CHAPTER 9
THE CONTRIBUTION OF *L. LEUCOCEPHALA*
TO NATURAL SUCCESSION

9.1 Introduction

For centuries, wood and living plants were used as materials for hills and slope stabilisation works. Today, some of these conventional techniques have been modified and reapplied due to the increasing failures of traditional methods and practices. What was thought successful in the past is being re-evaluated in the context of the impacts resulting from excessive and rapid urbanisation, and public awareness of these time-sensitive environmental issues. The revegetation process, for instance, has to be hastened to avoid further damage to environment, properties and more importantly, life. In order to achieve this purpose, the right propagation density and suitable plant type are, *inter alia*, critical. Amongst the plant type used, the introduction of the suitable pioneer species is crucial. For example, whether it accelerates the process of natural succession requires objective assessment.

Having successfully gone through a series of plant screening, in this Chapter, *L. leucocephala* was assessed on the newly cut slope. The capability of *L. leucocephala* in enhancing the process of natural succession and eventually producing a sustainable ecosystem on the slope was evaluated. Does *L. leucocephala* pave the way for other successors? Or, does it suppress the growth of other plants? In order to answer these curiosities, the gross performance of *L. leuccocephala* along with the plant community was assessed in terms of the development of LAI, biomass and plant diversity. The influences of these attributes on slope stability were also analysed.
9.2 Materials and Methods

9.2.1 Plant Materials

*L. leucocephala* seedlings were grown in an open-ended PVC pipe (Fig 6.1). The seedlings were transferred to the slope after reaching a height of 1.0 ± 0.1m (about two months after germination). Concurrently, four other species were also grown in PVC pipes until they reached about a similar height to *L. leucocephala*. These species, namely *Justicia betonica*, *Tabernaemontana corymbosa*, *Polycias* sp. and *Evodia latifolia*, were chosen based on the prominent criteria as slope plants in previous pilot trials (Normaniza, 1998; Suraya, 1998).

9.2.2 Natural Succession Experiment

Experiment was carried out in four treatments. Four treatment plots (1800 ft²/plot) were bioengineered on a barren slope at Rimba Ilmu (124 m altitude, longitude E 101° 39' 25.9", latitude N 03° 07' 51"), University of Malaya. The treatments were G (grass only), LL (planted with *L. leucocephala* only), SS (planted with four shrubs species) and LLSS (planted with *L. leucocephala* and four shrubs species). The creeper, *Pueraria phaseoloides*, was sown in all plots at 1100 seeds per metre length (germination rate was 30%) to improve the quality of the barren soil. When *Pueraria phaseoloides* has established on the slope (about three weeks), *L. leucocephala* and the other plant species, in five replications, were transferred into the respective plots. All plants were planted in a complete randomised design (CRD). The details of the plots are summarised and tabulated (Table 9.1). Physiological aspects of *L. leucocephala*, performance of the plant community and contribution of the species studied in enhancing natural succession, and hence slope stability was assessed throughout the two-year experimental period. This experimental slope becomes a showcase slope of Rimba Ilmu, University of Malaya.
Table 9.1: Description of the plots

<table>
<thead>
<tr>
<th>PLOT</th>
<th>TYPE</th>
<th>SPECIES</th>
</tr>
</thead>
</table>
| G    | Monoculture (grass only) | *Ischaemum muticum* (grass) — already grown on slope  
*Pueraria phaseoloides* (creepers) |
| LL   | Grass and  
*Leucaena leucocephala* | *Ischaemum muticum*  
*Pueraria phaseoloides* (creepers)  
*Leucaena leucocephala* (LL) |
| SS   | Mix-culture (without *Leucaena leucocephala*) | *Ischaemum muticum* (grass)  
*Pueraria phaseoloides* (creepers)  
*Justicia betonica*  
*Tabernaemontana corymbosa*  
*Polycias* sp.  
*Evodia latifolia* |
| LLSS | Mix-culture (with *Leucaena leucocephala*) | *Ischaemum muticum* (grass)  
*Pueraria phaseoloides* (creepers)  
*Leucaena leucocephala* (LL)  
*Justicia betonica*  
*Tabernaemontana corymbosa*  
*Polycias* sp.  
*Evodia latifolia* |
(a) Transplanting

The transplanting of *L. leucocephala* and the four shrub species were conducted using a Microclimate Plant Propagation Technique as previously described (6.2.3). The suitable soil depth used in this experiment was 0.6 m (Fig. 9.1). The range of soil pH was 4.5-5.0. Plant supplements were applied in the beginning of treatment (Fig. 9.1).

