Chapter 10
CHAPTER 10

THE CONTRIBUTION OF *L. LEUCOCEPHALA* TO SLOPE STABILITY: A TRIBUTE

10.1 Introduction

In the preceding chapters, considerable results on the use of *L. leucocephala* for erosion control and slope stabilisation have been established. This project strengthen the modes of application of *L. leucocephala* in performing its engineering role (7.3, 7.4, 8.3, 8.4 and 9.3.3) when combined together with the essential botanical (4.3 and 5.3) as well as ecological (6.3, 9.3.1 and 9.3.2) aspects related to slope stability. Intensive bioengineering project to assess the suitability of *L. leucocephala* in enhancement of slope stability is believed to be the first of its kind. It has unveiled distinguishing and prominent features of *L. leucocephala* whereby this species could be used to solve major problem in this part of the world. Amongst the features that make *L. leucocephala* useful in bioengineering is its good pioneering characteristic.

10.2 The Pioneering Characteristics of *L. leucocephala*

10.2.1 Drought Resistance Mechanisms

Significant physiological changes occurred in *L. leucocephala* in response to water stress. These changes include decreased photosynthesis (4.3.3), transpiration rate (4.3.4) and stomatal conductance (4.3.5), and increased WUE (4.3.6). Both photosynthesis and stomatal conductance were affected by water stressed condition at LWP below -0.8 MPa. All these criteria indicate the ability of *L. leucocephala* to regulate its water economy through water conservation mechanisms. Thus, the *modus operandi* of drought resistance in *L. leucocephala* is its conservative characteristic. The species studied limits water loss regardless of the stomatal conductance especially beyond 3.0 cm s\(^{-1}\) (4.3.5). The result is in line with Chapman and Aug (1994) who stated that a drought tolerant plant has a high
resistance to water loss and a high capacity to take in water. The experiments carried out under this project also showed that the species studied could maintain relatively high morning leaf water potential (4.3.1) and morning RWC (4.3.2) under WS conditions. Possibly due to this, the results also exhibit positive photosynthesis values even though the plant has been exposed to water stress for about 40 days. This implies that the plant has the potential to maintain a positive growth under intensified drought.

10.2.2 A Carbon Sink Potential

In the simulated CO₂ and light experiments, *L. leucocephala* showed the ability to utilise high concentrations of CO₂ and high irradiance. The plants exhibited high and prominent values of the photosynthetic components i.e. Aₘᵟₓ (5.3.1 and 5.3.4), A₄₀₀ (5.3.1) and no photo-oxidation was observed up to 2000 µE m⁻² s⁻¹, the maximum irradiance level tested (5.3.4). Moreover, high gₑ and QE (5.3.4) were observed regardless of the water condition of the plant.

Water stressed conditions was observed to have pronounced effects on the photosynthetic components of *L. leucocephala*, particularly Aₘᵟₓ and A₄₀₀ (5.4.2a and b) during low soil moisture (1200 hr). The decrease in photosynthetic and transpiration rates was attributed to the decrease in the stomatal conductance (5.3.2). This low stomatal conductance reduced the transpiration and ironically led to a high WUE in the stressed *L. leucocephala* (5.3.3). The results also suggest that the inhibition of photosynthesis in the species studied was caused by stomatal regulation when subjected to drought (5.3.2). In spite of this, drought conditions did not have much effect on gₑ, Γₐₖ (5.3.1), QE and Γᵢ (5.3.4) throughout the day of observation. This indicates the ability of stressed *L. leucocephala* to remain photosynthetically active at low CO₂ concentrations and that it is extremely resistant to water stress. As inferred from these findings, *L. leucocephala* has a good carbon sink potential even under drought condition.

