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# Effects of Mix Vegetation and Root Shear Strength Grown on Carbonaceous Shale

*[1]I. Isa, [1]J. Shamshuddin and [2]M.N. Khairuddin*

[1]Department Of Land Management, Faculty of Agriculture,
Universiti Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia
[2]Institute of Agricultural Production and Food Innovation (AGROPOLIS),
University Sultan Zainal Abidin (UNISZA), Tembila Campus, 22200 Besut, Terengganu, Malaysia

**Abstract:** *Brachiaria ruziziensis* and *Colopogonium mucunoides* was used as the mix vegetation to investigate the effect of chemical amendments on plant growth and root-shear strength relationship. The objective of this study: (1) to investigate the effect of compound fertilizer (Nitrogen, Phosphorus, Potassium) NPK, NPK + (Ground Magnesium Limestone) GML (NGL), NPK + GML + foliar fertilizer (Vita-Grow™) (NGF) and control (Ctrl) and; (2) to determine the soil shear strength, biomass and root growth. The soil samples were analyzed for pH, total nitrogen (TN), soil organic carbon (SOC), available phosphorus, exchangeable Al, Ca, Mg and K and trace nutrients (Fe, Mn, Cu and Zn). The carbonaceous shale was low in pH, total N, soil organic carbon, extractable P, basic cations (Ca, Mg and K) and micronutrients (Fe, Cu and Zn). Both P and Ca/Mg were low indicating inherent infertility and chemical constraints for root developments. The dry matter yield, root length and root weight of *Brachiaria ruziziensis* and *Colopogonium* mucunoides were increased significantly against NGF treatment. The increased of plant top and root dry weight treated with NGF were 26% and 38%, respectively, compared to the other treatments. The significant root-*?* relationship indicates that root enhanced shear strength by reducing the cohesion and increased the angle of internal friction component. The shear strength analysis from the direct shear test method is to determine the shear strength from the plotted graph. The shear strength analysis showed that NGF treatment was having high shear strength in 5.4, 10.9, 16.3 and 54, 109, 163 kN/m$^2$ of normal stress. Rapid vegetation growth observed within a 5-month period demonstrated that nutrient and lime application effectively ameliorated chemical constraints to plant growth. The plant mix species treated with NPK+GML+foliar (NGF) fertilizer indicated higher shear strength, dry matter yield and root densities in all layers.

**Key words:** Shear strength · Roots density-shear strength relationship · Root anchorage

## INTRODUCTION

In Malaysia, annual rainfall could reach as high as 4500 mm. This combined with yearlong high temperatures causing intense chemical weathering and formation of thick residual soil profiles which in certain locations can reach 100 m in depth. With these set of climate and geological conditions, combined with other causative factors, landslides are thus one of the most destructive natural disasters in Malaysia. From 1993 to 2006, around 20 major landslides were reported in Malaysia, involving both cut and natural slopes with a total loss of more than 100 lives. The most common types of landslides in Malaysia were shallow slides where the slide surface was usually less than 4 m deep and occurred during or immediately after intense rainfall[10]. Shale is one of the common rock types in Malaysia. Many of them are carbonaceous in nature. Some of the shale slopes could be observed along the main highways in Malaysia. The inability of vegetation to grow on this cut slopes contribute to soil erosion and in extreme cases slopes failures may occur. Most engineers claimed that carbonaceous shale along the main slope highway was fertile and might not create any instability after having heavy precipitation. The carbonaceous shale's slope was also difficult for plants to grow without application any

**Corresponding Author:** Isharudin Md. Isa, Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia (UPM), 43400 UPM Serdang, Selangor, Malaysia. Tel: +60389484860/+60125016806.

soil amendments. Appropriate soil amendments and suitable vegetation (plant mix species) to be grown on this cut slopes become vital and needs immediate action. The root system of plant mix species plays an important role in soil erosion control by binding soil particles physically into stable aggregates. The influence of the physical condition of soils on plant growth and associated with agricultural practices has been emphasized, but the physical properties has equal effects on the use of soils and soils material for non-agricultural purposes. Climate plays important role to influence the physiology of the plant species such as the roots [1]. The roots reinforced the soil through mechanical and hydrological mechanism. Roots controlled the soil water content from exceeding the field capacity [2]. Root absorbs and circulates the water to atmosphere rather than letting all infiltrates deep into the soil. The most important property of a soil for engineering uses is soil strength [3]. The method to determine the strength of a soil was obtained using shear strength analysis. Shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding along any plane inside it [4]. The presence of vegetation roots would result in an overall increase in the soil strength. This arises from combined effects of soil reinforcement by a mass of roots [5] and soil moisture depletion by evapotranspiration [6]. Other factors, which affect the strength of a soil, were soil moisture content, particle size distribution (soil texture) and the mineralogy of different soil particles.

Soil strength was derived from direct shear test method which the frictional resistance met by soil constituent particles when they were forced to slide over one another or to move out of interlocking positions, the extent to which stresses or forces were absorbed by solid-to-solid contact among the particles, cohesive forces related to chemical bonding of clay minerals and surface tension forces within the moisture films in unsaturated soils. The objectives of this study were: 1) to determine the effects of soil treatments in combination with plant mix species on dry matter yield and root proliferation and 2) to determine the root reinforcement against carbonaceous shale shear strength. Shear strength is a key determinant of slope stability and soil detachment during erosion processes. Therefore, the current study used the Mohr-Coulomb failure criterion as a framework for evaluating the effect of nutrient and lime application on root-induced shear strength properties. According to the limit equilibrium theory, the safety factor ($F_s$) is used to evaluate slope stability and soil susceptibility to detachment. Fs is the ratio of stresses resisting failure to the stresses required to bring the slope into a state of limiting equilibrium along a given failure surface [6];

$$F_S = \frac{s}{\tau} \tag{1}$$

where, $s$ is shear strength of the soil and $\tau$ is shear stress acting along the failure surface.

According to the Mohr-Coulomb [7, 8] failure criterion, the total shear strength or shear stress of earth material at failure consists of cohesion and friction components (Eqn. 2) [10]:

$$s = c + \sigma_n \tan\phi \tag{2}$$

where, $s$ is shear strength or shear stress at failure (kN $m^{-2}$), $c$ is cohesion (kN $m^{-2}$), $\sigma_n$ is the total stress normal to the shear plane (kN $m^{-2}$) and □ and tan □ are the angle and coefficient of internal friction of the material, respectively. Roots permeated earth materials behave like composite materials, in which elastic roots of high tensile strength are embedded in a relatively elastic soil matrix. Overall, roots contribute additional apparent cohesion ($c_r$), but have negligible influence on the frictional component of soil shear strength. Slope failures are associated with saturated conditions and excessive build-up of pore-water pressure [21]. When pore water pressure is significant, the total normal stress ($\sigma_n$) is replaced by effective stress ($\sigma_n - \mu$) [11]. Accounting for the effects of both roots and pore-water pressure on shear strength ($s$) yields Eqn. 3 [6]:

$$s = c' + c_r + (\sigma_n - \mu)\tan\phi' \tag{3}$$

where, $c'$ and $\phi'$ denotes effective stress parameters.

