Chapter 2
CHAPTER 2

LITERATURE REVIEW

THE INFLUENCE OF VEGETATION ON STABILITY OF SLOPE

2.1 Introduction

The role of vegetation cover in reducing surface run-off, soil erosion, sediment transport and landslide is well documented. While the documentation is extensive in most parts of the developed world, it is lacking in the developing world. Slope problems vary between different geographical regions. For instance, in the European countries, barren steep slopes are exposed to a range of fluctuating temperatures and humidity. Whilst in Malaysia, they are exposed to torrential rains. Due to this variability, their solutions are also different and have to be specifically tailored. Research on bioengineering is thus ubiquitously indispensable.

It is well known that vegetation affects both the surface and the mass stability of slopes (Gray, 1995). Barker (1996) suggests a tight, dense cover of grass or herbaceous vegetation provides one of the best protections against surficial rainfall and wind erosion. Conversely, deep-rooted, woody vegetation is more effective for mitigating or preventing shallow, mass stability failure. The loss or removal of slope vegetation can result in, inter alia, increased rates of erosion and higher frequencies of slope failure. These adverse consequences have been comprehensively summarised (Table 2.1).

Thus, plant cover is a very critical factor in the whole ecosystem and especially in slope protection and stabilisation. This has led to two significant contributions of vegetation to slope stability: soil reinforcement by root system and water relation element via soil-plant-atmosphere continuum.
Table 2.1: Adverse consequences of the absence of vegetation ground cover (Barker, 1996)

<table>
<thead>
<tr>
<th>Process</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosion</td>
<td>- Loss of surface soil</td>
</tr>
<tr>
<td></td>
<td>- Loss of soil in rills and gullies</td>
</tr>
<tr>
<td></td>
<td>- Loss of nutrients/fertility</td>
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<td></td>
<td>- Loss of slope form or geometry</td>
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<td></td>
<td>- Loss of slope stability</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>- Siltation of drains</td>
</tr>
<tr>
<td></td>
<td>- Siltation in fields, work places, housing areas and over</td>
</tr>
<tr>
<td></td>
<td>highway pavement and rail tracks</td>
</tr>
<tr>
<td></td>
<td>- Siltation of adjacent drainage lowlands</td>
</tr>
<tr>
<td>Flooding</td>
<td>- Flooding of rural, urban areas and transportation routes</td>
</tr>
<tr>
<td></td>
<td>- Flooding of adjacent lowlands</td>
</tr>
<tr>
<td>Human aspects</td>
<td>- Loss of life</td>
</tr>
<tr>
<td></td>
<td>- Loss of quality of life</td>
</tr>
<tr>
<td></td>
<td>- Loss of visual and recreational amenity</td>
</tr>
<tr>
<td>Ecological aspects</td>
<td>- Loss of habitat</td>
</tr>
<tr>
<td></td>
<td>- Loss of conservation merit</td>
</tr>
</tbody>
</table>
2.2 Root Reinforcement

It appears from numerous reports that woody vegetation enhances mass stability via root reinforcement. Root systems mechanically reinforce soil by transferring shear stress in the soil to tensile resistance in the roots (Kelly and MacMillan, 1986; Waldron and Dakessian, 1981). There have been a number of studies on the contribution of woody roots to increased shear strength or root cohesion (Gray and Ohashi, 1983; Maher and Gray, 1990). An extensive laboratory studies on fiber-reinforced soil have indicated that small amounts of fiber could provide substantial increases in shear strength. The main effect of fibers (roots) in soil is to provide a measure of apparent cohesion. This root cohesion can make a significant difference in the resistance of shallow sliding in sandy soils with little or no intrinsic cohesion (Wu et al., 1988a; Shewbridge and Sitor, 1989). These findings had been supported by field shear tests on root or fiber-permeated soil. Researchers (Gray and Ohashi, 1983; and Nilaweera, 1994) have discovered similar findings to the previous laboratories trials in which shear strength increase per unit fiber. In addition to root distribution and quantity (Fitter, 1993), it is asserted that the root architecture, especially the branching pattern has a close relationship with the strength of anchorage (Stokes et al., 1996). Woody and herbaceous plants may therefore behave very differently as tension is progressively transferred to soil and moves distantly along the root. Consequently, it is the proximal parts of the root that are responsible for anchorage strength (Ennos, 1990). Despite several studies and recommendations on the effects of roots, the bioengineering application of deep-rooted shrubs and trees has not been sufficiently carried out.

