3-D TRF and various grass growth effects on the Manning's coefficient in open channel flow

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ABSTRACT
Vegetated soil cover is one of the best management practice used to reduce runoff velocity and quantity through its roughness behavior and infiltration. A laboratory study was conducted to analyze the effects of Centipede, Carpet and Bahia grass and Rolled Erosion Control Products (RECPs) on the Manning's coefficient in channel flow. Sandy silt soil obtained from a reservoir in Kaohsiung (Taiwan), a three-dimensional RECP and the different grasses were used. The test conditions included each type of grass planted with and without the RECP at a planting density of 25 g/m^2. The grasses were tested at one, two and four month(s) after planting in reference of ASTM D6460 standard.
Installing RECP increased the vegetation area coverage one month from planting. The use of RECP had less or no effect on Carpet and Centipede grass height, only Bahia grass height was increased after one month. The total soil loss rate for the three growth stages were more for the conditions without RECP in both methods of computing soil loss rate (depth and weight methods). Carpet, Centipede, and Bahia grass recorded 2.20 %, 2.04 %, and 2.49 % respectively without RECP. Installing RECP reduced the total soil loss rates by weight to 1.28 %, 1.17 %, and 1.31 % for Carpet, Centipede, and Bahia grass respectively. The Manning's coefficient was directly proportional to vegetation growth and using RECP increased the coefficients after four weeks. The shear stress increased with the growth of vegetation and the use of RECP increased shear stress.

A cobertura do solo vegetal é uma das melhores práticas de manejo usadas para reduzir a velocidade e a quantidade do escoamento superficial através de seu comportamento de rugosidade e infiltração. Um estudo de laboratório foi realizado para analisar os efeitos da centopéia, do tapete e da grama da Bahia e dos produtos de controle de erosão laminada (RECPs) no coeficiente de Manning no fluxo do canal. Utilizou-se solo de lodo arenoso obtido de um reservatório em Kaohsiung (Taiwan), um RECP tridimensional e as diferentes gramíneas. As condições de teste incluíram cada tipo de grama plantada com e sem o RECP a uma densidade de plantio de 25 g / m2. As gramíneas foram testadas um, dois e quatro meses após o plantio, em referência ao padrão ASTM D6460.
A instalação do RECP aumentou a cobertura da área de vegetação em um mês após o plantio. O uso de RECP teve menos ou nenhum efeito na altura da grama Carpet e Centopéia, apenas a altura da grama Bahia foi aumentada após um mês. A taxa total de perda de solo nos três estágios de crescimento foi maior para as condições sem RECP nos dois métodos de cálculo da taxa de perda de solo (métodos de profundidade e peso). O tapete, a centopéia e o capim Bahia registraram 2,20%, 2,04% e 2,49%, respectivamente, sem o RECP. A instalação do RECP reduziu as taxas totais de perda de solo em peso para 1,28%, 1,17% e 1,31% para os capins Carpet, Centipede e Bahia, respectivamente. O coeficiente de Manning foi diretamente proporcional ao crescimento da vegetação e o uso do RECP aumentou os coeficientes após quatro semanas. A tensão de cisalhamento aumentou com o crescimento da vegetação e o uso de RECP aumentou a tensão de cisalhamento.

RESUMEN
An optional abstract in Spanish "RESUMEN" or Portuguese "RESUMO" may follow the English abstract. This abstract must not exceed 250 words.

