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Shear Strength Enhancement by *Digitaria Setivalva* Associated with NPK and Bio Green Application on Bungor Soil Slope

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ABSTRACT: *Understanding the chemical constraints to plant growth and their amelioration is critical for erosion control and slope stability on artificial landforms. Limited studies have investigated the effects of chemical amendments on grass growth, and effects on soil physical and chemical characteristics on the slope surface. Digitaria setivalva (Mardi Digit grass) was used as a grass coverage to control erosion on the steep man made slope. The current slope studies (45^{o}-50^{o}) on Bungor soil series to address two objectives; (1) to investigate the effects nitrogen (N)-phosphate (P)-potassium fertilizer (NPK) and Bio Green fertilizer (BG) on above-ground and root growth, and (2) to determine physico-chemical properties and root shear strength after application of treatments. The Bungor series was acidic pH (4.63), moderate soil organic carbon (1.42%), total N (0.12%), available P (12.2 mg kg^{-1}) and potassium (0.44 mg kg^{-}1), indicating low inherent infertility and chemical constraints to plant growth. Therefore, above-ground biomass (kg m^{-3}) for nutrient and organic amendments; NPK+BG (7.2), BG (6.1) > NPK (2.2) was more than double that of the unamended control (1.3). A similar trend was observed for root biomass density (kg m^{-3}); NPK+BG (272.94), BG (262.70)>NPK (133.76) > control (98.60) and root length density (cm m^{-3}); NPK+BG (8332.0), BG (8092.0) > NPK (5200.0) > control (4000.0). Rapid vegetation growth observed within a 6-month period demonstrates that NPK and Bio Green application effectively ameliorated chemical constraints to plant growth. Enhanced vegetation growth subsequently reduced soil leachates (N, P and K) from the slope significantly as compared to NPK and Control treatments. The application of NPK+BG and BG fertilizer showed significant effect in reducing nutrients loss, increased soil aggregate stability, water retention, hydraulic conductivity and improved macro- and micronutrients content. Enhanced vegetation growth subsequently increased shear strength (s) as evidenced by positive power relationships ($r^2 = 0.53$-0.69, $p<0.05$) between root density, and angle of internal friction (ϕ) and shear strength. The significant root-ϕ relationship indicates that root enhanced shear strength by increasing the frictional component but not cohesion. The increase in shear strength was attributed to increase in virtual density and reduced pore water pressure attributed to root water uptake associated with rapid vegetation growth. Root biomass and root length density may increase the shear strength and reduced pore water pressure attributed to root water uptake associated with rapid vegetation growth. Under field conditions, a dense canopy and root network also reduces soil detachment and transport by raindrop impact and runoff. These multiple vegetation-soil interactions are critical for erosion control and slope stability on artificial landforms such as cut slopes.*

Keywords: *Artificial landforms, chemical constraints, cut slopes, surface coverage, rapid growth, root relationships, vegetation-soil interactions.*

INTRODUCTION

Frequent slope failures through landslides and soil erosion pose significant risks to human life and infrastructure. Slope failure and erosion are prevalent on natural and man-made slopes in tropical environments, where rainfall occurs as high-intensity and erosive storms. The role of vegetation-soil interactions or ecohydrological feedbacks in controlling hydrology, flow hydraulics and geotechnical properties is well-recognized (Abernethy and Rutherfurd, 2000). For example, vegetation cover reduces soil detachment and erosion by dissipating rainfall and runoff flow velocity (Ludwig et al., 2005). On vegetated slopes, root water uptake and

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subsequent evapotranspiration also contributes to the hydrological balance by reducing soil moisture storage. Enhanced root water uptake prevents excessive build-up of pore-water pressure. Coupled with root reinforcement, reduced pore-water pressure increases shear strength of earth materials and hence slope stability. The effect of roots on soil mechanical properties, soil erosion and slope stability has received a lot of research attention in recent years. Existing studies focused on mechanical properties of roots (De Baets *et al.*, 2008; Mattia *et al.*, 2005; Preti and Giadrossich, 2009) and numerical modelling of root-soil aggregate stability relationships and root profile distributions (Abernethy and Rutherfurd, 2000; Preti *et al.*, 2010). For example, De Baets *et al.* (2008) evaluated the root reinforcement effects of 25 Mediterranean species and showed that the power relationship between root tensile strength and root diameter varied significant among species. Preti et al. (2010) used an analytical model based on hydrological, pedological and above-ground vegetation information and showed that the approach was effective non-destructive method for predicting root profile distribution for slope stability analysis.

For example, investigating the effect of root system morphology and architectural traits on shear strength, Ghestem *et al.* (2013) reported that root density, branching, length, volume, inclination and orientation significantly influence soil mechanical properties. Little is known about material properties constraining above-ground and root growth, and types of grass which have fast surface coverage on the slope associated with artificial landforms such as cut slopes. Cut slopes are common features associated with infrastructural development such as transportation highways, construction and urbanization. Due to potentially adverse chemical and physical conditions associated with freshly exposed geological materials, cut slopes are often unvegetated. Acordingly, cut slopes are highly susceptible to erosion and slope failure especially in tropical environments, where rainfall occurs as high-intensity and erosive storms. Extrapolation of findings from previous studies conducted on natural slopes (e.g. Rickli and Graf, 2009) and riverbanks (e.g. Abernethy and Rutherfurd, 2000; 2001; Micheli and Kirchner, 2002) is constrained by differences in site characteristics.

