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Original Article

Effects of Lignocellulosic Growing Media to The Prevention of Forest Soil Erosion[1]

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ABSTRACT

The forest slopes cause substantial local changes in soil properties and an increase in soil erosion after extreme rainstorms. The high soil erosion rates on forest slopes need the effective use of growing media to control the soil runoff. Therefore, we prepared six different lignocellulosic growing media such as peat, perlite, and wood meal as the base materials and carboxymethyl cellulose (CMC), glucomannan, starch, old corrugated containerboard, and computer printout as the additional materials for the prevention of simulated rainfall-induced runoff. The growing media containing old corrugated containerboard efficiently reduced the percentage of soil runoff; however, it could not completely cushion the influence of crust. The best results for plant growth, except in the leaf area, were also obtained with the growing media containing old corrugated containerboard, suggesting an interesting way of paper recycling and an economic benefit for plant or crop growth in forest slope.

Keywords : soil runoff, growing media, wood mill, plant growth, paper recycle

1. INTRODUCTION

Soil erosion is a major environmental and forest management problem worldwide.

With increasing mechanization of forest harvesting operations the impacts on soil have increased quite dramatically (Greacen and Sands, 1980). Responsibly managed timber harvest causes only minor increases in forest soil erosion, usually from channels and logging roads, but irresponsible timber harvest can increase erosion of soil to unacceptable levels (Patric, 1976). In forest slope, soil erosion occurs mainly due to the poor structural stability of the soil. The regulation of soil structure mainly depends on the organic matter content of soil (Bissonnais and Arrouays, 1997).

Forest manager could minimize rainfall-induced soil losses by the stringent use of minibasins and buried runoff pipes: however,

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these techniques are often too cumbersome or costly for adequate adoption (Orts *et al*., 2000). Furthermore, these techniques do not contribute to the improvement of organic matter. Kern and Johnson (1991) proposed increasing the input of organic matter by providing the stabilized exogenous organic matter to solve this problem. One of the organic matters is the steam-treated wood meal, which might become a basic component of forest soil and provide nutrients to the plants from the rotten wood chip in future (Jung *et al*., 2015).

Moreover, recently, an easy and effective tool has been added to these soil-loss minimizing measures by adding the quantities of materials, which play the role of stabilizers, to the growing media (Tian *et al*., 2015). The soil-loss control matter used additives, such as CMC, starch, and glucomannan, in the growing media. Smith *et al*. (1958) reported that the additive material CMC prevented soil erosion. Materials such as starch, sugar, cellulose, and other compounds obtained from wheat are commonly used as additives (Parker and Ring, 2005). Several studies have reported the effectiveness of recycled paper, one of the lignocellulosic materials, for preventing soil erosion (Nemati *et al*., 1999; Barriga *et al*., 2010). Campbell *et al*. (1995) demonstrated that a recycled paper mixture could be used as a soil amendment for preventing soil erosion and sustaining plant growth. Therefore, steam-treated wood meal and lignocellulosic additives, such as CMC and recycled paper, are expected to play important roles in the development of the growing media for reducing soil loss in forest slope.

The objective of this study was to evaluate the effect of growing media mixed with lignocellulose on preventing the simulated rainfall-induced soil runoff and sustaining plant growth. Furthermore, we determined the growing media characteristics that affected the runoff percentage and plant growth. Thus, we analyzed the correlation between the characteristics of growing media and runoff percentage and plant growth.

2. MATERIALS and METHODS

2.1. Growing Media Preparation

The growing media was prepared by mixing the basic materials, such as peat, perlite, and wood meal (*Quercus mongolica*), with the additives such as CMC, glucomannan, starch, old corrugated containerboard, and computer printout. The raw materials used in this study included commercial peat, classified as brown peat (pH 3.5-4.5, Satis International Co., Ltd. LA FLORA, Europe), and commercial perlite (particle size 2 mm; Landscape Architecture Co., Ltd., Korea). The wood chip and recycled paper (old corrugated containerboard and computer printout) were collected by Gyeongsang National University, Jinju City, Korea. We purchased the commercial CMC, glucomannan, and starch from. GL CHEM Co., Ltd., Korea. The wood chip was steam treated at 1.5 kg/cm^2 and 225℃ for 5 min (Jung *et al*., 2015). The recycled paper of 605 g was disintegrated for 10

Table 1. Composition of the growing media tested.

