Study on the analysis of simulated rainfall test for multifunctional planting net

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Abstract. In this study, Japan's multifunctional materials company was used to provide the phytosanitary materials jointly developed by Yamaguchi University, and the red soil of the National Pingtung University of Science and Technology Soil and Water Conservation Experimental Zone was used as the experimental soil matrix to test the densities (SP45 and SP60) and slopes (25, 35 and 45 degree) of different paving under the rainfall simulating test (with I=80mm/hr). The analysis found that uses the multifunctional planting net can effectively reduce runoff and soil loss. The steeper the slope, the more runoff and soil loss it produces. Multifunctional planting nets with higher density can reduce the effect of runoff and soil loss, this statistics have not yet reached significant variance levels. This experiment is discussing the slope commonly used in engineering. These results can be used as a reference for further experiment planning.

1. Introduction
Taiwan is narrow and densely populated, with mountains accounting for 74% of the island. Because the development of flats is approaching saturation, the development of mountains is increasing year by year, with the addition of fragile geological environment in Taiwan, typhoons and rainstorms often cause massive soil loss, which leads to severe disasters everywhere, such as collapse, landslip and debris flow. In view of this, based on the fact that the soil of steep hillslopes is often stabilized with planting nets, this study aims at investigating the changes in runoff and erosion caused in the red soil areas for analysis and exploration, so as to achieve sustainable operation and utilization. Fan and Han (1991) [1-4]proposed that, due to the existence of fish-scale pits and the effects of micro-topography including uneven ground, some water will be stored. However, with the increase of gradients, slopes will become steeper and the retention capacity will decrease, so that some water stored in fish-scale pits and depressions will generate runoff with the increase of gradients. Huang and Chang (2000) [5]suggested that the grass blocks, creeping stems, subterraneous stems or seeds of Bermuda grass can be used to build lawns. As a temperate seasonal perennial grass, it can adapt to tropical to subtropical climate with strong growth potential and rapid grass cover ratio, and can grow for years to generate green lawns.
Lin (2006) [6] proposed that applying artificial geo-textiles to bare slopes with poor geologic conditions and lack of planting substrate plates can create long-term good substrate plates, improve planting survival rate and rapidly protect planting and greening of hillslopes. Artificial geo-textiles can effectively isolate soil layers and prevent raindrops from hitting the soil directly, and the advantages of erosion control mesh are rapid hillslope planting and greening, effective protection of slope and low cost. Chen et al. (2008) [7] mentioned that, to improve the erosion control rate of artificial geo-textiles, its structural elements shall have high mulch ratio to reduce the soil areas hit by raindrops or the uniformly dispersed horizontal silt structures, so as to hold back sand and decrease runoff energy. Lin and Chang (2008) [8-10] indicated that, after planting on bare slopes, the overall density of soil decreases significantly and the organic matters increase significantly, which improves the plant growth substrate plates and benefits the future plant growth. Lin et al. (2011) [11-12] suggested that, the clad mesh materials can fix the spray planting base materials, so that the spray planting base materials are not easy to lose. Furthermore, combined with the clad mesh materials mulched slopes, it can increase the water retention capacity, leading to low death rate of the introduced planting. Jien et al. (2013) [13-15] proposed that, geosynthetic mesh ratio is the most important erosion control factor. Taking the common slope in Taiwan as an example (35°-40°), the mesh with the cover ratio about 75% can reduce the erosion by 65% (compared with the erosion under the condition without any geosynthetic mesh), the mesh with the cover ratio about 85% can reduce the erosion by 90% and the mesh with the cover ratio over 95% can reduce the erosion by 98%. From the above, few practical tests have been conducted on comparison of planting net materials. Therefore, in this study, the planting nets jointly developed by Japan's multifunctional materials company and Yamaguchi University were employed, and the red soil of the National Pingtung University of Science and Technology Soil and Water Conservation Experimental Zone was used as the experimental soil matrix to test the erosion control effects and planting growth under the nets with different densities and slopes. The laboratory experiment was conducted to test the permeability, breathability and moisture preservation of planting nets, to detect runoff, soil erosion and hillslope stability and to test the growth of bermuda grass, so as to provide reference for possible applications of this project in the future. The nets have the functions of preventing topsoil loss and improving permeability and water retention of topsoil and can be cooperated with the planting base materials selected in various soil & water conservation and greening works for planting restoration, and its most important feature is: entanglement and immobilization resulting from grass root growth are applied to achieve the purpose of preventing hill soil being eroded and environmental greening, to reduce raindrops hitting the topsoil and to increase the surface roughness, so as to reduce the surface runoff velocity, which helps to reduce soil erosion. There are four main protection functions of artificial geo-textiles for hillslope soil: splash protection, erosion control, water retention and reinforcement.