2.2.1 Shear Strength of Soil and Soil-Root System

Both load and resistance govern the stability of slopes (Wu, 1995). This is the driving force that causes the failure and the strength of the soil-root system. The weight of trees growing on a slope adds to the load but the roots of the trees serve as soil reinforcement
and increase the resistance (Wu, 1995). The process known as shear failure occurs when shear stresses set up in the soil mass exceed the maximum shear resistance which the soil can offer, that is its shear strength.

The theory of Mohr-Coulomb failure has commonly been used to define failure in soils (Wu, 1995). The theory states that failure in a soil occurs if the shear stress on any plane equals the shear strength of the soil. Coulomb defined the shear strength as a linear function of the normal stress. The relationship is expressed as follows;

\[
\tau_f = c + \sigma_n \tan \phi \quad \text{Equation 2.1}
\]

where \(c\) is the apparent cohesion (zero normal stress), \(\sigma_n\) is the normal stress, and \(\phi\) is the angle of internal friction (Wu, 1995). From the above equation, it can be seen that the shearing resistance of soils in simple terms is generally made up of two components: (1) friction (denoted by \(\tan \phi\)), which is due to the interlocking of particles and friction between them when subjected to normal stress, and (2) cohesion (denoted by \(c\)), which is due to internal force holding soil particles together in a soil mass.

Equation 2.1 defines a line that is referred to as the failure envelope. It represents the maximum shear stress that may be sustained in a soil (Fig. 2.1a). The line is obtained by computing the maximum shear stress at failure (\(\tau_{f1}, \tau_{f2}, \tau_{f3}\)) for the three different normal stresses (Fig. 2.1a). A linear line is then drawn with the same scale for maximum shear stress, kg/cm\(^2\), versus normal stress, \(\sigma_n = \text{kg/cm}^2\) (Fig. 2.1b). The intercept at the y-axis gives the value of apparent cohesion and the inclination of the average straight line with the horizontal give the angle of internal friction of the soil (\(\phi\)). The line is drawn tangential to stress circles known as the Mohr circles. Any stress conditions represented by a Mohr circle touching the failure envelope would initiate failure. If the circle for a given state of
Fig. 2.1a: Shear stress/displacement curves for specimens tested under three different normal pressures

Fig. 2.1b: Typical graph of shear strength. Maximum shear stress related to normal stress from shear box tests.
stress lies entirely below the Mohr envelope, then the soil is stable for that state of stress.

2.2.2 The Effect of Root System on Shear Strength

Where the soil contains roots, shear failure would involve failure of the soil-root system. A simple approach is to consider the root as a reinforcement which increases the shear strength by $c'_R$ (Wu, 1995). Then;

$$c = c' + c'_R \quad - \quad \text{Equation 2.2} \quad \text{(Wu, 1995)}$$

where $c'_R$ is the contribution of the roots to the shear strength (Fig. 2.2). This value of $c$ may then be used in the conventional methods of stability analysis.

2.2.3 The Effects of Stratigraphy on the Stabilising Effects of Roots

Vegetation is primarily effective for controlling surface erosion as well as shallow mass wasting. Mechanical restraint against sliding only extends as far as the depth of root penetration (Gray, 1995). The influence of root reinforcement and restraint for different slope stratigraphies and conditions is summarised (Fig. 2.3).