(b) Experimental Design

Four plots of the same soil condition and soil type were designed at the experimental slope.

In the beginning of experiment, all plots (except G plot) had the same number of plants i.e. 25. The schematic design of the showcase slope is sketched (Figure 9.2a and b).

9.2.3 Measurements

(a) Gross parameters

Photosynthetic rates and stomatal conductance were measured using the equipment and method described earlier (3.2.3a and 4.2.2c). Leaf area index (LAI) was measured randomly (five replicates) using the plant canopy analyser (LICOR, model LAI-2000, USA). Photosynthesis was measured diurnally at the end of experiment (24 months) to determine the growth rate of the species studied. The growth rate of *L. leucocephala* was determined by the following formula:

\[
\text{Growth rate (g/plant/day)} = (A \times C \times L \times t) - (R_N \times C \times L \times t) \\
= C \times L \times t \times (A - R_N)
\]

Where,

\[
\begin{align*}
A &= \text{net photosynthetic rate (\text{\mu mol m}^{-2} \text{s}^{-1})} \\
R_N &= \text{night respiration (\text{\mu mol m}^{-2} \text{s}^{-1})} \\
C &= \text{molecular weight of CO}_2 \text{ (44)} \\
L &= \text{Leaf Area Index (m}^2\text{)}
\end{align*}
\]
Figure 9.1: A Microclimate Plant Propagation Technique. Initial physiological processes of the plant takes place in a "micro-environment" which is more conducive for plant establishment and adaptation.
Figure 9.2a: Four treatments on a showcase slope, Rimba Ilmu, University of Malaya
(G=grass only, SS=shrubs, LL=L.leucocephala only and LLSS=L.leucocephala and shrubs)
Figure 9.2b: A schematic design of mix-culture plots (SS and LLSS). All plant species were planted in a complete randomized design in these plots. The monoculture (LL plot) was laid-out in the similar design to the mix-culture. Only *L.leucocephala* was grown in LL plot. The dashed line is *P.phaseoloides* (legume cover).
Quadrates (1m x 1m) were used to determine the plant diversity and biomass which were measured diagonally across each plot. For plant sampling (quadrates), the method of Austin (1981) was used. Plant samplings were taken from the permanent plot with three random subsamples through time. The relative frequency of each species was determined as follows: \[ \text{frequency of one species/} \sum \text{frequency of all species} \times 100\% \]. The measurements of photosynthetic rate and stomatal conductance were taken once (18-month), LAI and biomass, twice (12- and 24-month), and species diversity (0-, 6-, 12-, 18- and 24-month) that is every six months throughout the two-year treatment.

(b) Root and Soil Water Profiles

At the end of experiment, cylindrical soil cores (11 cm in diameter; 100 cm depth) were sampled using a soil coring machine (Eijkelkamp Agrisearch Equipment, Model Cobra, The Netherlands). In the laboratory, the soil core was divided into five equal divisions, 20 cm each, and three subsamples were taken and weighed (fresh weight=FW). The samples were placed in an oven at 80°C (5 days) to obtain constant dry weight (DW). Soil water content was calculated by a traditional method as follows: \[ \text{FW} - \text{DW/FW} \times 100\% \]. The remaining soil in the cylindrical cores was washed manually to clean the roots from the soil particles. The roots were cut into lengths of 20 cm and stained with methyl violet in the laboratory. The root length density was measured using the leaf area instrument as described earlier (7.2.2b) with a soil volume of 1901 cm³.

(c) Soil Penetrability

A penetrometer (Eijkelkamp Agrisearch Equipment, model 06.15, The Netherlands) was used to determine the resistance to penetration of soil. This equipment can penetrate up to 80 cm of soil depth using a 60° cone type (basal area of 1 cm²) at a constant speed of 2
cm/s. During the course of measurements, the penetration was done steadily. The apparatus automatically log the penetrability data. The observation was made twice (12- and 24-month) at three replications per plot.

(d) Shear Strength

Shear strength was measured by using the field inspection vane tester (Eijkelkamp Agrisearch Equipment, model 14.05, The Netherlands), which can provide values ranging from 0 to 260 kPa (±10%). The readings were taken manually. Similar to soil penetrability, the observation was made twice at three replications per plot.

