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Geo-textiles for Side Slope Protection: Preparation and Characteristics

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Abstract
The vegetation blanket is the most common choice for soil and water preservation. This is a feasible method that protects the land and environment according to basic agriculture and engineering theories. This study manufactured eco-friendly nonwoven vegetation blankets by using cotton fibers, far-infrared fibers, PLA fibers, and low melting-point fibers at a 1:1:7:1 ratio. This ratio yielded from the pilot study provides the resulting vegetation blankets' optimum air permeability and water absorption. This study further finds that a needle-punching density of 30 needles/cm^2 allows fibers to lie in a loose structure, and therefore yielding the optimum air permeability and water absorption. In plant growth evaluation, for nonwoven vegetation blankets that contain 50 wt% far-infrared fibers, the plant growth length is 1.3 times greater than that of blankets with 10 wt% far-infrared fibers. This result proves that far-infrared fibers have usually been applied to plant growth.

Key words: *soil and water preservation, vegetation blanket, polylactic acid (PLA) fibers, far-infrared fibers, nonwoven fabrics.*

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Introduction

Typhoons or rainy season in Taiwan often cause landslides, bringing about various levels of disaster by blocking roads, and destroying or burying numerous facilities, thus causing a a considerable wound and death toll and property losses. Without there being soil grip supported and sustained by plants, land is prone to fracture and collapse after a great amount of rainfall. Continuous heavy rains erode the land, and the water cannot be easily expelled, which results in landslides [1-3]. To prevent the loss of water and soil, it is essential to increase the grip traction between the land's surface and the object that covers it. The direct force from rainfall is then alleviated and run-offs on the land's surface are decelerated, thus decreasing the erosion of the topsoil.

Grass, wood, or withered branches and leaves are often used to cover land to protect soil from erosion by rain. This study used polylactic acid (PLA) fibers and low melting-point PLA fibers (low-Tm PLA) as the main body of eco-friendly vegetation blankets in combination with a smaller amount of far-infrared fibers and cotton fibers. Biodegradable PLA fibers have usually been applied in biomedical fields, such as in absorbable surgical sutures, artificial bone implants and nerve conduits, etc. due to their non--pollution effects on the environment [4-7], but rarely in soilless culture [8]. Far-infrared fibers radiate far-infrared rays between 4 to 14 μm, which helps plant growth [9, 10]. As PLA fibers, low-Tm PLA fibers and far-infrared fibers are synthetic, both of which have poor water absorption. Cotton fibers are thus added to compensate for this deficiency. In addition, nonwoven fabrics require only a short production time and have a low cost [11], both of which support the study's eco-friendly approach in terms of material selection and savings in manufacturing energy.

Experimental

Materials

Polylactic acid (PLA) fibers (Far Eastern Fibertech Co., Ltd, Taiwan) have a melt-pointing of 160°C, fineness of 2 D, fiber length of 50 mm, single fiber strength of 3.5 g/D, and elongation of 45%. Low melting-point (low-Tm) PLA fibers (Far Eastern Fibertech Co., Ltd, Taiwan) have a melting point of 130°C, fineness of 2 D, fiber length of 50 mm, single fiber strength of 3.2 g/D, and elongation of 50%. Far-infrared fibers (True Young Co., Ltd, Taiwan) are solid polyester fibers with a fineness of 6 D, fiber length of 64 mm, and the concentration of far-infrared powders added is 1.5%. Far infrared powders were added during the production of far-infrared fibers. Therefore the powders are not just adhered to the surface of the fibers. Cotton fibers have a fineness between 0.9 and 1.7 D, fiber length of 200-250 mm, and density of 0.57~0.74 g/cm^3. Centipedegrasses (Eremocholoa Ophiuroides) tend to crawl and spread over land, and possess good grip traction. They can also endure droughts and are attracted to sunshine. *Centipedegrasses* are the most common grasses used for side slope protection in water and soil preservation.

