The Soil-Root Strength Performance of *Alternanthera Ficoidea* and *Zoysia Japonica* as Green Roof Vegetation

Muhamad Firdaus Abdullah¹, Hartini Kasmin^{2,*}, Nor Azizi Yusoff¹, Safwan Mustafar², Shazren Salimun², Zaidi Embong¹ and Hanim Ahmad³

¹ Research Centre for Soft Soil (RECESS), Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

² Micropollutant Research Centre (MPRC), Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

³ Horticulture Research Centre, MARDI Headquarters, Serdang, P.O. Box 12301, 50774 Kuala Lumpur

Abstract. The rise of awareness on environmentalism has demanded that all parties involved in built environment to implement green technology in their construction projects. Great care must be taken when designing a green roof system including the selection of plants and appropriate substrates. This study was performed to investigate the soil-root composite strength of two types of green roof vegetation (*A. Ficoidea* and *Z. Japonica*) at different growth periods for up to 6 months. Both plants were planted in six plastic plots (45 cm × 29 cm × 13 cm) containing a mixture of perlite, vermiculite and organic soil. Every two months, a series of direct shear tests were conducted on a sample from each species to determine the root-soil shear strength. The tests continued until the 6th month. The average results showed that *Z. Japonica* had higher soil-root shear strength (49.1 kPa) compared to *A. Ficoidea* after two months of growth. In the 4th month however, *A. Ficoidea* managed to surpass *Z. Japonica* (28.7 kPa versus 18.5 kPa) in terms of shear strength. However, their average peak shear strength decreased sharply compared to the previous month. Lastly, in six months, *A. Ficoidea* sustained a higher average peak soil shear strength (56.5 kPa) compared to *Z. Japonica* (14.3 kPa). Therefore, it can be concluded that *A. Ficoidea* may offer a better soil reinforcement than *Z. japonica* and thus it could potentially be a good choice of green roof vegetation.

1 Introduction

Green roof is a green space which consists of layers of soil mediums, vegetation and drainage system. The concept of green roof nowadays has become increasingly popular as it brings many benefits towards the environment and helps promote a sustainable lifestyle

* Corresponding author: hartini@uthm.edu.my

[1]. The increase in the usage of green roof covers can potentially transform an urban environment into a cooler urban area.

Vegetation has been the basis of slope stabilization since ancient times. In more recent times, the roles of vegetation in some specific geotechnical processes have been recognized. Vegetation influences slope stability indirectly through its effect on the soil moisture regime. It will be able to intercept rainfall and draw water from the soil via evapotranspiration [2]. The depth of growing media is typically between 10 and 30 cm although some implementations (referred to as intensive green roofs) have deeper soils capable of sustaining large shrubs and even trees [3]. Fauzi et al, [4] reported the findings by Rowe [5] which stated that plant selection for different locations and climate requires a test on a myriad of plant species in order to evaluate their suitability for green roofs. A variety of plant species was used by Malaysian green roof researchers such as Johari [6] who has identified 3 family names of plants that can survive in Malaysian tropical climate which are *Crassulaceae*, *Portulacaceae* and *Neoregelia*. On the other hand, Ismail [7] used *Spodophyllum*, *I. batatas*, *I. horsfalliae*/*J. Sambac* and *I. pes-caprae* for thermal studies. Furthermore, Yusoff [8] used *Axonopus Compressus* and evaluated its soil-root strength performance. Therefore, these studies suggested that more species can be tested for their suitability as green roof vegetation.

Storm water runoff is considered as the main concern of green roofs [4,9,10]. During heavy rainfalls in Malaysia, the direct impact of rain drops on green roofs can be regarded as the main force causing the separation of soil particles. This situation will happen when the bond between the particles of soil structure weakens and this could lead to soil erosion [11]. As a result, green roof strength may decrease. Hence, the presence of vegetation might reduce soil erosion through rainfall interception as well as enhance the infiltration and extraction of soil moisture via plant transpiration [12].

Therefore, this study aims to investigate dynamic soil shear strength development of two types of vegetation based on the green roof vegetation growth rate. It is important to identify which species of grass or herbaceous plants are able to perform better in terms of soil reinforcement (soil shear strength). An experiment was designed to assess soil-root shear strength of two plants within stipulated months so that a suitable candidate for green roof vegetation can be identified.

2 Materials and methods

2.1 Plot preparation and substrate materials

The experiment was conducted at the Research Centre for Soft Soil (RECESS), UTHM. The two plant species, *Alternanthera Ficoidea* (*A. Ficoidea*) and *Zoysia Japonica* (*Z. Japonica*), were used in the experiment and were allowed to grow up to 6 months. Both plant species were chosen for this experiment due to their popularity for landscape purposes. The plants were planted in March 2016 in six rectangular plastic plots (45 cm (W) × 29 cm (L) × 13 cm (H)); three plots for each plant contained a mixture of organic soil, perlite and vermiculite by the weight ratio of 2:3:5 respectively (Fig. 1(a)). The mixture has a maximum water capacity of 50% and 0.00433 cm/s of soil permeability [13]. The mixture may potentially be an ideal substrate as recommended by Beattie and Berghage [14] because it comprises of lightweight, well-drained material and adequate water and nutrient holding capacity. The substrate depth was 80 mm. All the plots were placed in the shade to prevent exposure to direct sunlight.