Shear strength parameters can be determined in the laboratory using the triaxial and direct shear box methods. The shear box test is the simplest procedure for measuring the immediate or short-term shear strength of soils in terms of total stresses [9]. In principle, shear box test is an angle of internal friction test, in which one portion of soils is made to slide along another by the action of a steadily increasing horizontal shearing force, while a constant load is applied normal to the plane of relative movement. The procedure is repeated for a different normal stress ($\sigma_n$). A simultaneous solution of any two equations of the general form given by Eqn. 2 yields cohesion ($c$) and angle of internal friction (□). Alternatively, a graphical plot of at least two sets of normal and shear stresses yields a Mohr circle and the Mohr-Coulomb or failure envelope. The Mohr-Coulomb [7, 8] envelope depicts the relationship between maximum shear stress related to normal stress from shear box tests [12]. For practical purposes, this linear relationship holds good and it represents the most widely accepted criterion of failure. To derive the Mohr-Coulomb failure envelope, the shear stress at failure (*s*) against the corresponding normal stress ($\sigma_n$) for each specimen was plotted. The line of best fit is then drawn through the three points. For granular and non-cohesive, where *c* is equal to zero, the line should pass through the origin, thereby providing a fourth point. For cohesive soils, the *y*-intercept or value of *c* is higher than zero. This line is the failure envelope or the Mohr-Coulomb envelope. The angle of inclination □ of the failure envelope to the horizontal axis was measured to the nearest ½°. The cohesion intercept c (kN $m^{-2}$) on the vertical axis was identified after the graph has plotted [9]. In summary, the *y*-intercept and the angle of inclination are used to derive the two shear parameters, cohesion (*c*) and angle of internal friction (□).

## MATERIALS AND METHODS

**Soil Samples Site:** The site was located along the North-South Highway where the horizon A, B and C were exposed. Vegetation was able to establish on Horizon A and B but no vegetation was observed on Horizon C. Horizon C was identified as black carbonaceous shale and infertile for successful root development. It is also acidic and hardened under dry condition which prevents roots penetration for anchorage and water absorption [13]. The site was prone to erosion due to high rainfall events (2000-3000 mm/year) and temperatures ranging from 25.6 to 27.8°C throughout the year [14]. Most highways in Malaysia were constructed from rugged hills and mountain terrains and cutting the slopes was the common practices for a new road development. Poor growth of vegetation on the carbonaceous shale's slope probably causes a major soil erosion and in extreme case the occurrence of landslide.

**Soil Sampling and Physicochemical Analysis:** Samples of carbonaceous shale were obtained from a cut slope along Infoport highway at Universiti Putra Malaysia in Serdang, Malaysia (N 2.98343, E 101. 73806). The shale was 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 Al, Ca, Mg and K and trace nutrients (Fe, Mn, Cu and Zn) using standard analytical methods [22]. The 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 Al, 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. Exchangeable Al was determined by KCl method. Fe, Mn, Cu and Zn were extracted by the double acid procedure [12] and the filtered mixture was determined by using AAS.

**Experimental Layout:** A glasshouse experiment was set up to investigate the effects of nutrient and lime amendments on aboveground biomass, root growth, specific root length and root-shear strength relationships on carbonaceous shale. Ground magnesium limestone (L) was added to increase soil pH of the generally acidic shale and provide Ca and Mg, which are known to be deficient in shale [15]. Foliar fertilizer provides additional macro and micro-nutrients for plants establishment. The corresponding nutrient and lime amendments were mixed with the sieved (2 mm) shale and packed into 0.04 $m^3$ wooden boxes (dimensions: 0.2 m width x 0.2 m length x 1 m depth). Ground magnesium limestone and NPK were applied at planting. Thereafter, additional NPK fertilizer was applied monthly and incorporated into the soil manually. For treatment NPK+L+ Foliar the fertilizer solution was applied fortnightly at a rate of 10 ml per box per application, equivalent to 1000 ml per ha. The experiment was set up in a complete randomized design with five replicated per each treatment. In each box, a mixture of fast growing grass (*Brachiaria ruziziensis*) and herbaceous legume (*Colopogonium mucunoides*) were planted by transplanting in the ratio of 1:1. The selection of the two species was based on preliminary experimentation that showed rapid growth and high biomass production. The application of foliar fertilizer (NGF) was to provide additional macro and micronutrients to the plants. The GML application was to improve soil pH and the availability of Ca and Mg that were deficient in the carbonaceous shale. The box was grown with mixed plants species (*Brachiaria ruziziensis* and *Colopogonium mucunoides).* Conventional fertilizer was applied monthly, while foliar fertilizer was added every 2 weeks. The accumulated dry matter yield was determined after the first, second and the fifth month of planting.

**Biomass Parameter:** Dry above-ground biomass was measured to determine treatment effects on plant establishment and growth. Above-ground biomass was harvested three times; at first, second and the fifth month after planting. The biomass was cut manually at the base of the plants. Samples were cut into smaller pieces and oven-dried at 45-50°C for 2-3 days until a constant mass was attained. Thereafter, dry above-ground biomass was determined by weighing using a balance. Root length and root mass densities were determined at the termination of the experiment (fifth month). The 1.0-m thick soil mass containing the intact roots were cut into four 25-cm long sections. The roots were washed carefully with water to remove the carbonaceous shale. Root length and root dry weight were measured for each treatment. Root biomass was dried at 45°C for 2 days and then weighed to determine total root biomass density. Roots were predominantly medium to fine and fibrous.

