CORRELATION BETWEEN TREE ARCHITECTURE MODELS, SOIL AND WATER CONSERVATION AT GUNUNG HALIMUN-SALAK NATIONAL PARK

SANOU FAYE

GRADUATE SCHOOL
BOGOR AGRICULTURAL UNIVERSITY
BOGOR
2011
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Bogor Agricultural University

(Instiut Pertanian Bogor)
DECLARATION

I declare that this thesis titled “Correlation between tree architecture models, soil and water conservation at gunung halimun-salak national park.” was entirely completed by myself with resourceful help from the Department of Plant Biology, Bogor Agricultural University. Information and quotes which were sourced from journals and books have been acknowledged and mentioned where in the thesis they appear. All complete references are given at the end of the paper.

Bogor, July 2011

Sanou Faye
ID: G353098311
SANOU FAYE. G353098311. Correlation between Tree Architecture Models, Soil and Water Conservation at Gunung Halimun-Salak National Park. (Under supervision of DEDE SETIADI and IBNUL QAYIM)

Soil erosion by water is a worldwide environmental problem which degrades soil productivity and water quality. This research was conducted to find out how tree architecture models influence stemflow, throughfall, infiltration, surface runoff and erosion. The sample of the research was two trees at sub-montane zone Castanopsis argentea Bl. with Stone’s model and Michelia montana Blume. with Petit’s model. Soil conservation parameter measured for stemflow, throughfall, infiltration, surface runoff and erosion. Multiple linear regression and principal component analyses were used to get the correlation of each parameter. Correlation of the two models Stone and Petit is nearly pursuant to value of stemflow. Stemflow of Stone model (4.73 mm) is slightly smaller than Petit’s model (6.20 mm). The two models showed also tighter correlation pursuant to value of throughfall, which indicates 657.82 and 640.91 mm for Stone’s model and Petit’s model respectively. Runoff estimated was 15.74 and 10.87 mm for the same models. The two models Stone and Petit reduced runoff by 31.33 % and 45.37 %, respectively, as compared to the control surface. Similarly, soil loss was quantified in 1.98, 0.82 and 0.76 ton ha⁻¹ year⁻¹ for the Control, Stone model and Petit models, respectively. Above results show that Michelia Montana Blume. is better than Castanopsis argentea Bl. to be developed in soil and water conservation.

Keywords: tree architecture stone and petit models, stemflow, throughfall, infiltration, runoff, erosion
ABSTRAK

SANOU FAYE. G353098311. Korelasi Model Arsitektur Pohon dengan Konservasi tanah dan air di Taman Nasional Gunung Halimun Salak. (Dibimbing oleh DEDE SETIADI dan IBNUL QAYIM)

Erosi tanah merupakan salah satu masalah ekologi yang berkaitan dengan konservasi tanah dan air. Penelitian ini bertujuan untuk mengetahui pengaruh model arsitektur terhadap aliran batang, curahan tajuk, aliran permukaan dan erosinya. Sampel pada penelitian adalah dua pohon sub-montana yaitu Castanopsis argéntea dengan model Rauh dan Michelia montana dengan model Petit.

Parameter konservasi tanah yang diukur adalah aliran batang, curahan tajuk, infiltrasi, aliran permukaan dan erosinya. Regresi berganda dan analisis komponen utama digunakan untuk menentukan korelasi antara parameter. Korelasi pada kedua model mendekati untuk aliran batang. Aliran batang pada model Stone (4,73 mm) lebih kecil dibandingkan dengan model Petit (6,20 mm). Kedua model menunjukkan juga pola curahan tajuk yang sama. Curahan tajuk (640,91 mm) pada model Stone lebih kecil dibandingkan dengan Curahan tajuk model Petit (657,82 mm). Aliran permukaan pada model Petit (10,87 mm) lebih kecil dibandingkan dengan model Rauh (15,74 mm). Kedua model Stone dan Petit masing-masing mampu reduksikan 31,33% dan 45,37% aliran permukaan dibandingkan kontrolnya. Demikian pula erosi tanah pada model Petit (0,76 ton/ha/tahun) adalah yang paling kecil dibandingkan dengan model Stone (0,82 ton/ha/tahun) dan Kontrol (1,98 ton/ha/tahun). Hasil di atas menunjukkan bahwa Michelia montana Blume dengan model arsitektur Petit lebih baik daripada Castanopsis argéntea BI dengan model arsitektur Stone untuk mendukung usaha konservasi tanah dan air.

Kata Kunci: model arsitektur petit dan stone, aliran batang, aliran cabang, aliran permukaan, infiltrasi, erosi
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SUMMARY

SANOU FAYE. G353098311. Correlation between Tree Architecture Models, Soil and Water Conservation at Gunung Halimun-Salak National Park. (Under supervision of DEDE SETIADI and IBNUL QAYIM)

Soil erosion by water is a worldwide environmental problem which degrades soil productivity and water quality, causing a 17% reduction in crop production (Oldeman et al. 2003). Subsequent studies have shown that tree architecture models are a useful tool in water regulation, soil protection and conservation in different natural ecosystems. However, few studies were conducted at individual plant scale (De Baets et al. 2007), on which we could relate such effects to the tree architecture model and thereby provide necessary information to select suitable plant species for vegetation restoration. Model of tree architecture affect the amount of throughfall, stemflow and rainfall interception, each of which affect the runoff and soil erosion.

This study aims to determine the influence of tree architecture models Stone for Castanopsis argentea and Petit for Michelia montana on stemflow, throughfall, surface runoff, infiltration, as well as on erosion and soil physical property at the Gunung Halimun Salak National Park. The research was done at Cikaniki research station and its surrounding areas, from 23 November 2010 to 20 January 2011.

Materials used include plant species Castanopsis argentea and Michelia montana, Global Position System (GPS), altimeter, clinometer, roll meter, rain gauge, containers, pvc pipe, analytical balance, camera, an equipment for soil sampling and soil gravimetric process in laboratory.

Description of the tree architecture models based on the type of branching and canopy shape. We use the common rain gauge that consists of a large cylinder with a 20 centimeter in diameter funnel that collects water into the cylinder to measure rainfall. The method used in measurement of throughfall and stemflow gauges are made simple manually. Throughfall was collected from each tree using throughfall trough (area=1 m²). The throughfall trough beneath each tree was positioned in radial pattern extending out from the tree base to the crown perimeter. Stemflow drainage was collected from each tree using a stemflow collar consisting...
of high quality hose (2.5 cm inner diameter) that was slit longitudinally and sealed to the trunk. This plastic hose conduce water to a container where it will be measured after each storm.

Erosion and runoff plots were established at a 8-10% slope. Plots, 5 m long by 4 m wide (total area 20 m²), and delineated with strips of metal buried to 10 cm depth to restrict water flowing onto the plots from the adjacent areas, were established for Castanopsis argentea, Michelia montana and the Control. A metal-sheet plot end placed at the bottom of the slope to convey runoff into a 10 cm PVC pipe which, in turn, delivered water and sediment into a 100 L container. After each rainfall event, runoff was determined by measuring the water stage in the container. Eroded soil was collected from the drains, weighted and moisture content calculated.