2.2.4 Stability Analysis

A variety of failure modes can possibly be determined using shear strength parameters. Where roots are not present in sufficient numbers or are not so large as to influence the shape of the slip surface, solutions developed for soil slopes may be adapted for use. Thus, the safety factor ($F$) for a slope of infinite extent is as follow,

$$F = \frac{c}{\gamma z \sin \alpha \cos \alpha} \quad - \quad \text{Equation 2.3} \quad \text{(Wu, 1995)}$$

where $\gamma$ is the unit weight of the soil, $z$ is the depth of the slip surface and $\alpha$ is the slope
Fig. 2.2: The Mohr-Coulomb criterion describes shear strength of soils as $c'$ (see Equation 2.2). Root as a reinforcement factor would increase the shear strength by $c'_R$. The contribution of roots ($c'_R$) to the shear strength can be described as follows: $c = c' + c'_R$. 
Figure 2.3: Influence of slope stratigraphy on the stabilising effect of roots against slope stability (adapted from Tsukamoto and Kusakabe, 1984)

Type (A) – plane of weakness occurs at bedrock interface; (B) – roots can penetrate fractured bedrock and trunks act as restraint piles; (C) – thicker soil mantle contains transition layer, roots that penetrate the layer stabilise the slope and (D) – thick soil mantle extends below the root zone and roots do not penetrate across deep seated failure surfaces.
angle. For a simple case of infinite slope, the main influences of vegetation on the stability may be incorporated in the determinations of the safety factor as follows:

\[
F = (c' + c'_{R}) + \{(\gamma z - \gamma w h_{v}) + W\} \cos^{2}\beta + T \sin \theta \} \tan \phi' + T \cos \theta \quad \text{Equation 2.4}
\]
\[
\left[ (\gamma z + W) \sin \beta + D \right] \cos \beta
\]

where \(c'\) = effective soil cohesion and \(c'_{R}\) = enhanced effective soil cohesion due to soil reinforcement by roots and \(T\) = tensile root force acting at the base of the slip plane (Coppin et al., 1990). Thus, the greatest effects are due to the increase in cohesion through root reinforcement of the soil and to the tensile strength of the roots themselves across the potential slip surface. It is reported that the additional cohesion brought about by tree roots increased the factor of safety on wooded slopes in Hong Kong by 29% (Greenway, 1987).

2.3 "Soil-Plant-Atmosphere" Continuum

Most researchers have concluded that landslides and erosion of the slopes are caused, inter alia, by excessive amounts of soil water that saturate the slope soil (Bayfield et al., 1992). This phenomenon may be attributed to the higher ground water flow that in turn exerts weight and pressure on soil particles, ultimately impairing the stability of slopes. Previous studies have also revealed a strong negative relationship between soil water content and engineering parameters: soil shear strength and penetrability (Materechera and Mloza-Banda, 1997). Both parameters decrease with an increase in soil water content. In this regard, plants indeed play a significant role towards drying slopes through a catenary’s flow of water in soil-plant-atmosphere continuum (Fiscus and Kaufmann, 1990; Huang and Nobel, 1994). Water is driven through the plant from the soil to the atmosphere by the difference in the water potential between the atmosphere (very low potential) and the soil (relatively high potential). This flow is also influenced by hydraulic resistances in the plant such as the resistance regulated by the stomata (in leaves) and by the conductive system.
(root and stem xylem elements) of the plant. This drawn-dawn effects and suction system results in drier and more stable slopes.

