Soil Water Variation Due to Grass Water Uptake

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Abstract. Shallow landslide is the phenomenon of slope collapse frequently occurring in tropical rainforest regions such as Malaysia based on geotechnical problem. This paper aims to determine the effects of grass on the shallow slope's stability in terms of the variability of soil moisture, and to establish 1D suction of soil moisture due to grass water uptake. Moisture variations were used to compare the moisture content with time using GID and Fotran code tools. Based on the literature review findings, numerical simulation modelling was applied to achieve the most suitable condition for replicating grass water uptake within the soil slope. Six types of grasses were used in this research. The correlation between numerical simulation results is appropriate for these six types of grasses, but only Indropogon Gayanus grass with field monitoring results was achieved for validation. This paper assessed slope stability due to the influence of six types of grasses induced suction. The long grass roots are special between both kinds of grass, ranging from 0.3048 m to 4.000 m. This work gives a clear belief that Axonopus Compressus grass extracts water much faster than other grasses and is useful in preserving unsaturated soil stability.

1. Introduction
Slope can be categorized as natural slope and man-made slope. Natural slope consists of the slope of residual soil and surface. The man-made slope, however, is usually cut-back slope and filled with well-compact filled material. Surface protections are carried out on man-made slopes, including vegetation and soil concreting, with adequate surface drainage such as water channels, catch pits, and sand traps. This is to protect the slope surface from erosion caused by rainfall and to ensure that anticipated soil property capacities speak to soil conduct sensibly well [1].

Depending on the design, subsurface stabilization including soil nailing and ground anchors with underground drainage such as weep hole is required to keep the slope stable in position. Commonly, vegetation has two key roles in stabilizing slope stability; one is through mechanical reinforcement, and the other is through hydrological mechanisms that cause increased evapotranspiration, thus increasing suction or extraction of moisture from the soil [2-3]. The stabilizing effectiveness depends on the vegetation type with specific root distribution, including dense sod cover, grasses, herbs, shrubs, and trees [2,4]. This research focuses on the effects of variations in soil moisture due to water uptake.

2. Literature review
2.1. Root systems
Root systems for produces dense mats are the most crucial component of facilities considered by engineers as shown in Table 1.
Table 1. Length of grasses root

| No | Scientific name           | Grass name | Length of root (m) |
|----|----------------------------|------------|-------------------|
| 1  | Axonopus Compressus [5]    | Carpet     | 0.3048 (12 inches)|
| 2  | Pennisetum purpureum [6]   | Napier     | 2.6               |
| 3  | Andropogus Gayanus [7]     | Gamba      | 1                 |
| 4  | Brachiaria Humidicola [8]  | Bread      | 2                 |
| 5  | Melinis Minutiflora [9]    | -          | 1.2               |
| 6  | Digitaria Eriantha [10]    | Digit      | 4                 |

2.2. Grass
Appreciable grassroots concentrations hit a depth of 0.3 m to 0.5 m. The grass growth habit's most significant aspect is the ground level which is the critical growth stage. This implies that no permanent damage to the plant is done by mild mowing, grazing, burning, or abrasion [2].

3. Material and test methods

3.1. Data collection
The curve of soil water retention and hydraulic conductivity also act as two other soil hydraulic properties, which pose a significant concern in this research. Information on hydraulic conductivity properties was collected from different water retention curves and was merged into a single connection to reflect the entire soil profile. Genuchten obtained the water retention curve [11]. The result of the relationships is given as:

\[ \theta = \theta_s + \frac{\theta_s - \theta_r}{1 + (\alpha \psi)^n}^m \]  

(1)

Where \( \theta_s \) and \( \theta_r \) are residual and saturated water content, respectively, \( \psi \) is the capillary potential and \( \alpha, n \) and \( m \) are the empirical shape parameters. Table 2 presents the exact values of those parameters.