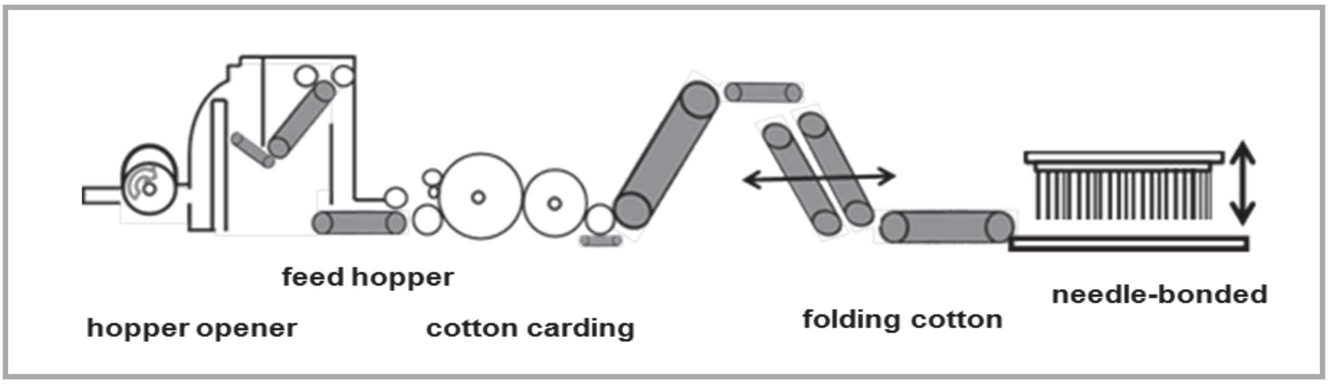

Figure 1. *Nonwoven process.*

Production of geo-textiles

First PLA fibers, far-infrared fibers, low-Tm fibers, and cotton fibers with a 1:1:7:1 ratio (i.e., 100 g, 100 g, 700 g, and 100 g, respectively) were produced into nonwoven vegetation blankets. Originally far-infrared fibers comprised only 10 wt% of the four fibers. Second the amount of far-infrared fibers was varied from 10, 20, 30, 40, to 50 wt%, with corresponding weights of 100g, 225 g, 386 g, 600 g, and 900 g, respectively, while the wt% of the other three fibers remained the same. All fibers underwent separation and fluffing by an opener, and then carding and stripping by the cylinder and doffer so that most fibers lay in the same direction, thus forming fiber nets. The fiber nets then underwent needle-punching to entangle and reinforce the final nonwoven fabrics with a compact structure, as indicated in ***Figure 1***. The needles have a specification of 15*18*36*3 1/2 R333 G and were purchased from GROZ-BECKERT, Germany. Nonwoven fabrics were then thermally bonded in an oven at 140°C, during which low-Tm PLA fibers melted and became viscous to create thermal bonding points where the fibers crossed, thus strengthening the nonwoven fabric. The nonwoven vegetation blankets prepared were evaluated in terms of air permeability, water absorption, tensile strength, tear strength, and plant growth.

Test

Tensile strength test

This test evaluated the tensile strength of the nonwoven fabrics, according to ASTM D5035-06 [12] (American Society for Testing Material) by means of an Instron 5566 (Instron, U.S.). The sample size was 180 × 25.4 mm, and the tensile speed 305 ± 13 mm/min. Five samples taken from each cross machine direction (CD) and machine direction (MD) were tested for their definitive values, determining the optimum manufacturing parameters for the nonwoven fabrics.

Tear strength sest

This test was performed on five samples, each taken along the MD or CD, based on ASTM D4533 [13] (Trapezoidal Method). Samples were cut into equilateral trapezoids. The short side, which is parallel to the long side, is cut perpendicular in its center with a 1-cm long cut. Samples were tested by an Instron 5566 (Instron, U.S.) with 75-mm wide gauges, gauge distance of 25 mm, and tensile speed of 150 mm/min.

Air permeability test

This test was performed according to ASTM D737 [14] by a FX3300, (TEXTEST, Switzerland). Samples had a size of 255 mm × 255 mm. When being tested, samples had to be held flat and the fixture edges enclosed firmly to seal the air. The number of samples were10 pieces, and the gas pressure was 125 Pa.

