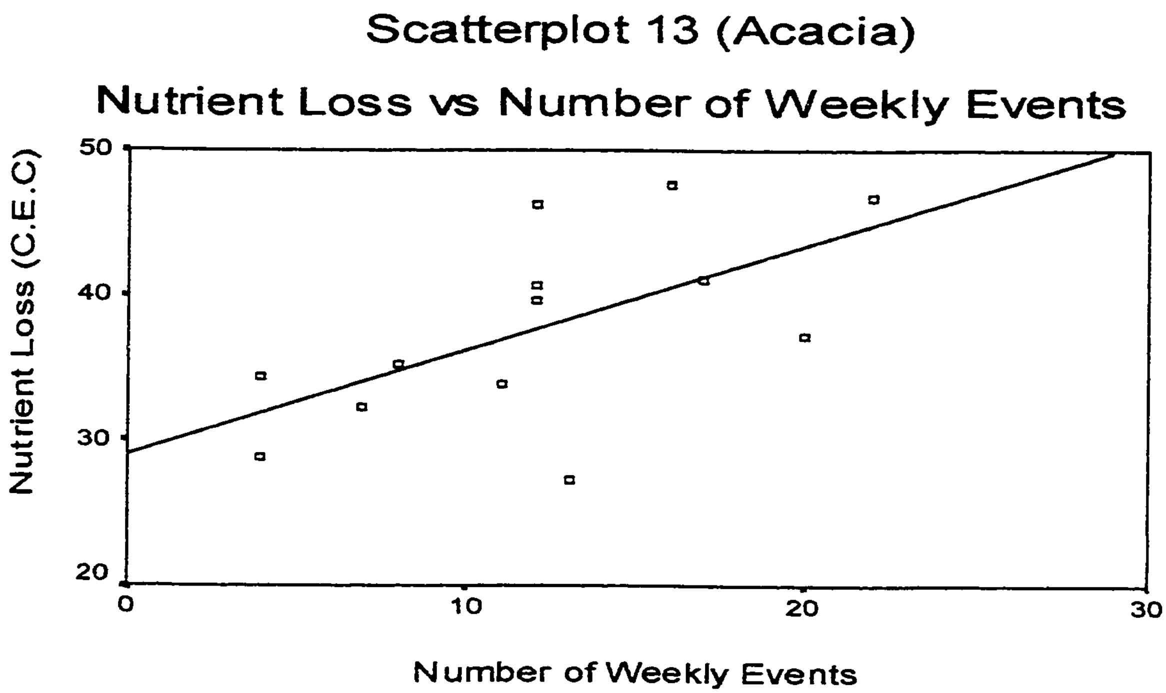

Scatterplot 8 (Mahogany)
Nutrient Loss vs Sediment Loss
Nutrient Loss (C.E.C)
80
70
60
50
40
30
20
10
0
-10
0
10
20
30
40
50
60
Sediment Loss (g)