**Shear Strength Analysis:** Soil shear strength or shear stress at failure was determined by the direct shear box test [9]. Briefly, 25-cm think intact soil samples (20 cm x 20 cm x 100 cm) were cut at 25-cm intervals in each wooden box and the edges carefully trimmed. The sample was packed in a metal shear box following the procedure described in literature [9]. The angle of internal friction was determined by placing the soil in a rigid metal box, square in plan, consisting of two horizontal halves. The lower half of the box could slide relative to the upper half when pushed (or pulled) by a motorized drive unit, while a yoke supporting a load hanger provides the normal pressure. During the shearing process, the relative displacement of the two portions of the specimen and the applied shearing force were both measured so that a load/displacement curve could be plotted. The vertical movement of the top surface of the specimen, which indicates changes of volume, was also measured and enabled changes in density and void ratio to be determined during shear. This shear box test was the standard quick test carried out in a 60 mm square shear box, which has been the most common size used in UK and the USA [9]. For each treatment, four 25-cm thick samples of the same size were carefully cut and trimmed using a sample cutter. The cutter ensured that the size of each sample can be uniformly controlled for a good fit into the shear box. The spacing and clamping screws for the shear box were loosed in the top half of the shear box. The soil sample were fitted into the lower half of the shear box and the two parts were then re-assembled and tightened with screws. The loading block was put in place, normal load $P_v$ was added and then vertical dial gauge was then attached to it. Total area of the soil samples were computed from the internal dimensions of the shear box. Measurements of the shear box dimensions were taken in order to compute the area. The sample was then placed in the shear box. Half of the shear box was carefully separated using spacing screws to set a gap slightly larger than the largest soil grains present. Clamping the loading head in place using the setscrews was done for that purpose and then the separation screws were taken out. The normal load needs to reflect the applied vertical load plus the weight of the load block and top half of shear box. Shear deformation dial gauge was attached and both vertical and horizontal gauges were set to zero. Horizontal (shear) loading was then started and readings of horizontal load shear displacement and vertical (volume-change) displacements were taken. The speed of 0.025 mm/min was used at regular intervals (every 30 seconds), readings of the load dial, the vertical movement dial and the time was recorded. Normal stress of 54, 109, 163 kN $m^{-2}$ were used for every layer of the carbonaceous shale profile samples. Shearing was continued until the maximum stress or peak point has been clearly defined, that is until at least four consecutive readings indicate a decrease or equal in load. If a peak was not observed, shearing should continue until the full length of travel of the box had been reached. At the end of the shear test the motor was switched off then waited until it has completely stopped and the reverse switch was on until the drive unit has returned to its starting position. After obtaining a set of three points on the Coulomb envelope, it was then repeated on two additional identical specimens under different normal pressures. A set of three specimens was usual but additional specimens were tested when required. A plot of the Mohr-Coulomb failure envelope is used to determine the shear parameters; cohesion (*c*) and internal angle of friction (□) as outlined in Section 3 [9]. Given the linear relationship between shear strength and *c* and □, evaluation of roots of shear properties was limited to shear strength. The coulomb envelope was the relationship between maximum shear stress related to normal stress from shear box tests [12]. In soil, for practical purposes, this linear relationship holds good and it represents the most widely accepted criterion of failure. The shear stress at failure, τf, against the corresponding normal stress, σn, for each specimen was plotted. Draw the line of best fit through the three points. If the soil was granular and non-cohesive, the line should pass through the origin (c=0), which provides a fourth point. This line is the failure envelope or the Coulomb envelope. The angle of inclination ? of the failure envelope to the horizontal axis was measured to the nearest ½0. The cohesion intercept c (kN/m2) on the vertical axis was identified after the graph has plotted [9].

**Statistical 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, specific root length and shear strength parameters (shear strength, cohesion and angle of internal friction). All statistical tests were done at probability level, $p = 0.05$ using SAS Statistical Analysis System [16].

Table 1: Chemical characteristics of fresh carbonaceous shale from a cut-slope at Infoport Highway, Universiti Putra Malaysia, Serdang, Malaysia

| Chemical properties | |
|---|---|
| pH | 4.43 |
| OC (%) | 0.43 |
| Total OM (%) | 0.89 |
| Total Nitrogen (%) | 0.02 |
| Available P ppm | 0.17 |
| Exchangeable Ca ppm | 14.13 |
| Exchangeable K ppm | 14.23 |
| Exchangeable Mg ppm | 1.53 |
| Exchangeable Al ppm | 32.2 |
| Fe ppm | 0.13 |
| Mn ppm | Not detected |
| Cu ppm | 0.43 |
| Zn ppm | 0.23 |

Source: Isa and Syed Omar [15]

## RESULTS AND DISCUSSION

**Chemical Properties of Shale:** Table 1 presents a summary of the chemical properties of the carbonaceous shale. The shale was inherently infertile, characterized by high acidity (pH = 4.43) and exchangeable aluminium (32.2 mg $kg^{-1}$). Soil organic carbon (SOC) (0.43%), total N (0.02%) and available P (0.17 mg $kg^{-1}$) were very low (Table 1). The concentrations of trace elements Fe, Mn, Cu and Zn were also low (<0.5 mg $kg^{-1}$) and at least one order of magnitude below typical soil values except for Zn, which was almost comparable to that of natural soils. In general, pH, SOC, total N, available P, exchangeable Al and trace elements were lower or higher than typical optimum ranges for plant growth (Table 1). On the other hand, the concentrations of exchangeable bases $Ca^{2+}$ (14.1 mg $kg^{-1}$), $Mg^{2+}$ (14.2 mg $kg^{-1}$) and $K^{+}$ (1.5 mg $kg^{-1}$) were relatively adequate for plant growth and at least three times higher than typical ranges observed in soils. Overall, these chemical conditions may pose restrictions to plant establishment and growth on carbonaceous shale. 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 nutrient and lime application on aboveground biomass, root growth and root-shear strength relationships of carbonaceous shale. The substrate represented typical freshly exposed geological material occurring on un-vegetated cut slopes associated with infrastructural developments in tropical Malaysia. The shale was inherently infertile as indicated by highly acidity and exchangeable aluminium and very low organic carbon, macronutrients and trace elements. 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 [14]. The low macronutrients and trace elements reflected the low organic carbon content and chemical composition of the shale. These adverse chemical conditions of the substrate imply that the potential for spontaneous re-vegetation is low as evidenced by shale cut slopes, which remain un-vegetated several years after exposure. To evaluate the constraints and facilitate re-vegetation, the current study evaluated the effect of nutrient and lime amendments on aboveground and root growth and their subsequent root-shear strength relationships.

Data in Figure 2 indicated that the results of dry matter yield for the second harvest. The dry matter yield of the mix plants species showed that there was a significant different in the treatments with NPK + GML + foliar (NGF) compared to NPK alone. The positive effect of foliar fertilizer over the NPK fertilizer could be observed on the dry matter yield of the mix plants species at this stage. One of the possible reasons might be that there was a better absorption of nutrients in particular the micronutrients contained in the foliar fertilizer. Similar finding was reported by Manna [13] that foliar spray showed positive effect on plant height and dry matter production of soybean. Data in Figure 3 shows the dry matter yield of the plants mix species after five months of growth. There was a significant increase in the dry matter yield in all treatments. The highest dry matter yield was observed in NPK + GML + foliar (NGF) treatment.