Water absorption test

This test was performed according to ASTM C97 [15]. Samples of 10 × 10 cm were weighed, and the weight recorded as W_0. Next they were immersed in water for 10 minutes, and then removed and placed on a porous net until dripping ceased. The samples were weighed again, and the weight recorded as W_1. Water absorption was calculated by $(W_1 – W_0) W_0 \times 100$.

Plant growth evaluation

In plant growth evaluation, *centipedegrass* seeds were grown with various nonwoven vegetation blankets. The pot was filled with 5 kg of soil and then the nonwoven fabrics were placed on top of the soils. The plant lengths were recorded for comparison, determining the optimum nonwoven vegetation blankets.

Statistical analysis

SPSS statistics software (version 20.0) was used in order to examine the influential factors. The alpha (α) level is commonly set at 5% with a confidence interval of 95%. When $p < 0.05$ is sustained, the results indicate significance. For specific analyses of variations between groups that are exemplified by the statistically significant differences in one-way ANOVA, this study then used the post hoc Scheffe's test in order to examine between what specified parameters the statistically significant difference was present.

Results and discussion

Effect of needle-punching density on air permeability of nonwoven vegetation blankets

Figure 2 (see page104) shows the influence of the needle-punching density on the air permeability of nonwoven vegetation blankets. The needle-punching density is inversely proportionate to the air permeability. When the needle-punching density increases from 30 needles/cm^2 to 120 needles/cm^2, the air permeability decreases from 166 $cm^3/s/cm^2$ to 120 $cm^3/s/cm^2$. This result is in conformity with the One-way ANOVA and Scheff's results, ranking the positive influence of needle punching density on the air permeability of nonwoven vegetation blanks from highest to lowest as 30>60, 90>120 needles/cm^2. Scheffe's test shows that the needle-punching density of 30 needles/cm^2 results in maximum air permeability. For both 60 needles/cm^2 and 90 needles/cm^2 there are no significant differences. The influence of a needle-punching density of 120 needles/cm^2 on the air permeability is significantly lower than for the other parameters.

This is due to the needle-punching process: The barbed-needle plates move up

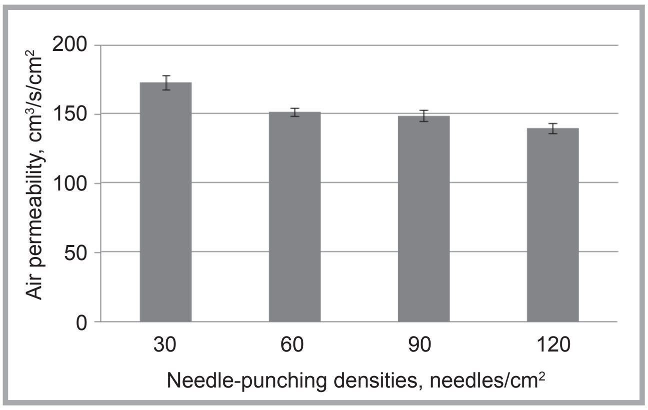

Figure 2. *Air permeability of nonwoven vegetation blankets with 10 wt% far-infrared fibers in relation to needle-punching densities. The thermal-bonding temperature is 140°C, and the thermal-bonding duration is 30 minutes.*

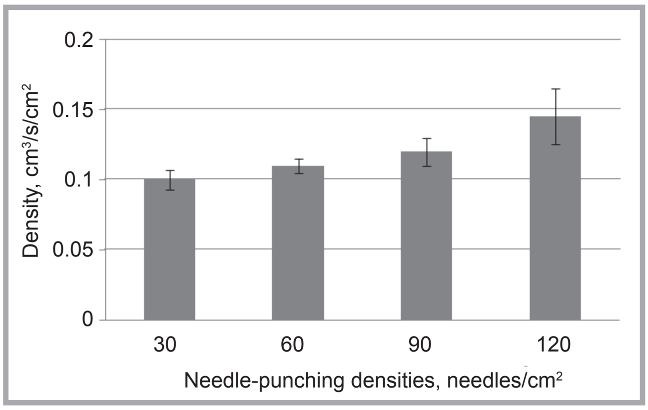

Figure 3. *Density of nonwoven vegetation blankets with 10 wt% far-infrared fibers in relation to needle-punching densities. The thermal-bonding temperature is 140°C, and the thermal-bonding duration is 30 minutes.*