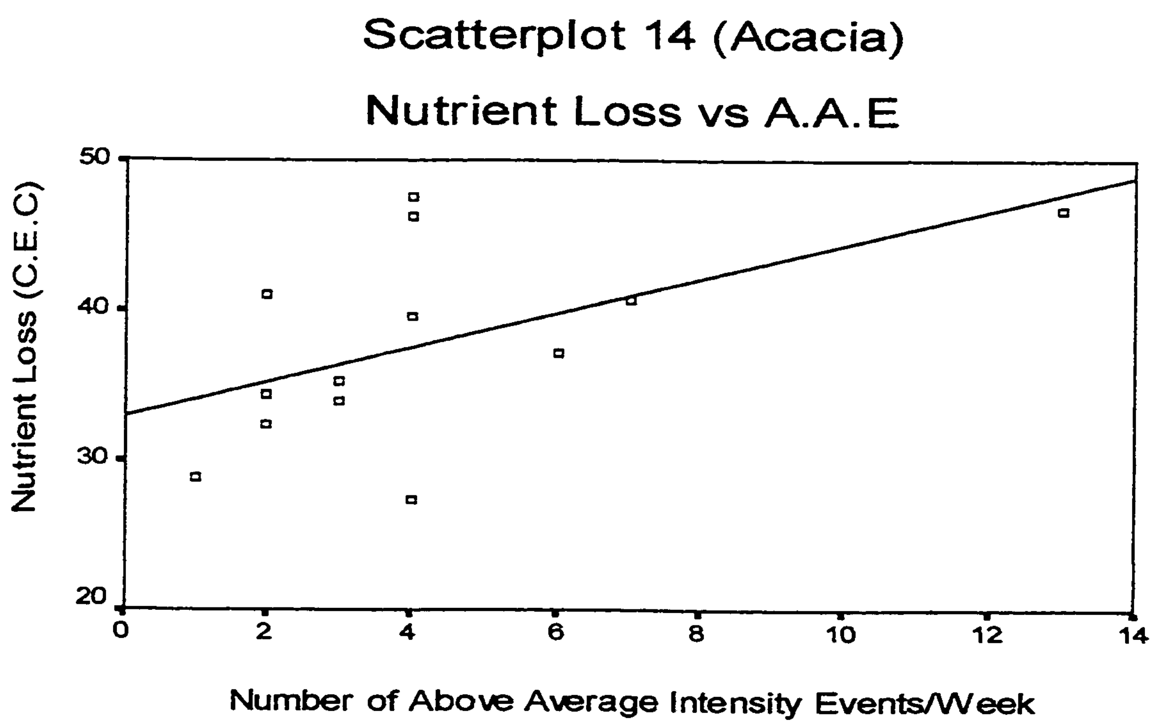

Scatterplot 9 (Mahogany)
Nutrient Loss vs Total Weekly Precipitation
Nutrient Loss (C.E.C)
80
70
60
50
40
30
20
10
0
0
100
200
Total Weekly Precipitation (mm)

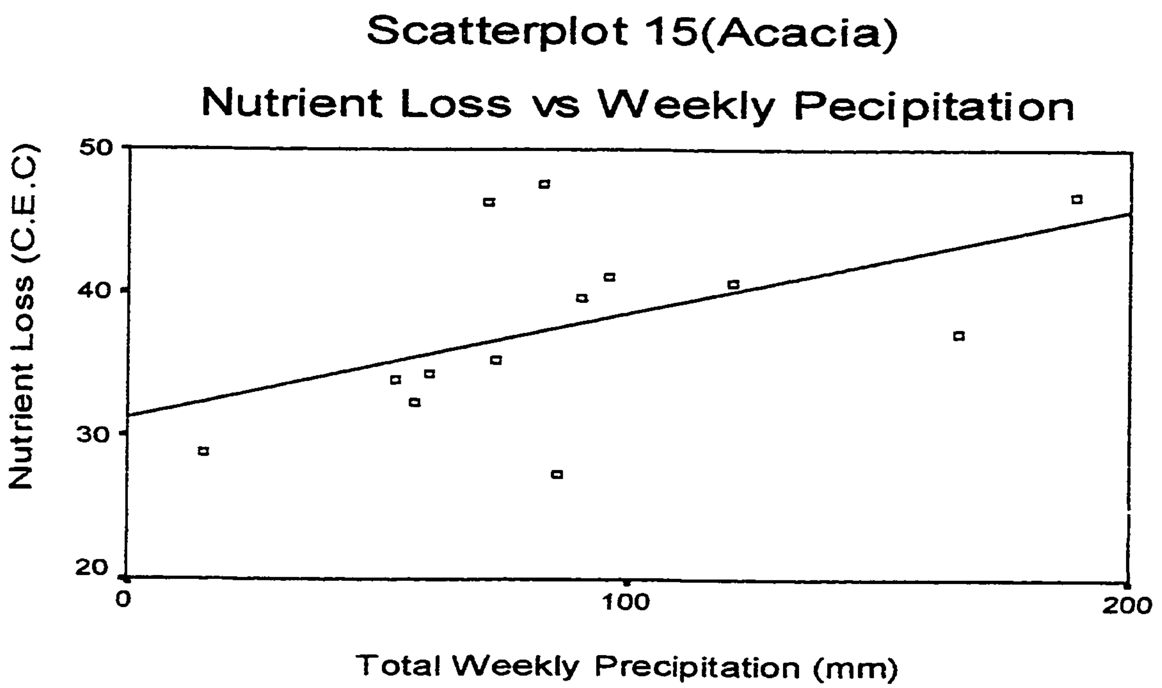

Scatterplot 10 (Acacia)
Runoff vs A.A.E
Runoff (mm)
30000
20000
10000
0
-10000
0
2
4
6
8
10
12
14
Number of Above Average Intensity Events/Week