Multiple regression analysis was done to interpret linear relationships between factors by examining the statistical significance of the coefficients of multiple determinations. Principal component analysis was used to examine the correlation among the factors (Jollife, 1986).

During the study period, fifty total rainfall events were registered, accounting for a total rainfall amount of 952.77 mm. This large water yield from Gunung Halimun Salak National Park illustrates that tropical rainforests usually receive considerably more rainfall compared to other biomes.

Measurements of stemflow and throughfall were found to represent 0.5 and 77.96% for Castanopsis argentea with Stone’s model, 0.7 and 80.02% for Michelia montana with Petit’s model, respectively of the cumulative precipitation input. Throughfall and stemflow importance varie from the total incident precipitation, depending on branch and stand morphology and on bark roughness.

Measured runoff and soil loss data showed that Castanopsis argentea and Michelia montana produced significantly less runoff and erosion than the Control. It was observed that an increase in rainfall did not produce an increment in runoff for the patches of Castanopsis argentea and Michelia montana likely the Control. On the contrary, increases in the amount of surface runoff lead to an increase in soil erosion for the control plot. However, these relationships are inconsistent in Castanopsis argentea and Michelia montana plots. Infiltration rate, is observed to
be higher with \textit{Castanopsis argentea} and \textit{Michelia Montana} compared to the Control plot. \textit{Michelia Montana} and \textit{Castanopsis argentea} are likely to release more litterfall that increased amounts of carbon, nitrogen, and phosphorus into the soil community and promote rainfall infiltration into the soil and reduces overland flow velocities, thus diminishing the soil erosion potential. However, contribution of these major categories of inputs from the canopy occurs with differences among tree species, and even among canopy layers. \textit{Michelia montana} more highly branched with a shell of drooping leaves on the outside of the crown appeared more efficient at intercepting the larger amounts of rainfall.

Soil conservation parameters are positively correlated with tree architecture Stone’s model for Castanopsis argentea and Petit’s model for Michelia. The relative correlation of each variable demonstrated clearly that throughfall and runoff are far more correlated with soil erosion than rainfall and stemflow. Total runoff measured was 49.32 mm for the Control, 15.74 mm for \textit{Castanopsis argentea} with Stone’s model and 10.87 mm for \textit{Michelia Montana} with Petit’s model. The two models Stone and Petit reduced runoff by 31.33 % and 45.37 %, respectively, as compared to the control surface. Cumulative soil loss values were quantified in 1.98 ton ha$^{-1}$ year$^{-1}$ for the Control, 0.82 for \textit{Castanopsis argentea} with architecture Stone’s model and 0.76 for \textit{Michelia Montana} with architecture Petit’s model.

Above results show that \textit{Michelia Montana} Blume with architecture Petit’s model is better than \textit{Castanopsis argentea} BI. with architecture Stone’s model to be developed in soil and water conservation.
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CORRELATION BETWEEN TREE ARCHITECTURE MODELS, SOIL AND WATER CONSERVATION AT GUNUNG HALIMUN-SALAK NATIONAL PARK

SANOU FAYE

A Thesis
As Partial fulfillment of the Requirement to obtain
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GRADUATE SCHOOL
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BOGOR
2011
External Member Supervisor Committee:

Prof. Dr. Ir. Cecep Kusmana, MS.
Title : Correlation between Tree Architecture Models, Soil and Water Conservation at Gunung Halimun-Salak National Park

Name : Sanou Faye

Registration Number : G353098311

Major : Plant Biology

Approved:
Advisory Committee

Prof. Dr. Ir. Dede Sediadi, MS.
Chairman

Dr. Ir. Ibnuq Qayim
Member

Agreed:
Coordinator of Plant Biology Major
Dean of Graduate School

Dr. Ir. Miftahudin, M.Si.
Dr. Ir. Dahrul Syah, M.Sc. Agr

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Penjelasan pada halaman sebelumnya tersebut melibatkan penelitian yang khusus terkait dengan bentuk operasi logam. Penelitian ini mencakup beberapa aspek penting dalam penelitian logam, mulai dari bentuk operasi logam, penelitian logam, dan penelitian logam. Untuk selanjutnya, penelitian logam ini diidentifikasi sebagai suatu model penelitian logam.

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Bogor, July 2011

Sanou Faye
**BIOGRAPHY**

Sanou Faye was born in 1976 in Motil N’done village, Fatick commune, Senegal. Sanou Faye was born as the second of four children. He finished Bachelors and Masters Degrees study in Natural Sciences in 2003 and 2004 respectively and continued with Pre-doctoral Degree study in Chemistry and Biochemistry of Natural Products from Plants and graduated in 2007 from Cheikh Anta Diop University, Dakar, Senegal. In 2008, he was awarded by the Indonesian Government to do Masters Degree in Bogor Agricultural University, majoring in Plant Biology under the Developing Countries Partnership Program (KNB – Kemitraan Negara Berkembang) with official permission from the Senegalese Ministry of Education for a period of Master Degree study program in Indonesia.
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I. INTRODUCTION

1.1. Background

Soil erosion by water is a serious and global environmental problem. About 85% of the land degradation in the world is associated with soil erosion, causing a 17% reduction in crop production (Oldeman et al. 2003). The problem of soil erosion is severe particularly in the tropics and sub-tropics where erosion rate range from 30 and 40 ton ha$^{-1}$yr$^{-1}$ (Pimentel, 2006).

Thus, soil erosion should be regarded as a natural disaster and controlled by appropriate measures. Many studies have proved increasing vegetation cover is an important measure to control water erosion, and to improve soil environments (Duran-Zuazo 2004; Xu et al. 2008). Quantitative and qualitative studies on the role of forests in water regulation, protection and conservation in different natural ecosystems have been published in a related Thematic Study on Forests and Water (FAO, 2010). These studies have suggested the influence exerted by the presence or absence of a good forest cover on regional climate (rainfall), total and seasonal water yield (floods, low flows), as well as on different forms of erosion and catchment sediment yield under humid tropical conditions in general and in Southeast Asia in particular. However, only a few studies are related to the interaction among vegetation cover, soil physical conditions and the surface hydrological processes of soil erosion and runoff (Chen et al. 2007; Bautista et al. 2007), and even fewer at individual plant scale (De Baets et al. 2007), on which we could relate such effects to the tree architecture model and thereby provide necessary information to select suitable plant species for vegetation restoration.

Tree architecture models are a useful tool in the description of tropical trees and have a clear phylogenetic component (Keller, 1994), but as yet relatively little progress has been made in relating particular models with particular ecological roles (Bongers and Sterck, 1998). This may be because the characters used to define the models are not precise enough to mirror any ecologically meaningful relationships of crown form. Two species of the same architectural model can look very different in the forest, and alternatively two species of different models can appear very similar. This does not mean that tree morphology is not relevant to ecology. Subsequent studies have shown that leaf placement and branch angles are...
highly efficient for light and rainfall interception in equitable environments of the humid tropics (Chazdon, 1985; Ackerly and Bazzaz, 1995; Pearcy and Yang, 1996), but crown shape and branch proportions may vary widely within a particular architectural model (Fisher and Hibbs, 1982; Fisher, 1986). Branching patterns affect leaf display, efficiency of mechanical support and supply of water. However, some workers still have questioned the value of architectural models as a way of analyzing ecological roles.