Growing media	Composition
Control	Peat, perlite and wood meal (3 : 1 : 6, w/w/w)
M1	Peat, perlite, wood meal and CMC (3 : 1 : 4 : 2, w/w/w/w)
M2	Peat, perlite, wood meal and glucomannan (3 : 1 : 4 : 2, w/w/w/w)
M3	Peat, perlite, wood meal and starch (3 : 1 : 4 : 2, w/w/w/w)
M4	Peat, perlite, wood meal and old corrugated containerboard (3 : 1 : 4 : 2, w/w/w/w)
M5	Peat, perlite, wood meal and computer printout (3 : 1 : 4 : 2, w/w/w/w)

min at the recycled paper/water ratio of 1/20. The peat and steam-treated wood chip were sieved to separate the particles below 2 mm. The growing media are shown in Table 1. The growing media were prepared by mixing three raw materials (peat, perlite, and wood meal) with one of the additives (CMC, glucomannan, starch, old corrugated cardboard, and computer printout) at the ratio of 3 : 1 : 4 : 2 (w/w/w/w). The control media comprised of peat, perlite, and wood meal at the ratio of 3 : 1 : 6 (w/w/w), and all raw materials were used after air drying for 48 h.

2.2. Analytical Methods of Growing Media

The porosity of the growing media was calculated by the following equation: (1 - Bulk density / Particle density) × 100 (Atiyeh *et al*., 2001). The bulk density was measured using the core method (Blake and Hartge, 1986). A metallic core of 5 cm inner diameter and 5 cm height was inserted into the packed pots to take out the undisturbed samples of growing media. The samples were dried in an oven at 105℃ for 24 h or till the weight of samples became constant. The ratio of the oven-dry weight of the sample in the core and the internal volume of metallic core was expressed as bulk density. The particle density was determined by the method of Ribeiro *et al*. (2007). The water-holding capacity was determined using the loosely packed cores and methods adapted from Evans *et al*. (1996). The pH of the growing media was analyzed in a water-soluble extract or suspension (1 : 5, v/v) (European Standard 13037, 1999). The C and N concentrations were analyzed by Kjeldahl digestion (Bremner and Mulvaney, 1982) using macro elemental analyzer (vario MACRO cube, USA). Samples were analyzed directly with no sample preparation other than drying and fine grinding.

2.3. Simulated Rainfall

The runoff rates were calculated using a rainfall simulator (Moreno-Ramón *et al*., 2014). The rainfall simulator was composed of a woody structure of the following dimensions: 30 cm height × 2 cm width × 15 cm length. A water emitter with a precipitation rate of 122 mm/h and an average droplet diameter of 5.7 mm and a device with droppers were placed at the side of the woody structure. The rainfall simulation was carried out on air-dried growing media samples with different compositions as listed in Table 1. Growing media were deposited in the woody structure by volume and we put growing media weight record respectively. The runoff percentage was calculated by determining the weight of growing media in dropper after artificial rain. Percent of runoff was calculated using the following equation:

$$\text{Runoff percent (\%)} = \frac{\text{Air-dry weight of growing media after artificial rain (g)}}{\text{Air-dry weight of growing media before artificial rain (g)}} \times 100$$

2.4. Plant Growth Experiment

The growth experiment was carried out to evaluate the potential use of growing media (Table 1) in Chinese cabbage (*Brassica campestris* ssp. *pekinensis*) growth. Chinese cabbage was selected because of its rapid growth and ability to keep growing after being cut several times. Growing media were put into each 9 cm diameter petri dish by the volume. Subsequently, the Chinese cabbage seeds were transferred into the growing media, with 50 seeds per dish and 1 cm or larger distance between the seeds (Yang and Watts, 2005). Petri dishes were covered after adding distilled water and sealed with Parafilm, and placed in an incubator. After incubating the petri dishes at 20℃ for seven days in the dark, the germination was halted and the number of germinated seeds was counted. The seed germination rate was calculated using the following equation:

$$\text{Germination (\%)} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds}} \times 100$$