2. Materials and Method

2.1. Experimental materials

1. Tested soil

The soil in the National Pingtung University of Science and Technology Soil and Water Conservation Experimental Zone was adopted, and is featured of a lack of alkali metals and alkaline-earth metals and being rich in iron and aluminum oxides. The soil is strongly acidic to extremely acidic, topsoil and subsoil PH5.0-5.5, undersoil PH4.0, mainly composed of clay loam and loam, that is to say, the effects of paving method are shown at different gradients and overshadow those of the variables set in the experiment oam, high in viscosity and plasticity, developed in soil structure, well-drained and low in organic matters.

2. Experimental equipment

SP-45 and SP-60 planting nets provided by Japan's multifunctional materials company were used and respectively numbered 45 and 60, and they are featured of preventing water and soil loss, accelerating of natural vegetation import and stabilizing hillslope planting and greening.
The main material is polyester fiber, and the reinforced meshes are polyethylene. The advantages of nets are:

1. Preventing soil erosion: being able to prevent damages to soil structure resulting from rainfalls hitting the surface, to achieve the feature of soil fixation.

2. Planting function: cooperating with seed germination, so that the seeds can adhere to the slope effectively.

3. Environmental safety: the used materials will not produce heavy metal pollution and dissolution.

4. Construction economy: the prices of the materials are lower than those at the same grade by using the same construction method.

2.2. Experimental method
In this study, artificial rainfall simulation where the variables are easy to control was adopted. A drip-type artificial rainfall simulator was used as the device and the experimental equipment included rainfall devices, water pumps, and flow and control valves of water supply tanks.

The rainfall simulation test instrument is about 300cm high and the instrument support length is about 250cm long. In the support, there is a water pipe loop where there are holes being used for installing medical needles. In the experiment, the planting nets and bare lands with different densities were paved, under the conditions of 1 soil, 3 gradients and 4 times, to regularly test the soil erosion produced by rainfall simulation under different conditions.

Experimental steps of indoor artificial rainfall simulators

1. Constant head was achieved, so that the water flow is stable.

2. Standards were made according to the rainfall intensity I=80mm/hr.

3. The gradients of the slope racks of experimental articles were respectively 25°, 35° and 45°.

4. Soil plates were placed on the slope racks and put under the rainfall simulators to prepare for the experiment.

5. The rainfall time was 60min, and the data of erosion and runoff were collected once every 10min.

2.3. Research Process
The purpose of this study is to determine the changes in runoff and erosion of steep slopes when planting net materials are applied to red soil matrix through indoor rainfall experiment, and the research process is shown in Figure 1.
3. Results and Discussion

3.1. Comparison of experimental results

In this study, the experimental results without restoration period (paved directly without waiting for the subsequent plant growth) were sampled in every 10min and then accumulated and drawn, as shown in Figures 2 to 7, Figure 8 and Figure 9.
Figure 2. Runoff of SP-45 at different gradients without restoration period.

Figure 3. Soil loss of SP-45 at different gradients without restoration period.

Figure 4. Runoff of SP-60 at different gradients without restoration period.