Understanding chemical constraints and evaluation of strategies for promoting rapid vegetation growth on the slope is critical for controlling soil erosion and slope failure such as cut slopes. Steepland soils tend to be low of chemical fertility through soil erosion. The loss of surface layer that contain high nutrients can cause a rapid declined in soil productivity. Therefore, a study was conducted on Bungor series slope planted with *Digitaria setivalva* to investigate two related hypotheses; (1) nitrogen (N)-phosphate (P)-potassium compound fertilizer (NPK) and Bio Green (BG) ameliorate chemical constraints and significantly enhance above-ground and root growth, and (2) subsequent vegetation-soil interactions will in turn significantly increase soil physical properties.

MATERIALS AND METHODS

Samples were obtained from a cut slope of Bungor series (45°-50°) at Universiti Putra Malaysia in Serdang, Malaysia (N 2.98343, E 101.74070). The area of the slope is 200cm in length and 30 cm in width for each treatment. The area was divided into four equal blocks for multiple treatments of each grass. The soil samples were air-dried, ground and sieved through a 2.0-mm sieve. The samples were analyzed for pH, total nitrogen (TN), soil organic carbon (SOC), available phosphorus, exchangeable Ca, Mg and K using standard analytical methods (Page *et al.*, 1982). pH was determined in 1: 1 soil: water suspension using a pH electrode. Total N, SOC and available P were determined by the Kjeldahl, Walkley-Black and and Bray-1 methods, respectively. Exchangeable Ca, Mg and K were extracted with 1.0 M NH_4OAc buffered at pH 7.0. Ca and Mg in the extract were determined by atomic absorption spectrophotometry (AAS) and by flame photometry. Soil leachates from the slope and other physical properties such bulk density, aggregate stability, water retention and hydraulic conductivity were measured after 6 month of experimental period.

A slope experiment was set up to investigate the effects of nutrient and organic (Bio Green) amendments on aboveground biomass, root growth, root length density and root biomass density. Four treatments consisting of nutrient-organic combination were investigated; (1) unamended soil (control), (2), [135 kg N, 60 kg P and 2 kg K per ha] (NPK), (3) NPK and [20 kg per ha] Bio Green (NPK+BG), and (4) Bio Green (BG:20 kg/ha).

The experiment was set up in a complete randomized block design (RCBD with four replicates per each treatment. In each box, a fast-growing grass (*Digitaria setivalva*) was planted by transplanting method. The selection of this grass was based on preliminary experimentation that showed rapid growth and high biomass production (Munir, 2014).

Data analysis

Data were tested for analysis of variance (ANOVA) assumptions of normality and homogeneity of variances using the Shapiro-Wilk's and Bartlett's tests, respectively. One-way ANOVA was done to test the effects of treatments on above-ground biomass, root biomass and length densities and shear strength parameters (shear strength, cohesion, angle of internal friction). Non-normal data that could not be normalized by transformation were subjected to the non-parametric Kruskal–Wallis test. Regression was used to test the relationship between root density, and shear strength, cohesion and angle of internal friction. All statistical tests were done at probability level, p = 0.05 using SAS Statistical Analysis System (SAS Institute, 1999).

Experimental set up

Results on Dry matter yield and Soil Physical Properties

The result shows the Bungor soil was inherently infertile, characterized by quite acidic (pH = 4.80), exchangeable aluminium (1.89 mg kg^{-1}) and soil organic carbon (SOC) (0.94%). In general, pH, SOC, exchangeable Al were lower than typical optimum ranges for plant growth. On the other hand, the concentrations of exchangeable bases Ca^{2+} (0.22 mg kg^{-1}), Mg^{2+} (0.15 mg kg^{-1}) and K^{+} (0.12 mg kg^{-1}) were relatively low for plant growth. Overall, these chemical conditions may pose restrictions to plant establishment and growth on this steep slope.

Aboveground biomass

Plate 1 and 2 shows the establishment of *Digitaria setivalva* (Mardi digit grass) after 6 month of planting on Bungor series soil with 45^0 of slope. Fast surface coverage and appropriate treatments applied give high dry matter yield and strong roots anchorage of Mardi digit grass on the slope. Nutrient and Bio Green amendment of the slope significantly ($p<0.05$) increased above-ground biomass (Figure 1) relative to the unamended control after 6-month study period, total aboveground biomass yields for NPK (T2 : 131.13 g), Bio Green (T3 : 182.41g) and NPK+Bio Green (T4 : 216.05 g) were more than double that of the unamended control (T1 : 78.9 g). This strongly suggests the important usage of Bio Green or mixture of NPK and Bio Green fertilizer that contains adequate macro- and micronutrients in enhancing the growth of Mardi digit grass on this steep slope.