Table 2. Basic soil properties [12]

| \( \theta_s \) | \( \theta_r \) | \( K_s (m/d) \) | \( \alpha \) | \( L \) | \( n \) | \( M \) |
|-------------|-------------|----------------|----------|------|------|------|
| 0.0286      | 0.3658      | 2.5x10^{-4}    | 0.0280   | 0.5  | 2.2390 | 0.553 |

Soil hydraulic conductivity relationship is determined using the water retention curve above along with the pore size distribution model [13] for obtaining:

\[ K = K_s \left[ \left( l + \alpha \psi \right)^n - \alpha \psi \right]^{n-1} \left( l + \alpha \psi \right)^{n-2} \]  

(2)

Where \( K_s \) is the saturated hydraulic conductivity, and where \( l \) is a parameter specific to soil. The appropriate values for the parameters used in this case are also set out in Table 2. The water retention and hydraulic conductivity relationships are shown in Figure 1 respectively.
3.2. Numerical simulation

The simplest type of model for water uptake assumes a linear variation with depth in water extraction. It is assumed that the possible conditions for transpiration, $S_{\text{max}}$, is given by,

$$S_{\text{max}} = a_j - b_j z$$

(3)

Where $S_{\text{max}}$ is the extraction rate, $a_j$ and $-b_j$ are the intercept and slope on the $j$th day, respectively and $z$ is the rooting depth, whereby $z_{rj}$ is the maximum depth of the root zone. The boundary condition at the bottom of the root zone ($z = z_{rj}$) is $S_{\text{max}} = 0$, therefore:

$$a_j - b_j z_{rj} = 0$$

(4)

The total transpiration, $T_j$, across the root zone is then obtained through active depth integration which is:

$$T_j = \int_0^{z_{rj}} S_{\text{max}} \, \partial z$$

(5)

Combining equation (3) and (5) gives:

$$T_j = \int_0^{z_{rj}} \left(a_j - b_j z \right) \partial z$$

(6)

Combining Equation (6) yields:

$$T_j = a_j z_{rj} - \frac{b_j z_{rj}^2}{2}$$

(7)

The root zone equation at the bottom (4) gives:

$$a_j = b_j z_{rj}$$

(8)

The provision of replacing equation (8) into equation (7) produces:

$$b_j = \frac{2 T_j}{z_{rj}^2}$$

(9)
Substituting equation (9) with equation (8) then gives:

$$a_j = \frac{2 T_j}{z_{rj}}$$

(10)

Equations integrating (3), (9), and (10) yields:

$$S_{max} = \frac{2 T_j}{z_{rj}} - \frac{2 T_j}{z_{rj}^2} z$$

(11)

This can be re-arranged as:

$$S_{max} = \frac{2 T_j}{z_{rj}} \left(1 - \frac{z}{z_{rj}}\right)$$

(12)

Equation (12) is only valid under optimal levels of soil moisture. If the moisture content is low, then the real transpiration is less than the potential value. A model describes the sink term for accurate transpiration as follows [9]:

$$S(\psi) = \alpha(\psi) S_{max}$$

(13)

Where $\alpha(\psi)$ (dimensionless) is a defined function of the capillary potential referred to as a water-stress function. For more conditions drier than wilting point and wetter than a certain anaerobiosis point, it may be assumed that the water uptake by the roots is zero.

Feddes [15] makes two assumptions: the first is that no water uptake by the roots occurs at the Anaerobiosis spot with a head pressure of -50 cm, and second is that linear water uptake variability is assumed when the pressure head is less than -50 cm, respectively. The analysis requires moisture and impact pressure head to yield quality of various vegetable crops. Feddes [15] concludes that the water pressure head in the ground for these plants usually begins to restrict plant growth by around -400 cm. Consequently, the intake of water by roots is constant and does not exceed -400 cm (h2) << -50 cm (h1). It is expected that the water uptake for the plant will decrease linearly between $h_3 = -400$ cm and $h_4 = -15000$ cm. Thus, when soil moisture is limited, equation (14) becomes:

$$S(\psi, z) = \frac{2 T_j}{z_{rj}} \alpha(\psi) \left(1 - \frac{z}{z_{rj}}\right).$$

(14)

This simulation uses the size of the time step at 86400 seconds, 345600 seconds, 1296000 seconds, 2592000 seconds, 5184000 seconds, and 7776000 seconds, all of which were constant for the entire period considered. Preliminary numerical tests were conducted to ensure that the solutions for the domain size and the size of the time step at 86400 seconds (day 1) were concentrated. The simulation was analysed and covered for a period of 90 days.