9.3 Results and Discussion

9.3.1 Physiological Performance of *L. leucocephala*

The increment of LAI was about 87% and 60% higher in LLSS treatment than that of LL, in 12 and 24 months, respectively (Fig. 9.3). This implies that *L. leucocephala* is induced to grow better when there is competition with other species in terms of nutrient or water (see 9.3.2c). Apart from that, the results (Fig. 9.4) also showed that the treatments affect photosynthetic rate (A) and stomatal conductance (g_s). This was shown by a highly significant difference between LLSS and LL treatments. Both parameters of *L. leucocephala* in the LLSS plot were 68% (A) and 153% (g_s) higher than that of in the LL. The results imply that *L. leucocephala* grew and adapted well on slope in the mix-culture system.

9.3.2 Growth Rate

Results showed that the growth rate of *L. leucocephala* was higher in LLSS than in LL plot. The growth rate was 72.6 and 29.1 g/plant/day, respectively (Fig. 9.5a and b). The faster
Figure 9.3: LAI of *L. leucocephala* in LL and LLSS plots. Vertical bars represent standard deviation and vertical lines represent LSD at p<0.05.
**Figure 9.4:** Gross parameters of *L. leucocephala* in LL and LLSS plots at 18 months. Vertical bars represent standard deviation and vertical lines represent LSD$_{p<0.05}$.
Figure 9.5: Diurnal photosynthetic rate of *L. leucocephala* in LL and LLSS plots (value of growth rate was indicated within bracket)
growth rate observed in LLSS treatment is presumably attributed to the high competition amongst the species in terms of light, space, nutrient and water. The species studied seems to enhance inherent resources use efficiency when competing with other species. Therefore, the photosynthetic activity and hence, the development of leaf area (9.3.1a) were enhanced. This result also reflects the high level of carbon sink of species studied in the mix-culture system. In perspective, the comparison in growth rate is assessed between *L. leucocephala* and other potential slope trees (Table 9.2). The growth rate of *L. leucocephala* is observed to be the highest amongst the plants, followed by *Evodia latifolia* (54.4 g/plant/day) and *Swietenia mahogany* (53.3 g/plant/day). The fastest growth rate shows a remarkable characteristic of *L. leucocephala*, essential for slope coloniser. A faster growing plant can contribute to reduce initial surface erosion via acting as a barrier e.g. enhance rainfall interception and decrease velocity of rainfall.

9.3.3 Performance of Plant Community

(a) Species Diversity (6, 12, 18 and 24 months)

Species diversity was analysed only in LL and LLSS plots in order to see the effect of monoculture and mix-culture treatments on the performance of *L. leucocephala* as a pioneer. After 24 months of growth, 46 plant species had established in the LLSS plot, consisting of different species of grasses, shrubs, ferns and medium size trees (see Appendix 20). The plot showed steady enhancement of biomass and was in fact fully covered by diverse species in 12 months (Fig. 9.6). Species composition and life form diversity of the plant communities changed rapidly in the LLSS plot. The results showed that species diversity of the mix-culture system increased tremendously, by five fold of the initial number of species after 12 months of observation (Fig. 9.7). The results imply that in this system, *L. leucocephala* and other planted shrubs has a positive role in increasing
Table 9.2: Growth rate of potential slope plants

<table>
<thead>
<tr>
<th>Species</th>
<th>Growth rate (g/plant/day)</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Leucaena leucocephala</em></td>
<td>72.6</td>
<td>1</td>
</tr>
<tr>
<td><em>Swietenia mahagonyi</em></td>
<td>53.3</td>
<td>3</td>
</tr>
<tr>
<td><em>Evodia latifolia</em></td>
<td>54.4</td>
<td>2</td>
</tr>
<tr>
<td><em>Tectonia grandis</em></td>
<td>41.1</td>
<td>5</td>
</tr>
<tr>
<td><em>Hopea orodata</em></td>
<td>51.4</td>
<td>4</td>
</tr>
</tbody>
</table>

1 Shamsiah, 2003
Figure 9.6: Percentage of barren soil in LL and LLSS plots.
Figure 9.7: Percentage of diversity increment in LL and LLSS plots (arrow shows the time of soil erosion in the LL treatment)
plant diversity. The colour and nectar of the flowers (of shrubs) and the young green pods
\textit{(L.leucocephala)} attract insects and birds into the ecosystem. In addition, these insects and
birds are also the agent of dispersal because they carry seeds from other places into this
plot. Thus, this flora-fauna interaction also allows the influx of other species and
consequently increases in biodiversity.