2.4 The Environmental and Physiological Nature of Stress

2.4.1 Water Stress

The stress of water deficits is a persistent threat to plant survival. It can be caused by several factors such as intense evaporation and osmotic binding of water in salinised and rigid soils (Greenway and Munns, 1980). In relation to this, slope plants often encounter unusual or extreme conditions which may have significant impact on their physiology, development and survival. Some plants survive by establishing a deep rooting system that penetrates the water table to ensure an adequate water supply under conditions in which more shallow-rooted plants would experience drought (Rodrigues et al., 1995). Some other plants are able to tolerate various degrees of water deficit. The diverse forms of plants have therefore evolved several drought resistance strategies i.e. drought escaping, desiccation avoidance and tolerance (Splunder et al., 1996)

2.4.2 Acidic Soil

Soil acidity, is another major constraint of plant growth on slopes. Excess metal, particularly aluminium (Al), was reported to be a growth-limiting factor for plants growth in acid soils (Foy, 1992). In Malaysia, it has been reported that areas for pasture production are generally acidic (pH 4.2-4.5) and exhibited Al saturation of 37-86% (Wong and Davendra, 1982). In such conditions, plants growth is affected in several ways. Al toxicity does affect plant in terms of inhibition of root growth (Bennet et al., 1991), stunted leaves (Foy, 1992) as well as plant physiology and morphology (Edmeades et al., 1991). On the other hand, some tolerance mechanisms e.g. high Al accumulation in foliage and high shoot dry weight have been observed to reduce the harmful effects of excessive
exposure to metal ions (Spehar, 1994; Foy, 1996). In the areas of high intensity of rainfall, Luttge (1997) reported that there is a positive correlation between soil pH and the concentration of soluble Al in plant (Al accumulator). The correlation does not always occur in drier areas with alkaline soil conditions and relatively low rainfall. The Al accumulation in plant species, however, is partly due to genetic control of plants metabolic pathway (Cuenca et al., 1991). Previous studies have also concluded that Al accumulators have displayed some characteristics including thick and yellow-green colour of leaves, and blue colour of fruits and flowers (Chenery, 1948a).

2.4.3 Carbon Sink Potential

Carbon sink is defined as a natural entity, process, activity or mechanism such as forest and coral which can alleviate green house gases from the atmosphere. It has been reported that forests for example the tropical rainforest, is one of the largest carbon sinks in the world (Myers and Goreau, 2001). Thus, deforestation due to the development of hilly areas has caused several environmental problems including slope instability and reduction of carbon reservoir (or sink). The potential of plant species to absorb carbon dioxide (CO$_2$) from the atmosphere for the photosynthetic process assists in reducing the high concentration of CO$_2$, thus reducing the green house effect. There are numerous documentations on carbon sink in terms of the response of plants to the elevated CO$_2$ (Long et al., 1993, Evans et al., 2000). The higher the potential of the plant to absorb CO$_2$, the greater is the capacity of the plant to be a carbon sink potential. Thus, the role of vegetation is not only for erosion control but also as a carbon sink plant.

2.5 The Process of Natural Succession

2.5.1 The Concept of Natural Succession

The process of succession is the tendency of a plant community to change through time
Changes in plant species composition during succession are interpreted as the result of a dynamic equilibrium between colonisation, persistence and extinction. Subsequently, studies on succession continue in order to establish hypotheses, models, generalisations and predictions, which give rise to various interpretations of succession (Fig. 2.4). In one classical theory, Clements (1916) describes six processes (sets of interactions mechanism) important in succession: nudation (or disturbance), migration, ecesis (or establishing), growth, reaction (or modification of the environment by the organisms) and stabilisation.

2.5.2 Natural Plant Succession of the Slope

(a) Biomass

Changes in biomass during succession were caused by population processes and changes in soil characteristics (Tilman, 1988). Three successional trends in biomass have been observed: linear towards a climax (Sprugel, 1985), increase to a maximum, and then decrease (e.g. death of larger trees and replacement by smaller trees) to an intermediate level at climax (Shugart, 1984), and increase to a maximum, then a significant decline with a subsequent recovery to the steady-state value (Peet, 1981a).