1. INTRODUCTION

Vegetated soil cover is one of the best management practices used to minimize runoff velocity, flow capacity by recharging groundwater through infiltration, and reducing pollution through increased filtration (Yu et al., 2001). The installation of vegetated channel is a possible solution to which rainwater needs to be conveyed from impermeable surface like pavements, slowed down, disposed in a manner that prevent the formation of gullies, and allowed to infiltrate into the soil. Fullen and Booth (2006) mentioned that the presence of a well-developed vegetation cover automatically reduces runoff and sediment flow in channels.
The period before the grass matures and become fully established is important due to the high susceptibility of a poorly covered channel to soil erosion. For this reason, Rolled Erosion Control Products (RECPs) are the most suitable materials that can be used with the vegetation for additional protection at the soil-lining interface in channels during that

period (Hann and Morgan, 2006). The main functions of RECPs are the direct protection of the soil surface from the eroding action of rain-splash and runoff, and the promoting of vegetation growth. Well established vegetation in a channel affects the velocity of flow and the extent depends on the nature of the vegetation species, distribution, and flexibility, degree of submergence, vegetation density and height (Rizalihadi, 2019). The reduction in the average flow velocity at a channel cross-section is mostly caused by the flow resistance from the stems and leaves of the vegetation. Ahmad et al. (2018) mentioned that the growth stage and density of the vegetation affect the velocity of flow in a channel and both are directly proportional to the Manning's coefficient (n). The Manning's coefficient is one of the most important parameters used to study water flow in an open channel. This is the roughness or friction applied to the flow by the channel and any interference including vegetation grown in the channel.

Many studies concluded that vegetation in channel flow increase the Manning's coefficient values, but this is very arduous due to the many parameters involved. One of them being the different vegetation types used in channels which makes it difficult for authentic prediction of the channel's roughness. Due to the importance of the Manning's coefficients in channel design, it is imperative to do more research including the type of vegetation, growth stage, and the use of RECPs. So, the objectives of this study are to determine the effects of RECP and vegetation growth (Carpet, Centipede, and Bahia grass) on the Manning's coefficient in channel flow.

2. TEST PROGRAM, EQUIPMENTS AND MATERIALS

2.1 Test program

Sets of channel erosion tests were conducted to determine the effects of RECP and different grass growth on the Manning's coefficient in channel flow. Test standard ASTM D6460 was used to carry out the experiment. The Manning's coefficients were computed by using the Manning's equation. Sandy-silt soil obtained from a local (Kaohsiung, Taiwan) reservoir, Agongdian was used in this study. A three-dimensional curled erosion control geomat which is made locally and three different grasses (Carpet, Centipede, and Bahia grass) were used. The test conditions included each type of grass planted with and without RECP at a planting density of 25 g/m^2. Due to the different seed sizes of the grasses, the planting density was 66 150, 24 825, and 15 175 seeds/m^2 for Carpet, Centipede, and Bahia grass respectively. The grasses were tested in three different growth stages; one, two, and four month(s) after planting. The tests were conducted in a fixed channel slope of 1 % using 90 HP pump capacity and the duration for each test was 30 minutes.

2.2 Test equipments

The experiment was conducted in an indoor rectangular test channel measuring 24 m long, 0.6 m wide, and 0.6 m high with an adjustable slope of 0 ~ 5 %. An over-view of the test channel is shown in Figure 1. Three hydraulic pumps with capacities of 15 HP, 40 HP, and 50 HP which can be arranged to meet different flow requirements needs were used. The grasses were planted in two types of stainless-steel boxes; Type I measuring 0.8 m long, 0.535 m wide and 0.15 m high, and Type II measuring 0.8 m long, 0.59 wide and 0.15 m high as shown in Figure 2 (a) and (b) respectively. There were five test boxes used in each test; two Type I and three Type II test boxes placed in the channel as shown in Figure 1. The stainless-steel boxes were lifted and carried from outside to placement within the channel flume using a mechanical crane. The flow velocity was measured using the USGS Type AA current meter which was moved within the middle three (Type II boxes) samples in this study. This current meter is suspended in the water using a cable with sounding weight or wading rod and will accurately measure streamflow velocities from 0.025 to 7.6 m/s (Hjalmarson, 1965).