In contrast, only six species was observed in the LL plot at the end of experiment (24
months). A lack of flora-fauna interaction may lead to low plant diversity. The rate of
succession is also low compared to LLSS plot. This can be observed in a high percentage
of barren soil (about 40% of ground cover) even after 12 months of observation (Fig. 9.6).
In fact, there was a sign of eroding soil in November 2000 (after 12-month observation).
This presumably is due to the high intensity rainfall, about 550 mm, which was also the
peak of the year (see Appendix 21). Furthermore, some species e.g. \textit{Ischaemum muticum}
(grass) and \textit{Axonopus compressus} (grass) in the plot faded away and caused barren almost
30% of the ground cover, resulting in low sustainability and stability of the plot (24
months).

The plant diversity in LLSS plot increased by more than double (6 and 12 months) and
even triple (24 months) that of the LL (Fig. 9.7). This indicates that \textit{L.leucocephala}
performs better in the mix-culture system in accelerating the process of natural succession.

\textbf{(i) Performance of Pioneer Species}

The percentage of ground cover and frequency of \textit{L.leucocephala} gradually increased in
both LL and LLSS (Fig. 9.8a and d). This implies that \textit{L.leucocephala} has vigorously
grown in both plots. This observation may be attributed to the presence of \textit{L.leucocephala}
seedlings at both plots, indicating the plant is easily-grown and has high growth rate. The
Figure 9.8: Percentage of ground cover and frequency of pioneer species
results also indicate that the plant studied can withstand the high competition amongst the adverse species in the LLSS plot without influencing its growth. This has been proven by a significantly high LAI of the species studied at the end of the observation (Fig. 9.3). In terms of relative frequency, *L. leucocephala* in the LLSS treatment exhibited a higher value than those in the LL throughout the observation (Fig. 9.8d). More seedlings were also observed in the LLSS plot.

The legume cover crop, *P. phaseoloides*, which was sown along with *L. leucocephala* in both experimental plots, vigorously grew in the LLSS plot at the beginning of the trial (6 months) but its relative ground cover and frequency decreased with time (Fig. 9.8b and e). Apparently, the legumes faded in both plots and were replaced by other species. The legumes ultimately decreased by 91.6% and 27.3% in both LLSS and LL treatments, respectively. A similar trend was observed in the grass species, *I. muticum* (already in existence on the slopes in both trials). In both treatments, the grass showed high increments in both ground cover and frequency, especially in the LL plot, but only up to six months of observation. Both parameters gradually decreased beyond that period, presumably due to the shading effect from the canopy of the tree species (Fig. 9.8c and f).

(ii) **Performance of Dominant Successors**

Amongst the established successors, *Melastoma malabathricum* has consistently persisted in almost all plots during and beyond the six months of observation. This species occupied 4% to 15% of ground cover at the end of the observation (Fig. 9.9a and b). The result suggests that this species appears to be the best invader of the slopes. Another dominant species observed was *Axonopus compressus* (grass species), showing an increment in the relative frequency and ground cover in the LL plot (Fig. 9.9b and e). *Stachytarphets indica* (shrubs) and *Dicranopteris lineanis* (fern species) were established after six and twelve months of trials, respectively (Fig. 9.9b, c, e an f). The frequency and ground cover of
Figure 9.9: Percentage of frequency and ground cover of planted species in the MXC treatment.
these species rapidly increased beyond the one-year observation (Fig. 9.9c and f).

(b) Leaf Area Index

The results showed that there was a considerable increase of LAI between 12 and 24 months in all treatments (Fig. 9.10). The value increased by 76%, 19%, 27% and 44% in G, LL, SS and LLSS plots, respectively. Although G plot exhibited the highest increment amongst the plots, its LAI value was the lowest in both 12 and 24 months of observation. The highest increment in G plot is a fallacy because the initial value was very low. The results imply that there was little plant succession and establishment of new seedlings in the plot. Even if there was seed dispersal into this plot, the probability of germination was low due to high surface runoff.