1.2. Research Objective

The objective of the research was to find out the influence of Castanopsis argentea Bl. and Michelia montana Blume architecture models on stemflow, throughfall, surface runoff, infiltration, as well as on erosion and soil physical properties.

1.3. Research Benefits

This study is expected to provide information that accelerate restoration processes by focusing on selecting species that can effectively control water runoff and soil loss, as well as on designing effective vegetation restoration patterns.

Castanopsis argentea or saninten in local name has big nuts. The nuts only fall after mature. Then there are many nuts under the mother trees. Many animals come to eat the nuts. Castanopsis argentea trees are important food resource for animals.

Michelia montana flowering throughout the year, the color ranges from yellow to orange. The flowers are used as frangrances and raw material of essential oils. Michelia montana woods has a fine fiber, classified into Strength Class II and Durability Class II and can be used as raw material for industry, construction, furniture, veneer, plywood, particle board, carving and decoration items (Martawijaya, 1989).
II. LITERATURE REVIEW

2.1. Tree Architecture Models

Tree architecture and its influence on whole-plant function and forest processes have been approached from a variety of perspectives, involving both the spatial arrangement of leaves considered in physiological process models and the genetically influenced programme of development considered in morphological models (Room et al. 1994). The concept of architectural modeling is a dynamic one, since it refers to the genetic information which determines the succession of forms of the tree. In order to understand architectural models, one has to observe trees as individuals at different stages, including at least the earliest part of their life and in as optimal an environment as possible so that the model is expressed freely.

Building on previous morphological studies, Halle, Oldeman and Tomlinson (1978) proposed that tropical trees could be described in terms of 23 architectural models (Fig 1), based on the behaviour of apical meristems in producing branching systems. According to this concept of ‘architectural analysis’ each plant conforms throughout its ontogeny to an architectural model that is an abstraction for the deterministic genetic blueprint on which the construction of the plant is based.

To a large extent, architectural models can be interpreted in terms of the behaviors of meristems and the phytomers that they produce: whether meristems are active continuously or intermittently; whether they undergo a fate change (e.g. vegetative to reproductive); whether branching is terminal or axillary; whether branches grow orthotropically, plagiotropically, or with some intermediate orientation; and whether phytomers elongate equally, unequally or not at all. This system is a typology of the genetically controlled component of aerial axis organisation based on character states for number of main axes, branching, presence of resting periods in development, relative apical dominance and positions of inflorescences. These aspects of meristem and axis behavior are currently the subject of physiological, genetic, and molecular analyses that are expected to lead to new ways to regulate meristem function and to generate new plant architectures.
Fig 1 Tree architecture models (Halle et al. 1978)

Under optimal growth conditions, the development and architecture of
the plant conform strictly to the model, but varied environmental conditions and
interactions with other organisms may result in deviations from the model. Thus,
most developmental morphologies of plants represent a balance between
deterministic genetic and opportunistic environmental events (Hallé, 1999).

Recently, Robinson (1996) has used symbolic logic to represent and analyse
the Halle´ and Oldeman system. Heinferred the possible existence of several, as yet,
unreported models. Many trees in the forest do not appear to conform to one of the
23 basic models, even when allowance is made for loss of branches due to damage
or disease. This failure to conform is often due to a process that Halle´ and Oldeman
called reiteration (Halle´ et al. 1978). One or more meristems, instead of carrying on
with the original model in the appropriate place, begin again, sometimes with a
completely different model altogether. Reiteration appears to be an important
process in the development of tree form. It allows the tree greater architectural
flexibility. Some trees never reiterate but conform to a single model throughout
their lives. For large trees, Halle´ (1986) pointed out three groups where this occurs
quite commonly. These are conifers, angiosperm families and fast-growing tropical
trees.
2.2. Soil Water Balance

All the water that is transpired by natural communities comes from precipitation, if the locations are such that the groundwater is well below the rooting zone. Before plants can use precipitation, it will be stored temporarily in the pore space of the soil in a plant-available form. By considering the precipitation as intake into the soil and the water transpired as an output from soil, the concept of a water balance has been developed (Gerten et al. 2004). The surplus rain water that does not add to the plant available water in the soil reservoir, and therefore does not contribute to meeting the actual transpiration, will drain through the subsoil towards the groundwater. But depending on local conditions part of the precipitation may not infiltrate the soil profile but flows away as surface runoff. It therefore follows that the soil water balance comprises the input quantity of precipitation and various output quantities. The balance acts as a feedback system with plants (Fig 2), which have a great need for water, taking priority. The water balance equation reads:

\[ P = E + I + T + D + R + \Delta S \text{ (mm)} \]

Fig 2  Schematic representation of the water balance computed for each grid cell by the dynamic global vegetation model (Lund-Posdam-Jena, LPJ). The thick arrows indicate water fluxes; the abbreviations of these fluxes are defined in the text (Gerten et al. 2004).
The P stands for precipitation, E for evaporation (the unproductive loss of water from the soil surface to the atmosphere), I for interception (the evaporative loss to the atmosphere of precipitation that was retained on leaf surfaces), T for transpiration (the productive loss of water by the plants to the atmosphere via stomates), D for subsoil drainage, R for runoff and ΔS for change in soil water storage. The change may be positive (gain of soil water) or may be negative (loss of moisture from the soil profile). All the terms listed are considered for specified time intervals, i.e. days, months or years.

Quite frequently the terms E and T are put together. ET, the evapotranspiration, is often used, as it is quite troublesome to separate E and T when measuring the balance in the field. Also the interception, I, is usually not recorded as a separate term, and therefore is often included in ET.

2.3. Water Erosion

On a global scale, water erosion is the most severe type of soil erosion. Rain splash and running water are two of the most important detaching agents that remove soil particles from soil surface. Detached soil particles are transported by running water (Fig 3). When sufficient energy is no longer available to transport soil particles, a third phase, deposition, occurs.

According to previous studies, relevant variables for soil erosion can be grouped into rainfall impact, flow characteristics, and bed conditions (ICHE 2006).

Fig 3 Particle detachment, transport and deposition on bare soil surface (International Conference on Hydroscience and Engineering, ICHE). Sep 10-13, 2006. Philadelphia, USA.
2.4. Factors Affecting Water Erosion

2.4.1. Climate

All climatic factors (precipitation, humidity, temperature, evapo-transpiration, solar radiation, and wind velocity) affect water erosion. Precipitation is the main agent of water erosion. Amount, intensity, and frequency of precipitation determine the magnitude of erosion. Intensity of rain is the most critical factor. The more intense the rainstorm, the greater the runoff and soil loss. High temperature may reduce water erosion by increasing evapotranspiration and reducing the soil water content. High air humidity is associated with higher soil water content. Higher winds increase soil water depletion and reduce water erosion.

2.4.2. Topography

Soil erosion increases with increase in field slope. Soil topography determines the velocity at which water runs off the field. The runoff transport capacity increases with increase in slope steepness. Soils on convex fields are more readily eroded than in concave areas due to interaction with surface creeping of soil by gravity. Degree, length, and size of slope determine the rate of surface runoff. Rill, gully, and stream channel erosion are typical of sloping watersheds. Steeper terrain slopes are prone to mudflow erosion and landslides.