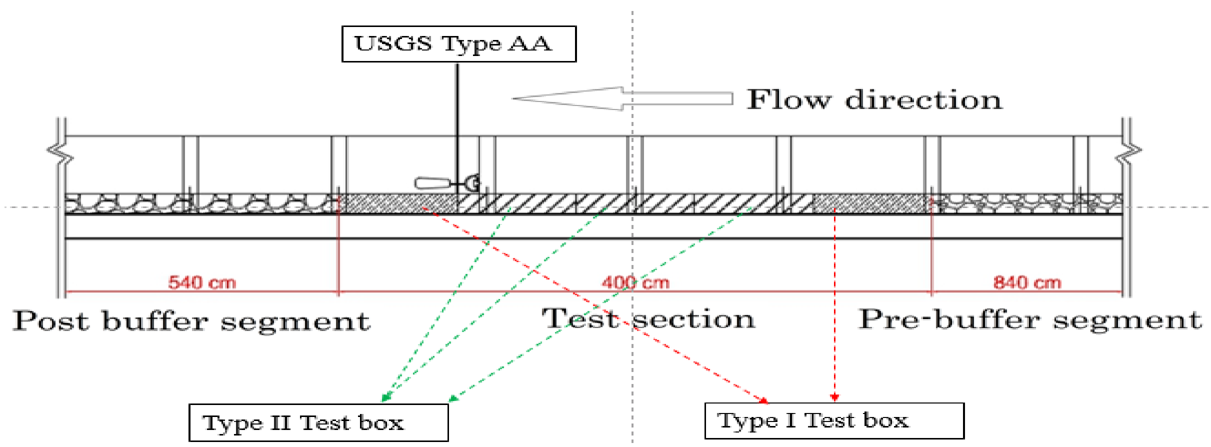
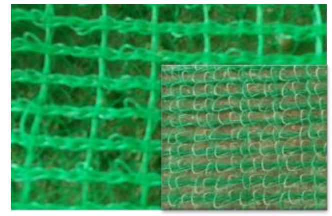


Figure 1. Schematic view of the test channel showing the test box positions

(a) Type I Test Box (b) Type II Test Box

Figure 2. The two types of Test Boxes



3-D curled erosion geomat

Figure 3. Test RECP

2.3 Test Materials

A three-dimensional RECP made from polyethylene shown in Figure 3 was used in this study. The typical engineering properties of the RECP are listed in Table 1. According to ASTM D6460 and D698 standards, the test soil was compacted to around 93 % of its maximum dry weight in three layers in the test boxes. The three types of grasses used were Carpet, Centipede, and Bahia grass shown in Figure 4 a, b, and c respectively which were tested one, two, and four month(s) after planting. The grasses were planted with and without the use of the RECP.

Table 1. RECP typical engineering properties

Measured Parameter	Standard Test Method	Units	Results
Mass per unit area	ASTM D6566-14	g/m^2	261.5
Nominal thickness	ASTM D6525-14	mm	5.15
Light penetration	ASTM D6567-14	%	56.24
Tensile strength (MD)	ASTM D6818-14	kN/m	10.28
Ultimate elongation (MD)	ASTM D6818-14	%	31.86
Tensile strength (XD)	ASTM D6818-14	kN/m	2.10
Ultimate elongation (XD)	ASTM D6818-14	%	234.26

(a)Carpet grass with RECP (*Axonopus fissifolius*), 16 weeks (b)Centipede grass with RECP (*Eremochloa ophiuroides*), 16 weeks (c)Bahia grass without RECP (*Paspalum notatum*), 6 weeks

Figure 4. The three different grasses

The Manning's equation was used to compute the roughness coefficient in the channel. It is a function of the flow velocity, flow area, and channel slope as shown in equation 1. n is the Manning's roughness coefficient, v is the flow velocity (m/s), R_h is the hydraulic radius (m), and S_o is the channel slope (%). The shear stress was calculated using equation 2. τ is the shear stress (kPa), γ is the unit weight of water (kN/m^3), d is the average water depth measured from the top of the grass to the water surface during testing, and S is the water surface slope (%)