4. Test results and analysis

4.1. Axonopus Compressus grass

Figure 2 shows the number of variations in soil moisture content with time for grass carpets formally named Axonopus Compressus. There was a comparison of the moisture contents for numerical simulations in four measures over a 15, 30, 60, and 90-day simulation period. Figure 2 provides a calculated numerical result when the soil moisture was at a depth of 0.2 m, which was 0.02877 cm$^3$/
cm$^3$, and increased marginally to 82.90 percent when it reached a depth of 5 m on day 15 where the soil moisture content became very wet as the depth rose. The simulated result was at a depth of 0.2 m to 5 m, which increased to 63.70 percent at day 30. Day 60 showed the difference between depths of 0.2 m and 5 m with a slight increase in the moisture contents of 0.07 percent. Day 90 indicated just 0.02 percent increase or remained steady with the moisture contents from 0.2 m to 5 m range. The analogy for moisture contents decreased rapidly for the soil where the day was prolonged. The main differentiation is seen in Figure 2 which has the same depth of 0.2 m, but with an observed difference from the measurement of 90 days where the moisture content steadily decreased by 0.58 percent. The moisture content suddenly dropped to 0.05263 cm$^3$/cm$^3$ at a 15-day duration of 5 m depth and to 0.02861 cm$^3$/cm$^3$ for a depth of 5 m at a duration of 90 days.

Figure 2. Numerical Simulation of Moisture content variation with time for Axonopus Compressus day15, 30, 60 and 90

4.2. *Pennisetum Purpureum* grass

Figure 3 displays the effects of the *Pennisetum Purpureum* grass moisture content as corresponding to the amount of time it is measured, while Figure 4 indicates the 15, 30, 60 and 90 days of the numerical simulation. The soil result for moisture content gradually increased from 0.2 m to 5 m depth, which is 10.5 percent. Besides, the simulated result increased steadily to 15.8 percent from 0.2 m to 0.5 m depth indicative of day 60 of moisture content and the difference between the 0.2 m and 5.0 m depth is 0.00835 cm$^3$/cm$^3$ or 20 percent. Day 90 showed that the soil moisture content steadily rose by 20.60 percent from 0.2 m to 5 m depth. Comparing a depth of 2 m for days 15 and days 90, it was found that the moisture content decreased significantly to 18.5 percent. The moisture content from depth 2 m to 5 m somehow reduced to 1.66 percent within a period of day 1 to day 90. Figure 3 explains that the moisture content dropped gradually to 11.03 percent at a depth of 5 m from day 1 to day 90.

Figure 3. Numerical Simulation of Moisture content variation with time for *Pennisetum Purpureum* day 15, 30, 60 and 90
4.3. Andropogon Gayanus grass
Gamba grass known scientifically as Andropogon Gayanus is as shown in Figure 5 which shows the moisture content outcomes over a 90-day span. The graph for Day 15 showed that the moisture content increased to 38.61 percent at a depth of 0.2 m to 5 m ground. The moisture content rose up to 40.24 percent at day 30, and at day 60, the moisture content fell to 29.76 percent, while the moisture content increased only marginally when the length increased by 0.21 percent by day 90 at a depth of 0.2 m to 5 m. Between day 1 and day 90 at the same soil depth of 0.2 m, the effective rate decreased by 17.75 percent compared to the duration moisture content. The rate of moisture content decreased to 17.58 percent at a depth of 0.2 m to 5 m from day 1 to day 90. The rate of moisture content showed a drastic decrease of 40.54 percent at the same depth of 0.5 m from day 1 to day 90.

4.4. Brachiaria Humidicola grass
The graph presents the number of variations in soil moisture content within a period for bread grass which is scientifically known as Brachiaria Humidicola. The four-step numerical simulations reveal clearly that there was a difference in the moisture content. Day 15 indicated that the simulated numerical result for soil moisture at a depth of 0.2 m was 0.045245 cm$^3$ / cm$^3$ which increased marginally to 16.31 percent, and the soil moisture content was wet up to a depth of 5 m on day 15 when the depth increased. Day 30 showed the simulated result at a depth of 0.2 m to 5 m where it rose to 23.09%. Day 60 showed the difference between depths of 0.2 m and 5 m, where the moisture content increased to 26.40 percent. Day 90 indicated that the moisture content increased from 0.2 m to 5 m depth by 24.10 percent. The difference in the moisture content decreased rapidly for soil where the days were extended. The discrepancy between the 90 days with the same depth of 0.2 m was noticed as the moisture content steadily decreased by 21.17 percent. The moisture content suddenly dropped to 0.05263 cm$^3$ / cm$^3$ for 15 days for 5 m depth, and to 0.04426 cm$^3$ / cm$^3$ for 90 days for 5 m depth.
depth. The moisture content also rose as the depths increased depending on the time from day 15 to day 90.