(b) Soil Development and Nutrient Flows

Some important changes usually take place in soil nutrient availability during succession, and these changes are generally not consistent with increased fertility (Vitousek et al., 1988). It has been recorded that in diverse systems of disturbed land; infertile sands (Tilman, 1988), lava flows (Vitousek et al., 1988), open land left by receding glaciers (Bormann and Sidle, 1990), fertility often declines when delay in succession. It has been reported that total phosphorus (P) steadily declines and soil nitrogen (N) availability also changes during succession (Inouye et al., 1987). The low N: P ratio favours the invasion of
Figure 2.4: Various interpretations of succession. 1. The Clementsian view. 2. Relay floristics. 3. Initial floristics.
nitrogen fixers which then increases N availability (Vitousek et al., 1988).

(c) **Species Diversity**

Species diversity or species richness is a community attribute that reflects the combined influence of such processes as immigration, speciation, competition, predation and extinction. The assumed potential of species diversity has been observed to increase to an asymptote over time (Peet, 1981a). Owing to the harsh conditions for establishment, few species invade early in such sites. However, gradual immigration of additional species plus some amelioration of environmental extremes by established plants result in a maximum increase in climax ecosystem. Species number in steady-state ecosystem is strongly related to soil pH and soil cation content (Peet and Christensen, 1988).

(d) **Stability**

In the steady-state or climax ecosystem, biomass is roughly constant at an intermediate level, production is relatively constant and nutrients lost from the system roughly balance their influx.

### 2.5.3 Model of Plant Succession of the Slope

The surrounding abiotic and biotic environments, modifying factors, processes or mechanisms that drive landslide succession influence the process of plant succession of the slopes. This can be illustrated in a succession model (Walker et al., 1996) which represents a conceptual model of a tropical landslide succession (Fig. 2.5). The diagram shows the factors that drive landslide succession namely rainstorms, earthquakes, anthropogenic disturbances, variables that influence vegetation inputs (e.g. surrounding vegetation) and soil development (atmospheric deposition, nitrogen fixation, litter-fall). Plant colonisation is dependent on the presence or absence of patches of seeds and vegetation expansion. Although, early colonists may inhibit new colonists, mature forest
Fig. 2.5: A conceptual diagram of landslide succession. Vegetative development is shown in the upper portion of the diagram, soil development in the lower portion (Walker et al., 1996)
vegetation is eventually established. Soil development is determined by the presence or absence of patches of surviving forest soil. Hence, development on exposed mineral soils is influenced by mineral weathering, nutrient uptake and loss, and decomposition of in situ and exogenous litter-fall input.

All stages of vegetation and soil development are subjected to erosion, which can reset succession.

2.6 Introduction to *Leucaena leucocephala*

2.6.1 General Aspects

(a) Origin and Distribution

*Leucaena leucocephala* probably originated in the calcareous lowland soils of Mexico and Guatemala (Duke and Cellier, 1993). It was widespread at the time of the arrival of the Spaniards in 1520, and traveled to The Philippines by the end of the century. It thrives on limestone rich soils, including highly alkaline soils and can grow on a wide range of soil moisture and acidity (Tham et al., 1977). Although the plant grows on soils with a wide range of pH, it performs better on alkaline, calcareous and clayey soils (Duke and Cellier, 1993). In Malaysia, leucaena usually grows in limestone areas or in the more fertile areas of the coastal alluvium (Wong and Davendra, 1982).

(b) Botany

*Leucaena leucocephala* (Lam.) de Wit has several botanical names, including *L. glauca* and *L. latisiliqua* (Duke and Cellier, 1993). It is an arborescent legume belonging to the Mimosaceae subfamily. The descriptions of the legume denote discrepancies in the length of the pinnae, flowers, pods, seeds per pod and relative size of the trees. The species varies widely from small shrubs to handsome trees, reaching a height of 20m in height. The
leaves are 15 to 20cm long and bipinnately compound. The flowers are white and in compact heads of about 150 flowers. It is fully self-fertile and rarely outcrosses, making 4-10 pods per head. The brown pods hang vertically, with about 15 seeds per pod and 10,000-20,000 seeds per kilogram (Duke and Cellier, 1993). It is widely known as 'Leucaena', 'White popinac' or 'Horse tamarind'. In Malaysia, it is commonly known as 'petai belalang'.