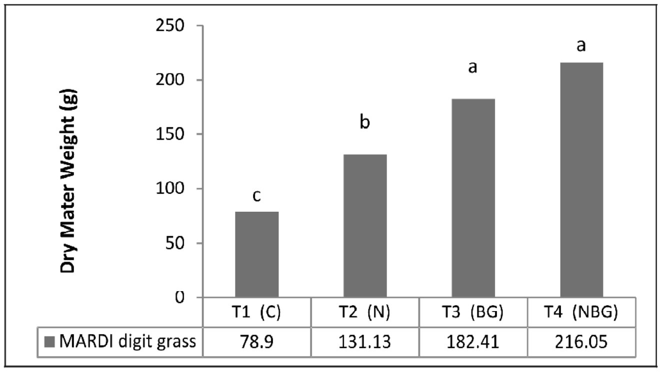

Figure 1: Dry matter weight after 6 months of planting. (Means with the same letter are not significantly different at p<0.05)

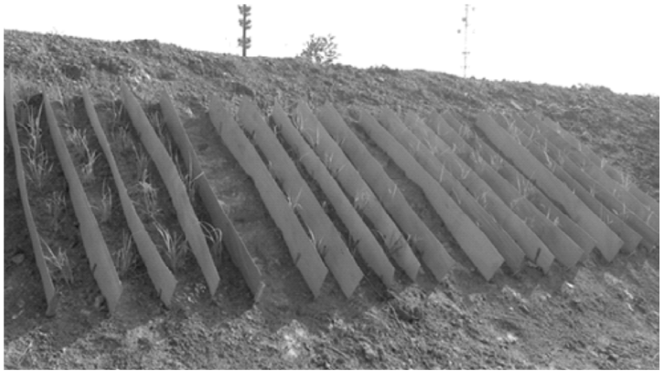

Plate 1: Field layout on soil sloped area after 1 week of planting

Plate 2: Vegetation establishment on slope after 6 month of planting

Soil Aggregate Stability

Soil aggregate stability affects movement of water, plant root growth and soil erosion, which influences on the quality of the soil (Seybold and Herrick, 2001). The higher percentage of soil aggregate stability indicates that the soil is stable against wind and water erosion because it's provide a large range of micro and macropores within the aggregates and increased water infiltration rates and root growth. Figure 2, MARDI Digit grass with Bio Green (T3:BG) (50.09%) and the mixture of Bio Green and NPK (T4:NBG) (50.75%) had shown significant different in aggregate stability analysis compared to the NPK (T2:N) (25.97%) and control (T1:C) (24.44%).

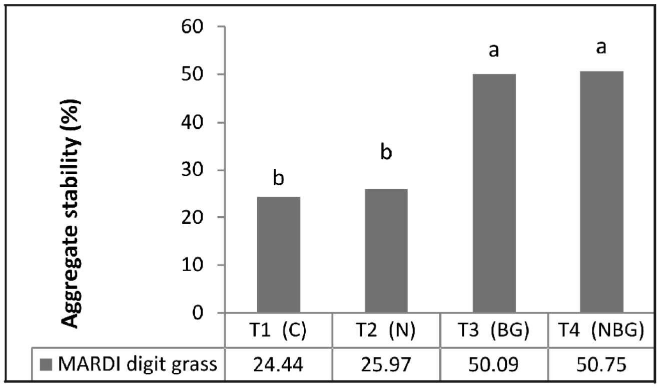

Figure 2: Soil aggregate stability after 6 months of planting

(Means with the same letter are not significantly different at p<0.05)

The higher percentage of soil aggregate stability, the higher ability of soil to resist wind and water erosion (Jamal and Sung, 2006). The soil with strong bond of aggregate will cause less erosion as it provides vital information on the sensitivity of soil toward erosion. Treatments with T3 and T4 indicated that soil aggregate stability was significantly improved in this experiment.

Soil bulk density, porosity and saturated hydraulic conductivity

Figure 3 shows that treatment with NPK+Bio Green (T4) gave the lowest bulk density which is significantly different compared to T1 and T2. Soil bulk density is a basic soil property to indicate soil compaction, which influenced by some soil physical and chemical characteristics such as soil texture, amount of organic matter in soils, constituent of minerals and porosity (Ghestem *et al.,* 2013). For porosity status after treatments application, T3 and T4 was shown significantly different compared to T1 and T2. Bulk density is closely related to soil porosity.