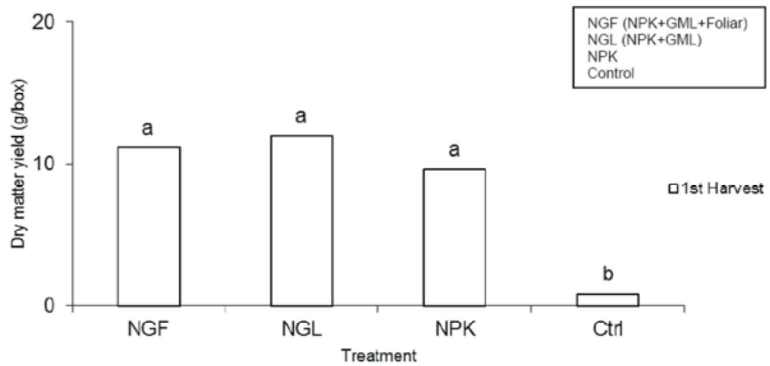


Fig. 1: Effect of soil treatments on dry matter yield of *Brachiaria ruziziensis* and *Colopogonium mucunoides* after one month grown on carbonaceous shale (means not significantly different at P<0.05)

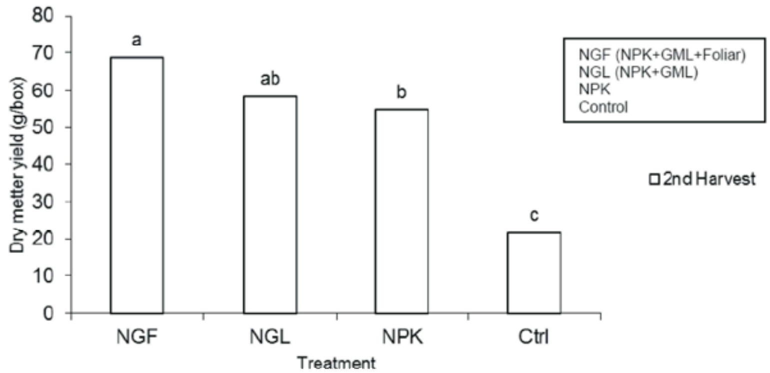


Fig. 2: Effect of soil treatments on dry matter yield of *Brachiaria ruziziensis* and *Colopogonium mucunoides* after two month grown on carbonaceous shale (means not significantly different at P<0.05)

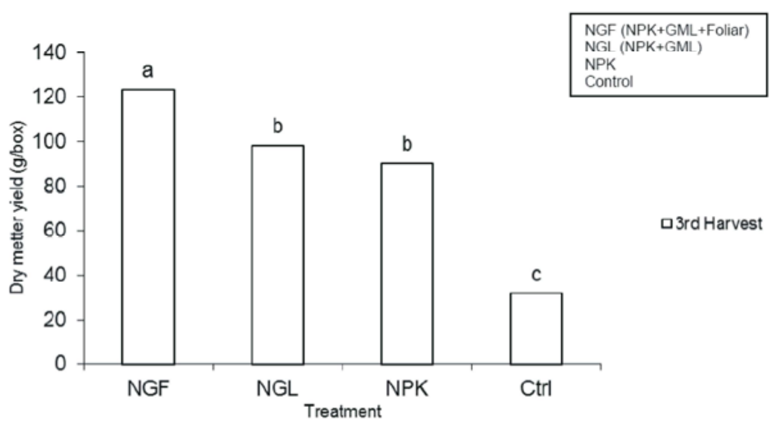


Fig. 3: Effect of soil treatments on dry matter yield of *Brachiaria ruziziensis* and *Colopogonium mucunoides* after the four month of planting (means not significantly different at P<0.05)

This strongly suggests the important usage of foliar fertilizer that contains micronutrients to enhance the growth of mixed cover crops. The rapid growth of *Brachiaria ruziziensis* and *Colopogonium mucunoides* and fast root distribution through the carbonaceous shale play an important role in controlling erosion through binding soil particles physically into stable aggregates.

**Effect of Soil Treatments and Plants Mix Species on Roots Length:** Root length was determined after the fifth month to observe the effect of various treatments on roots growth on the carbonaceous shale. Data in Fig. 4 showed that the root elongation after amending with different soil treatments after the fifth month of planting. Treatment with NPK + GML + foliar (NGF) showed the

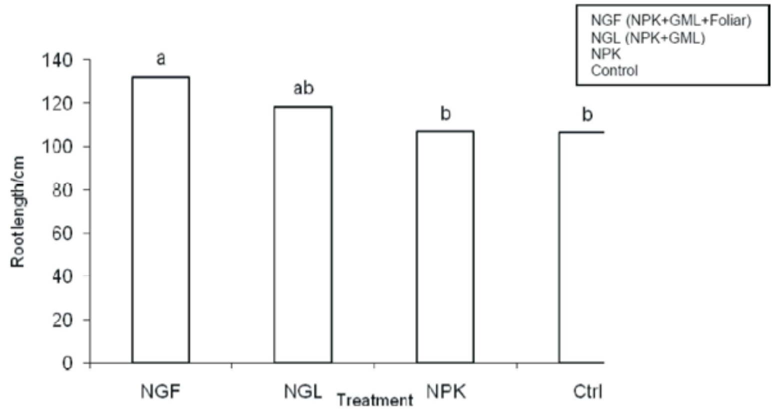


Fig. 4: Effect of soil treatments on roots length of *Brachiaria ruziziensis* and *Colopogonium mucunoides* after the fifth month of planting (means not significantly different at $P<0.05$)

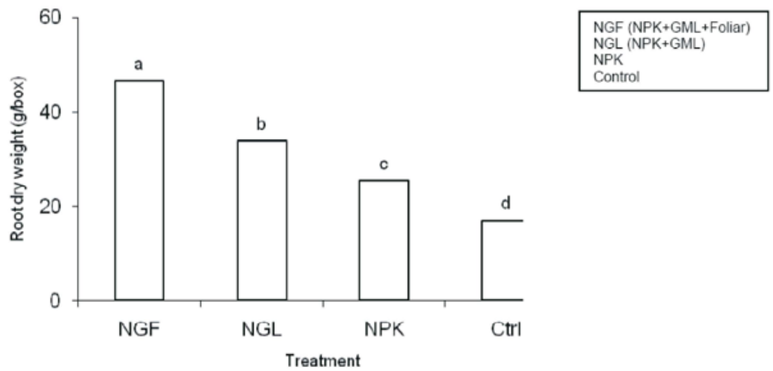


Fig. 5: Effect of soil treatments on roots weight of *Brachiaria ruziziensis* and *Colopogonium mucunoides* after the fifth month of planting (means not significantly different at $P<0.05$)

highest roots length which could proliferate throughout the carbonaceous shale profile after the final period of planting. With this treatment, it is possible that the roots could extend above one meter deep to absorb immobile nutrients and reserved moisture. In addition to that, roots from these plant mix species could give better anchorage and stability to the soil structure in the presence of adequate water and better aeration. Better root length in treatment of NGF would most probably due to adequate nutrients (macro- and micronutrients) plus conducive soil pH with the lime addition.

**Effect of Soil Treatments and Plants Mix Species on Roots Weight:** Data in Fig. 5 indicated that the results of root weight of the plant mix species experiment. Treatment with NPK + GML + foliar (NGF) showed highly significant difference of root dry weight compared to other treatments. These results were similar to plant dry matter yield and root length determination after the fifth month of planting. The increased of plant dry matter yield and root dry treated with NGF were 26% and 38%, respectively compared to NGL treatment. A good foliar fertilizer gave a quick plant response, accurate timing and minimize nutrient fixation in the carbonaceous shale. However, only limited amounts of NPK could be applied through foliar application. This is because only a little water could be held in the leaf surfaces before the surplus drips off and high concentrated solutions may damage the plants tissue. As mentioned earlier, foliar fertilizer used in this experiment contained macro- and micronutrient, which became the additional nutrients supply for the plant mix species uptake.