and down repeatedly, pushing and then pulling the fibers through the net. Namely horizontal fibers from the surface are caught by the barbed-needles and move vertically, displacing fibers upwards and downwards. During this process, needles and responding fibers also create a certain extrusion in the net, drawing fibers closer and entangling the horizontal and vertical fibers. This movement also reduces the thickness of nonwoven fabrics. After needle-punching, when experiencing stress, nonwoven fabrics are able to avoid the slip of horizontal fibers, and the fiber structure thus becomes compact, resulting in a greater density and lower air permeability. ***Figure 3*** shows that following an increase in needle-punching density from 30 needles/cm² to 120 needles/cm², the density of nonwoven fabrics increases from 0.1011 to 0.1489 g/cm³. Hence the greater the needle-punching density, the lower the air permeability of the nonwoven vegetation blankets. The thermally-treated nonwoven vegetation blankets have an air permeability that is dependent on the amount of low melting point PLA fibers. The melted sheath of low melting point PLA fibers can form thermal bonding points that join the fibers. These thermal bonding points shield the pores in the nonwoven fabrics, thereby decreasing their air permeability.

Effect of the proportion of far-infrared fibers on the air permeability of nonwoven vegetation blankets

Table 1 lists the influence of the various proportions of far-infrared fibers on air permeability. Regardless of the proportions of far-infrared fibers, nonwoven vegetation blankets all exhibit high air permeability, ranging from 148 to 161 cm³/s/cm². This is attributed to the fineness of the far-infrared fibers, which is 6 dtex, which is thick. When nonwoven fabrics are composed of thick fibers, larger pores form between fibers, which allow airflow to pass easily, resulting in high air permeability.

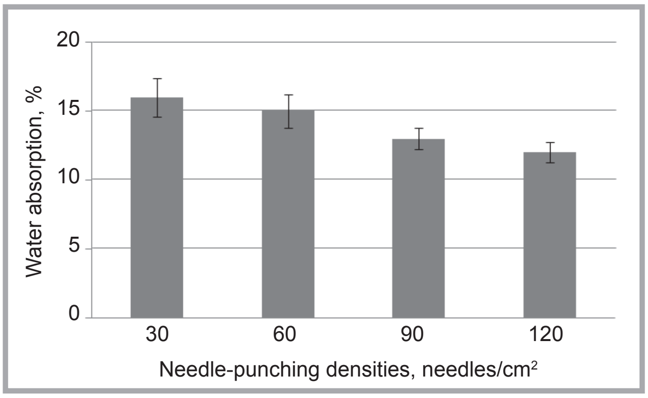

Figure 4. *Water absorption of nonwoven vegetation blankets with 10 wt% far-infrared fibers. The thermal-bonding temperature is 140°C, and the thermal-bonding duration is 30 minutes.*

Table 1. *Air permeability of nonwoven vegetation blankets in relation to various proportions of far-infrared fibers.*

Proportion of far-infrared fibers, wt%	Air permeability without thermal-bonding, cm³/s/cm²	Air permeability with thermal-bonding, cm³/s/cm²
10	145.3±1	148.2±1
20	159.6±1	155.8±1
30	166.0±1	158.5±1
40	166.5±1	160.2±1
50	170.7±1	161.2±1

Effect of needle-punching density on the water absorption of nonwoven vegetation blankets

Figure 4 illustrates the influence of needle-punching density on the water absorption of nonwoven vegetation blankets. The greater the needle-punching density, the lower the water absorption. This result is in conformity with the One-way ANOVA and Scheff's results, ranking the positive influence of needle punching density on the water absorption of nonwoven vegetation blanks from highest to lowest as 30>60, 90,120 needles/cm². Scheff method results indicate that the water absorption of a needle-punching density of 30 needles/cm² is significantly higher than for the other parameters. With a density of 30 needles/cm², the blankets exhibit a water absorption of 16.04%. However, when the needle-punching density increases to 120 needles/cm², water absorption decreases to 12.17%. This decrease occurs because with a greater needle-punching