The stem lengths of the Chinese cabbage seedlings were measured immediately after harvest at seven days after seeding. The stem length was measured from the top of the root to the top of the leaf using a Vernier Caliper. The leaf area was calculated as the product of the total length and the breadth at the broadest point of the longest leaf on the plant. Area of leaf was calculated using the following equation (Pan, 2006):

$$\text{Leaf area (cm}^2\text{)} = \text{Lamina length} \times \text{Maximum width}$$

2.5. Correlation Analysis

The data values from the experiments used to determine the physical and chemical properties of the growing media were compared with the runoff percent and plant growth properties by correlation analysis. The aim was to determine whether the methods used to determine the physical and chemical properties of the growing media were effective in predicting the plant growth. Pearson analysis (R program, i386 3.2.2 version) was performed for each substrate and variations were assessed based on the variations in the physical and chemical properties of the growing media.

Table 2. Physical and chemical properties of growing media

Growing media	Porosity, %	Water holding capacity, %	pH	C/N ratio
Optimal range [1)]	> 85	55 - 70	5.0 - 6.5	20 - 40
Control [2)]	91.2 ± 0.1b[8)]	13.2 ± 0.3b	4.3 ± 0.2d	0.5 ± 0.0f
M1 [3)]	92.8 ± 0.1a	13.3 ± 0.3b	4.8 ± 0.0b	29.8 ± 0.0e
M2 [4)]	92.5 ± 0.2a	14.0 ± 0.3b	4.5 ± 0.1c	34.0 ± 0.0b
M3 [5)]	91.7 ± 0.5b	13.6 ± 0.5b	4.8 ± 0.0b	33.6 ± 0.0c
M4 [6)]	92.5 ± 0.3a	23.8 ± 1.6a	5.0 ± 0.2ab	31.0 ± 1.0d
M5 [7)]	93.0 ± 0.3a	24.4 ± 0.9a	5.1 ± 0.1a	34.4 ± 0.0a

1) Goh and Haynes, 1977
2) Peat, perlite and wood meal (3 : 1 : 6, w/w/w)
3) Peat, perlite, wood meal and CMC (3 : 1 : 4 : 2, w/w/w/w)
4) Peat, perlite, wood meal and glucomannan (3 : 1 : 4 : 2, w/w/w/w)
5) Peat, perlite, wood meal and starch (3 : 1 : 4 : 2, w/w/w/w)
6) Peat, perlite, wood meal and old corrugated containerboard (3 : 1 : 4 : 2, w/w/w/w)
7) Peat, perlite, wood meal and computer printout (3 : 1 : 4 : 2, w/w/w/w)
8) Values with different alphabets in the same column are significantly different at $p < 0.05$

2.6. Significance Analysis

Each treatment was conducted with three replicates, and the results were presented as mean ± SD (standard deviation). The statistical analysis of the experimental data was performed using the Duncan's test. Each of the experimental values was compared to its corresponding control. The statistical significance was accepted when the probability of the result assuming the null hypothesis (p) was less than 0.05. The significance analysis was conducted using the SAS software, version 9.4.