(c) Establishment and Germination

Rapid and uniform germination can be obtained if seeds from ripe pods are scarified. The standard treatment is to immerse the seeds for 2-4 minutes in water maintained at 80°C, followed by rapid drying (Gray, 1962). A more rapid and uniform emergence of seedlings (80% versus 10% after 6 days) is observed in laboratory studies in which treated seeds are allowed to imbibe in water up to 72 hours, or until radicles begin to emerge, and it is then dried (Jones and Bray, 1982).

Unlike some other tropical-pasture legumes, the seedlings of leucaena tolerate shade well (Egara and Jones, 1977). Even at 35% relative photosynthetic quantum flux in a glasshouse, the relative growth rate of shoots is little affected and the leaf area index still increases. Root growth, however, is greatly reduced. This results in a reduction of the plant's ability to compete for nutrients.

(d) Rhizobium Requirements

Like other plants of the legume family, *L. leucocephala* has a built-in source of fixed nitrogen. Small lateral roots near the soil surface carry nitrogen-fixing *Rhizobium* nodules which are usually 2.5-15mm in diameter. They frequently have multilobes and are bright pink on the inside. Leucaena-*Rhizobium* symbiosis is capable of annually fixing more than
500kg/ha (Duke and Cellier, 1993). Rhizobia effective on leucaena are the consistently fast-growing and acid-producing strains (Norris, 1965). Rhizobial inoculation is needed prior to the germination of *L. leucocephala* seeds.

(e) **Multipurpose Uses**

Amongst the 700 nitrogen fixer trees, *Leucaena leucocephala* is reported to be the most versatile multipurpose tree (Brewbaker, 1987). In Latin America, it serves as a food source (beans). It has many uses worldwide: a source of fuelwood and charcoal, pulp for paper and rayon, leaves for fodder and green manure, timber for building, furniture, poles and crafts, shade for trees like coffee and cocoa, seeds for crafts and gum for glues (Shelton and Brewbaker, 1994). In early 1900, the first agricultural importance was cited in literature on coffee grown in Java, Indonesia, where *L. leucocephala* was mentioned in connection with the shading and fertility maintenance of the soil (Jones and Bray, 1982). In Malaysia, leucaena is used to increase the protein in animal feed and as a nurse crop, particularly for teak (Wong and Davendra, 1982; Ng et al., 1982).

It is also used for medicinal purposes. The young leaves are traditionally used to treat coughs and measles. The fruit is claimed to be beneficial for health when eaten raw (Muhamad and Mustafa, 1998). It has also been reported that its dry leaves can heal boils and scabies (Hashnan, 2001).

2.6.2 **An Erosion Control Plant**

*Leucaena leucocephala* had been used as a soil-erosion control plant as early as the 1950s (Djkman, 1952). However, there is a lack of documentation on its contribution with regards to slope stability. Only in the last two decades has it been increasingly used as green manure in teak plantations in agroforestry schemes and as a means of erosion control. For example, in Indonesia, *L. leucocephala* has been widely planted to stabilise slopes (Parera,
1982). It was reported that the plantations managed to conserve the hydrological efficiency of the land. In The Philippines, the potential of leucaena as a soil-erosion control plant has been investigated thoroughly amongst other hedgerow species (Hernandez et al., 1996). In such situations, the soil nutrient status was observed to have improved. Phosphorus and potassium levels were also observed to have increased by 120% and 416%, respectively, when planted with leucaena (Table 2.2). The runoff and soil loss of the non-hedgerow plots was found to be 138% greater than that of contour hedgerows (including leucaena) (Hernandez et al., 1996).

Similar findings were reported in alley cropped maize with *L. leucocephala* where runoff and soil loss was reduced as compared with maize monoculture (Presbitero et al., 1995). In more recent studies, *L. leucocephala* showed high tolerance and survival and is a potential plant in the revegetation of lagoon ash in China (Cheung et al., 2000). There is, however, limited documentation on the contribution of this species in terms of physiological criteria and slope stability parameters in Malaysia as well as in other countries.