The influence of the mix-culture treatments (LLSS and SS) clearly shows that *L. leucocephala* enhances the LAI in a plant community. LAI value had also significantly increased with the presence of *L. leucocephala* in the mix-culture plot (LLSS), which was almost double that of the SS (without *L. leucocephala*). These results suggest that the mixed culture model that is integrated with *L. leucocephala* would result in higher development of LAI. The observation is possibly attributed to the high photosynthetic activity and growth rate of the diverse species, which resulted in a greater competition for light and subsequently accelerated growth of the whole plant community (see 9.3.3c).

c) Biomass

The highest percentage of increment (between 12 and 24 months) in biomass was observed in LLSS (112%), followed by LL (74%) and SS (47%) (Fig. 9.11). No significant difference was observed in G plot. The results also imply that the mix-culture system with *L. leucocephala* (LLSS) had greater biomass compared to the mix-culture system without *L. leucocephala* (SS). This portrays a positive role of *L. leucocephala* in accelerating stable
Figure 9.10: LAI in four different plots after 12 and 24 months. Vertical bars represent standard deviation and vertical lines represent LSD$_{p<0.05}$
Figure 9.11: Biomass in four different plots after 12 and 24 months. Vertical bars represent standard deviation and vertical lines represent LSD$_{p<0.05}$.
ecosystem through the enhancement in biomass. In addition, in the task of enhancing the process of plant succession and vegetation establishment on slope ("succession management"), biomass could not be enhanced by planting merely grasses (as in G plot). Succession management is more likely to be beneficial when mixed culture is practiced, especially involving *L. leucocephala*. The results also showed that there was a significant increase in biomass between 12 to 24 months in both LL and LLSS treatments. The LLSS also showed higher biomass by 180% (12 months) and 340% (24 months) than those in the LL treatment, displaying the influence of mixed culture environment on biomass.

The above observations may be attributed to high plant diversity (9.3.2a) and LAI (9.3.2b) observed in the LLSS plot. This postulation was tested by linear correlation amongst the parameters studied. Biomass seems to strongly correlate with diversity (r=0.95, Fig. 9.12a) and LAI (r=0.99, Fig. 9.12b). The high species-richness in the indicated plot is possibly attributed to the high above-ground biomass and *vice versa*. The observation also implies that plant biomass, density and diversity are important factors to consider in the task of slope stabilization, in coherence to the finding of Thorne (1990). However, this result contrasted with the results of Tatoni and Roche (1994) who stated that species diversity decreased as LAI increased. The contrast may be attributed to a function of light interception which is low in *L. leucocephala* due to its leaf morphology. The species studied was also reported to have a prominent criterion in terms of shade tolerance as its leaf area and growth rate were not affected by shading (Egara and Jones, 1977).

The good performance is related to the "carrying capacity" of the LLSS ecosystem. Carrying capacity is defined as the largest number (and biomass) of any given species that can be supported indefinitely upon the available resources of that ecosystem (http://fo.rollins.edu/jsiry/carcap.html). Although the abiotic factors of the slope were unfavourable for plant growth, the biotic factors are compensated to thrive within the
Figure 9.12: Relationship amongst the gross parameter studied
ecosystem. Amongst these "compensating act" includes the well known habit of nitrogen fixing plant to fix nitrogen when the soil condition is deprived of the nutrient. In the LLSS plot, the biotic communities which can fix nitrogen are *L. leucocephala* (leguminous tree), *P. phaseoiloides* (leguminous creeper) and *A. compressus* (grasses). They have a tremendous capacity to benefit from the initial phosphate and other supplements to perform the process of biological nitrogen fixation. This process benefited the whole plant community, which, like a chain reaction, transforms initially infertile soil to, within one year, a biologically enriched soil. This enrichment in the soil factors is reflected in increasing trend of the above-ground biomass with time as they receive more nutrients.

The increased above-ground biomass results in increased size of the plants in the LLSS ecosystem. The enhanced canopy necessitates their spatial partitioning according to the rules of nature; the shade tolerance will occupy the shaded portion of the ecosystem whilst the high PAR seekers occupy the unshaded part. In this way, optimisation in photosynthetic activity is achieved via optimised use of light energy at different trophic levels within the canopy (see also Wang et al., 2003).

Due to transpiration and subsequent water absorption of the soil, water turbulence is created in the ground. This turbulence causes water and nutrients from areas outside the root zone to move to areas of the root zone. Thus, actively transpiring plant have accessed to water and plant nutrients beyond the root zone. With a greater rate of transpiration (and water absorption), more areas beyond the root zone is accessible to the plant. It is thus an irony that more plants create more turbulence and more water and nutrients available to them (see also Eamus, 2003).