3. RESULT and DISCUSSION

3.1. Characteristic of Growing Media

The growing media characteristics are among the parameters which must be defined and controlled, to ensure that they are not growth limiting. Therefore, the growing media must have optimal physical and chemical characteristics (porosity, water holding capacity, pH, and C/N). Characteristics of the all growing media are listed in Table 2. All growing media were evaluated as highly porous materials with their porosities varying from approximately 91.2 to 93.0%. All growing media, except M3, showed an increase in the porosity when mixed with additives. The higher media porosity might promote the higher biomass growth (Show and Tay, 1999). The additives provided a high air porosity and exceptional water-holding capacity to the growing media (Beardsell *et al*., 1979). Therefore, the growing media M1, M2, M4, and M5 showed higher porosity than control, and were found to be beneficial to plant growth. The water-use efficiency of both dry and irrigated lands will need to be substantially improved in order to meet the growing demand of crops (Oki and Kanae, 2006). Therefore, the water-holding capacity was an important characteristic of the growing media. In this study, the water-holding capacity of M4 and M5 were the highest among all growing media; however, it was not the optimal range for plant growth. With low water-holding capacity, water should be applied frequently, and in small amounts, as leaching might occur easily (Garcia-Gomez *et al*., 2002). Therefore, the growing media M4 and M5 were relatively optimal for the crop or plant growth. Furthermore, the pH values of both M4 and M5 were within the optimal range for plant growth, i.e., between 5.0 and 6.5 (Goh and Haynes, 1977). The pH of the growing media was closely correlated with water alkalinity (Bunt, 1988), and thus, it is an important factor for crop or plant growth. Therefore, among all growing media, M4 and M5 were the most suitable for crop or plant growth. Rosen et al. (1993) suggested that the growing media C/N ratio for ideal plant growth ranged between 15 : 1 and 20 : 1, whereas Ozores-Hampton et al. (1998) suggested a 25 : 1 ratio or less, and Ingelmo et al. (1998) obtained optimal results for the growth of *Cupressus sempervirens* using different substrates with biosolid components and C/N ratios of approximately 25 : 1. In the present study, all growing media, except control, showed high C/N ratios and optimal Chinese cabbage growth because the optimal C/N ratio ranged from 20-40 (Ostos *et al*., 2008). Moreover, this could be an advantage to avoid N immobilization due to high C/N ratio (García *et al*., 1992), and thus, all growing media, except control, were available for crop or plant growth. The C/N ratio of the control media (C/N : 0.5) was the lowest among all growing media. The crop or plant production was also affected by the C/N ratio of the growth media, and the extent of these effects also depended on the N source used, particularly at low C/N ratio (Engelkes *et al*., 1997).

3.2. Growing Media Runoff on Simulated Rainfall

In spite of the disadvantages, such as problems in extrapolating the results to conditions, rainfall simulations are widely used because of their low cost and ease of operation (Walsh *et al*., 1998), and also because of the possibility for study under controlled condition (Navas *et al*., 1990). The results of the rainfall simulation tests can be used for comparative purposes (Foster *et al*., 2000). The growing media runoff patterns shown in Fig. 1 and Table 3 indicated that the runoff percentages of all growing media, except control, decreased with the incorporation of all additives. Control was runoff by a tenth part of the surface after 1 week (as determined through visual approximation). On the other hand, the runoff of the growing media with old corrugated containerboard was found to be slightly prevented with rainfall as visualized by the naked eye. Among all growing media, the average runoff was the lowest in the media containing old corrugated containerboard (M4) (Table 3). The average runoff of the control media was statistically significantly higher than all growing media, in which the average runoff was reduced by 1.9-3.5 times with the addition of additives. The comparative data be-

Table 3. Runoff percent of growing media surface layer after rainfall simulation

Growing media	Runoff percent, %
Control [1)]	12.5 ± 3.2a [7)]
M1 [2)]	6.2 ± 2.1bc
M2 [3)]	6.7 ± 0.6b
M3 [4)]	5.4 ± 1.3bc
M4 [5)]	3.6 ± 0.5c
M5 [6)]	5.1 ± 1.7bc

1) Peat, perlite and wood meal (3 : 1 : 6, w/w/w)
2) Peat, perlite, wood meal and CMC (3 : 1 : 4 : 2, w/w/w/w)
3) Peat, perlite, wood meal and glucomannan (3 : 1 : 4 : 2, w/w/w/w)
4) Peat, perlite, wood meal and starch (3 : 1 : 4 : 2, w/w/w/w)
5) Peat, perlite, wood meal and old corrugated containerboard (3 : 1 : 4 : 2, w/w/w/w)
6) Peat, perlite, wood meal and computer printout (3 : 1 : 4 : 2, w/w/w/w)
7) Values with different alphabets in the same column are significantly different at $p < 0.05$

tween the control and M4 media revealed that the runoff was reduced on an average by 71%. Therefore, M4 was one of the most effective growing media for preventing soil loss. Chepil *et al*. (1962) reported that the starch treatments were ineffective to control soil erosion under the experimental conditions. However, our results showed that starch was relatively effective in preventing soil loss (56.8% reduced soil loss). The application of polysaccharides, such as starch and cellulose, might accelerate the soil macro-aggregate formation related to soil loss (Mizuta *et al*., 2015). The old corrugated containerboard was a lignocellulosic material; therefore we speculated that it was effective in preventing soil loss. Biopolymers are known to reduce soil loss and runoff (Sojka *et al*., 2005); however, the effects of lignocellulosic materials, such as old corrugated containerboard, on soil loss are not yet clear. In this study, we confirmed the potential of old corrugated containerboard to prevent soil loss.