Usually, plants need balanced and adequate nutrients for optimum growth. Quick response fertilizer is important to increase the growth and minimize damage to the plants. The best agronomic option to improve carbonaceous shale is to plant *Brachiaria ruziziensis* and *Colopogonium mucunoides*, which give rapid growth and high dry matter yield. The application of NPK + GML + foliar (NGF) fertilizer on these species gave high dry matter yield, root length and root weight, therefore, it would be able to become the most sustainable plants species and fertilizer treatments for re-vegetation on the bare area of carbonaceous shale as a practical solution of conservation method.

**Roots Shear Strength:** Data in Figures 6, 7, 8 and 9 indicated that the results of four different treatments with different plant mix to examine the effects of root reinforcement towards the shear strength of carbonaceous shale profile. Figure 10 illustrated that the carbonaceous shale profile inside the wooden box where the metal shear box was fitted before determining the root density and shear strength. The plant mix treated with NPK+GML+foliar fertilizer (NGF) was significantly different on the dry matter yield and root biomass. The higher density of plant roots in this treatment enhanced better anchorage and aggregates stability of the carbonaceous shale. Generally, the graph showed the shear strength was obtained after the application of normal stress at 54 $kNm^{-2}$, 109 $kNm^{-2}$ and 163 $kNm^{-2}$ in all samples. The peak strength or shear strength was plotted for each layer of carbonaceous shale that was treated with various soil treatments. Relatively, among the layer of control treatment the cohesion, c, was quite high while the angle of internal friction, □, would decline and the shear stress at failure could be obtained from the shear strength equation. The maximum shear strength in control treatment (75-100 cm layer) was 107.5 $kN/m^2$, □ was 22.1° and the root density was observed at 3.9 $gm^{-3}$ (Table 2). The layer with higher root density at 0-25 cm with 15.6 $gm^{-3}$ showed the decreasing of cohesion value to 33.5° and ? value was slightly increased. The plant mix species treated with NPK+GML+foliar (NGF) fertilizer indicated higher shear strength in all layers (Table 3) compared to the control treatment (Table 2). The highest shear strength was identified at 0-25 cm layer with 152.3 $kN/m^2$ and 77.2 $gm^{-3}$ of root density. The higher root density would increase the shear strength of carbonaceous shale. Ali [6] reported that roots system and roots density increased shear strength of the soil. The cohesion value in every layer in NGF treatment relatively, was slightly lower compared to the other treatments. While the cohesion value was lower, the □ value tends to increase and results in higher value of shear strength. Generally, the shear strength result of this treatment was found to be higher in all sub-stratums correlated to the control. The angle of internal friction, □, at 0-25 cm depth was 39.4° slightly higher than the control treatment as compared within the same depth. The highest total root density with 1140.5 $gm^{-3}$ was accumulated in this treatment corresponded with the changes of cohesion and angle of internal friction, □, which tend to be increased as compared to the control treatment (Table 3).

Data in Fig. 10 indicated that the effect of soil treatments on root density where with NGF treatment gave the highest root density as compared to the others treatment. The higher root density in the NGF treatment would affect the carbonaceous shale strength, which becomes more failure resistance. A similar trend was observed in NPK+GML (NGL) treatment where higher shear strength was obtained as compared to control (Fig. 8). The peak strength was obtained at 0-25 cm depth measuring 140.6 $kN/m^2$ with 61.7 $gm^{-3}$ of root density. The □ value was identified higher comparatively with the control. In addition to that, the depth of 0-25 cm, the shear strength was slightly lower as compared to NGF. Shear strength at 0-25 cm depth gave the highest value when treated with NGF treatment. This was presumably due to the presence of higher root weight that enhanced the root reinforcement against the carbonaceous shale material. In the NPK fertilizer treatment, a similar trend could be observed where higher shear strength was obtained compared to the control in each layer. The root density was 635 $gm^{-3}$ that contributed to the increase of shear strength (Fig. 9).

Due to the higher presence of root at 0-25 cm depth, the shear strength was indicated higher at 120$kNm^{-2}$ as compared to control within the same layers. Generally, the application of fertilizer treatment would enhance the root density and the shear strength of carbonaceous shale and therefore become more stabilize and consistent when exposed to erosion. Although the effect of GML on cohesion was either negligible or negative, overall, treatments incorporating GML application had consistently higher shear strength than without GML especially at higher normal stress (Fig. 8). This suggests that besides roots, lime may play a part in increasing shear strength. Divalent basic cations ($Mg^{2+}$ and $Ca^{2+}$) promote soil aggregation and may account for the increase in cohesion and angle of internal friction. This observation is consistent with previous findings indicating that liming of soils increased shear strength [17, 18]. For example, Saranya and Muttharam [18] observed that lime stabilized clay had higher undrained cohesion and angle of internal friction than unamended control. Living tree roots could contribute up to 20 kPa to the soil shear strength [19]. The lateral roots contributed most to binding because of their greater density whereas the vertical roots added most of the tensile strength and, where they crossed a