Thus, in all three compensating acts, the biologically fixed nitrogen, optimised light use and access to more water and plant nutrients naturally increases the carrying capacity of
this ecosystem. All these phenomena resulted in increased biodiversity and biomass, above as well as below the ground level.

9.3.4 Stability of the Slopes

(a) RLD of Plant Community (24 months)

The RLD of both treatments decreased with soil depth, with the penetration of the root to a soil depth of 100 cm in LLSS (restricted by sampling technique) and 80 cm in both LL and SS plots (Fig. 9.13). It is expected that the root may penetrate beyond 100 cm in the LLSS plot. The results also imply that the mix-culture system with *L. leucocephala* exhibited a higher total RLD which was almost double that of the plot without *L. leucocephala*, related perhaps to dense vegetation cover in particular plot (Table 9.3). All treatments displayed the highest RLD at the first 20 cm of soil depth, contributing 54.7-64% of the total RLD (Table 9.3). In slope stability aspect, this result probably implies that the root of *L. leucocephala* can function as a surface erosion control as well as due to its deep rooting system, as ground anchorage of deep-seated slope stability.

(b) Soil Penetrability (24 months)

The range of resistance to soil penetration in all plots, except LLSS, was 0.97 to 2.85 MPa (Fig. 9.14). This range was considered lower compared to the previous survey of the highway slopes in Malaysia (Normaniza, 1998). In contrast, the range of the LLSS plot was 2.12 to 3.78 MPa which was the highest range amongst the plots. Moreover, the value of this plot fitted the range of penetrability of stable slopes (Normaniza, 1998), indicating a stable and sustainable slope. The soil penetrability of LLSS and LL increased up to 50.0 cm of soil depth and decreased beyond that (Fig. 9.14). These increments are in similar trend with the root profile of these plots (Fig. 9.13). The observation indicates that highest
Figure 9.13: Root length density (RLD) in four different plots.
Table 9.3: Root length density (RLD) of the bioengineered plots at Rimba Ilmu, University of Malaya

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>G (m m$^{-3}$)</th>
<th>G (%)</th>
<th>SS (m m$^{-3}$)</th>
<th>SS (%)</th>
<th>LL (m m$^{-3}$)</th>
<th>LL (%)</th>
<th>LLSS (m m$^{-3}$)</th>
<th>LLSS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>553</td>
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<td>6446</td>
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<td></td>
<td>0</td>
<td>0</td>
<td>316</td>
<td>1.3</td>
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<tr>
<td>TOTAL (m m$^{-3}$)</td>
<td>859</td>
<td></td>
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<td></td>
<td>9,413</td>
<td></td>
<td>23,784</td>
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<tr>
<td>Km m$^{-3}$</td>
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<td>8.8</td>
<td></td>
<td>9.4</td>
<td></td>
<td>23.8</td>
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</table>
Figure 9.14: Soil penetrability of the experimental slopes after 24 months of experiment.
soil penetrability was attributed to the extensive root profile at particular depth (40-50cm). Thus, high resistance to penetration is expected.

(c) Shear Strength (12 and 24 months)

Overall results show that there was a significant difference (LSD$_{p<0.05}$=20.0) amongst the plots (Fig. 9.15a). The LLSS plot displayed the highest shear strength value at a soil depth of 30cm. Moreover, the value was almost double that of other experimental plots. It is worth-noting that G plot also displayed similar value of soil shear strength with those of LL and SS plots. Other factors may contribute to this observation such as the variability in components and properties of the soil in this plot.

In addition, the shear strength was observed to enhance with time with the presence of *L. leucocephala* in both plots (LL ad LLSS) either at 10 or 30cm of soil depth. The increment of shear strength was even prominent in LLSS plot, indicating the positive effect of the mix-culture system in terms of the stability enhancement (Fig. 9.15b). Zhou *et al.* (1997) concluded that soil is reinforced when shear strength is increased. This phenomenon occurs when there is more vertical as well as lateral root reinforcement. The shear force is expected to be even higher as the vertical root penetrates deeper into the ground and plays a pivotal role in soil reinforcement. Lateral roots from neighbouring plants (included in the core) may create maximum resistance thus producing a maximum bonding force in the soil-root interface. Therefore, in this experiment, the results may be attributed to the reinforcement by the root system with increasing depth. It is hypothesised that the shear strength at 30cm is more relevant to slope stability mechanisms, for instance, since most slope failures occur at a depth of 20 to 50cm.
Figure 9.15a: Soil shear strength (at 30cm of soil depth) in four plots. Vertical bars represent standard deviation and vertical lines represent \( \text{LSD}_{p<0.05} \).