3.3. Growth of Plant (Chinese cabbage) Growth

In general, the germination rate of the Chinese cabbage seeds grown in control media was significantly lower than that of the seeds grown with additives in all growing media (Fig. 2). The germination rate of the control media was lower (66.5%) than that of the other growing media with additives. Germination of Chinese cabbage in M4 media was the highest among all growing media and approximately 1.2 times higher than that in the control media. The starch (77.8%) and computer printout paper (74.6%) were also relatively effective in increasing seed germination. The lowest seed germination rate in the control media might have resulted because of the low pH of the mixture of peat, perlite, and wood meal (Table 2). Warman (1999) confirmed that the Chinese cabbage seeds showed low germination rate in the low pH condition. In acidic growing media, the high concentration of soluble ion is the primary

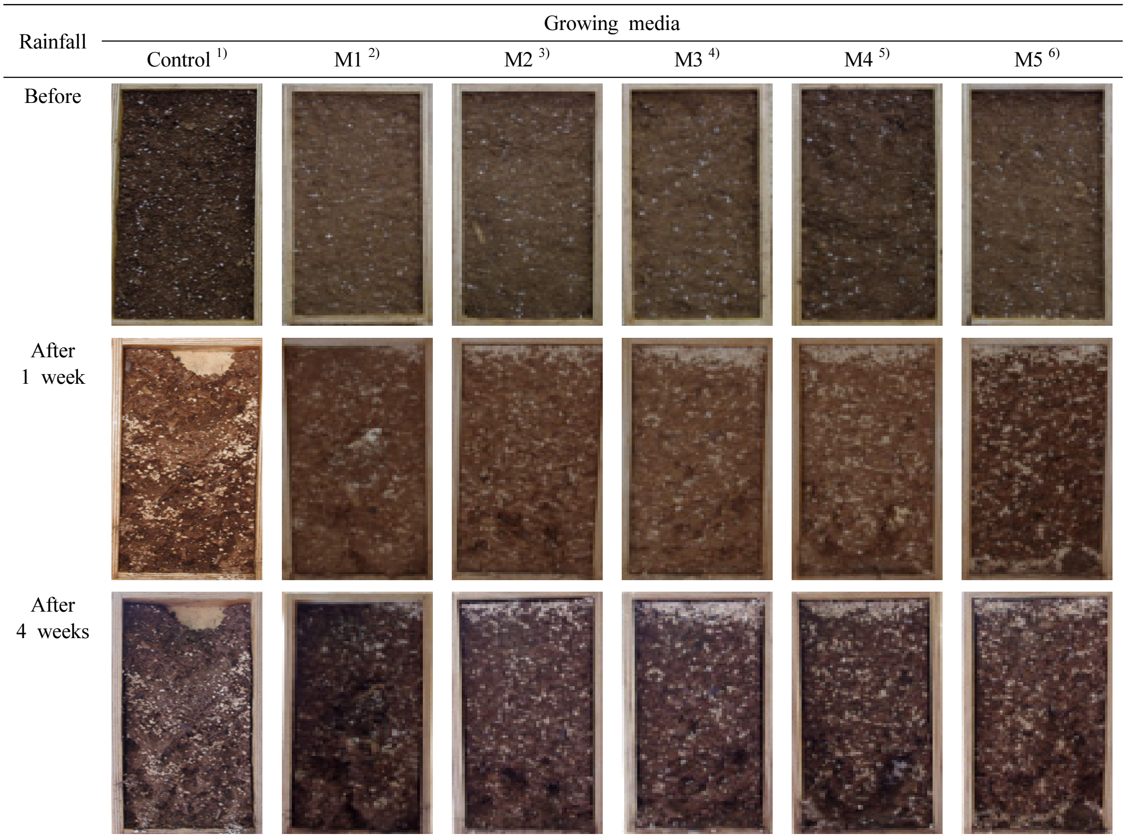

Fig. 1. Characteristic of soil surface layer after rainfall simulation ([1] peat, perlite and wood meal (3 : 1 : 6, w/w/w); [2] peat, perlite, wood meal and CMC (3: 1: 4: 2, w/w/w/w); [3] Peat, perlite, wood meal and glucomannan (3 : 1: 4 : 2, w/w/w/w); [4] Peat, perlite, wood meal and starch (3: 1: 4: 2, w/w/w/w); [5] Peat, perlite, wood meal and old corrugated containerboard (3 : 1 : 4 : 2, w/w/w/w); [6] Peat, perlite, wood meal and computer printout (3 : 1 : 4 : 2, w/w/w/w)).

cause of plant germination restriction (Foy *et al*., 1978). Therefore, our results suggested that the high germination rate of M4 media was caused by its relatively high pH (Table 2).