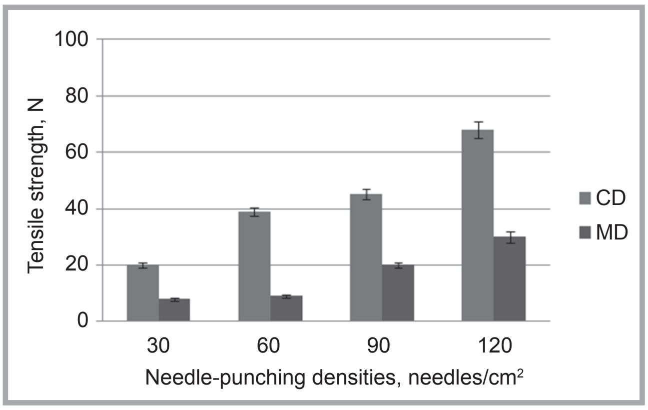

Figure 5. *Tensile strength along the CD or MD of the nonwoven vegetation blankets with 10 wt% far-infrared fibers in relation to various needle-punching densities. The thermal-bonding temperature is 140°C, and the thermal-bonding duration is 30 minutes.*

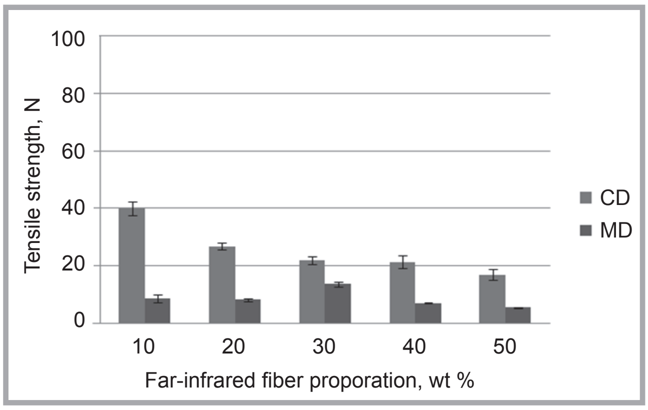

Figure 6. *Tensile strength along the CD or MD of nonwoven vegetation blankets with 10 wt% far-infrared fibers in relation to various proportions of far-infrared fibers. The thermal-bonding temperature is 140°C, and the thermal-bonding duration is 30 minutes.*

density, a larger amount of fibers from the nonwoven fabric surface are pushed downward through the fabric. The needle-punching machine compresses the nonwoven fabric, decreasing the size of the fabric's pores. Thus water molecules are not prone to be absorbed inside nonwoven fabrics.

Effect of the proportion of far-infrared fibers on the water absorption of nonwoven vegetation blankets

Table 2 reports the relationship between the proportions of far-infrared fibers and the water absorption of nonwoven vegetation blankets. Regardless of the proportions of far-infrared fibers, the blankets exhibit high water absorption, ranging from 15 to 16%. Far-infrared fibers have a fineness of 6 dtex, and being so thick they comprise larger pores when they are made into a fiber net. Water is then absorbed between these fibers, thus increasing the water absorption.

Effect of needle-punching density on the tensile strength of nonwoven vegetation blankets

Figure 5 shows the influence of various needle-punching densities on the tensile strength of nonwoven vegetation blankets, with each taken along the CD or MD, and ***Table 3*** reports their coefficient of variation percent (CV %). Based on ***Figure 4***, regardless of bieng along the CD or MD, the tensile strength increases with an increase in needle-punching density. This result is in conformity with the One-way ANOVA and Scheff's results, ranking the positive influence of needle punching density on the tensile strength of nonwoven vegetation blankets from lowest to highest as 30<60<90<120 needles/cm^2. Scheffe's test shows that the needle-punching densities have a significant difference from each other from 30 needles/cm^2 to 120 needles/cm^2. The influence of a needle-punching density of 120 needles/cm^2 on the tensile strength is significantly higher than for the other parameters. The greater the needle-punching density, the greater the needle-punching effect is distributed in each unit area. The barbed-needle plate brings more fibers from the surface to the interior of the nonwoven fabrics, reinforcing the combination and entanglement of the vertical and horizontal fibers as well as heightening the fabric density. In the tensile strength test, the reduction of slippery fibers is responsible for the increased strength of the blankets. With an increase in needle-punching density from 30 needles/cm^2 to 120 needles/cm^2, the tensile strength along the CD increases from 20.9 N to 73.9 N, and that along the MD increases from 7.1 N to 36.4 N. The CV percent, either along the CD or MD, is between 3.69~11.69 and falls within a rational range.