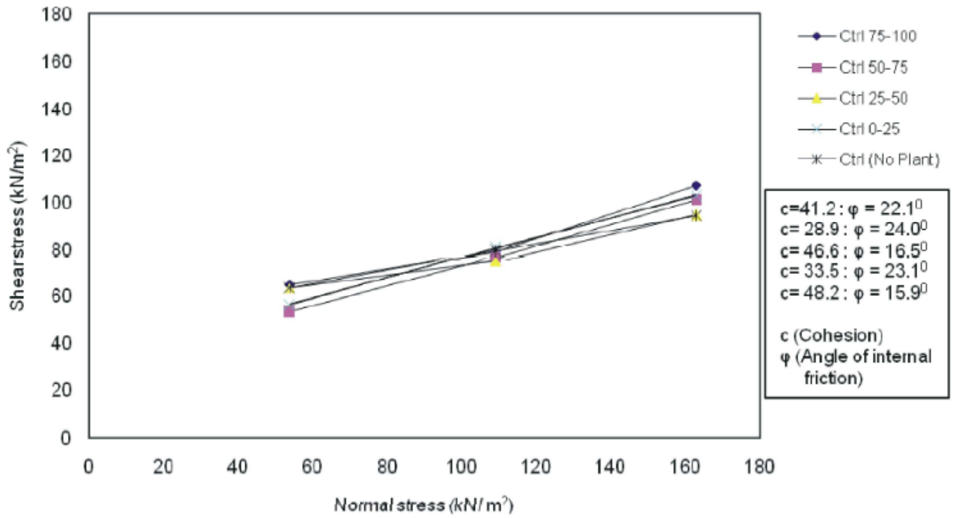


Fig. 6: Shear stress versus normal stress for control profile

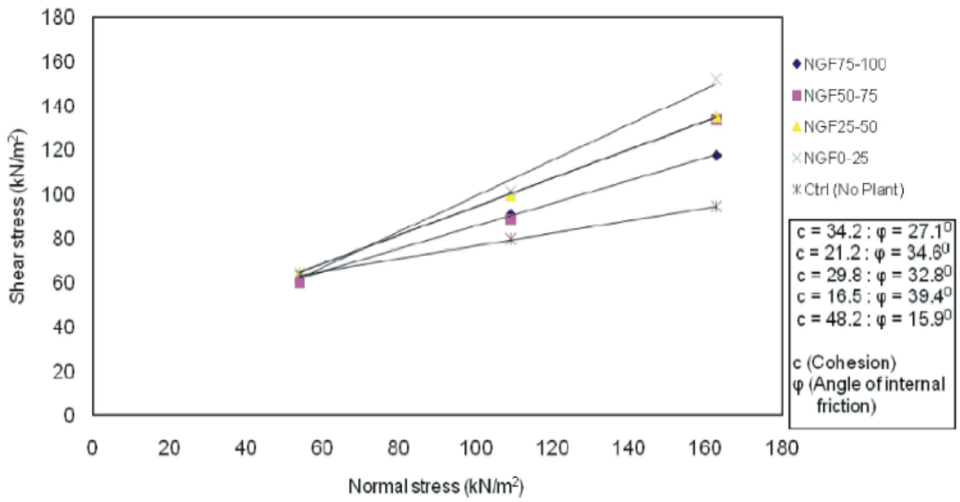


Fig. 7: Shear stress versus normal stress for NGF (NPK+GML+Foliar) profile

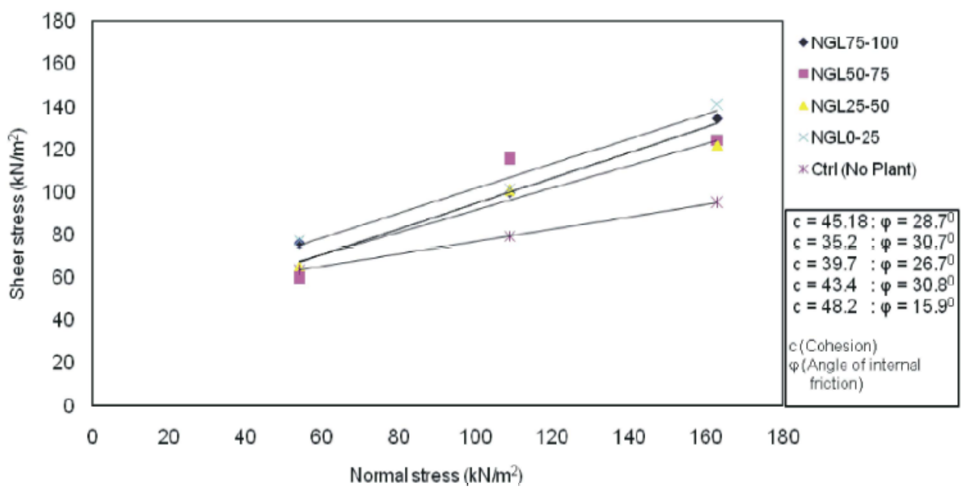


Fig. 8: Shear stress versus normal stress for NGL (NPK+GML) profile

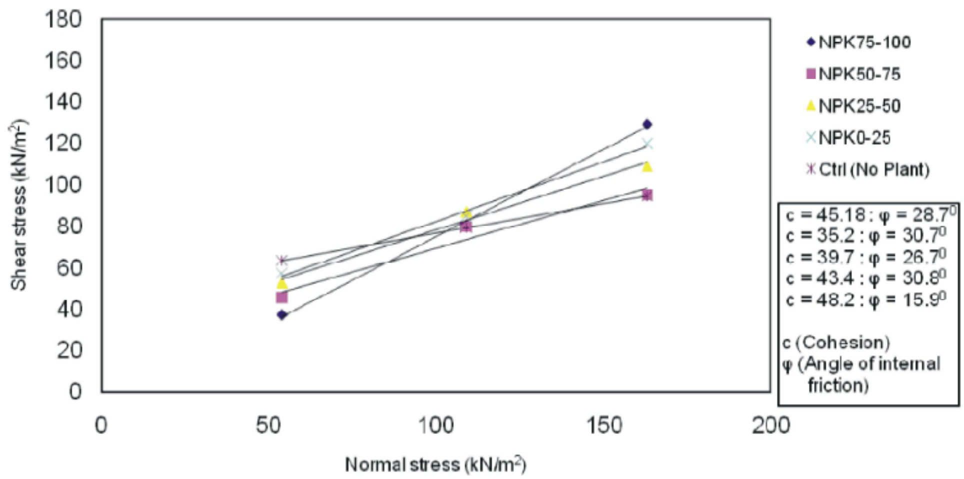


Fig. 9: Shear stress versus normal stress for NPK profile

Table 2: Control treatment indicated root density and shear strength parameter of carbonaceous shale

| Control (Ctrl) Treatment | | | | | |
|---|---|---|---|---|---|
| Depth (cm) | Root density (g/m$^3$) | Root distribution (%) | Cohesion (c) | Angle of Internal Friction (?) | Shear strength (kN/m$^2$) ($\tau$) |
| 0-25 | 15.6 | 57.1 | 33.5 | 23.1° | 103.1 |
| 25-50 | 3.9 | 14.2 | 46.6 | 16.5° | 95.0 |
| 50-75 | 3.9 | 14.2 | 28.9 | 24.0° | 101.5 |
| 75-100 | 3.9 | 14.2 | 41.2 | 22.1° | 107.5 |

Table 3: Treatment with NPK+GML+foliar (NGF) indicated root density and shear strength parameter of carbonaceous shale

| NGF treatment | | | | | |
|---|---|---|---|---|---|
| Depth (cm) | Root density (gm$^{-3}$) | Root distribution (%) | Cohesion (c) | Angle of Internal Friction (?) | Shear strength (kN/m$^2$) ($\tau$) |
| 0-25 | 77.2 | 31.8 | 18.5 | 39.4° | 152.3 |
| 25-50 | 63.6 | 26.1 | 29.8 | 32.8° | 134.9 |
| 50-75 | 52.2 | 21.4 | 21.2 | 34.6° | 133.7 |
| 75-100 | 50.0 | 20.5 | 34.2 | 27.1° | 117.6 |

potential slide plane, helped anchor the soil onto the slope [10]. Therefore, the combined effect of root reinforcement and liming could account for the observed overall improvement of shear strength of the shale. 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.

Carbonaceous shale without planting material indicated that the cohesion value was high (48.2) and □ was low at 15.9° as compared within the treatments in this experiment. The shear strength which was identified at 94.7 kNm$^{-2}$ was the lowest relatively to all the treatments (Fig. 11). This was probably unstable after heavy precipitation as compared to the carbonaceous shale with the presence of plant mix. This condition would expose the carbonaceous shale material prone to fail or land sliding to take place. The trend of the result had shown that due to the presence of vegetation and the effects of root reinforcement treated with NGF treatment would increase the angle of internal friction with low cohesion, c, resulted in higher shear strength of the carbonaceous shale. Similar trend was observed in this experiment where the plant mix species treated with NPK+GML+foliar (NGF) fertilizer gave the highest shear strength at 0-25, 25-50 and 50-75 cm depth compared to other treatments due to the highest root density accumulation (Table 3). Additionally, the angle of internal friction was found to be the highest compared to all treatments within the same depth.