Figure 9.15b: Soil shear strength (kPa) in LLand LLSS plots at 4" (10cm) and 12" (30cm) of soil depth. Vertical bars represent standard deviation and vertical lines represent \( \text{LSD}_{p<0.05} \).
(d) Soil Water Content (24 months)

The range of SWC was lower in the mix-culture plots than in the monoculture (Table 9.4). The SWC of the G plots was almost saturated, a characteristic of failing slopes. The results may conceivably be due to the low RLD (Fig. 9.13), thus less amount of water is presumably absorbed which leads to the slope ultimately remaining unstable. The LLSS and SS plots, however, had a dense vegetation cover above ground as well as an extensive root system below the ground. Thus, this type of plant community has high leaf area for transpiration. These plots had median SWC values of 10.4% and 15.2%, respectively. The values were about 52% and 60% of their FC, a characteristic of stable slopes.

In comparing between the two plots, LLSS had a lower SWC compared to LL (Fig. 9.16). The range, median and mean of SWC in LLSS was half that of LL plot (Table 9.4). The results represent a remarkable role of the mixed culture system to enhance the absorption of soil water by roots. However, the soil in LL was not saturated, with mean SWC of about 78% of its FC. Although there was a sign of surface erosion (see 9.3.2b), the plot looked stable due to the high percentage of root density at a soil depth of 20 cm (9.3.4a) and moderate value of shear strength at the particular depth (Fig. 9.15a).

9.4 General Discussion

From visual observation, *L.leucocephala* successfully grew in the mix-culture system (LLSS). The species studied is fast growing, an essential characteristic of a slope stabiliser. The plant successfully accelerated the process of natural succession via influx of other species. Species diversity had increased by 3.5 fold after six months of observation. Within two years, the vegetation dynamics of the LLSS plot at the slope of Rimba Ilmu, University of Malaya had markedly increased to 46 plant species, comprising grasses, shrubs and small trees. Other dominant successors observed were *Melastoma*
Table 9.4: Percentage of SWC and FC of the experimental plots
Values of FC indicated within brackets.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Range</th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>28.2 – 34.3</td>
<td>31.5</td>
<td>31.3</td>
</tr>
<tr>
<td></td>
<td>(33.6 – 36.8)</td>
<td>(35.4)</td>
<td>(35.2)</td>
</tr>
<tr>
<td>LL</td>
<td>21.5 – 25.5</td>
<td>23.8</td>
<td>23.5</td>
</tr>
<tr>
<td></td>
<td>(29.2 – 31.4)</td>
<td>(30.5)</td>
<td>(30.3)</td>
</tr>
<tr>
<td>SS</td>
<td>10.4 – 20.0</td>
<td>15.0</td>
<td>15.2</td>
</tr>
<tr>
<td></td>
<td>(19.9 – 29.5)</td>
<td>(23.8)</td>
<td>(24.7)</td>
</tr>
<tr>
<td>LLSS</td>
<td>8.3 – 12.5</td>
<td>11.1</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>(15.5 – 24.1)</td>
<td>(17.5)</td>
<td>(19.9)</td>
</tr>
</tbody>
</table>
Figure 9.16: SWC and FC of the two plots (LL and LLSS)
malabathricum which covered up to 15.0% of ground cover, Stachytarphets indica (shrubs) and Dieranopteris lineanis (fern). Axonopus compressus (grass) gradually decreased in the LLSS plot, implying a high competition with other species that suppressed its growth. In terms of slope stability, the SWC and the total RLD of the LLSS plot were 8.3-12.5% and 23.8 Km m$^{-3}$ respectively as opposed to 21.5-25.5% and 9.4 Km m$^{-3}$ of the LL plot (Table 9.5). The result was primarily due to a high biomass (9.3.2c) which most likely resulted in a high soil water loss through transpiration (data not presented). The penetrability and shear strength of the LLSS treatment was also observed to be almost double and triple, respectively, to that of LL (Table 9.5). The results may be attributed to the increase of the suction induced by water absorption and the physical impedance of root.