Effect of proportions of far-infrared fibers on the tensile strength of nonwoven vegetation blankets

Figure 6 shows the influence of the proportion of far-infrared fibers on the tensile strength of nonwoven vegetation blankets. The greater the amount of far-infrared fibers, the lower the tensile strength along the CD, due to the fact that an increase in the amount of far-infrared fiber means a decrease in the amount of PLA fibers with a smaller fineness in each unit area. Fibers with a low fineness create larger contact areas between them and an ensuing greater friction between them as well, thus reinforcing the tensile

Table 2. *Water absorption of nonwoven vegetation blankets in relation to various proportions of far-infrared fibers.*

Proportion of far-infrared, fibers wt%	Water absorption, %	Standard Deviation
10	15.09	0.597
20	16.01	0.541
30	16.28	0.813
40	16.04	0.853
50	15.71	0.346

Table 3. *Coefficients of variation percent (CV%) of tensile strength along the CD or MD of the nonwoven vegetation blankets in relation to various needle-punching densities.*

Needle-punching density, needles/cm^2	CV% of tensile strength along the CD	CV% of tensile strength along the MD
30	10.36	4.03
60	5.76	3.69
90	5.25	11.68
120	4.67	5.75

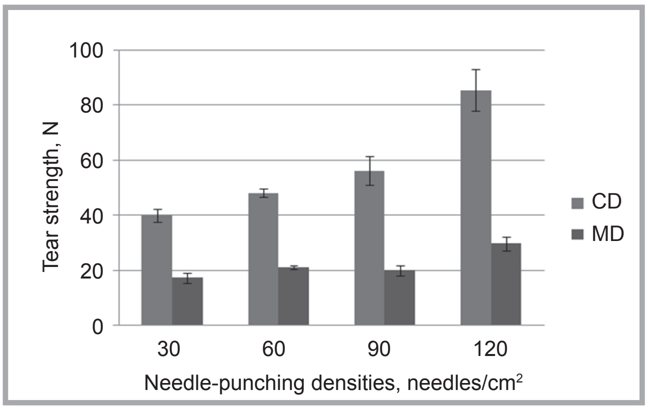

***Figure 7.** Tear strength along the CD or MD of nonwoven vegetation blankets with 10 wt% far-infrared fibers on relation to needle-punching density. The thermal-bonding temperature is 140°C, and the thermal -bonding duration is 30 minutes.*

strength of nonwoven fabrics. However, when nonwoven fabrics are composed of fibers with a high fineness, the fibers have smaller contact areas and their friction is low, thus decreasing the tensile strength of the blankets.