The effects of growing media additives on stem length and leaf area were shown in Fig. 3 and 4, respectively. The stem length obtained with M4 was significantly higher than that obtained with the other growing media. The same effect could be achieved in the germination rate of Chinese cabbage seeds. M1 and M3 showed higher leaf area than the other growing media, and all growing media with additives showed significantly higher leaf area than the control media.

Yasunori *et al*. (2000) determined the effect of low pH on the growth of lettuce seedlings. The growth (stem and root length) of lettuce seedlings was highly suppressed with the lowering of the media pH. Hidenori *et al*. (2003) hypothesized that auxin and ethylene were involved in

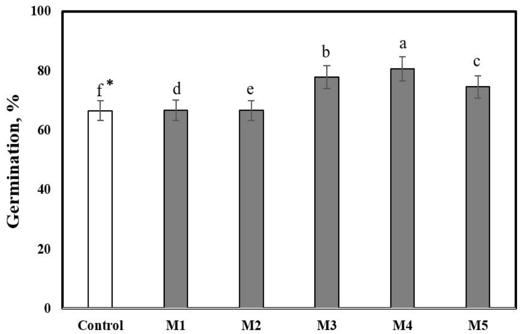

Fig. 2. Changes in seed germination of growing media during the growing period. Control: Peat, perlite and wood meal (3 : 1 : 6, w/w/w); M1: Peat, perlite, wood meal and CMC (3 : 1 : 4 : 2, w/w/w/w); M2: Peat, perlite, wood meal and glucomannan (3 : 1 : 4 : 2, w/w/w/w); M3: Peat, perlite, wood meal and starch (3 : 1 : 4 : 2, w/w/w/w); M4: Peat, perlite, wood meal and old corrugated containerboard (3 : 1 : 4 : 2, w/w/w/w); M5: Peat, perlite, wood meal and computer printout (3 : 1 : 4 : 2, w/w/w/w).
* Values with different alphabets in the same column are significantly different at $p < 0.05$.

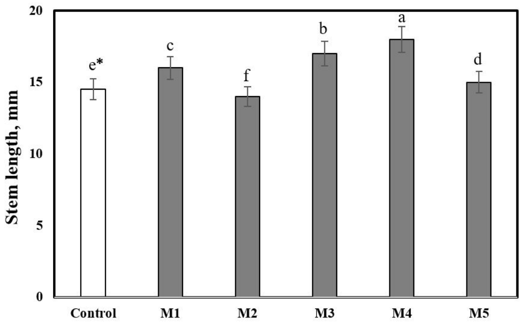

Fig. 3. Changes in stem length of growing media during the growing period. Control: Peat, perlite and wood meal (3 : 1 : 6, w/w/w); M1: Peat, perlite, wood meal and CMC (3 : 1 : 4 : 2, w/w/w/w); M2: Peat, perlite, wood meal and glucomannan (3 : 1 : 4 : 2, w/w/w/w); M3: Peat, perlite, wood meal and starch (3: 1: 4: 2, w/w/w/w); M4: Peat, perlite, wood meal and old corrugated containerboard (3: 1: 4: 2, w/w/w/w); M5: Peat, perlite, wood meal and computer printout (3 : 1 : 4 : 2, w/w/w/w).
* Values with different alphabets in the same column are significantly different at $p < 0.05$.