4.5. Melinis Minutiflora grass
Figure 6 shows the moisture content of the grass with the scientific name of Melinis Minutiflora indicating the moisture content outcomes depending on the time. Results for the soil shows that the moisture content increased gradually from the depths of 0.2 m to 5 m, which is by 10.5 percent. For day 30, simulations increased steadily to 32.6 percent at depths of 0.2 m to 0.5 m. As shown in Figure 6, on day 60 the moisture content indicated a difference between 0.2 m and 5.0 m depth of 0.01067 cm$^3$/cm$^3$ or 33.0 percent. The soil's moisture content gradually increased by 22.25 percent from 0.2 m to 5 m depth. The difference between day 15 and day 90 at a depth of 2 m indicated that the moisture content gradually decreased to 22.21%. The moisture content from day 1 to day 90 reduced to 17.06 percent from a depth of 0.2 m to 5 m showing a static drop to 28.29%.

![Figure 6. Numerical Simulation of Moisture content variation with time for Melinis Minutiflora day 15, 30, 60 and 9](image)

4.6. Digitaria Eriantha grass
Figure 7 indicates the moisture content of the Digit grass, scientifically named Digitaria Eriantha. The moisture content for 15 days appeared to increase slowly to 4.80 percent at a depth of 0.2 m to 5 m. In the meantime, day 30 indicated that the moisture content increased to 7.60% for 30 days and to 11% for up to 60 days, while it also increased gradually as the duration multiplied by 12.47% for day 90 at a depth of 0.2 m to 5 m. For a period of 90 days, the moisture content reduced to 17.75 percent at the same depth of 0.2 m that is proportional to the soil. From day 1 to day 90 at a depth of 0.2 m to 5 m, the rate was 12.03 percent as the moisture content decreased. At almost the same depth from day 1 to day 90 of 0.2 m to 5 m, the moisture content rate showed a slight or steady decrease with a rate of 1.06%.

![Figure 7. Numerical Simulation of Moisture content variation with time for Digitaria Eriantha day 15, 30, 60 and 9](image)
4.7. Result validation between computer simulation and field measurement result

Figure 8 indicates the results of computer simulation and field measurement [16]. The result at depth 0.4 m is differences of 0.00620 cm³/cm³ or 20.06 percent. The difference increases to 21.21% at depth 0.6 m, and that is 0.00681. At a depth of 0.6 m, the gap rose to 21.21 percent, and that is 0.006811. The difference between the two approaches is 22.01% at the next depth, which is 0.8 m. The difference is 0.00743 or 22.86 percent at a depth of 1 m and gap at a depth of 1.2 m is 23.70 percent. The difference is 25.56 percent or 0.00808 at the end of validation at a depth of 1.4 m. Therefore, the comparison of field measurement with the outcome of numerical simulation is appropriate.

![Figure 8. A comparison between field measurement and numerical simulation result](image)

5. Discussion

Figure 9 presents the graph for six types of grasses with a current period range of their moisture content at a depth of 5 m. The grasses used for this research are Axonopus Compressus, Pennisetum Purpureum, Andropogon Gayanus, Brachiaria Humidicola, Melinis Minutiflora, and Digitaria Eriantha. It is apparent from the graphs that the grassroots have short-term rate of soil moisture content and faster drying rate, and the higher rates are seen in comparison to the grass-root length. For Axonopus Compressus of 0.3048 m, the drying rate is 45.63% for the six grass types for 90 days and 40.54% for Andropogon Gayanus with a root length of 1 m in the same period for the six grass types. Minutiflora Melinis grass also shows the highest rate among the three water absorption rate, 28.29 percent for the soil with root length of 1.2 m. By contrast, with the three other types of grasses with the root lengths in the range of 2 m to 4 m, the water absorption rates and moisture content on the soil occurred very slowly within 90 days. As for Pennisetum Purpureum and Brachiaria Humidicola, the drying rate is 11.03 percent and 15.89 percent, respectively, and this made them be known to be low rates and the length of their grass-roots is 4 m, each. Here, it can be inferred that shorter roots have a faster absorption rate compared to longer roots, as well as water intake. The difference can be seen at a depth of 5 m where the rate of water absorption by the grass with the shortest roots was faster than that with longer roots like Axonopus Compressus. Also, long-rooted grass consumes water at prolonged rate, for example, Digitaria Eriantha.

![Figure 9. Combination of six types of grasses at a depth of 5m moisture content with time](image)
6. Conclusions
The result of this research as shown in Table 1 from the literature review indicated that the suction rate for the short duration of the grassroots is strong at the top. Therefore, it can be inferred from the table that the moisture content depends on the length of the grassroots.