Figure 5. Soil loss of SP-60 at different gradients without restoration period.

Figure 6. Runoff of bare soil at different gradients without restoration period.

Figure 7. Soil loss of bare soil at different gradients without restoration period.

Figure 8. Multifunctional planting net sample without restoration period.

Figure 9. Bare soil sample without restoration period.

As shown in Figure 8 and Figure 9, the samples without restoration period mainly show the differences of the planting net materials. The cotton-like materials shown in Figure 8 are the main
materials and fixed with PVC mesh lashings. Seeds, fertilizers or buffer agents can also be added into the materials. In this study, no substance was added.

SP-45 has a thin layer of polyester fiber (made by means of staple accumulation and dispersion) that absorbs runoff and reduces soil splash erosion. Figure 2 shows that the saturation point is reached at about the 40th minute with the set rainfall intensity and the runoff begins to increase. Figure 3 shows that the minimum soil loss appears at the gradient of 25°, and the soil stability under this condition cannot be compared with that of the sample at a lower angle as the angle increases. The topsoil is still somewhat eroded despite of the protection of the net.

Figures 2 and 4 show that the net thickness is inversely proportional to the runoff. As the data show, the thicker SP-60 net is significantly stronger than the SP-45 net in water absorption. Because it can protect the soil, the soil loss is less than that caused by SP-45. At the gentle gradient of 25°, because the slope is protected by thick materials and the net can absorb water at a rate equal to the amount dropped by the rainfall simulator (set at 80mm/hr), an important factor of water infiltration into soil is reduced. Figure 5 shows that the soil loss is stable.

However, for the bare samples without net protection, the soil and the rainwater contact directly and thus cause splash erosion. At the gradient of 25°, due to gentle slope, there is time for the rainwater infiltration. Figure 6 shows that there is no sharp data increase or decrease in runoff and soil loss. At the gradient of 45°, due to steep slope, the rainwater infiltration is slow, resulting in extremely high soil loss at the beginning. As a result of splash erosion, small pits gradually appear in the area where the soil is hit by raindrops.

3.2. Statistical comparison of experimental results

The data obtained from the experiment was collected to get the average values (as shown in Table 1, among them, the results in red were deleted due to large difference in values in the third time), and then the two-way ANOVA was conducted with the results shown in Tables 2 and 3. According to the analysis results of runoff shown in Tables 1 and 2, the treatment differences of bare land, SP-45 and SP-60 are significantly. Although the values show the effects of gradients, that is, more runoff will be generated with higher gradient, the differences are not statistically significant. That is to say, the effects of paving method are shown at different gradients and overshadow those of the variables set in the experiment.

| Experimental gradient (degree) | Experiment number | Runoff (ml) | Soil loss (g) |
|-------------------------------|-------------------|-------------|--------------|
|                               | Bare land         | SP-45       | SP-60        | Bare land | SP-45 | SP-60 |
| BARE LAND                     |                   |             |              |           |       |       |
| 25                            | 1                 | 606         | 601          | 361       | 36.271| 0.428 | 0.145 |
|                               | 2                 | 615         | 592          | 370       | 36.033| 0.439 | 0.155 |
|                               | 3                 | 610.5       | 596.5        | 365.5     | 36.152| 0.4335| 0.15  |
|                               | Average           | 610.5       | 596.5        | 365.5     | 36.152| 0.4335| 0.15  |
| 35                            | 1                 | 733         | 691          | 397       | 52.036| 1.803 | 1.419 |
|                               | 2                 | 718         | 703          | 396       | 51.344| 1.788 | 1.423 |
|                               | 3                 | 725.5       | 697          | 793       | 51.69 | 1.7955| 2.842 |
|                               | Average           | 725.5       | 697          | 396.5     | 51.69 | 1.7955| 1.421 |
| 45                            | 1                 | 857         | 709          | 385       | 71.286| 2.327 | 1.916 |
|                               | 2                 | 870         | 712          | 391       | 71.355| 4.538 | 1.916 |