Some correlations amongst the stability parameters have also been studied. The soil penetrability is negatively related to SWC (Fig. 9.17). This result is similar to the previous findings (Materechera and Mloza-Banda, 1997; Laboski et al., 1998) where the penetration resistance increases with a decrease in SWC. However, the soil penetrability is consistently low beyond the SWC value of 12%, implying that there is a critical value of SWC which influences soil penetrability. As SWC values below this critical value characterise unstable slopes. A hyperbolic rectangular relationship was observed between RLD and penetrability (Fig. 9.18). Soil penetrability increases with increasing RLD, possibly due to the tensile property of the higher roots and the increment in root-soil bond (Zhou et al., 1997). However, the soil penetrability is constant beyond the RLD value of 8 Km m$^{-3}$. Similar to SWC, RLD also exhibits critical value, above which characterise stable slopes. There is a positive relationship between shear strength and RLD, implying that a dense root density could help to reinforce the soil by increasing its shear strength (Fig. 9.19). Dwyer et al. (1988) also indicates that maximum rooting development increases with decreasing available soil water. This phenomenon may contribute to the flow of water in the soil-plant-atmosphere continuum (SPAC) and help avoid the super-saturated
**Table 9.5:** The difference in slope stability parameters between two treatments.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LL</th>
<th>LLSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil water content (%)</td>
<td>21.5-25.5</td>
<td>8.3-12.5</td>
</tr>
<tr>
<td>(Field capacity (%))</td>
<td>(29.2-31.4)</td>
<td>(15.5-24.1)</td>
</tr>
<tr>
<td>Root length density (Km m$^{-3}$)</td>
<td>9.4</td>
<td>23.8</td>
</tr>
<tr>
<td>Penetrability (24 months) (MPa)</td>
<td>1.44-2.01</td>
<td>2.12-3.78</td>
</tr>
<tr>
<td>Shear strength (at 30&quot; soil depth in 24 months) (kPa)</td>
<td>50.0</td>
<td>180.0</td>
</tr>
</tbody>
</table>
Figure 9.19: Relationship between shear strength (kPa) and RLD (Km m$^{-3}$).

\[ y = 16.2x - 31.3 \]

\[ r = 0.97 \]
condition of the slope. Thus, this inference is in coherent to the observed finding of a strong inverse relationship between SWC and shear strength (Fig. 9.20). Hence, all these evaluations can be used as slope stability indicators (Table 9.6); they can predict potential slope failure, for instance in monitoring of cut slopes.

In this project, it is shown that a bioengineered slope is self-regenerating and sustainable ecosystem (see Plate 10.1a and b); once *L.leucocephala* was established, they modify the ecosystem through changes in plant biomass, soil and microclimate conditions. *L.leucocephala* has successfully improved the soil condition *via* its ability to fix nitrogen. Its potential as a nitrogen fixer is reflected in its prominent growth in terms of LAI, biomass and RLD. Similar finding of the potential of *L.leucocephala* to fix nitrogen has been reported by Vanlauwe *et al.* (1998). Sandhu *et al.* (1990) reported that nitrogen release from the decomposing litter of *L.leucocephala* helps in soil amendment of barren soil: leaves (13.2 g m\(^{-2}\)), fruits (10 g m\(^{-2}\)), twigs (4.4 g m\(^{-2}\)) and roots (3.4 g m\(^{-2}\)). In the subsequent successional phase, new species for example *Melastoma malabathricum*, *Stachytarphets indica* and *Dicranopteris lineanis*, whose optimum growth range fits these new set of conditions can be established and grown in a short period of time. In addition, the study also shows that *L.leucocephala* does not exhibit allelopathic characteristics where it allows the influx and growth of plant species. It sustains in the midst of high competition for space, nutrients, water and light in the plant community. Thus, the process of natural succession is enhanced with increasing biodiversity. This, in return, enhances slope stability, lowering the risk of potential erosion and landslide especially in newly cut slopes.
Figure 9.20: Relationship between soil water content (%) and shear strength (kPa)

\[ y = -0.07x + 25.32 \]

\[ r = 0.98 \]
Table 9.6: Critical value of slope stability

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Critical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil water content *</td>
<td>12.0 – 15.0 %</td>
</tr>
<tr>
<td>Root length density</td>
<td>8.0 Km m⁻³</td>
</tr>
</tbody>
</table>