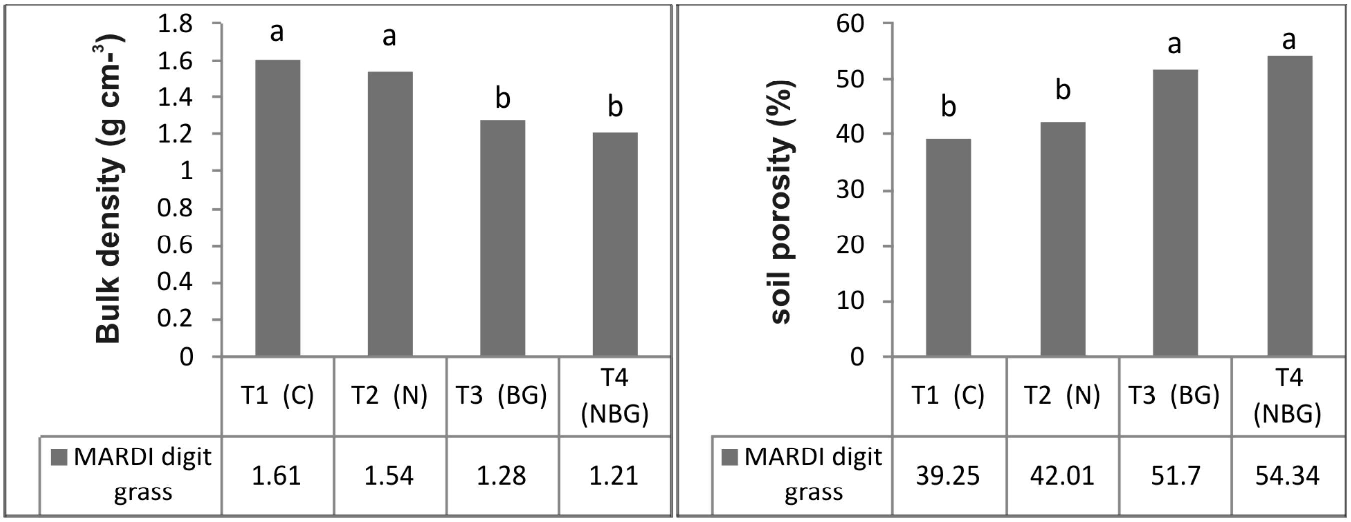

Figure 3: Bulk density and porosity measurement after application of treatments

(Means with the same letter are not significantly different at p<0.05)

Soil porosity of the Bio Green (T3:BG) and the mixture of Bio Green and NPK (T4:NBG) increased and bulk density decreased. Soil porosity is important for water infiltration, water and nutrient movement within soil, and ability of the soil to hold water.

The soil hydraulic conductivity (Figure 4) for the Bio Green (T3:BG) (0.61 cm min^{-1}) and the mixture of Bio Green and NPK (T4:NBG) (0.61 cm min^{-1}) was significantly different from the control (T1:C) (0.31 cm min^{-1}) and NPK (T2:N) (0.34 cm min^{-1}). There are many factors that can affect the soil hydraulic conductivity. Soil with high percentage of clay has slow infiltration rate than in sandy soil. High bulk density and less soil pores also may cause in low soil hydraulic conductivity. The addition of amendment in soil was associated with the increase in soil aggregation and macro-porosity, which lead in increasing soil hydraulic conductivity (Eusufzai and Fujii, 2012).

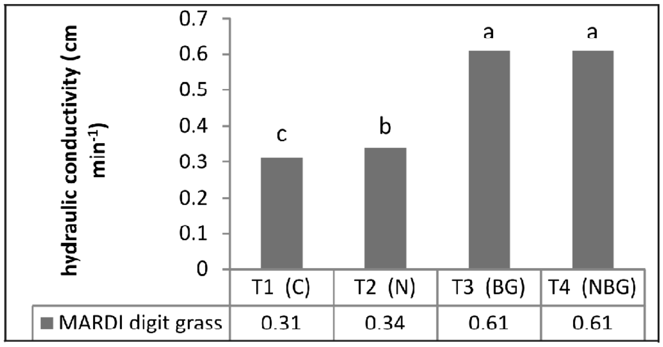

Figure 4: Hydraulic conductivity measurement after application of treatments

(Means with the same letter are not significantly different at p<0.05)

Root Dry matter yield, length and root biomass density

Root dry matter yield (g) varied significantly ($p<0.05$) among all treatments, increasing in the order; control (78.9) < NPK (131.13) <BG (182.41) < NBG (216.05). From Figure 5, NPK and Bio Green application increased root dry biomass of the Bungor series by approximately between 36 to 43% compared to control treatment. Comparing NBG and BG showed that both fertilizer application significantly enhanced root biomass growth. Root length measurement (cm) for NPK+Bio Green (NBG : 20.83) was similar to that of Bio Green (BG : 20.23), but significantly ($p<0.05$) higher than that of NPK (N: 13.0) and control (C : 10) (Figure 5). This suggested that NBG and BG fertilizer significantly ($p<0.05$) increased root length and dry matter yield whereas the effect of NPK alone was not evident.