2.4.3. Plant cover

Vegetative cover reduces erosion by intercepting, adsorbing, and reducing the erosive energy of raindrops. Plant morphology such as height of plant and canopy structure influences the effectiveness of vegetation cover. Surface residue cover sponges up the falling raindrops and reduces the bouncing of drops. It increases soil roughness, slows runoff velocity, and filters soil particles in runoff. Soil detachment increases with decrease in vegetative cover. Dense and short growing (e.g. grass) vegetation is more effective in reducing erosion than sparse and tall vegetation. The denser the canopy and thicker the litter cover, the greater is the splash erosion control, and the lower is the total soil erosion. Vásquez-Méndez et al. (2010) reported that greater canopy and ground vegetation covers in vegetation patches of semiarid areas in Central Mexico reduced significantly runoff and soil loss as compared to the Control surface.
Moreover, the litterfall of native vegetation mulches prevented the direct impact of raindrops on bare soil and thus decreased surface sealing and lengthened the residence time for water to infiltrate into the soil (Bhatt and Khera 2006).

Plant strips protected soil from the erosive action of runoff water, by offering resistance to the movement of water and shielding the soil from such effects. The plant strips also interrupted raindrop splash and overland flow, thereby reducing erosion. Francia et al. (2006) and Martinez et al. (2006) reported that plant strips efficiently buffered the mechanical impact of the raindrops on the soil surface, diminishing runoff. Duran zuazo et al. (2009) reported that more soil erosion and runoff were registered in the Non-tillage without plant strips (NT) compared to the Non-tillage with native vegetation strips (NVS) treatment in olive orchards.

The plant roots penetrating the soil matrix favoured porosity and thus infiltration, allowing the root zone to act as a partial sink for runoff. Root species that deployed their roots mainly in the topsoil helped reduce soil erosion by bolstering soil shear strength, while the increased root density with higher species numbers enhanced soil antiscourability (Francia et al. 2006; Martinez et al. 2006). The differences were clearly visible in the field—both the roots and stems increased the roughness of the soil surface and thus soil permeability, improving infiltration and avoiding soil disturbance treatment with detached soil particles.

2.4.4. Soil properties

Texture, organic matter content, macroporosity, and water infiltration influence soil erosion. Antecedent water content is also an important factor as it defines the soil pore space available for rainwater absorption. Soil aggregation affects the rate of detachment and transportability. Clay particles are transported more easily than sand particles, but clay particles form stronger and more stable aggregates. Organic materials stabilize soil structure and coagulate soil colloids. Compaction reduces soil macroporosity and water infiltration and increases runoff rates. Large and unstable aggregates are more detachable. Interactive processes among soil properties define soil erodibility. Soil erodibility refers to soil’s susceptibility to erosion. It is affected by the inherent soil properties.
III. MATERIALS AND METHODS

3.1. Time and Place

The research was done at Cikaniki research station and its surrounding areas, Gunung Halimun-Salak National Park from 23 November 2010 to 20 January 2011.

3.2. Materials and Equipment

Materials used include plant species *Castanopsis argentea* and *Michelia montana*, Global Position System (GPS), altimeter, clinometer, roll meter, rain gauge, containers, pvc pipe, analytical balance, camera, an equipment for soil sampling and soil gravimetric process in laboratory.

3.3. Methods

3.3.1. Tree architecture model identification

Architectural models are recognized mainly by criteria which relate to primary growth. Radial growth from a vascular cambium which brings about secondary increase in thickness serves to stabilize the primary system. In this study, two architecture models we have so far recognized are Stone and Petit models. Each architectural model is named after we have examined in greater or lesser details and are based on field notes and sketches supplemented by photographs on the plant exhibiting the model. A description and short definition of the two architecture models have been done. In addition each model is illustrated initially by species which show the model well.

3.3.1.1. Stone’s model

The model was illustrated by Stone (1970). *Pandanus pulcher* endemic to Madagascar represents the model in striking fashion. The architecture results from the continuous growth of the meristem of the orthotropic trunk, which produces orthotropic branches either continuously or diffusely. Further branches develop sympodially below terminal inflorescences, and the trunk may flower terminally. This model is illustrated by *Castanopsis argentea* (Fig 4), a tree 10 to 20 m tall. A free vegetative terminal meristem and secondary growth permit unlimited branch extension, which seems to account for the greater efficiency of Stone’s model.
3.3.1.2. Petit’s model

The model named after E. Petit, who has contributed to the understanding of the architecture trees in his study of Africa Rubiaceae belonging to the tribe Gardenieae (Petit, 1964). Many of the trees which conform to this model are small and there is a high degree of reduction in the organization of their branch modules. The model is illustrated initially by *Gossypium hirsutum* (Malvaceae, Tropical America) widely cultivated as one of the commercial cottons. The architecture of the tree is determined by the continuous growth of a monopodial, orthotropic trunk axis which produces, either continuously or in a diffuse manner, plagiotropic branches with spiral or decussate phyllotaxis. In many examples this continuous growth, once branch initiation has begun, results in continuous branching, i.e., a branch at every node on the trunk. Branches are modular, plagiotropic by substitution, each module being hapaxanthic. Large trees may conform to Petit’s model, as is indicated by *Michelia montana* Blume. (Fig 5), a common tree of the Gunung Halimun Salak Forest which reaches a height of 10 to 20 m. All parts of the plant are big and leaves are arranged throughout. This tree is most characteristic of steep hillsides where large populations of young, suppressed trees may occur. Trees which conform to this model occupy a wide variety of habits, ranging from the lowest to the higher levels of rain-forest, but also in savana, even in quite dry places. The main biological feature in this model is the strong tendency towards...
specialization of the plagiotropic system, mainly indicated by reduction in the number of parts in each nodule.

![Image](image_url)

Fig. 5  Petits model, (a) *Michelia montana* Blume (Magnolioideae, Halimun Salak Forest) and Petits ideal model, (b) *Gossypium hirsitum* (Malvaceae, Tropical America, Petit, 1964).

### 3.3.2. Vegetation measurement

#### 3.3.2.1. Basal area measurement

The crown cover (cc) of each tree measured by a meter tape that laid out on the ground from one side of the tree crown across the center to the other side of the crown perimeter. This results in one diameter reading. Since crowns do not usually form a perfect circle, it was necessary to run at least a second crown diameter measurement more or less perpendicular to the first one. The crown cover (cc) obtained from the formula (Mueller-Dombois and Ellenberg, 1974):

\[
cc = \left(\frac{D_1 + D_2}{4}\right) \pi ,
\]

where D1 equals the first measurement crown diameter and D2 equals the second measurement.

#### 3.3.2.2. Tree diameter and height measurements

Representative individuals of *Castanopsis argentea* and *Michelia montana* were studied. Total individual plant height of the trunk from the ground to the first branch bifurcation and diameter breast height were measured using a roll meter.
3.3.3. Soil conservation parameter measurement

3.3.3.1. Rainfall

We use the rain gauge that consists of a large cylinder with a 20 centimeter in diameter funnel that collects water into the cylinder to measure rainfall (Fig 6).