Root effects of cohesion are partly explained improved soil binding and aggregation. However, at 75-100 cm depth, the shear strength was slightly lower compared to all the treatments excluding control treatment within the same depth. The highest carbonaceous shale strength with NGF treatment in 0-25, 25-50 and 50-75 cm substratum was due to the contribution of roots reinforcement against the particles. The root could interact with the soil to form a composite material in which root fibers of relatively high tensile strength reinforce a matrix of lower tensile strength. In addition, soil strength

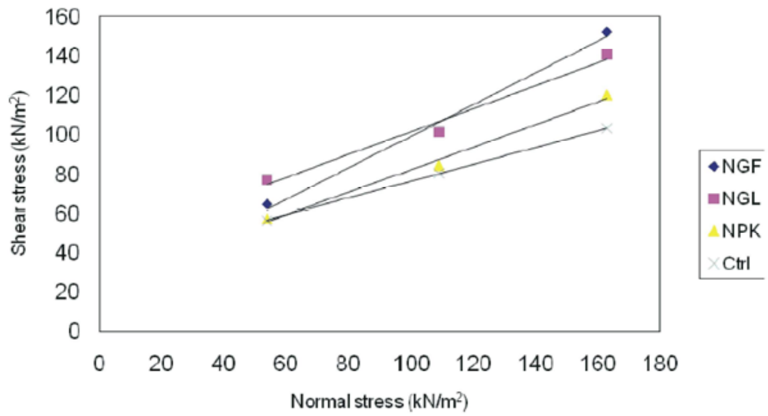


Fig. 10: The comparison of increasing carbonaceous shale shear strength at 0-25 cm depth with the application of various treatments which due to the increasing of root density

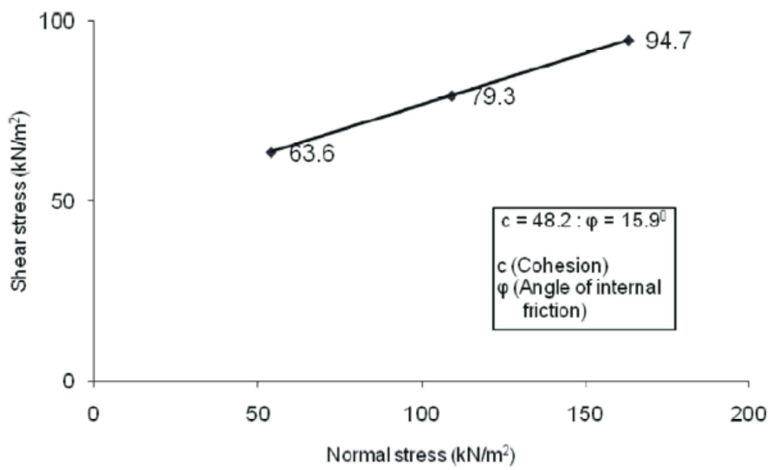


Fig. 11: The shear strength of carbonaceous shale without any plant mix species

was increased by the adhesion of soil particles to the roots. Roots could make significant contributions to the cohesion of the soil, even at low shear strength. Grasses and legumes could reinforce soil down to depths of 0.75 to 1.0 meter and trees could enhance soil strength to depths of 3 meter or more [20]. Plant mix species that was treated with NGF would probably, become the best option to be adopted because the roots could anchor and increase the carbonaceous shale strength up to 100 cm depth. Root embedded in soil that consisted of fibers of relatively high tensile strength resulting in adhesion within a matrix of lower tensile strength. The shear strength of the rooted soil mass was enhanced due to the presence of root matrix which was observed under NGF treatment. The roots of this plant mix species increased the strength through the binding action with the carbonaceous shale mass and contributed to the resistance from sliding.

Vegetation increased the infiltration of water into the soil and could cause problems where rainfall amounts and intensities were very high. Thus, by reducing runoff, it would help control surface erosion; the increased moisture content of the soil may exacerbate the risk of mass soil failure. This would cause shallow failure to occur within 0.75-1.0 meter depth where there are insufficient densities of grass and legume roots to bind with the soil aggregates thus limit the enhancement the strength of the soil. This would depend on the extent to which root reinforcement has increased the cohesive strength of the soil and root penetration across the potential slide plane has anchored the soil mass to the underlying material. Figure 12 indicated the comparison of carbonaceous shale shear strength under NGF treatment and control without any planting material. The highest shear strength at 0-25 cm with NGF treatment that was due to the highest accumulation of roots density showed that

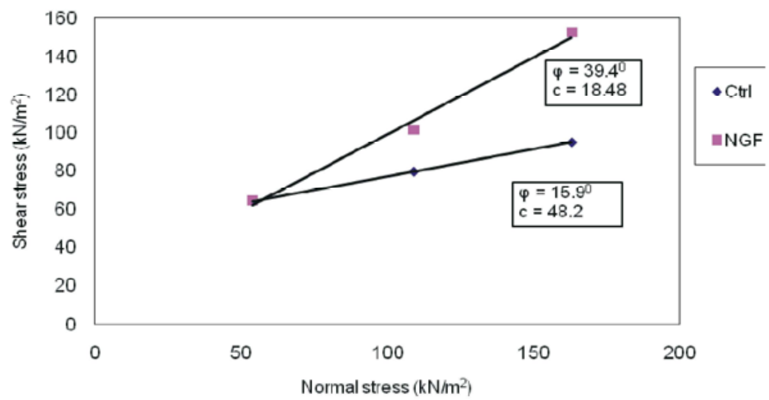


Fig. 12: Effect of treatments by comparison between the treated plant mix species with NGF and the control (without any plant species)