2.2 Plot maintenance

The plants were irrigated to excess once a day to ensure that they obtain enough water to survive. However, the frequency of watering the plants is usually influenced by several factors. Among the factors are weather, age of plants, species and soil types. Besides, plant supplements such as NPK fertilizer (with the ratio of 21% for each nutrient) was applied in the beginning of the treatment. This will ensure the successful growth of the plants.

Fig. 1. Plot preparation; (a) substrate materials, (b) *A. Ficoidea* and (c) *Z. Japonica*

2.3 Species sampling

2.3.1 Soil water content measurement

Prior to shear testing, to ensure that the soil water content of both plots (*A. Ficoidea* and *Z. Japonica*) is about the same, the plots were poured with excess water until the soil was fully saturated. Then, the plots were left in a dark room for 24 hours before the sampling process began. This was done to minimize the effect of soil suction on shear testing and to maintain soil moisture reading each time the test was performed.

2.3.2 Core sampling

Every two months, three individual *A. Ficoidea* plants were sampled from the plot by penetrating a square soil core (all sides equal to 8 cm as shown in Fig. 2(a)) diagonally across the plot [15]. The same sampling method was employed to retrieve three soil samples from the *Z. Japonica* plots (Fig. 2(b)). A portion of soil from those three samples per plot was taken and weighed before being placed in an oven at 105°C for 24 hours to obtain soil moisture content. Then the sample was transferred into a sample ring with a dimension of 6 cm × 6 cm × 2.5 cm. After skimming, the soil sample ready to be transferred to a direct shear apparatus.

2.4 Direct shear tests

Drained direct shear tests were carried out using Shear Trac II machine (Geocomp Inc, USA) available at RECESS, UTHM. It is a fully automatic direct shear testing machine that controls the whole process beginning from the consolidation phase until the end of the shear phase. An automatic data logging system of the machine will be able to download all

required data from the tensiometer, displacement transducer and load cell to a computer using software named ‘SHEAR’. Soil samples from the ring with 2.5 cm thickness were inserted into the shear box carefully by using a special pressing tool (Fig. 2(c)) so that it would minimize the disturbance to the soil sample.

Prior to the direct shear test, the sample will go through a consolidation phase with a small vertical stress of 1 kPa applied on it. Such a little amount of stress was used after taking into consideration the shallow depth of the samples in the pots (less than 8 cm). Thus, it is important to adapt to the actual situation on the ground near to the surface. After the consolidation graph shows a constant result (Fig. 3), the direct shear test will commence. The test was carried out with a shearing rate of 1.0 mm/minute and a maximum displacement of 20 mm (33.3% strain).

Fig. 2. Sampling process: (a) a square soil core, (b) three soil samples of *Z. Japonica* retrieved diagonally across the plot and (c) soil sample transferred into a shear box [16]

Fig. 3. Sample was consolidated with a vertical stress of 1 kPa until it reached a constant value

2.5 Above-ground biomass measurements

During the core sampling process, all the upper parts of plants including stems and leaves that were confined inside the square soil core (8 cm × 8 cm) were collected and kept in sealed plastic bags. The vegetation samples were later weighed and dried in an oven at 70°C for approximately two days until a constant sample weight indicated that all available water has been removed. The dried vegetation was weighed to a precision of 0.001g, yielding an estimate of above-ground biomass for every shear strength measurement. The biomass values were calculated by dividing the dry weight of vegetation by soil core area.

3 Results and discussion

3.1 Drained direct shear test

Fig. 4(a) shows the results of the direct shear tests of *A. Ficoidea* and *Z. Japonica* soil samples in the 2nd month which are 63, 33 and 13.5 kPa for *A. Ficoidea* samples 1, 2 and 3 respectively. The average peak shear strength for *A. Ficoidea* in the 2nd month was 37 kPa, denoted by a bold red dotted line in that figure. Peak shear strength in the 2nd for *Z. Japonica*'s soil samples 1, 2 and 3 were 62, 32 and 53 kPa respectively. Their average value is indicated by a bold green dotted line with a peak value equals 49 kPa, which is larger than *A. Ficoidea* of the same age.

After 4 months of growth, compared to the results for the past two months, the average soil shear strength had slightly decreased to 28.7 kPa and 18.5 kPa for *A. Ficoidea* and *Z. Japonica* respectively.

Fig. 4(b)). This time, *A. Ficoidea* has higher soil shear strength than *Z. Japonica*. Its shear stress values (sample 1 to 3) ranged from 24 to 33 kPa, which are higher than *Z. Japonica* (13 to 28 kPa). The decrease in shear strength for both species might be due to increasing soil moisture content and decreasing above ground biomass when compared to readings for the past two months.