### 2.6.3 Acid-Tolerant Plant

On acidic soils, leucaena grows poorly and this is attributed to aluminium or manganese toxicity (Noble et al., 1998). However, studies have indicated that rhizobial inoculation and lime-pelleting of *L. leucocephala* are essential for successful establishment and growth. The results from solution-culture experiments show that leucaena growth is greatly reduced in solutions containing more than 4 ppm of Al (Table 2.3). However, the detrimental effects of high aluminum concentration can be ameliorated to some extent by increased calcium levels.
Table 2.2: Influence of hedgerows and alley crops on soil nutrient levels (Hernandez et al., 1996)

<table>
<thead>
<tr>
<th>Hedgerows</th>
<th>Organic Matter (% )</th>
<th>P (ppm)</th>
<th>K (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>Farmers’ Practice</td>
<td>2.19</td>
<td>1.41</td>
<td>5.68</td>
</tr>
<tr>
<td>Leucaena</td>
<td>2.01</td>
<td>2.01</td>
<td>5.68</td>
</tr>
<tr>
<td>Gliciridia</td>
<td>2.22</td>
<td>1.70</td>
<td>9.99</td>
</tr>
<tr>
<td>Guinea Grass</td>
<td>2.51</td>
<td>1.65</td>
<td>5.68</td>
</tr>
<tr>
<td>Natural Vegetation</td>
<td>2.70</td>
<td>1.52</td>
<td>11.36</td>
</tr>
</tbody>
</table>
Table 2.3: Effect of Al and calcium concentration on the growth of leucaena *in vitro* (Wong and Devendra, 1982)

<table>
<thead>
<tr>
<th>Growth (g/plant)</th>
<th>0</th>
<th>4</th>
<th>16</th>
<th>0</th>
<th>4</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al in Ca (ppm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1 mM)</td>
<td></td>
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<tr>
<td>Al in Ca (ppm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5mM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf</td>
<td>2.47</td>
<td>1.93</td>
<td>0.10</td>
<td>3.69</td>
<td>2.52</td>
<td>0.46</td>
</tr>
<tr>
<td>Stem</td>
<td>1.12</td>
<td>0.73</td>
<td>0.04</td>
<td>1.48</td>
<td>0.48</td>
<td>0.13</td>
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<tr>
<td>Root</td>
<td>1.64</td>
<td>1.66</td>
<td>0.11</td>
<td>1.96</td>
<td>1.60</td>
<td>0.43</td>
</tr>
<tr>
<td>RTY%</td>
<td>73.5</td>
<td>60.6</td>
<td>3.5</td>
<td>100</td>
<td>69.9</td>
<td>14.3</td>
</tr>
</tbody>
</table>

RTY% = relative total yield expressed as percentage of maximum total yield
2.7 The Need for Investigation

The delay of the natural succession process is not acceptable in the real world. While waiting for the soil properties and plant community to be ameliorated and modified by early successional plant species, more tragedies of landslides and erosion, triggered by high intensity of rainfall and adverse climatic changes of the slopes occur (Woo, 1996). The safety aspect necessitates that disturbed areas be returned to stable ecosystems as rapidly as possible. Hence, the program to revegetate slopes should aim at accelerating the successional process of establishing a stable and productive plant community. In addition, numerous studies (Barakbah, 1994; Barker, 1996) have reported that a bioengineering technique can assist in accelerating the process of natural succession of the slope. In more recent studies, researchers have used and suggested some plant species including *L.leucocephala* for the revegetation (Cheung *et al.*, 2000) and agricultural program (Smolikowski *et al.*, 2001). However, the information of the contribution of the species to slope stability is lacking. Therefore, further investigation on contribution of *L.leucocephala* to slope stability is essential.