![Rain gauge](image)

**Fig 6** Rain gauge used for measuring rainfall at Gunung Halimun Salak.

3.3.3.2. Throughfall

Throughfall was collected from each tree using throughfall trough (area=1 m²). The throughfall trough beneath each tree was positioned in radial pattern extending out from the tree base to the crown perimeter (Fig 7).

![Throughfall design](image)

**Fig 7** Throughfall design utilized at Gunung Halimun Salak.

3.3.3.3. Stemflow

Stemflow drainage was collected from each tree using a stemflow collar consisting of high quality hose (2.5 cm inner diameter) that was slit longitudinally and sealed to the trunk. This plastic hose conducts water to a container where it will be measured after each storm (Fig 8).
3.3.4. Erosion and runoff measurements

Erosion and runoff plots were established at a 8-10% slope. Plots, 5 m long and 4 m wide (total area 20 m$^2$), and delineated with strips of metal buried to 10 cm depth to restrict water flowing onto the plots from the adjacent areas, were established for *Castanopsis argentea*, *Michelia montana* and Control. A metal-sheet plot end placed at the bottom of the slope to convey runoff into a 10 cm PVC pipe which, in turn, delivered water and sediment into a 100 L container (Fig 9). After each rainfall event, runoff was determined by measuring the water stage in the container. Eroded soil was collected from the drains, weighted and moisture content calculated.

3.4. Statistical Analysis

Multiple regression analysis was done to interpret linear relationships between factors by examining the statistical significance of the coefficients of multiple determinations. Principal component analysis was used to examine the correlation among the factors (Jollife, 1986).
IV. RESULTS AND DISCUSSION

4.1. Tree characteristics

Throughfall, stemflow, runoff and soil erosion were collected during the study period from *Castanopsis argentea* and *Michelia montana* which represent common canopy tree species at Gunung Halimun Salak National Park.

*Castanopsis argentea* (Fagaceae) saninten in local name is one of the most dominant species around Cikaniki. Fagaceae is one of the most dominant trees on tropical mountain forest.

*Mickeia montana* belongs to the Magnoliaceae’s family. Magnoliaceae is familiar plants for people in Gunung Halimun Salak National Park. Though most magnolia in cool climate are deciduous, those in tropical forests are evergreen. In nature the tree can reach 50 m high with a trunk diameter of 1.8 m.

In Indonesia this species distributes in Sumatra, Jawa, Sulawesi and Lesser Sunda islands. It grows at an altitude of 250-1500 m above sea level (Oyen and Dung, 1999), at climate type A or B according to Smith and Ferguson classification with rainfall ranging from 1000 to 2000 mm/year (Saputra, 1991 in Iskandar, 2003). In Java, *Michelia montana* cultivation is carried out on land up to about 1200 m above sea level (Heyne, 1987). *Michelia montana* grows well in soils dominated by clay, slightly moist soil conditions and normal pH (Iskandar, 2003).

In this study, each species was represented by one canopy tree having crown fully exposed to vertical rainfall inputs. Full characteristics of the selected trees are shown in Table 1. The forest floor of each of these trees is covered by *Pinanga coronata*, *Angiopteris*, *Cyathea*, *Rottans*. The trees have many epiphytes of orchids, ferns (*Aslpenium nidus*, *Drynaria*, *Nephrolepis*), and *Freycinetia*.

Table 1 Plant species characteristics

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Plot Area (m²)</th>
<th>Crown Cover (m²)</th>
<th>Trunk Diameter (cm)</th>
<th>Total Height (m)</th>
<th>Architecture Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Castanopsis argentea</em></td>
<td>20</td>
<td>5-15</td>
<td>10-20</td>
<td>4-10</td>
<td>Stone</td>
</tr>
<tr>
<td><em>Michelia montana</em></td>
<td>20</td>
<td>5-15</td>
<td>10-20</td>
<td>4-10</td>
<td>Petit</td>
</tr>
</tbody>
</table>
4.2. Soil Conservation Parameters

Soil conservation parameter measurements at each plot were made over the study period between November 2010 and January 2011. Throughfall, stemflow, runoff, and soil erosion measurements from *Castanopsis argentea*, *Michelia montana*, and Control plots are presented in Table 2.

### Table 2 Throughtfall, stemflow, runoff, and soil erosion from *Castanopsis argentea*, *Michelia montana*, and Control plots at Gunung Halimun

<table>
<thead>
<tr>
<th>Rainfall Events</th>
<th>Throughfall (mm)</th>
<th>Stemflow (mm)</th>
<th>Runoff (mm)</th>
<th>Soil erosion (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$X_1$</td>
<td>$X_2$</td>
<td>$X_1$</td>
<td>$X_2$</td>
</tr>
<tr>
<td>1</td>
<td>18.10</td>
<td>10.21</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>2</td>
<td>25.30</td>
<td>25.30</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>3</td>
<td>19.99</td>
<td>20.06</td>
<td>0.17</td>
<td>0.23</td>
</tr>
<tr>
<td>4</td>
<td>27.99</td>
<td>28.00</td>
<td>0.16</td>
<td>0.16</td>
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<tr>
<td>5</td>
<td>29.59</td>
<td>29.51</td>
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<td>0.26</td>
</tr>
<tr>
<td>6</td>
<td>18.74</td>
<td>18.74</td>
<td>0.10</td>
<td>0.19</td>
</tr>
<tr>
<td>7</td>
<td>12.29</td>
<td>12.36</td>
<td>0.15</td>
<td>0.14</td>
</tr>
<tr>
<td>8</td>
<td>8.80</td>
<td>9.06</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>9</td>
<td>28.70</td>
<td>23.25</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>10</td>
<td>25.80</td>
<td>21.89</td>
<td>0.20</td>
<td>0.16</td>
</tr>
<tr>
<td>11</td>
<td>62.34</td>
<td>62.34</td>
<td>0.37</td>
<td>1.20</td>
</tr>
<tr>
<td>12</td>
<td>5.30</td>
<td>5.40</td>
<td>0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>13</td>
<td>19.81</td>
<td>19.90</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>14</td>
<td>17.89</td>
<td>17.99</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>15</td>
<td>8.70</td>
<td>12.15</td>
<td>0.14</td>
<td>0.15</td>
</tr>
<tr>
<td>16</td>
<td>18.60</td>
<td>18.69</td>
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<td>0.16</td>
</tr>
<tr>
<td>17</td>
<td>26.38</td>
<td>26.28</td>
<td>0.27</td>
<td>0.38</td>
</tr>
<tr>
<td>18</td>
<td>19.10</td>
<td>19.17</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>19</td>
<td>31.30</td>
<td>25.49</td>
<td>0.07</td>
<td>0.37</td>
</tr>
<tr>
<td>20</td>
<td>15.06</td>
<td>15.13</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>21</td>
<td>13.75</td>
<td>13.84</td>
<td>0.13</td>
<td>0.07</td>
</tr>
<tr>
<td>22</td>
<td>25.19</td>
<td>25.29</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>23</td>
<td>16.77</td>
<td>16.77</td>
<td>0.18</td>
<td>0.12</td>
</tr>
<tr>
<td>24</td>
<td>15.09</td>
<td>15.17</td>
<td>0.12</td>
<td>0.07</td>
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<tr>
<td>25</td>
<td>11.00</td>
<td>12.08</td>
<td>0.14</td>
<td>0.13</td>
</tr>
<tr>
<td>26</td>
<td>14.36</td>
<td>14.44</td>
<td>0.13</td>
<td>0.06</td>
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<tr>
<td>27</td>
<td>33.75</td>
<td>33.84</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>28</td>
<td>16.61</td>
<td>16.70</td>
<td>0.11</td>
<td>0.45</td>
</tr>
<tr>
<td>29</td>
<td>6.82</td>
<td>6.90</td>
<td>0.14</td>
<td>0.05</td>
</tr>
<tr>
<td>30</td>
<td>17.12</td>
<td>17.21</td>
<td>0.11</td>
<td>0.16</td>
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<tr>
<td>31</td>
<td>12.32</td>
<td>12.40</td>
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<td>0.14</td>
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<td>32</td>
<td>22.56</td>
<td>22.56</td>
<td>0.18</td>
<td>0.26</td>
</tr>
<tr>
<td>33</td>
<td>12.70</td>
<td>12.79</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>657.8</td>
<td>640.9</td>
<td>4.73</td>
<td>6.20</td>
</tr>
</tbody>
</table>