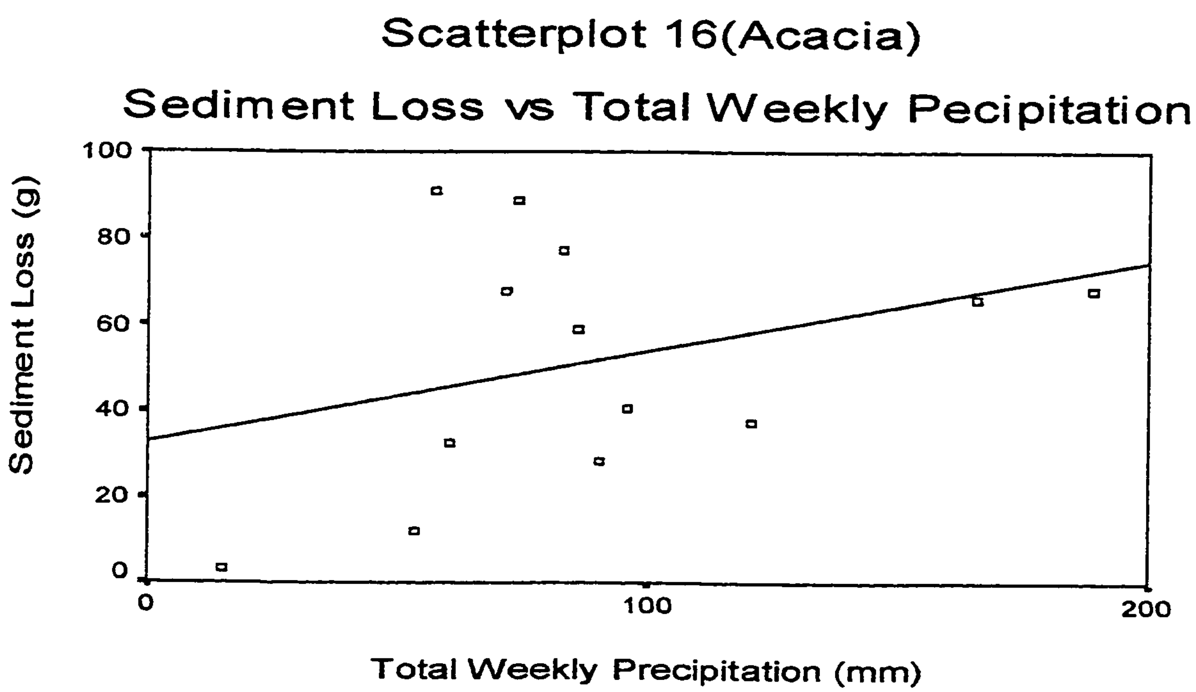

Scatterplot 11 (Acacia)
Runoff vs Total Weekly Precipitation
Runoff (ml)
30000
20000
10000
0
-10000
0
100
200
Total Weekly Precipitation (mm)


Scatterplot 12 (Acacia)
Runoff vs Maximum Weekly Intensity
Runoff (ml)
30000
20000
10000
0
-10000
0
20
40
60
80
100
Maximum Weekly Intensity (mm/hr)


Scatterplot 13 (Acacia)
Nutrient Loss vs Number of Weekly Events
Nutrient Loss (C.E.C)
50
40
30
20
0
10
20
30
Number of Weekly Events


Scatterplot 14 (Acacia)
Nutrient Loss vs A.A.E
Nutrient Loss (C.E.C)
50
40
30
20
0
2
4
6
8
10
12
14
Number of Above Average Intensity Events/Week


Scatterplot 15(Acacia)
Nutrient Loss vs Weekly Pecipitation
Nutrient Loss (C.E.C)
50
40
30
20
0
100
200
Total Weekly Precipitation (mm)


Scatterplot 16(Acacia)
Sediment Loss vs Total Weekly Pecipitation
Sediment Loss (g)
100
80
60
40
20
0
0
100
200
Total Weekly Precipitation (mm)

APPENDIX D

CORELLATION MATIXES

	Nutrient Loss	Total Precip.	Runoff	Sediment Loss	Vege.	A.A.E.
Nutrient Loss	1.00	.718	.916	.772	.422	.843
Total Precip.	.718	1.00	.572	.412	.378	.873
Runoff	.916	.572	1.00	.875	.498	.641
Sediment Loss	.772	.412	.875	1.00	.577	.528
Vege.	.422	.378	.498	.577	1.00	.219
A.A.E.	.843	.873	.641	.528	.219	1.00

Corellation Matrix 1: Mahogany Plantation

	Nut. Loss	Sed. Loss	Runoff	Total Precipi	No. Events	Dur.	A.A.E.	Max. Int.
Nut. Loss	1.00	.303	.388	.514	.609	.266	.537	.445
Sed. Loss	.303	1.00	.019	.347	.300	.338	.251	.045
Runoff	.388	.019	1.00	.791	.511	.210	.824	.512
Total Precipi	.514	.347	.791	1.00	.860	.654	.876	.514
No.of Events	.609	.300	.511	.860	1.00	.581	.720	.237
Dur.	.266	.338	.210	.654	.581	1.00	.442	.388
A.A.E.	.537	.251	.824	.876	.720	.422	1.00	.585
Max. Int.	.445	.045	.512	.514	.237	.388	.585	1.00

Corellation Matrix 2: Acacia Plantation