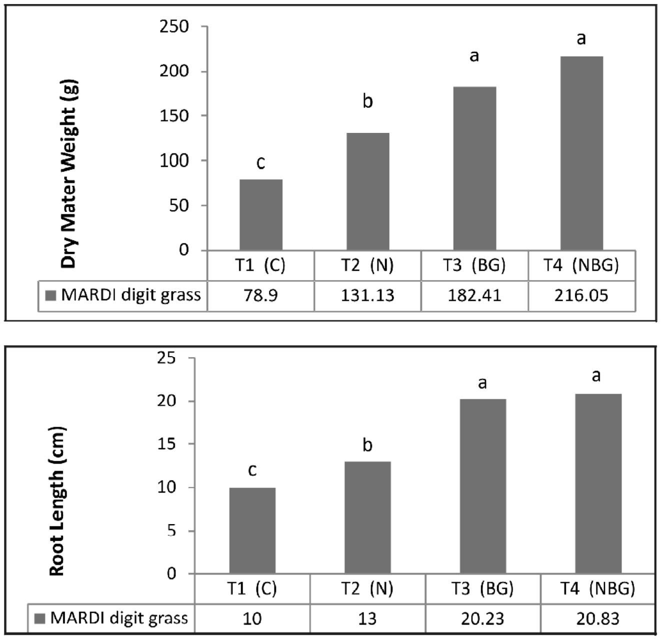

Figure 5: Effect of treatments on Dry matter yield and Root length

Figure 6 depicts the effects of NPK and Bio Green application on the depth distribution of root biomass density where NPK and Bio Green amended Bungor had significantly ($p<0.05$) higher root biomass density than the control. As expected, root biomass showed a general decrease with increasing soil depth for all treatments. The maximum decline in root density occurred at the 25-50 cm depth in all cases, although more gradual than the sharp exponential decline often observed in field studies (e.g. Gwenzi et al., 2011). The observed root profiles have corresponding implications on depth distribution of shear strength parameters.

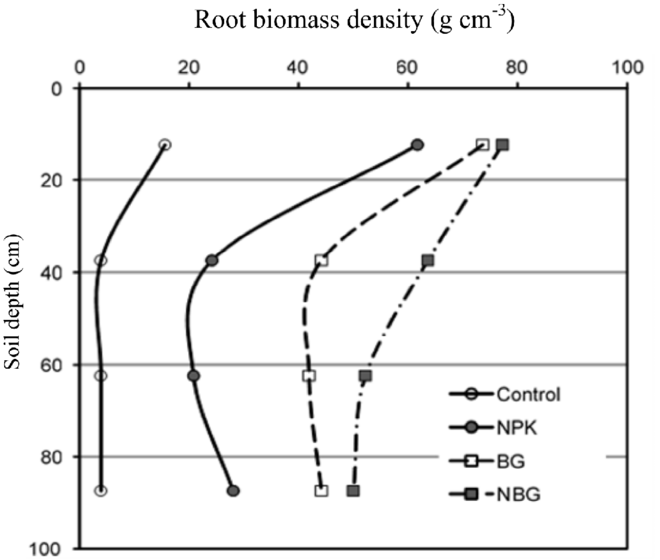

Figure 6: Effects of NPK and Bio Green application on depth distribution of root biomass density on Bungor slope. NPK: N: P: K fertilizer, BG: Bio Green, NBG: NPK + Bio Green.

Soil Leachates and pH

Similar trend was shown in Figure 7 for nitrogen and potassium leachates which was collected at the downslope. Treatments with Bio Green (BG) and NPK+ Bio Green (NBG) were shown significantly different compared to NPK and control. Potassium and nitrogen leachates that was collected from the downslope showed very low amount leached from the upper slope. The highest losses of nutrients were showed in control (T1:C). Thus, the addition of organic matter (BG) was able to minimize the nutrient loss caused by erosion as organic matter is able to hold and bind nutrients to the soil (Lal, 2003). Moreover, the canopy and roots of the vegetation also important in prevent losses of nutrients due to runoff and erosion.

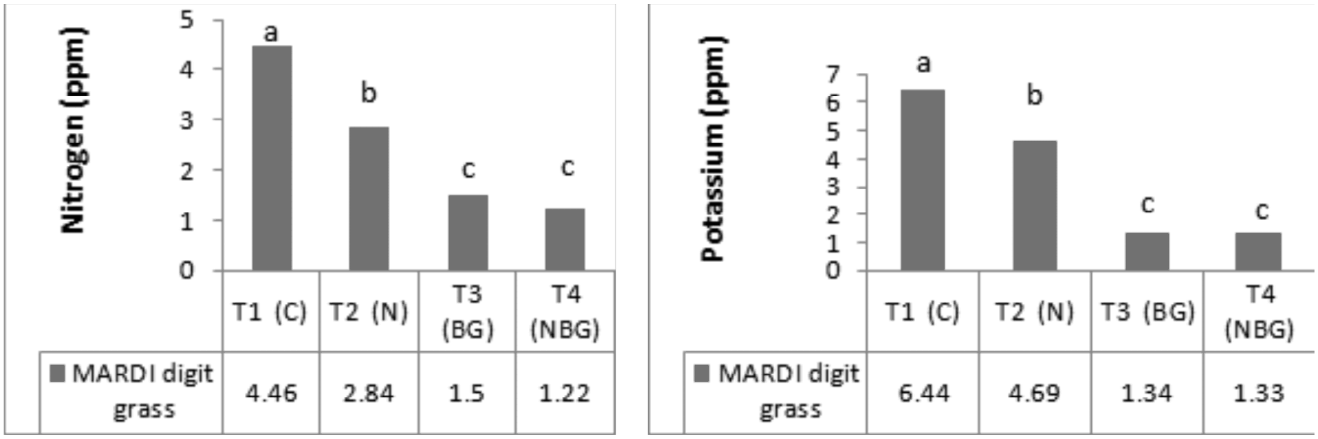

Figure 7. Nitrogen and Potassium loss after 6 months of planting.