The observation above proves that the root length does not guarantee the roots' durability in absorbing water from the soil, especially for shallow slopes. If the diffusion rate is high in water, the soil will become too moist, and the grass will not be suitable for shallow slopes as it may collapse. Axonopus Compressus grass is also used to prevent soil erosion in shallow slopes. While planting this grass, it is not essential, however, it is the main factor that has led to landslides' problems as planting grasses with long grassroots allow the roots to drain the water from the soil gradually. Axonopus Compressus grass is seen from the graph showing the depth of the grass by day as contributing to a faster rate of dry soil. It is compatible for use in the occurrence of prolonged rainfall, as the grass roots will help to absorb the water quickly and reduce the pressure of pore water while increasing soil shear strength [17]. Although the roots are essentially long, it is suggested from the computational simulations that the soil moisture content takes time to dry up within 90 days and is therefore not ideal for shallow slopes, when compared to other grasses, especially Digitaria Erianta grass. Generally, stress on the slope may be altered by increasing shear stress or decreasing the significant normal stress on movement by reducing the shear strength of the material within the landslide [17]. Also, moisture content will impact the strength of the soils and weathered materials. The humid tropics deep residual soils can often have relatively high hydraulic conductivities that allow rainfall to infiltrate. Hydraulic conductivity will vary for the research situation for unsaturated soils as a function of the moisture content compared to saturated soil as it depends on the different hydraulic conductivity of their structure and composition [18]. Lastly, an environmental change may have a potential impact on slope stability [19].

7. References
[1] Ismail S S A and Ali N 2018 Hysteresis of filter paper method on laterite soil, International Journal of Latest Transactions in Engineering and Science 3 28-34
[2] Coppin N and Richards I 1990 Use of Vegetation in Civil Engineering Construction Industry Research and Information Association, Butterworths, London
[3] Greenwood J, Norris J and Wint J 2004 Assessing the Contribution of Vegetation to Slope Stability, Proceedings of the Institution of Civil Engineers-Geotechnical Engineering 157 199-207
[4] Gray D H and Sotir R B 1996 Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control (United State: Wiley-Interscience)
[5] Plant Care Today. Available at https://plantcareday.com/carpet-grass.html
[6] Nobuhito S 2013 Distribution and quantity of root systems of field-grown erianthus and napier grass American Journal of Plant Sciences 4 16-22
[7] Department of Agriculture, Fisheries and Forestry 2013 National Gamba Grass Strategic Plan 2-10
[8] Heuzé V, Sauvant D and Tran G 2013 Bread grass (Brachiaria brizantha) Retrieved on Jun 20, 2021 from https://www.feedipedia.org/node/490
[9] D’Antonio, Carla M, Hughes R F and Peter M 2001 Factors influencing dynamics of two invasive C4 grasses in seasonally dry Hawaiian woodlands, Ecology 82(1) 89-104.
[10] Duke J A 1981 Handbook of legumes of world economic importance Plenum Press, New York pp 33–37
[11] Genuchten V M 1980 Closed form equation for predicting the hydraulic conductivity of unsaturated soils, Soil. Sci. Soc. Am 44 892 – 898
[12] Ali N and Rees S W 2008 Preliminary analysis of tree-induced suction on slope stability Proceedings of The First European Conference on Unsaturated Soils, Durham, United Kingdom. CRC Press, Taylor & Francis Group, London, UK 811 – 816
[13] Mualem Y 1976 A new model for predicting the hydraulic conductivity of unsaturated porous media Water Resource Res 12 513 – 522.
[14] Ali N 2007 The influence of tree-induced moisture transfer on unsaturated soil PhD Thesis University of Cardiff, Cardiff) 45-60
[15] Feddes R A, Kowalik P J and Zaradny H 1978 Simulation of field water use and crop yield (Wageningen: Wageningen Center for Agriculture and Documentation) 189
[16] Razi 2014 The Influence of Tree Water Uptake on Suction Distribution in Unsaturated Tropical Residual Soil Slope Phd Thesis Universiti Teknologi Malaysia 42-61
[17] Coetes D R 1977 Landslide Properties in: Lanslides. Geological Society of America 3-38
[18] Feddes R A, Kowalik P J, Malink K K and Zaradny H 1976 Simulation of field water uptake by plants using a soil water dependent root extraction function J. Hydro 31 13 – 26.
[19] Christofer K, Rahardjo H and Satyanaga A 2017 Effect of variations in rainfall intensity on slope International Soil and Water Conservation Research 5(4) 258-264

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