Fig. 4. Shear stress against displacement curves for direct shear tests on three replicates of *A. Ficoidea* and *Z. Japonica* of growth period; (a) month 2, (b) month 4 and (c) month 6. (d) Peak shear strength values of both plant species for the whole growth period (month 2, 4 and 6)

Fig. 4(c) shows the result of direct shear testing of *A. Ficoidea* and *Z. Japonica* after 6 months of growth. Surprisingly, the shear stress of *A. Ficoidea* is observed to be higher than *Z. Japonica* for all its samples although its readings were quite erratic. *Z. Japonica* seems to perform poorly as shown in the previous test (month 4), even its current average shear stress (14 kPa) was the lowest throughout the study. On the other hand, the average

shear stress of *A. Ficoidea* was 57 kPa, which is the highest average shear strength recorded for the study. Based on

Fig. 4(c), the average of the shear stress curve of *A. Ficoidea* increased drastically at the early stage of the test (less than 3 mm displacement). It also has two distinct peak values at 14 and 19 mm displacement of its average shear curve. According to [17], the first peak value is due to maximum lateral root resistance whereby the second peak value is the maximum mobilized tap root resistance. This might be contributed by the resistance of both lateral and tap roots.

Overall, *A. Ficoidea* was able to improve soil shear strength better than *Z. Japonica* (Fig. 4(d)). This is proven by the increasing trendline with R^2 equals 0.238 of *A. Ficoidea* in the figure. Low R^2 value is due to a high variation in soil shear strength values recorded in the 2nd month and the 6th month. Meanwhile, *Z. Japonica* shows a decline in its shear strength throughout the study, indicated by a negative trendline with R^2 equals 0.7111. Despite its bad performance, it has a high R^2 value indicating a low variation in shear strength measured.

3.2 Soil moisture content

Fig.(a) shows the soil moisture content of *A. Ficoidea* and *Z. Japonica* for every soil sample tested every 2 months. There is no general trend observed for *A. Ficoidea* but *Z. Japonica*’s moisture content decreased with time (month). The readings for the moisture content in the 2nd month for *A. Ficoidea* were varied substantially (large standard error). However, the researcher managed to maintain soil moisture content in a range between 120 to 220 %.

3.3 Plant biomass

The above-ground biomass production of *A. Ficoidea* was observed to be higher than *Z. Japonica* for all months except the 2nd month (Fig. 5(b)). This is due to very little foliage of *A. Ficoidea* during its juvenile age. Meanwhile, *Z. Japonica* shows a slight decrease in biomass with an average value of around 400 g m⁻². There was no below-ground biomass as the mass of roots beneath the ground was too small and the root screening process was tedious.

Fig. 5 (a) Soil moisture content against planting months and (b) Above-ground biomass of two plants after 2, 4 and 6 months. Vertical bars indicate standard error

3.4 Relationship between shear strength, moisture content and biomass

The results reveal correlations between shear strength and other parameters. It can be observed that the peak shear strength of *A. Ficoidea* correlates negatively ($R^2 = 0.667$) with moisture content (Fig. 6(a)). However, the relationship between peak shear strength of *Z. Japonica* is unusual. Normally, when soil moisture content decreases, the shear strength of soil will increase. As discussed by [18], saturation of soil will reduce the shear strength due to buoyancy reduction in normal force and it could also destroy the capillarity and apparent cohesion of soil.

Based on Fig. 6(b), there is no clear relationship between the peak shear strength of *A. Ficoidea* and above-ground biomass due to very low R^2 value (0.0176). In addition, the vertical trendline with high gradient ($R^2 = 0.548$) implies that above ground biomass of *Z. Japonica* does not have influence on its peak shear strength throughout its growth period. It should be noted that stable soil is primarily due to high biomass, which likely resulted in high soil water loss through plant transpiration [18]. However, it seems that the rule does not apply in this situation.

Fig.7 shows the relationship between soil moisture content and above-ground biomass for *A. Ficoidea* and *Z. Japonica*. Similarly, there is no clear relationship between moisture content of *A. Ficoidea* and its above-ground biomass due to very low R^2 value (0.0392). Besides, it is observed that the effect of above ground biomass towards moisture content is unusual, particularly on *Z. Japonica*. Generally, the increase in above-ground biomass will help to decrease soil moisture content. High biomass particularly above the ground would demand a large amount of water absorption by the root to produce soil-plant-atmosphere continuum (SPAC) [19]. Furthermore, 99% of water lost is due to transpiration and only 1% is due to evaporation [20].

Fig. 6. Relationship between shear strength and other parameters; (a) moisture content and (b) above-ground biomass

Fig. 7. Relationship between moisture content and above-ground biomass

4 Conclusion

Therefore, it can be concluded that the soil-root shear strength of *A. Ficoidea* has increased over the study period. It also performed better than *Z. Japonica* in terms of soil shear strength, removal of soil moisture and biomass production. Hence, *A. Ficoidea* is an ideal species for the purpose of green roof vegetation compared to *Z. Japonica*. However, further study is required to accurately investigate the correlation between shear strength, biomass and moisture content of both plants as the current results are not entirely convincing.

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