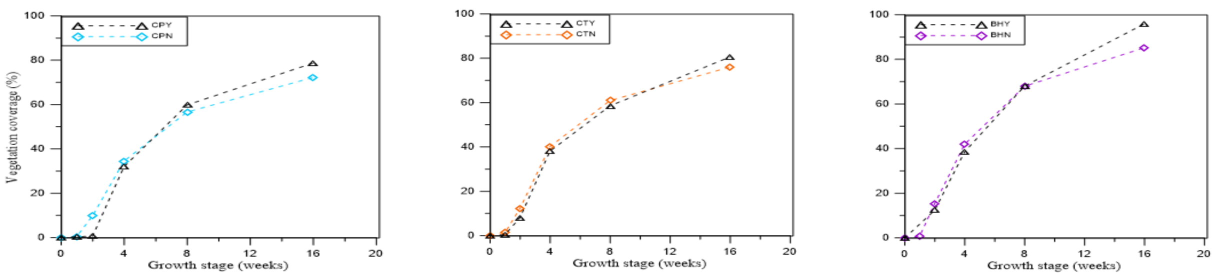
$$n = \frac{1}{V} R_h^{\frac{2}{3}} S_o^{\frac{1}{2}} \quad [1]$$

$$\tau = \gamma \times d \times S \quad [2]$$

3. RESULTS AND DISCUSSIONS

3.1 Vegetation coverage

The percentage vegetation area coverage was computed using Image J software and the results show that at four months Bahia grass recorded more than 80 % and 90 % without and with RECP respectively while Carpet and Centipede grass recorded 80 % or less in both conditions. This might be related to the high growth rate and longer leaves of Bahia grass. Figure 5 shows the vegetation coverage for each grass. The results show that at one month the conditions without RECP were slightly taller than that with RECP. At two to four months the grass heights for Carpet and Centipede grass were almost the same in both conditions (with and without RECP). Bahia grass showed slight increase in grass height after installing the RECP. It was observed that during testing the conditions with RECP were slightly taller than that without RECP. This was the case even if the height of the grass was the same in both conditions before testing. The ratio of the height of grass during testing to the height of grass before testing was referred to as bending ratio.

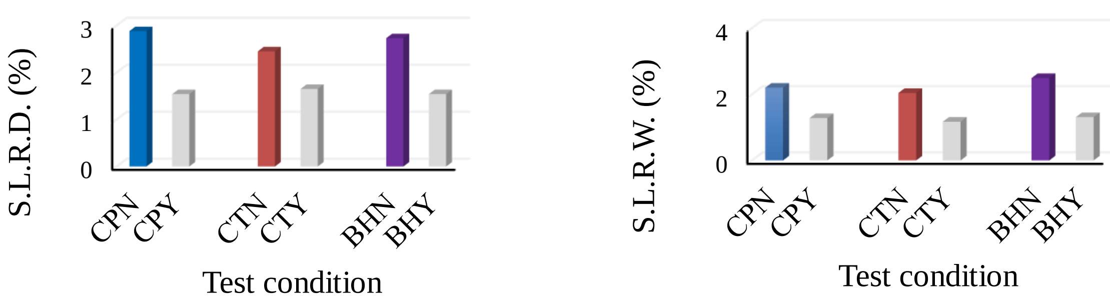


(a) Carpet grass (b) Centipede grass (c) Bahia grass

Figure 5. Vegetation coverage for each grass

3.2 Soil Loss Rate

The total soil loss rate was computed by adding the soil loss rates for each stage test of the same method. For example, the total S.L.R.D. is the summation of soil loss rate by depth at one, two and four month(s). When using the depth method of computing the soil loss rate, Carpet grass without RECP had the highest total soil loss rate (2.88 %), followed by Bahia (2.73 %) and lastly Centipede grass without RECP (2.45 %). Carpet and Bahia grass with RECP recorded the least total soil loss rates of 1.54 % while Centipede grass was slightly higher (1.65 %). On the other hand, Bahia grass had the highest total soil loss rate by weight (2.49 %) followed by Carpet (2.2 %) and Centipede grass (2.04 %) all without RECP. The least total S.L.R.W. was recorded by Centipede grass (1.17 %), Carpet was next with 1.28 % and lastly Bahia grass (1.31 %) all with RECP. Figure 6 shows the total soil loss rate for the three grasses.