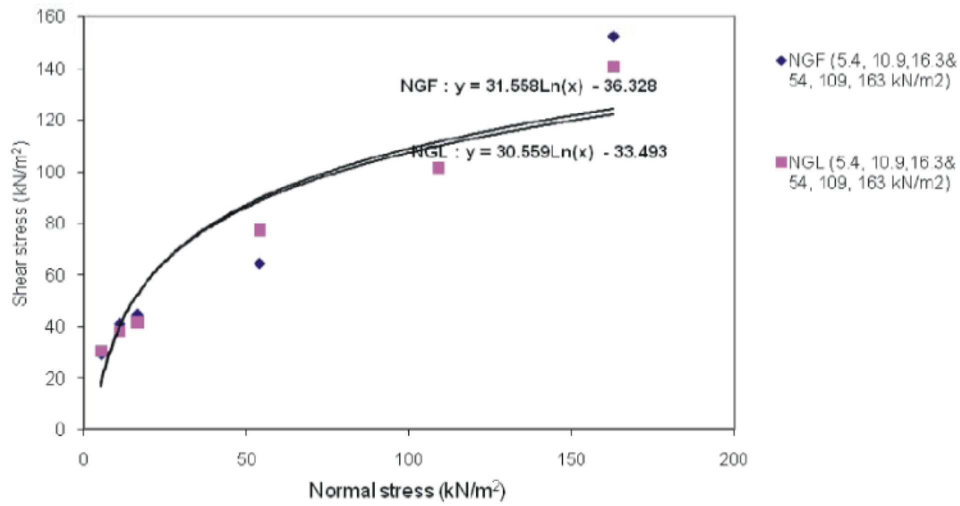


Fig. 13: Effect of root reinforcement of NGF and NGL treatments on shear strength parameter of carbonaceous shale

the function of root reinforcement acted on carbonaceous shale as compared to the control without any plants. This was probably because the roots could bind with the carbonaceous shale structure to form a composite material in which root fibres reinforced the carbonaceous shale aggregates by increasing the shear strength. The ability of root in this plant mix species to proliferate deep inside the carbonaceous shale profile until 100 cm especially with NGF treatment, could increase the stability and infiltration thus prevent from erosion mechanism.

The function of the deep-rooted grass such as *Brachiaria ruziziensis* to anchor the carbonaceous shale and rapid growth characteristics would become the best vegetation cover for erosion control. Some grass mainly *Cynodon dactylon* and *Pennisetum clandestinum* which non- deep rooted was also used to control surface erosion on 30-650 road banks in eastern Nepal had caused the shallow slides because the increased of infiltration [10]. In order to reduce the risk, deeper root grass, such as *Saccharum spontaneum* and *Pennisetum purpureum* were adopted. The deep-rooted characteristics of this species were similar to that *Brachiaria ruziziensis* which was adopted in this experiment where it would become more stable for anchorage and increased the soil consistency. The higher density of root and the ability to proliferate deep inside the soil profile were the important characteristics to be adopted as a plant cover for erosion control.

Figure 13 indicated the application of normal stress at 5.4, 10.9, 16.3 and 54, 109, 163 kN/m2 to the plant mix species treated with NGF and NGL. The plant mix species treated with NGF showed the higher shear strength as compared to NGL treatment at 5.4, 10.9 and 16.3 kN/m$^2$. The trend of the increasing shear stress at failure with increasing normal stress is shown in Figures 22 and 23. Normal stress at 5.4, 10.9 and 16.3 kN/m$^2$ would become a good indicator for shear strength measurement with the presence of root up to 100 cm depth. This was because, soil erosion always occurs in thin sheets or when the raindrops strike the surface of the soil.

Water would detach particles and overland flow carried the detached soil from the field. Sheet or splash erosion occurred when there was little or no concentration of water flow over the soil surface. In this experiment, NGF treatment showed higher shear strength in both 5.4, 10.9, 16.3 and 54, 109, 163 kN/m$^2$ of normal stress. The plant mix species treated with NGF together with the application of normal stress at 5.4, 10.9, 16.3 kN/m$^2$, the root would result in increased the shear strength leading to the binding of the carbonaceous shale particles into stable structure. The results on the highest dry matter yield suggest that additional nutrients supply from foliar fertilizer application in the presence of micronutrients is necessary. Foliar fertilizers gave a quick response and increased the maximum growth of the plant mix species possibly due to the absorption of the macro- and micronutrients directly through the leaf tissues. The NGF treatment has shown deeper plant roots penetrating the carbonaceous shale and is possible that the roots could extend beyond one meter deep to give better anchorage and stability to the soil structure. The increased of plant dry matter yield and root dry weight treated with NGF were 26% and 38% respectively compared to NGL treatment. After the fifth month of planting there was a significant difference on the dry matter yield of the NPK+GML+foliar (Vita-Grow™) (NGF) compared to the other treatments. Similar trend was observed in the root length treated with NGF compared to the others treatments. The root with this treatment extended to one-meter depth that could give better anchorage and stability to the carbonaceous shale profile. Roots embedded in carbonaceous shale with root elongation (approximately one meter) penetrating through the profile, tend to bind the carbonaceous shale and increase the resistance to sliding. The roots that were penetrated successfully in carbonaceous shale profile indicated the conditions of adequate nutrients, water content and better aeration which help the root growth. The root weight of the plant mix species showed the application of NGF still give the significant result against the other treatments. This experiment has presented important information where the combination of NGF with plant mix species would give better plants growth compared to none- combination of treatment and mix species. Plant mix species *(Brachiaria ruziziensis* and *Colopogonium mucunoides)* and the combination treatment, NGF, could be adopted as the sustainable fertilizer management programs for cover crops grown on carbonaceous shale for better and practical erosion control.

In the shear strength analysis, the results showed that the plant mix treated with NGF fertilizer gave the highest shear strength at 0-25, 25-50 and 50-75 cm depths compared to other treatments. This was probably due to the higher root density accumulation and the contribution of roots reinforcement against the carbonaceous shale particles. The highest root density and the highest shear strength obtained at 0-25, 25-50, 50-75 cm depths from NGF treatment indicated the contribution of roots reinforcement to the stability of carbonaceous shale. Vegetation cover such as *Brachiaria ruziziensis* and *Colopogonium mucunoides* could play an important role in reducing erosion and surface runoff. The roots of this plant mix increased the shear strength through the binding action with the carbonaceous shale mass and contributed to the resistance from sliding. The low shear strength especially in control treatment would expose the carbonaceous shale to erosion and enable the detachment process to occur. The presence of roots had shown the greatest difference where higher shear strength was achieved compared to carbonaceous shale without any plant mix species. The higher roots density, the higher shear strength was identified due to the reinforcement of roots against the carbonaceous shale material.

## CONCLUSION

The plant mix species (*Colopogonium mucunoides* and *Brachiaria ruziziensis*) treated with NGF would become the best option to be adopted as a vegetation cover for the future. It is shown in this experiment that with suitable fertilizer treatment and appropriate plant mix species, the roots reinforcement could help to increase the carbonaceous shale strength and making it more stable if it could be employed on the carbonaceous shale slope. The function of the deep-rooted grass, rapid growth and highest root biomass such as *Brachiaria ruziziensis*, gave better anchorage to the carbonaceous shale and thus would become the best vegetation cover for erosion control. Furthermore, *Colopogonium mucunoides* (legume) may help to fix soil-N from the atmosphere and the litter would enrich the soil organic matter content and soil nutrients with time to ensure sustainable, economical and successful vegetation establishment on areas covered with the carbonaceous shale. In the future, the interaction between the moisture content of the carbonaceous shale and the chemical compositions of clay particles needed to be measured. The presence of organic matter and Ca cations should be favorable to aggregate stability and simultaneously increase the strength of the soil. High moisture content correlated to the decreased of carbonaceous shale shear strength. The NGF (NPK+GML+Foliar) was the best treatments which increased the shear strength by decreasing cohesion and increased angle of internal friction.

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