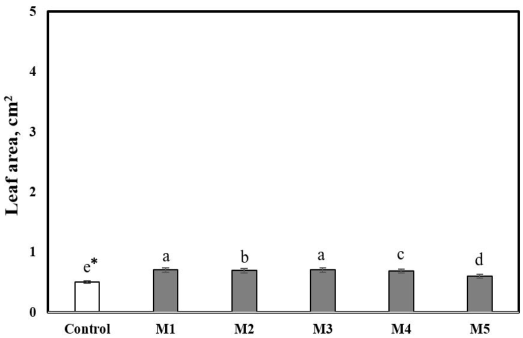

Fig. 4. Changes in leaf area of growing media during the growing period. Control: Peat, perlite and wood meal (3 : 1 : 6, w/w/w); M1: Peat, perlite, wood meal and CMC (3 : 1 : 4 : 2, w/w/w/w); M2: Peat, perlite, wood meal and glucomannan (3 : 1 : 4 : 2, w/w/w/w); M3: Peat, perlite, wood meal and starch (3 : 1 : 4 : 2, w/w/w/w); M4: Peat, perlite, wood meal and old corrugated containerboard (3 : 1 : 4 : 2, w/w/w/w); M5: Peat, perlite, wood meal and computer printout (3 : 1 : 4 : 2, w/w/w/w).
* Values with different alphabets in the same column are significantly different at $p < 0.05$.

the process of low-pH-induced root hair initiation. Therefore, pH was considered an important factor for plant growth. Our results also suggested that the low pH of the control media was favorable for Chinese cabbage growth.

Furthermore, Bellamy *et al*. (1993) reported that the paper waste was effectively applied to plant growth. Campbell *et al*. (1995) confirmed that the paper waste had a potential for the amendment of low-quality growing media or soil. Ostos *et al*. (2008) reported that the recycled paper with a certain pH value and high organic matter was useful for plant germination and growth. Our results also showed that the addition of paper waste to the growing media led to an increase in Chinese cabbage growth.

Table 4. Correlation between growing media characteristic and runoff percent and plant growth properties

	Runoff percent		Seed germination		Stem length		Leaf area	
	Pearson	Significance[1)]	Pearson	Significance	Pearson	Significance	Pearson	Significance
Porosity, %	-0.51	*	0.83	**	0.63	**	-0.21	ns
Water holding capacity, %	0.78	**	0.84	**	0.66	**	0.22	ns
pH, 1:5 (v/v)	-0.21	ns	-0.09	ns	-0.05	ns	-0.19	ns
C/N	-0.44	*	0.37	ns	0.35	ns	0.52	*

[1)] ns: $p > 0.05$; * $p < 0.05$; ** $p < 0.01$

3.4. Correlation Analysis

Considering the key characteristics of growing media, it is necessary to identify the factors that directly or indirectly affect plant growth (Letey, 1958). The results of a correlation analysis involving the characteristics of growing media and the calculated indices of runoff percent and Chinese cabbage growth properties are presented in Table 4. The water-holding capacity showed the highest correlation with the runoff percent ($r = 0.78$, $p < 0.01$). The slope of the land, soil composition, and extent of vegetative cover influenced the rate of erosion, and the water-holding capacity influenced the soil productive capacity (Pimentel *et al*., 1995). In this study, the water-holding capacity was most correlated with the germination rate ($r = 0.84$, $p < 0.01$) and the stem length ($r = 0.66$, $p < 0.01$). Akhter *et al*. (2004) found a correlation between the water-holding capacities of growing media and seed germination rates.

In this study, we tested six growing media with different additives such as CMC, glucomannan, starch, old corrugated containerboard, and computer printout. Our results confirmed that these materials could be used effectively to enhance crop or plant growth. The major impact of adding old corrugated containerboard to the growing media was an increase its porosity, water-holding capacity, pH, and C/N ratio, resulting in the positive effects on plant growth, especially on the germination and growth of Chinese cabbage. The outcomes of this study showed clearly that the growing media could be applied to reduce soil erosion problems. The growing media with old corrugated containerboard could be used as an erosion protector because it decreased the stimulated rainfall-induced runoff percentage. The correlation analysis proved the relationships between the water-holding capacity of the growing media and the runoff percent as well as the germination and stem length of Chinese cabbage.

4. CONCLUSION

While the growing media containing old corrugated containerboard are rarely used in the current commercial practices, their frequent use might lead to the immediate and obvious benefits in crop production. This is true, particularly if they are readily available, because old corrugated containerboard is a common and less expensive material than the traditional growing media materials. In the long term, the increased usage of recycled paper in response to the environmental conditions will position the growing media industry at the top of the environmentally friendly chart for being proactive in managing recycled paper.

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