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10.2.3 A Relatively Acidic Tolerant Species

The microclimate propagation technique has unleashed the possibility to further investigate and revegetate acidic soil. A suitable planting depth and right supplements, CaSO₄ and sphagnum moss, used in this experiment prolonged the growth of 20% of *L. leucocephala* for about 160 days (6.3.2a). Smaller and thinner leaves (6.3.1), leaf necrosis (6.3.2a) and reduced number of leaves (6.3.2a) were observed as mechanism to reduce leaf area. Interestingly, the high concentration of Al suggests that *L. leucocephala* is an Al accumulator, one of the mechanisms to resist acidic conditions (6.3.2c). Thus, this initial attempt and positive findings somehow implies that with further modification, perhaps on the planting technique, the tolerance mechanism of *L. leucocephala* to encounter acidity condition could be improved.

10.2.4 Engineering Properties of *L. leucocephala*

(a) Root Profile

The soil stabilising capability of *L. leucocephala* is a function of its extensive and dense rooting (7.3.2) and depth of penetration (7.3.1). These aspects, to some extent, could provide surficial (7.3.2) as well as deep-seated erosion control. Prominent physiological criteria were also observed including high stomatal conductance, WUE (7.3.6) and WAC (7.3.3). A high WAC would increase suction, thus lowering the groundwater level. Hence, it could be envisaged that the ability of the root system is not only to reinforce soil but also to potentially extract water at the greater depth. When *L. leucocephala* is grown on slopes, this hydrological role together with the engineering properties would ultimately result in a drier, and thus a more stable, slope.

(b) Soil-Root Matrix Shear Strength

One of the major contributions of *L. leucocephala* to slope stability is the increase in shear strength of the soil arising from its root system. The root matrix of the species studied
significantly affects cohesion but not the angle of friction (8.3.1). The effect varies with increasing depth and age of plant depending on the root length density of the species (8.3.3). In this project, the magnitude of the root-reinforcement was successfully evaluated in terms of shear strength parameters (8.3). After six months of growth, the species studied had tremendously increased in the cohesion factor by two to five fold (0.1m – 0.5m soil depth) (8.3.1a). This range almost reached the values of those in the twelve-month treatment (8.3.1c). The results also revealed a high residual strength (8.3.2), indicating a high contribution of the root system to soil-root reinforcement.

10.3 Can *L. leucocephala* be a Good Pioneer?

As a pioneer, *L. leucocephala* was observed to establish rapidly in the mixture of *L. leucocephala* and four species of shrubs situation (9.3.1a and b). The species in the mix-culture system was more successful in terms of plant physiological criteria such as LAI (9.3.1a), photosynthetic rate and stomatal conductance (9.3.1a), and fast growth rate (9.3.1b). Moreover, the species can be a good competitor without exhibiting any allelopathic feature (9.3.2ai). In terms of the plant community, *L. leucocephala* had also tremendously accelerated the plant succession of the slope. Within two years, 46 species comprising various species of grasses, shrubs and small trees colonised in the mixed culture treatment (9.3.2a). The plant diversity increased drastically, about five (12 months) and eight fold (24 months) of its initial (0 month) diversity against 2.5 (12 months) and three fold (24 months) in the monoculture treatment (9.3.2b). Related to this species-richness, LAI (9.3.2b) and biomass (9.3.2c) of the plant community was enhanced in the mix-culture system. In addition, *L. leucocephala* facilitated the plant establishment and enhanced complete ground cover in about six months of the observation (9.3.2a). This implies that the critical erosion period could be shortened and the desired technical and ecological efficiency achieved more quickly.
10.4 The Contribution of *L. leucocephala* to Slope Stability

No erosion or landslide occurred in the mix-culture system during the experiment. However, sign of erosion had occurred in the monoculture system twelve months after the transplanting. This observation indicates that the stability of the slope was enhanced in the mix-culture ecosystem. The enhancement has been illustrated by an increase in soil penetrability (9.3.3b) and shear strength (9.3.3c). A high correlation between both parameters and RLD (9.4) was observed. These results were probably due to the extensive root system of the plant community (9.3.3a). Higher RLD also implies higher WAC (see 7.3.7). Thus, it can be envisaged that on the slopes which has higher RLD, low SWC would result as a consequence of the higher WAC. Ultimately, high penetrability and shear strength would be obtained as proven in the relationship between both penetrability and shear strength with SWC (9.4). The relationship interestingly showed critical values of 12% and 8 Km m⁻³, respectively, for SWC and RLD.