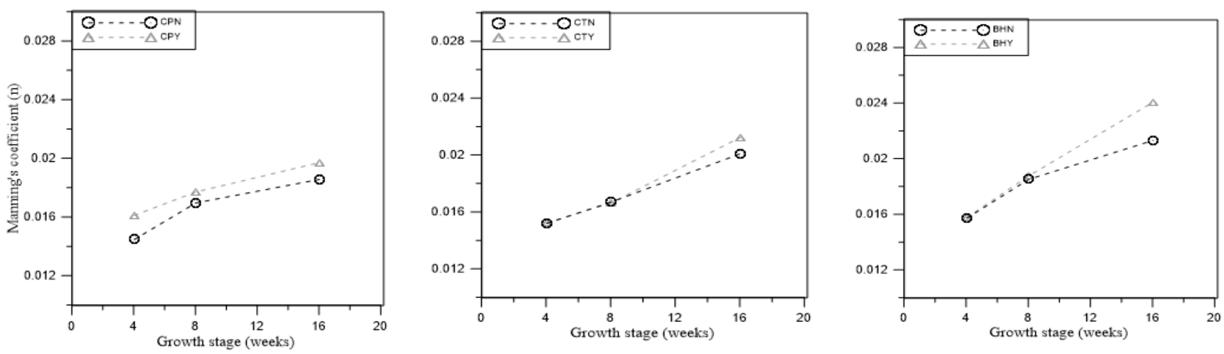


(a) Depth method (b) Weight method

Figure 6. Total soil loss rate

3.3 Manning's coefficient

The results show that the Manning's coefficient is directly proportional to grass growth in channel flow. When the grass grows, the stem become stronger and the leaves increase in size increasing the roughness of the channel bed. The results are in line with that of Mohammed et al., (2006) who mentioned that vegetation lower the flow velocity in channels due to the resistance from the stems and leaves of vegetation. Bahia grass had higher Manning's coefficients in both conditions compared to Carpet and Centipede grass. The Manning's coefficients of the vegetation with RECP were slightly higher than that without RECP. At four months, Carpet grass recorded the least coefficient values in both conditions; with and without RECP. This might be caused by the flexibility of the stems and poor growth resulting to increased flow velocity. Figure 7 shows the Manning's coefficients for the three grasses with and without RECP during the study. Installing RECP on Centipede and Bahia grass had a positive effect on the Manning's coefficient after two months. The effect was more significant on Bahia grass with a coefficient of 0.0241 and 0.0213 with and without RECP respectively at four months. This might be related to the higher growth rate of Bahia grass than the other grasses. On the other hand, the effect of RECP on Carpet grass was observed from the first month. The results also show that grass height and Manning's coefficient are directly proportional. The resistance produced by the grass increases with growth resulting to further decreased flow velocity. The effect of RECP on the Manning's coefficient was more on Bahia at four months than Centipede grass while the effect on Carpet grass was observed from the first month.