(Means with the same letter are not significantly different at $p<0.05$)

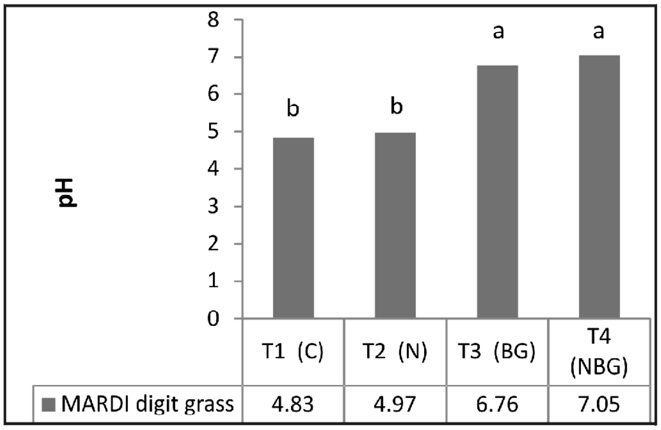

Figure 8. Soil pH after 6 months of planting.

(Means with the same letter are not significantly different at $p<0.05$)

Most nutrients are available for root uptake when the pH of the soil ranges from 6.0 to 7.5. When soil pH below 6.0, some nutrients such as nitrogen, phosphorus and potassium are less available in the soil. The result shows (Figure 8) a significant different between the mixture of Bio Green and NPK (T4:NBG) (pH 7.05) and the Bio Green (T3:BG) (pH 6.76) with the NPK (T2:N) (pH 4.97) and control (T1:C) (pH 4.83).

Shear strength parameters

The enhanced root growth associated with NPK and Bio Green amendments had significant effect on depth distribution of cohesion and angle of internal friction (Figure 9). At a normal stress of 163 kN m^{-2}, the unamended Bungor soil had a cohesion (c) and angle of internal friction (ϕ) of 48.2 kN m^{-2}) and 15.9°, respectively and a shear strength of 94.7 kN m^{-2}. This shear strength is lower than the corresponding values for amended Bungor soil at a normal stress of 163 kN m^{-2}. Cohesion values for the control and BG were similar, but both were significantly higher than NPK and NBG at all depths (Figure 9a). On the other hand, NPK and Bio Green effects on depth distribution of angle of internal friction were generally consistent with root depth distribution. Bio Green and NPK+Bio Green had significantly ($p<0.05$) greater angle of internal friction that the control particularly in the top 50-cm depth. The gradual decline in angle of internal friction with depth was generally consistent with the pattern observed for roots except NPK, which showed a drop from about 30° at 0-25 to about 22° at 50-75 cm depth. In general, roots reduced cohesion while increasing the angle of internal friction. Comparison of shear strength at 54, 109 and 163 kN m^{-2} showed that the strength increased with normal loading (Figure 9).

Figure 10 shows the depth variation of shear strength at normal stresses of 54, 109 and 163 kN m^{-2}. NPK and Bio Green amendments had a significant ($p<0.05$) effect on shear strength at high normal stresses (109 and 163 kN m^{-2}), but no clear treatment effects were evident at low normal stress (54 kN m^{-2}) (Figure 7). In particular, BG and NBG had significantly higher strength that NPK and the control. For most treatments, shear strength was highest in the top 25 cm depth and showed a general decline with increasing soil depth. Interestingly, the depth distribution of shear strength in Figure 8 mirrored the depth distribution of angle of internal friction especially at normal stress of 163 kN m^{-2}. This observation is consistent with the shear strength equation for Mohr-Coulomb failure criterion. Comparison of NPK to treatments incorporating

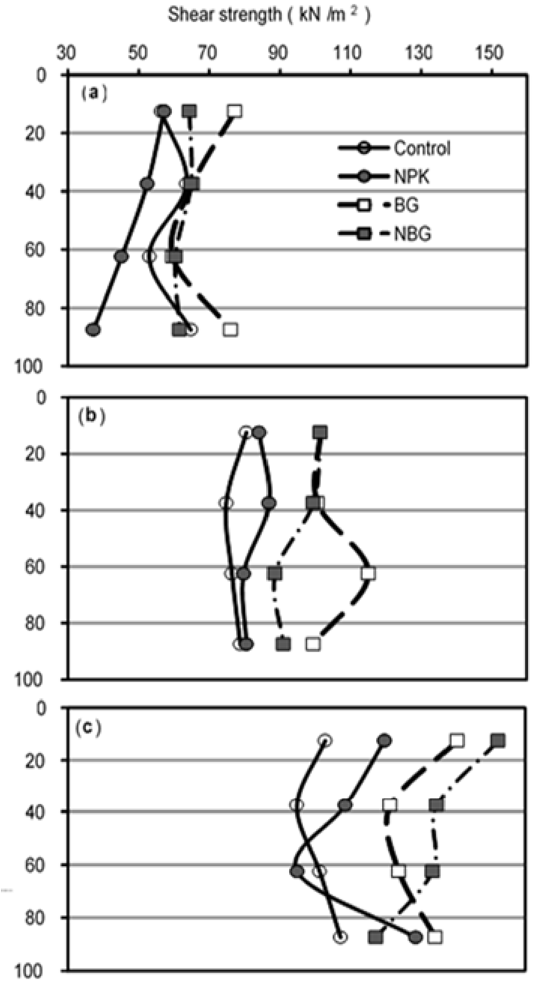

Figure 9: Depth distribution of shear strength on NPK and Bio Green amended of Bungor soil at normal stresses (kN m^{-2}) of 54 (a), 109 (b) and 163 (c). NPK: N: P: K fertilizer, BG: Bio Green, NBG: NPK+ BG

organic fertilizer (BG and NPK+BG) revealed that organic fertilizer resulted in generally higher shear strength than unamended control and NPK (Figure 9). This increase in shear strength due to additional Bio Green (BG) is particularly evident at normal stresses of 109 and 163 kN m^{-2} (Figures 10a and 10b).