10.5 Interaction with Various Parameters Studied

The overall results have proven the ability of *L. leucocephala* to exhibit good pioneer characteristics in terms of accelerating the process of natural succession of the slope via influx of other species as well as enhancing slope stability (Fig. 10.1, Plate 10.1a and b). A well-grown ecosystem has established within two years and the species studied is competed well with other colonised species in the ecosystem. The root profiles increase with increasing biodiversity at the upper ground. Related to this phenomenon, high water absorption capacity by root was observed, resulting in low soil water content (SWC) of the slope. Thus, low SWC with high soil shear strength and penetrability characterise a stable slope.
Fig. 10.1: Various interactions in determining the role of *Leucaena leucocephala* in accelerating the process of natural succession and stability of slope.
Plate 10.1a: A showcase slope at Rimba Ilmu, University of Malaya, six months after planting (January 2000).
Plate 10.1b: Showcase slope revisited (January 2004). The present ecosystem, initiated by fast growing *L. leucocephala*, is enriched in biodiversity, more stable and sustainable.
10.6 Contribution of the Project

This project has accomplished an insight on the use of vegetation for slope stabilisation. To the scientific community, it assembles and classifies the protocol towards establishment of a stable slope in the disciplines of botany, ecology as well as engineering. This study thus provides, *inter alia*, a cost-effective solution to solve slope problems. A bioengineering approach arguably is the most effective way to control slope problems e.g. surface run-off, erosion and landslides. It also enhances the carbon sink strength in an ecosystem. These aspects of bioengineering are important enough to warrant the relevance and needs of this project, and others with similar objectives.

10.7 Challenges Ahead

Even though the importance of bioengineering has been largely accepted, the knowledge has not developed sufficiently. In global context, there is still insufficient knowledge regarding bioengineering discipline. For example, the choice of species is limited. Surveys on diverse indigenous species which have good pioneering characteristics are still lacking. In addition, although acidity is believed to be amongst the major slope problems, there is insignificant attempt to identify suitable species tolerant to acidic condition. Due to the improper way of cutting slope, steep inclination has become amongst the major factors which cause slope failure. In particular, research on how plant can better establish on steep inclination and poor soil quality is wrongfully considered trivial. Meanwhile, not many researchers have investigated on the root profile and its influence on slope stability directly (enhance slope shear strength) and indirectly (enhance Water Absorption Capacity of plants).

In the Malaysian perspective there is an added problem; the emphasis on Research and Development (R&D) is badly lacking. This problem, however, can be alleviated if the
corporate organisations especially highway operators and the real estate developers are sensitive to the stability problem and realised the importance of R & D. For example, a construction company falsely tries to save capital expenditure by skipping R & D in a task of cutting vast areas of slope only to realise later more expenditure is essential to repair damaged slopes. The cost of repair is sometimes greater than initial expenditure creating cost-over run, delayed completion in addition to possible irreversible damage to the environment. Therefore, for public safety and preservation of the environmental, it is vital for all organisations including government, corporate and private institutions to establish standard procedures and etiquettes in slope cutting and management. It is a challenge to inculcate bioengineering technique, in tandem with engineering and geological techniques, as a long-term solution to slope stability.

10.8 Conclusion and Recommendations

The contribution of the species studied as slope stabiliser is apparent because it has outstanding features especially fast growth, good carbon sink potential, drought tolerance, acid tolerance and extensive root system which had enhanced the stability of slope in terms of soil water content, soil shear strength and penetrability. Thus, the project ascertains the contribution and the potential of this species in improving the environment and alleviating major stability problem by enhancing natural succession, the revegetation process as well as slope stability. Hence, bioengineering is a viable technique and *L. leucocephala* is amongst the right species in this option.