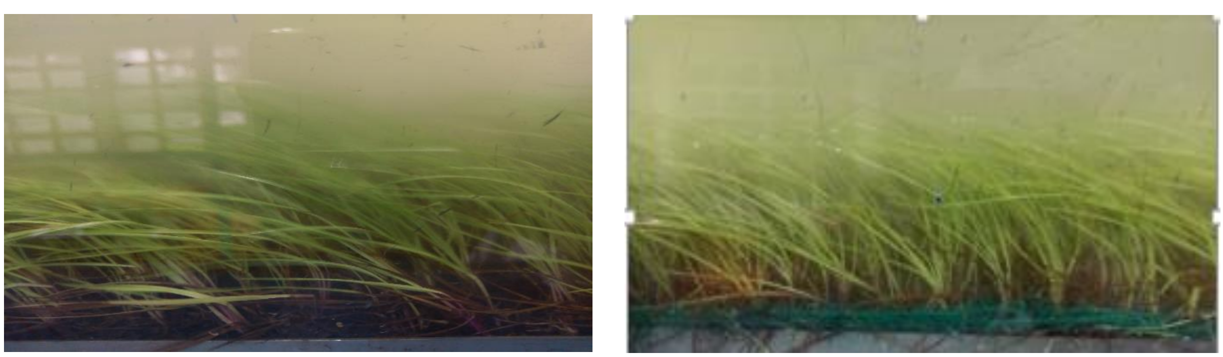
(a) Carpet grass

(b) Centipede grass

(c) Bahia grass

Figure 7 Manning's coefficient for each grass

The friction in the channel fluctuate greatly with the velocity of flow caused by the bending of the vegetation and depth of flow due to the increased energy absorbing area. The Manning's coefficients for the conditions with RECP are slightly more than that without RECP. This is caused by the bending of the vegetation during water flow. The more the grass bend the higher the flow velocity. In this study, the RECP provided strength to the grass stems leading to less bending of the grass as shown in Figure 8. On the other hand, the grass without RECP was susceptible to bending because it did not have any support. The flexibility of the grass contributes to the overall roughness in channel flow.



(a) Without RECP

(b) With RECP

Figure 8. Bending of Bahia grass during testing at four months

The force of moving the water against the bed of the channel (Shear stress) was computed using the Equation 2. The results show that shear stress is directly proportional to vegetation growth. At one month the shear stress was less than at two and four months in all conditions. Bahia grass had the highest shear stress both with and without RECP in all the growth stages except in the first month without RECP. It was followed by Carpet grass and the least shear stress was recorded by Centipede grass

4. CONCLUSIONS

This study presents the effects of RECP during the growth of different grasses on the Manning's coefficient in an open channel flow. Three types of grasses have been used in conducting this experiment and these are Carpet (*Axonopus fissifolius*), Centipede (*Eremochloa ophiuroides*), and Bahia (*Paspalum notatum*) grass.

Bahia grass had the highest vegetation area coverage than Carpet and Centipede grasses either with or without RECP. Installing RECP increased the vegetation area coverage two months after planting in all the grasses. At four months the vegetation area coverage without RECP was 85 %, 76 %, and 72 % while with RECP it was 96 %, 81 %, and 79 % for Bahia, Centipede, and Carpet grass respectively.

The height of Bahia grass was higher than that of Carpet and Centipede grass in both conditions. At four months the heights of Carpet and Centipede grass were 0.07 m and 0.06 m respectively without and with RECP. Bahia grass was 0.1 m and 0.12 m without and with RECP at four months. The use of RECP had no or less effect on the heights of Carpet and Centipede grasses in this study.

The total S.L.R.W. for the grasses without RECP were much higher than when RECP was used. Carpet, Centipede, and Bahia grass recorded 2.2 %, 2.04 %, and 2.49 % respectively without RECP. Installing RECP reduced the total S.L.R.W. to 1.28 %, 1.17 %, and 1.31 % for Carpet, Centipede, and Bahia grass respectively. The erosion rates were also reduced after installing the RECP when the depth method of computing soil loss was used.

The Manning's coefficient is directly proportional to the grass growth, the coefficients increases with time. The grasses with RECP had slightly higher coefficients than without RECP. At four months Carpet, Centipede, and Bahia grass had coefficients of 0.0186, 0.0201, and 0.0213 respectively without RECP. Using RECP increased the coefficients to 0.0197, 0.0212, and 0.0241 for Carpet, Centipede, and Bahia grass respectively. Grass height was found to be directly proportional to the Manning's coefficient and shear stress.

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