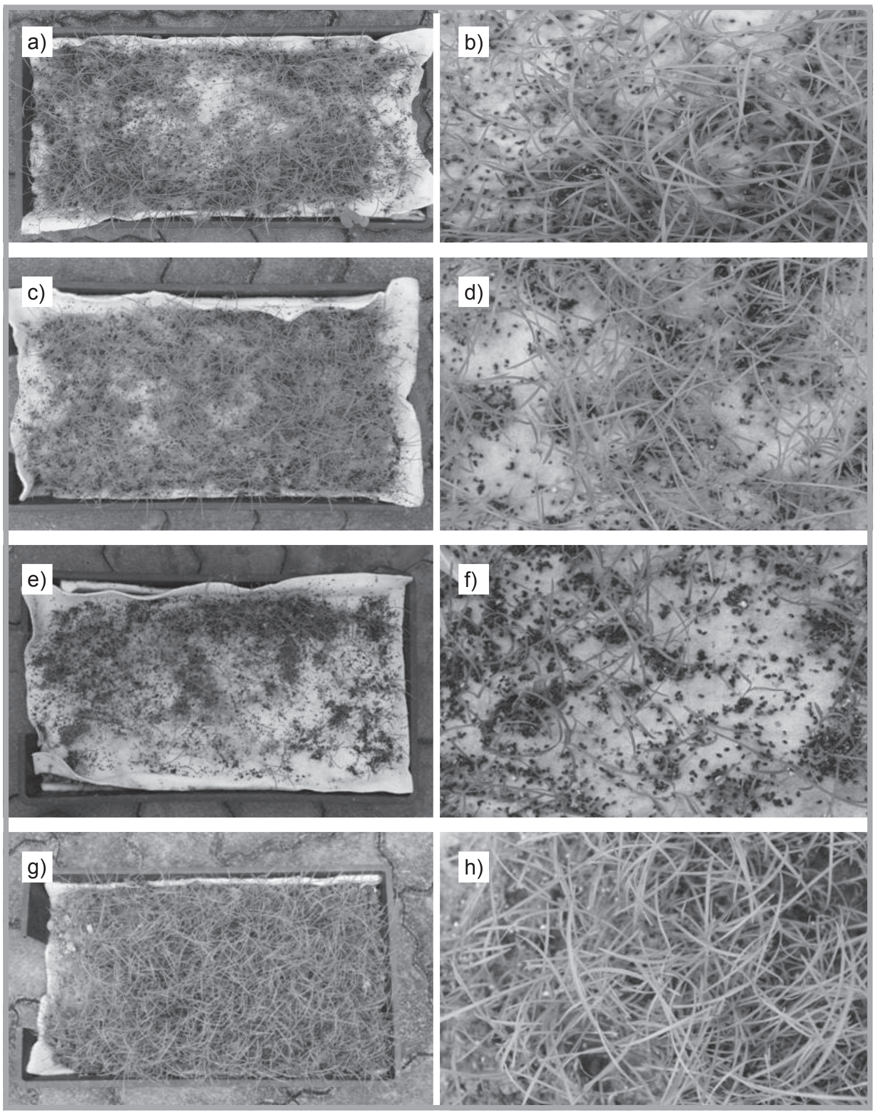

***Figure 8.** Plant growth from the blanket with 10 wt% far-infrared fibers. Needle-punching density is 30 needles/cm2. (a) is the plant growth, and (b) is the magnified squared area (Magnification 3.5×). Plant growth from the blanket with 50 wt% far-infrared fibers. Needle-punching density is 30 needles/cm2. (c) is the plant growth, and (d) is the magnified squared area (Magnification 3.5×). Plant growth from the blanket with 10 wt% far-infrared fibers. Needle-punching density is 120 needles/cm2. (e) is he plant growth, and (f) is the magnified squared area (Magnification 3.5×). Centipedegrass planted with pure soil. (g) is the plant growth, and (h) is the magnified squared area (Magnification 3.5×).*

Effect of needle-punching density on the tear strength of nonwoven vegetation blankets

Figure 7 illustrates the influence of needle-punching density on the tear strength along the CD or MD of nonwoven vegetation blankets, and ***Table 4*** reports the CV% of their tensile strength. According to ***Figure 7***, with an increase in needle-punching density, the tear strength along the CD or MD increases. This result is in conformity with the One-way ANOVA and Scheff's results, ranking the positive influence of needle punching density on the tear strength of nonwoven vegetation blanks from lowest to highest as 30<60<90<120 needles/cm^2. Scheff method results indicate that the tear strength of a needle-punching density of 120 needles/cm^2 is significantly higher than for the other parameters. With a higher needle-punching density, there are more fibers from the surface pushed downward and brought upward from the horizontal to vertical by the barbed-needle plate in a unit area of nonwoven fabrics, entangling and combining horizontal and vertical fibers. Therefore when the needle-punching density is increased from 30 needles/cm^2 to 120 needles/cm^2, the tear strength along the CD is increased from 62.14 N to 132.92 N and that along the MD from 26.22 N to 46.4 N. In ***Table 4***, regardless of being along the CD or MD, the CV% of the tensile strength is between 3.84 to 10.18, which is within a rational range.