Table 1. Table of experimental data.
Table 2. Analysis results of runoff by two-way ANOVA.

| Variable | SS     | Variance | MS       | F        | P-value | Critical value |
|----------|--------|----------|----------|----------|---------|----------------|
| Line     | 25880.17 | 2        | 12940.08 | 3.573334 | 0.128775 | 6.944272       |
| Column   | 207665.2  | 2        | 103832.6 | 28.6728  | 0.004252 | 6.944272       |
| Fault    | 14485.17  | 4        | 3621.292 |          |         |                |
| Sum total | 248030.5 | 8        |          |          |         |                |

Table 3. Analysis results of soil loss by two-way ANOVA.

| Variable | SS        | Variance | MS       | F        | P-value | Critical value |
|----------|-----------|----------|----------|----------|---------|----------------|
| Line     | 261.2135  | 2        | 130.6067 | 1.431069 | 0.339783 | 6.944272       |
| Column   | 5324.425  | 2        | 2662.213 | 29.17009 | 0.004117 | 6.944272       |
| Fault    | 365.0606  | 4        | 91.26515 |          |         |                |
| Sum total | 5950.699 | 8        |          |          |         |                |

According to the analysis results of soil loss shown in Tables 1 and 3, the treatment differences of bare land, SP-45 and SP-60 are significantly. Although the values show the effects of gradients, that is, more soil loss will be generated with higher gradient, the differences are not statistically significant, that is, the effects of paving method are shown at different gradients and overshadow those of the variables set in the experiment.

3.3. Comprehensive discussion

The materials of multifunctional planting nets are featured of rapid initial protection to topsoil of bare slope and can achieve the significant differences in both runoff and soil loss through the experiment, which shows that the materials seem thin but have the functions same as the effects of facial masks. According to the experiment, the runoff is generally reduced by 50% and the soil loss is generally reduced by 90% within 1 hour. We believe that this circumstance will be helpful to the subsequent growth of plants. In addition, after growth, erosion control can be further extended and strengthened and direct runoff can be reduced. Therefore, we are looking forward to relevant experiments and discussions in the future.

In this experiment, the ratios close to 1:2 and 1:1.5 and 1.1 which are commonly used in engineering and the gradients of 25°, 35° and 45° were selected for comparison and discussion. The result data show more runoff and soil loss with steeper slopes, but this condition is not significant statistically. Particularly, the runoff of SP-60 at various gradients is roughly the same and lower, which may result from the distinctiveness of the materials. This can also be deeply discussed in the future. In material design, because SP-60 is thicker and denser than SP-45, the experimental results also show better effects, particularly in runoff. SP-60 is more effective in moisturizing and can promote plant restoration. However, if erosion control of the materials is the only feature considered, SP-45 can achieve fairly good effects. Therefore, the experimental results can be referred to if light weight, price and constructability are considered in future promotion. Nevertheless, how the multifunctional planting net materials can achieve such a significant mechanism of protecting bare slopes and reducing soil erosion shall be understood and broken in the future.
4. Conclusion and Suggestion

4.1. Conclusion
1. The multifunctional planting net SP-45 is thinner than SP-60 and absorbs less water, so the runoff cannot be effectively reduced. However, compared with the bare land without planting net in the control group, it still has the function of improving runoff, and the moisturizing effect of the material is greatly helpful to the soil surface and plant restoration.

2. The two materials with different densities both have significant effects on erosion. At the gradient below 25°, SP-60 can almost completely retain the soil without producing any erosion.

3. At the gradient of 45° (too steep), in terms of runoff, multifunctional materials cannot fully functional, but can effectively reduce erosion if combined with planting in the future.

4.2. Suggestion
The planting restoration period can be included in the comparison items, to discuss the effects of planting restoration period on erosion and runoff. Moreover, correlation analysis can be conducted based on its erosion, runoff and planting restoration period.

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