DISCUSSION

Erosion and slope failure occur frequently on cut slopes in tropical environments partly due to the combined effects of high-intensity storms and lack of vegetation. The current study investigated the effect of NPK and Bio Green application on aboveground biomass, root growth and root-shear strength relationships of Bungor soil slope. The Bungor soil was inherently infertile as indicated as acidic, very low organic carbon and macronutrients. The acidic pH could be attributed to the hydrolysis of the aluminium ions (Al^{3+}) and subsequent release of H^+ ions. Low pH (4-5) and aluminium toxicity restrict root growth and is a common problem on extremely weathered tropical soils in Malaysia. To evaluate the constraints and facilitate revegetation, the current study evaluated the effect of NPK and Bio Green amendments on aboveground and root growth, and their subsequent root-shear strength relationships.

Basal NPK and Bio Green fertilizer application more than doubled above-ground biomass relative to the unamended (control), demonstrating their effectiveness in alleviating the acidic pH and multiple nutrient deficiencies associated with Bungor soil. Bio Green increases soil pH and is a source of Ca and Mg. Increased biomass growth due to BG application could be attributed to accurate timing of application,

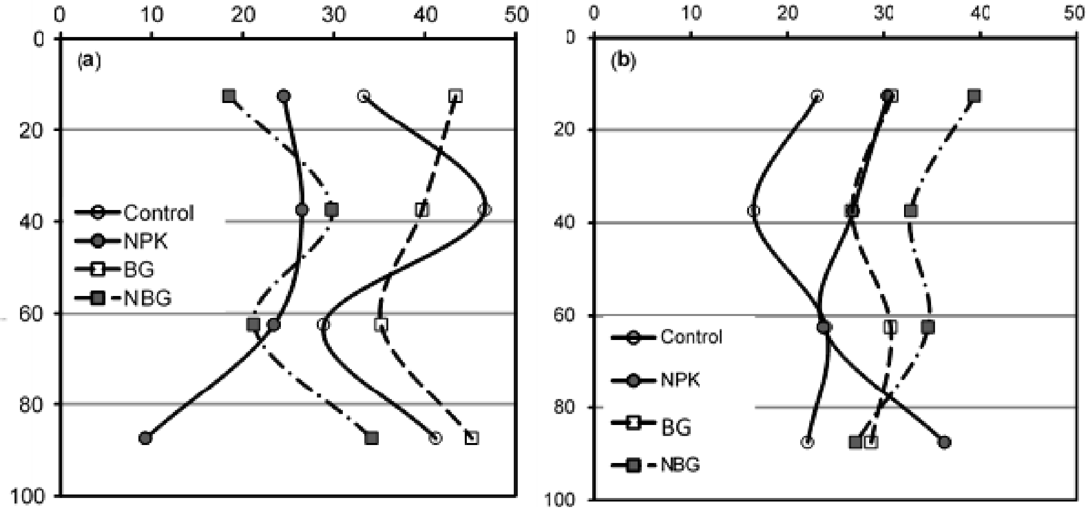

Figure 10: Depth distribution of cohesion (a) and angle of internal friction (b) in nutrient and lime amended carbonaceous shale. NPK: N: P: K fertilizer, Bio Green:BG, NPK+BG:NBG fertilizer

reduced nutrient fixation by soil and provision of additional macro and trace nutrients. However, the response of above-ground biomass to NPK and BG fertilizer was significant compared to that of basal NPK fertilizer. This high biomass yield attained within a short period (6 months) demonstrate the rapid growth and dense canopy of the grass species.

The increase in above-ground biomass associated with NPK and BG application enhanced the root growth. The observed significant differences in root biomass among all treatments points to BG, NPK+ Bio Green (NBG) fertilizer interaction effects on root growth, and further confirms the inherent low fertility, acidic pH and aluminium toxicity. Combining NPK with Bio Green (NBG) and Bio Green application was significantly increased root length compared to the control and NPK which had no significant effect on root length. The non-significant effect of NPK on root length was unexpected, and probably reflects changes in root morphology and physiology induced by chemical toxicities and low inherent fertility (Gwenzi *et al.,* 2011). Plants have a plastic shoot and root system exhibiting multiple adaptive responses to nutrient deficiency (Suriyagoda *et al.*, 2012). These adaptive root responses entail morphological and physiological changes including release of exudates such as carboxylates to solubilize nutrients (Suriyagoda *et al.*, 2012) and proliferation of fine roots that increases surface area for nutrient and water uptake (Gwenzi *et al.,* 2011).