Plant growth evaluation

Only three nonwoven vegetation blankets are selected based on their air permeability and water absorption properties. *Centipedegrasses* were planted with three types of nonwoven vegetation blankets, as listed in ***Table 5***, as well as with pure soil (control group) for a comparison of plant growth.

Figures 8 (a) – 8 (f) show *centipedegrass* growth with various nonwoven vegetation blankets, and ***Figure 8 (e)*** and ***Figure 8 (f)*** shows the *centipedegrass* growth with pure soil. Blankets are made of cotton fibers, far-infrared fibers, PLA fibers, and low-Tm PLA fibers; the amount of the first three fibers is constant, but that of the last fiber is varied. All four fibers are needle-punched with various densities and then thermally bonded at 140°C for 30 minutes, forming nonwoven vegetation blankets. ***Figure 8 (a, b)*** shows blankets with 10 wt% far-infrared fibers that

Table 4. *CV percent of tear strength along the CD or MD of nonwoven vegetation blankets with 10 wt% far-infrared fibers in relation to needle-punching densities. Thermal-bonding temperature is 140°C, and the thermal-bonding duration is 30 minutes.*

Needle-punching density, needles/cm²	CV% of tensile strength along the CD	CV% of tensile strength along the MD
30	6.28	10.18
60	3.84	4.04
90	8.46	8.98
120	9.10	7.44

Table 5. *Various nonwoven vegetation blankets.*

Nonwoven vegetation blanket	Proportion of far-infrared fibers, wt%	Needle-punching density, needle/cm²	Thermal-bonding temperature, °C	Thermal-bonding duration, min
A	10	30	140	30
B	50	30	140	30
C	10	120	140	30

are needle-punched at 30 needles/cm². ***Figure 8*** (***c***, ***d***) shows blankets with 50 wt% far-infrared fibers that are needle-punched at 30 needles/cm². ***Figure 8*** (***e***, ***f***) shows blankets with 10 wt% far-infrared fibers that are needle-punched at 120 needles/cm².

In comparison with ***Figure 8*** (***a-f***), ***Figure 8*** (***g***) and **8** (***h***) shows a greater amount of plant growth without the use of nonwoven vegetation blankets. The soils are rich in minerals, organisms, and soil microorganisms, which provide what plants need for growth. Synthetic fiber blankets lack the aforementioned nutrients, which can only be supplemented by adding fertilizer.

Comparing the influence of various proportions of far-infrared fibers using ***Figure 8*** (***a***) and ***Figure 8*** (***c***), the amounts of plants with 10 wt% or 50 wt% of far-infrared fibers are similar. However, the growth length is proportionate to the amount of far-infrared fibers; the growth length is around 5.4 cm with 10 wt% far-infrared fibers and around 7cm with 50 wt% far-infrared fibers. Far-infrared rays experience resonance with water molecules, thus refining water molecule groups and further activating water molecules inside the plants. Plants grow better as a result of the activation of their tissue cells. Slopes tend to lose a great amount of unprotected soil with the force of rainfall. Hence vegetation blankets with plants that are formed within a short time is considered beneficial to protect plant growth at an early stage.

Figures 8 (***a***, ***b***) and ***8*** (***e, f***) show the effect of various needle-punching densities on plant growth. The greater the needle-punching density, the lower the amount of plant growth. When the nonwoven vegetation blankets have a density of 120 needles/cm², the amount of plants is low. This decrease is ascribed to the density of blankets, which severely influences air permeability and water absorption, both inversely proportionate to the blankets' densities. Plant growth closely depends on the amount of water and air available, and plants do not grow well with insufficient air and water in blankets with 120 needles/cm².

Conclusion

The results of the experiments of nonwoven vegetation blankets are reported. With an increase in the needle-punching density from 30 needles/cm² to 120 needles/cm², air permeability decreases from 166 cm³/s/cm² to 120 cm³/s/cm². Far-infrared fibers are beneficial to plant growth, demonstrated by the plant growth length. The greater the amount of far-infrared fibers, the taller the plants grow. As with air permeability, water absorption is hampered by a high needle-punching density. When the density is 120 needles/cm², the blankets feature low air permeability and water absorption, resulting in poor plant growth.

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