Estimated erosion rate (ton/ha/year) 0.81 0.75 1.98

Note: $X_1 = *Castanopsis argentea* (Stone model); $X_2 = *Michelia montana* (Petit model); $X_3 = Control plot
4.2.1. Rainfall

Fifty total rainfall events were registered during the study period starting from 23 November 2010 to 20 January 2011, accounting for a total rainfall amount of 952.77 mm. Thirty three runoff-producing events, accounting for a total amount 822 mm were evaluated. More than 87% of the raindays had gross rainfall totals of more than 8 mm day$^{-1}$, ranging from 8.22 to 63.51 mm day$^{-1}$. This large water yield illustrates that the climate, as Gunung Halimun National Park in general, belong to type A of Schmidt and Ferguson (1951) classification with the annual rainfall of 4000-6000 mm. Similarly high yields have been reported for other montane forests. For instance, the tropical forests on Barro Colorado Island, Panama, receive on average 2612 mm of rainfall annually (Windsor 1990). Rainforests are one of the most efficient systems for retaining and recirculating freshwater on the planet. In general, tropical rainforests usually receive considerably more rainfall compared to other biomes.

However, such forests are potentially under threat from climate change, which could result in reduced cloud water interception and improved conditions for evaporation. The net effect of these changes is reduced yield, which is important hydrologically, and altered moisture conditions, which could also be disastrous for plant and animal species dependent on wet and humid conditions.

4.2.2. Throughfall and stemflow for the different plots

Stemflow and throughfall values were respectively 4.73 and 640.91 mm for Castanopsis argentea, 6.20 and 657.82 mm for Michelia montana. Stemflow and throughfall were found to represent 0.5 and 77.96% for Castanopsis argentea with Stone’s model, 0.7 and 80.02% for Michelia Montana with Petit’s model, respectively of the cumulative precipitation input. Measurements of both throughfall and stemflow for the two species are within the range of values found in other rainforest ecosystems. At the Educational Forest Mountain Gunung Walat, Sukabumi, Aththorick (2000) reported 3.850 and 427.421 mm for throughfall and stemflow respectively for Trema orientalis tree with Rauh’s model. Stemflow value of Massart’s model (6.455 mm) found by the same author was nearly to value of stemflow of Michelia montana (6.20 mm). The cumulative throughfall (%) value for our study falls within the upper range of cumulative
throughfall (%) values reported by Navar et al. (1999) for six study plots within the Northern Gulf of Mexico Coastal Plain (73.4-83.7%). Cumulative stemflow (%) generated, although not significantly different, is similar to the average values observed by Navar et al. (1999) (0.4-6.5%). Other observations have been made for other montane rainforests. At the Australian tropical rainforest, McJannet et al. (2007) reported 65% (3739 mm) and 7% (418 mm) of gross precipitation for throughfall and stemflow respectively. The significant discrepancy between these findings warrants further attention. Throughfall and stemflow importance vary from the total incident precipitation, depending on branch and stand morphology and on bark roughness.

In this study, comparison of the two species of tree indicated the importance of crown form. *Michelia Montana* was found in sites with more direct overhead rainfall interception on average than *Castanopsis argentea*, generally small leaves in the canopy. *Michelia Montana* was more highly branched with a shell of drooping leaves on the outside of the crown. *Castanopsis argentea* had whorled branches in tiers with planar foliage arrays. *Michelia montana* appeared more efficient at intercepting the larger amounts of rainfall available in rain forest understorey sites.

4.2.3. Erosion and runoff for the different plots

Measured runoff and soil loss data from the vegetation patches showed that *Castanopsis argentea* and *Michelia Montana* produced significantly less runoff and erosion than the Control. The maximum values of runoff were approximately 2.45, 1.54 and 1.28 mm for the Control, *Castanopsis argentea* and *Michelia montana*, respectively. Total runoff measured was 49.32, 15.74 and 10.87 mm, for plots. Runoff values were similar among *Castanopsis argentea* and *Michelia montana*, and they differ from the Control. The plots of *Castanopsis argentea* and *Michelia montana* reduced runoff by 31.33% and 45.37%, respectively, as compared to the control surface. Runoff coefficients estimated from the observed data were 0.06, 0.019, and 0.013 for the Control, *Castanopsis argentea*, and *Michelia montana*, respectively. The values for *Castanopsis argentea*, and *Michelia montana* are similar to those reported by Vásquez-Méndez et al. (2010) for *Acacia farnesiana* and *Opuntia sp* (0.01) in a semiarid area in Central
Mexico. Nevertheless, the value for the Control plot was lower than those reported by the same authors (0.33).

It was observed that an increase in rainfall did not produce an increment in runoff for the patches of *Castanopsis argentea* and *Michelia montana* likely the Control (Fig 10). Given the leaf area index and woody surface area index that characterize *Castanopsis argentea* and *Michelia montana*, the probability of a raindrop passing through the canopy without contacting a vegetative surface is relatively low even under strong wind conditions. The aerial structures of the two species intercept a significant amount of rainfall, which is subsequently translocated as stemflow to the soil, increasing infiltration and diminishing the potential for runoff. Cumulative soil loss values were quantified in 1.98, 0.82 and 0.76 ton ha\(^{-1}\)year\(^{-1}\) for the Control, *Castanopsis argentea* and *Michelia montana*, respectively. Increases in the amount of surface runoff lead to an increase in soil erosion. However, these relationships are inconsistent in *Castanopsis argentea* and *Michelia montana* plot. This result suggests that vegetation patches of *Castanopsis argentea* and *Michelia montana* create soil fertility where soil organic matter contents are greater, bulk densities are lower, and consequently, the stability of aggregates and water intake increases, reducing the amount of runoff and soil erosion.