Enhanced above-ground and root growth associated with nutrient and lime application was accompanied by an improved shear strength reflecting a significant increase in angle of internal friction. Shear strength increased with normal loading (Figure 9), implying that under natural conditions, strength of the shale may increase with depth due to changes in cohesion and angle of internal friction (Terwilliner and Waldron, 1991). The depth distribution angle of internal friction and shear strength mirrored root profiles. Increase in shear strength in root-reinforced soils is often attributed to additional cohesion arising from mobilization of root tensile strength (Graf *et al.,* 2009; Ghestem *et al.*, 2013). This notion forms the basis for the pioneering shear failure models for root-reinforced earths (Waldron, 1977). Our results confirm the findings of a few other recent studies showing that roots increase angle of internal friction (Graf *et al.*, 2009; Frei, 2009). Our findings and those of earlier studies (e.g. Graf *et al.,* 2009; Frei, 2009) cast doubts on the universal validity of widely held notion that roots have negligible effects on angle of internal friction (Abernethy and Rutherfurd, 2000; 2001).

Several studies have revealed that the Waldron (1977) model based on this assumption overestimate shear strength by between 200-400% (De Baets *et al.,* 2008; Graf *et al.*, 2009). Boll and Graf (2001) and subsequent studies (Graf *et al.*, 2009; Frei, 2009) proposed the concept of virtual density to account for the increase in shear strength in root reinforced soils. The concept explains the increase in shear strength and soil stability due to vegetation as a virtual increase in the dry unit weight and assigns the shear strength parameter of pure soil at the corresponding higher dry unit weight to the planted soil at lower dry unit weight (Graf *et al.*, 2009). Based on this concept, some researchers propose that changes in the stress-dependent component (σ_n tan ϕ) of the shear strength best represent the effects of roots on shear properties than cohesion (Graf et al., 2009).

Studies interpreting enhanced shear strength in terms increases in cohesion argue that roots and root exudates bind soils to form aggregates and improve cohesion. The current study showed no evidence of improved apparent cohesion due to presence of roots. On the contrary, the effects of roots on apparent cohesion was inconsistent; ranging from negligible (BG) to a reduction in cohesion (NPK and NBG) (Figure 8a). Literature shows that the effects of roots on cohesion vary considerably among studies. Whereas the current findings are consistent with a few earlier studies (Graf *et al.,* 2009; Ghestem *et al.* 2013), others reported an increase in cohesion corresponding to an increase in cross-sectional area and tensile strength of roots (Operstein and Frydman, 2000). Reduced cohesion in root-permeated soils similar to that evident for NPK and NBG has also been reported by Ghestem *et al.* (2013) who showed that an increase in angle of internal friction was accompanied by a decrease in cohesion.

Therefore the combined effect of root reinforcement and organic matter could account for the observed overall improvement of shear strength of the Bungor soil. The rapid and dense aboveground and root biomass may also enhance root water uptake and evapotranspiration thereby reducing pore water pressure, and subsequently increase effective shear strength. Overall, the current study demonstrated that NPK and Bio Green application could effectively ameliorate chemical constraints and promote rapid vegetation growth on freshly exposed geological materials. Subsequently, the dense root network on amended Bungor soil increased shear strength, reflecting an increase in angle of internal friction. The enhanced vegetation growth has hydrological and biomechanical implications for erosion control and slope stability on degraded and man-made landscapes such as cut slopes.

CONCLUSIONS

Overall, the current study provided insights on chemical constraints to plant growth, and practical amelioration strategies for achieving rapid and successful revegetation and stabilization of fresh geological substrates associated with artificial landforms. Further research combining field studies and modelling should investigate the impacts of Bio Green (organic fertilizer)-induced vegetation growth on root parameters and spatial distribution, hydrological behaviour, soil erosion and slope stability on artificial landforms. Subsequent NPK and Bio Green applications effectively ameliorated the chemical constraints and facilitated rapid plant establishment and growth within a short period (6 months). Enhanced root growth stimulated by nutrient and lime application had a profound effect on shear strength by increasing the angle of internal friction but not cohesion. The findings confirmed that original hypothesis that nutrient and lime applications ameliorate chemical constraints and enhance vegetation growth, which in turn increased shear strength of the substrate. The increased shear strength was attributed to increased virtual density of the root reinforced soils (Graf *et al.*, 2009). Moreover, root water uptake of soil moisture and subsequent evapotranspiration associated with rapid vegetation growth and dense root network reduce pore water pressure and increase the frictional component of the shear strength. A dense above-ground and root network also reduces soil detachment and transport by raindrop impact and runoff. Under field conditions, these multiple vegetation-soil interactions control the hydrological and biomechanical behaviour of root-permeated earth materials. Understanding these complex vegetation-soil interactions and their spatial and temporal variability is crucial for erosion control and slope stability especially in tropical environments, where rainfall predominantly occurs as high-intensity storms. The application of Bio Green (organic fertilizer) was able to improve soil physical and chemical properties in this study. Therefore, fertilizer application played a major role in reducing runoff and soil loss by improving the vegetation canopy and root establishment to protect the soil from raindrop impact and soil erosion (Pansak et al., 2008). The addition of Bio Green fertilizer was able to supply sufficient nutrients for root plant uptake, then improved the plant growth performance in this study.

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