![Fig 10 Runoff relationship (A) and rainfall-erosion relationship (B) for different plots.](image)

### 4.3. Correlation Between Soil Conservation Parameters

Linear multiple regressions onto rainfall, throughfall, stemflow, runoff and erosion are computed:
Erosion_{Castanopsis} = 0.02 + 0.004 \text{ rainfall} + 0.06 \text{ throughfall} + 14.8 \text{ runoff} - 0.4 \text{ stemflow}
Erosion_{Michelia} = 0.65 + 0.03 \text{ rainfall} + 0.16 \text{ throughfall} + 8.76 \text{ runoff} + 0.34 \text{ stemflow}

The coefficients of multiple determination (R^2 = 0.961 and 0.97) are high which, given r = 0.98, is significant (P<0.01). This indicates that soil erosion is significantly correlated to rainfall, throughfall, stemflow and runoff. These correlations are summarized in Tables 3 and 4 and the results of the Principal components analysis (PCA) are showed in the biplot (Fig 11).

Table 3 Matrix correlation for Castanopsis argentea

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rainfall</th>
<th>Throughfall</th>
<th>Runoff</th>
<th>Stemflow</th>
<th>Erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throughfall</td>
<td>0.919</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Runoff</td>
<td>0.872</td>
<td>0.966</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stemflow</td>
<td>0.659</td>
<td>0.761</td>
<td>0.758</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Erosion</td>
<td>0.868</td>
<td>0.956</td>
<td>0.979</td>
<td>0.741</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Table 4 Matrix correlation for Michelia montana

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rainfall</th>
<th>Throughfall</th>
<th>Runoff</th>
<th>Stemflow</th>
<th>Erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Throughfall</td>
<td>0.891</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Runoff</td>
<td>0.852</td>
<td>0.976</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stemflow</td>
<td>0.747</td>
<td>0.791</td>
<td>0.811</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Erosion</td>
<td>0.881</td>
<td>0.979</td>
<td>0.977</td>
<td>0.803</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Fig 11: Biplot of soil conservation parameters using data from (A) Castanopsis argentea and (B) Michelia montana.
The biplots display graphically the five variables within a coordinate system where the relative positions of the variables reflect correlations. The relative correlation of each variable demonstrated clearly that throughfall and runoff are far more correlated with soil erosion than rainfall and stemflow. Interpretation of this ordination is that the volume of rainfall per unit projected crown area from the same rainfall event is primarily in the form of throughfall and stemflow, with relative contribution of throughfall to runoff being somewhat more important. In fact, since runoff and erosion are measured in the same unit data, the three variables throughfall, runoff and erosion were found to be more correlated than rainfall and stemflow.

Compared to throughfall, stemflow represented a small component of precipitation flux and its contribution to runoff seems to be very small. Moreover, the average Herwitz (1986) funnelling ratio derived for woody stem plants suggests that stemflow is an important water flux, delivering an average of times more water to the base of the plant than to runoff flux.

4.4. Infiltration rate for the different plots

In addition to vegetation observations, experimental measurements of infiltration were made. The infiltration rate curves are presented in Fig 12.

![Infiltration rate curves](image)

Fig 12 Infiltration rate curves for *Castanopsis argentea*, *Michelia montana* and Control plots.
There is a notable difference between the infiltration rate curve from the Control plot and the infiltration rate curves from *Castanopsis argentea* and *Michelia montana*. Infiltration rate is observed to be higher with *Castanopsis argentea* and *Michelia montana* compared to the Control plot. This is because in the Control plot, the impact energy of water drops cause surface sealing and crust formation, reducing evolution of infiltration rate and producing higher runoff. Comparing the infiltration curves determined in both *Castanopsis argentea* and *Michelia montana* plots, there is a notable increase in the infiltration rate in the second case, especially for durations of less than 50-60 min, implying that changes in soil surface conditions are related in this study to a greater contribution of organic matter by the leaves and roots of both *Castanopsis argentea* and *Michelia montana* species. Their contribution is discussed from viewpoints of mineral cycling. The stable woody structures of *Castanopsis argentea* and *Michelia montana* provide various habitats for microbes, animals, and their slow decay rates contribute to conservative mineral cycling due to continuous breaking of solid physicochemical properties (Seastedt and Crossley, 1984). These pathways combine to introduce increased amounts of carbon, nitrogen, and phosphorus into the soil community and promote rainfall infiltration into the soil and reduces overland flow velocities, thus diminishing the soil erosion potential (Regués and Torri, 2002). However, contribution of these three major categories of inputs from the canopy occurs with differences among tree species, and even among canopy layers (Heatwole et al. 1997). *Michelia montana* with upward sloping branches and dense foliage is likely to release more litterfall than *Castanopsis argentea*. 
V. CONCLUSION AND SUGGESTION

5.1 Conclusion

Based on the results mentioned above, significant positive correlations were found between soil conservation parameters and tree architecture Stone and Petit models. The relative correlation of each variable demonstrated that throughfall and runoff are far more important than rainfall and stemflow for explaining the variation in soil erosion.

Stemflow for Castanopsis argentea (4.73 mm) was slightly smaller than stemflow for Michelia montana (6.20 mm). The values of throughfall indicate 7.82 and 640.91 mm for Castanopsis argentea and Michelia montana respectively. Runoff measured was 49.32, 15.74 and 10.87 mm for the Control, Castanopsis argentea and Michelia montana respectively. Soil loss was quantified in 1.98, 0.82 and 0.76 ton ha\(^{-1}\) year\(^{-1}\) for the Control, Castanopsis argentea and Michelia montana respectively. The Infiltration rate is observed to be higher with Michelia montana compared to Castanopsis argentea. These results show that Michelia montana is better than Castanopsis argentea to be developed in soil and water conservation.

5.2 Suggestion

We suggest that more attention be directed to the position and form of individual tree architecture models in studies of soil erosion. Such information is important because it provides a more precise picture on how or in what manner rainfall is received and distributed within an ecosystem.
REFERENCES


Appendix: Illustrated Key to the Architectural Models of tropical Trees (Halle et al. 1978)

1a. Stem strictly unbranched (Monoaxial trees)..............................................................2

1b. Stem branched, sometimes apparently unbranched in Chamberlain’s model
(Polyaxial trees)...............................................................................................................3

2a. Inflorescence terminal.................................................Holtum’s model

- e.g., Monocotyledon: Corypha umbraculifera (Talipot palm-Palmae)
  Dicotyledon: Sohnreya excelsa (Rubiaceae)

2b. Inflorescences lateral..............................................................Corner’s model
Growth continuous

- e.g., Monocotyledon: Cocos nucifera (coconut palm-Palmae)
  Elaeis guineensis (African oil palm-Palmae)
Dicotyledon: *Carica papaya* (papaya-Caricaceae)

Growth rhythmic

etc., Gymnosperm: Female *Cycas circinalis* (Cycadaceae)

Dicotyledon: *Trichoscypha ferruginea* (Anacardiaceae)

3a. Vegetative axes all equivalent, homogenous (not partly trunk, partly branch), most often orthotropic and modular .........................................................

3b. Vegetative axes not equivalent (homogenous, heterogeneous or mixed but always clear difference between trunk and branches) ................................................................

4a. Basitony, i.e., branches at the base of the module, commonly sugterranean, growth usually continuous, axes either hapaxanthic or pleonanthic........................................

.................................................................................................................................Tomlinson’s model

Hapaxanthy, i.e., each module determinate, terminating in an inflorescence

E.g., Monocotyledon: *Musa cv.* Sapientum (banana- Musaceae)
Dicotyledon: *Lobelia gibberoa* (Lobeliaceae)

Pleonanthy, i.e., each module not terminate, with lateral inflorescences

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e.g., Monocotyledon: *Phoenix dactylifera* (date palm-Palmae)

4b. Acrotony, i.e., branches not at the base but distal on the axis..........................5

5a. Dicotomous branching by equal division of apical meristem...Schoute’s model

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e.g., Monocotyledon:
Vegetative axes orthotropic-*Hyphaene thebaica* (doum palm-Palmae)
Vegetative axes plagiotropic-*Nypa fruticans* (nipa palm-Palae)

5a. Axillary branching without dichotomy...................................................6

6a. One branch per module only; sympodium one-dimensional, linear monocaulous, apparently unbranched, modules hapaxanthic, i.e., inflorescences terminal...........

.................................................................................................Chamberlain’s model
e.g., Gymnosperm: Male *Cycas circinalis* (Cycadaceae)

Monocotyledon: *Cordyline indivisa* (Agavaceae)

Dicotyledon: *Talisia mollis* ( Sapindaceae)

6b. Two or more branches per module; symposium three-dimensional, nonlinear, clearly branched; inflorescences terminal.............................. Leeuwenberg’s model

7a. Vegetative axes heterogenous, i.e., differentiated into orthotropic and plagiotropic axes or complexes of axes................................................................. 8

7b. Vegetative axes homogenous, i.e., either all orthotropic or all mixed.

8a. Basitonic (basal) branching producing new (usually subterranean) trunks.....

............................................................................................................ McClure’s model

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e.g., Monocotyledon: *Dracaena draco* (dragon tree-Agavaceae)

Dicotyledon: *Ricinus communis* (castor-bean-Euphorbiaceae)

*Manihot esculenta* (Cassava-Euphorbiaceae)
i.e., Monocotyledon: *Bambusa arundinacea* (bamboo-Gramineae-Bambusoideae)

Dicotyledon: *Polygonum cuspidatum* (Polygonaceae)

8a. Acrotonic (distal) branching in trunk formation (never subterranean).................9

9a. Modular construction, at least of plagiotropic branches; modules generally with functional (sometimes with more or less aborted) terminal inflorescences..............10

9b. Construction not modular; inflorescences often lateral but always lacking any influence on main principles of architecture........................................................................13

10a. Growth in height sympodial, modular..............................................................11

10b. Growth in height monopodial, modular construction restricted to branches..12

11a. Modules initially equal, all apparently branches, but later unequal, one becoming a trunk........................................................................................................Koriba’s model

e.g., Dicotyledon: *Hura crepitans* (sand-box tree-Euphorbiaceae)
11b. Modules unequal from the start, trunk module appearing later than branch modules, both quite distinct..........................................................Prevot’s model

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Example of species:

- Euphorbia pulcherrima (poinsettia - Euphorbiaceae)
- Alstonia boonei (emien - Apocynaceae)

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12a. Monopodial growth in height rhythmic........................Fagerlind’s model

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Example of species:

- Cornus alternifolius (dogwood - Cornaceae)
- Fagraea crenulata (Loganiaceae)
12b. Monopodial growth in height continuous........................................Петит’s model

e.g., Dicotyledon: *Gossypium* species (cotton-Malvaceae)

13a. Trunk a sympodium of orthotropic axes (branches either monopodial or sympodial, but never plagiotropic by apposition)......................Нозеран’s model

e.g., Dicotyledon: *Theobroma cacao* (cocoa-Sterculiaceae)

13b. Trunk an orthotropic monopodium......................................................14

14a. Trunk with rhythmic growth and branching.........................................15

14b. Trunk with continuous or diffuse growth and branching..........................16

15a. Branches plagiotropic by apposition....................................................Aubreville’s model
b. Branches plagiotropic but never by apposition, monopodial or sympodial by substitution.......................................................... Massart’s model

e.g., Gymnosperms: *Araucaria heterophylla* (Norfok island pin-Araucariaceae)

Dicotyledon: *Ceiba pentandra* (kapok-Bombacaceae)

*Myristica fragrans* (nutmeg-Myristicaceae)

16a. Branches plagiotropic but never by apposition, monopodial or sympodial by substitution.........................................................................................................................17

16b. Branches plagiotropic by apposition................................................Theoretical model
17a. Branches long-lived, not resembling a compound leaf...............Roux’s model

e.g., Dicotyledon: *Euphorbia sp.* (Euphorbiaceae)

17b. Branches short-lived, phyllomorphic, i.e., resembling a compound leaf......

........................................................................................................... Cook’s model

e.g., Dicotyledon: *Coffea arabica* (coffee-Rubiaceae)

*Bertholetia excelsa* (Brazil nut-Lecythidaceae)

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e.g., Dicotyledon: *Castilla elastica* (Ceara rubber tree-Moraceae)
18a. Vegetative axes all orthotropic ................................................................. 19
18b. Vegetative axes all mixed ............................................................................. 22
19a. Inflorescences terminal, e.g., branches sympodial and, sometimes in the
periphery of the crown, apparently modular .................................................... 20
19b. Inflorescences lateral, i.e., branches monopodial ........................................ 21
20a. Trunk with rhythmic growth in height .......................................................... 20

..........................................................................................................................
Scarrone’s model

20b. Trunk with continuous growth in height ...................................................... 21

..........................................................................................................................
Stone’s model

e.g., Monocotyledon: *Pandanus vandamii* (Pandanaceae)

Dicotyledon: *Mangifera indica* (mango-Anacardiaceae)

e.g., Monocotyledon: *Pandanus pulcher* (Pandanaceae)

Dicotyledon: *Mikania cordata* (Compositae)
21a. Trunk with rhythmic growth in height

Rauh’s model

e.g., Gymnosperm: *Pnus caribaea* (Honduran pin-Pinanceae)

Dicotyledon: *Hevea brasiliensis* (Para rubber tree-Euphorbiaceae)

21b. Trunk with continuous growth in height

Atim’s model

e.g., Dicotyledon: *Rhizophora racemosa* (Rhizophoraceae)

22a. Axes clearly mixed by primary growth, at first (proximally) orthotropic, later distally (plagiotropic)

Mangenots’ model
41.

b. Axes apparently mixed by secondary changes........................................23

a. Axes all orthotropic, secondarily bending (probably by gravity). ..............

..........................................................................................

Champagnat’s model

e.g., Dicotyledon: *Strychnos variabilis* (Loganiaceae)


b. Axes all plagiotropic, secondarily becoming erect, most often: *Bougainvillea glabra* (Nyctaginaceae)


b. Axes all plagiotropic, secondarily becoming erect, most often after leaf-fall...

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Troll’s model

e.g., Dicotyledon: *Annona muricata* (castar apple-Annonaceae)

*Avrroha carambola* (carambola-Oxalidaceae)

*Delonix regia* (poinciana-Leguminosae-Caesalpiniaeae)
Trunk a monopodium (e.g., Cleistopholis patens - Annonaceae)

Trunk a sympodium (e.g., Parinari excelsa - Rosaceae)