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Research Article

Improvement of Saemangeum Dredged Soils Using Coffee Sludge for Vegetation Soil

Daehyeon Kim, Minseok Kim, Munchae Kim, and Kyungho Park

Department of Civil Engineering, Chosun University, Gwangju 501-759, Republic of Korea

Correspondence should be addressed to Kyungho Park; munhakng@nate.com

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In Korea, a large scale national project (Saemangeum Project) has been underway that requires a huge amount of dredged soils and their reclamation. Although a lot of dredged soil is needed for reclamation, only about 10% of the dredged soil is used. For this reason, much effort should be made to extensively use the dredged soil. The objective of the study is to find reasonable ways of improving the dredged soils in the Saemangeum area so that they can be used for vegetation of land plants. In order to develop ameliorating methods, we treated silty sand samples, the representative dredged soil of Saemangeum, with mountain soil (0% and 30%), sawdust fertilizer (0% and 6%), bioameliorant (0% and 6%), and coffee sludge (3%, 6%, and 9%), measured the germination rate of bent grass, and applied the lab experiment results to the field for validation. As a result, it was verified that when a mixture of coffee sludge and sawdust fertilizer was used, the chemical and physical properties of dredged soil were significantly improved. This implies that the beneficial use of the dredged soil can be facilitated.

1. Introduction

(1) Background and Objective. Seventy percent of the Korean land is composed of mountains, which makes available land area very small compared to the population density. Therefore, it is essential to efficiently use and expand the land. For this reason, Korea has carried out large-scale dredging projects to develop coastal and marine spaces, to construct and redevelop ports, and to secure fairway depth, resulting in a huge amount of dredged soil. However, there has been no known method for using this dredged soil.

Currently, the treatment of dredged soil mostly relies on landfill or offshore dumping. This results in various adverse effects on the environment, such as coastal environment damage, degradation of fisheries, and even pollution by heavy metals from the contaminated dredged soil. In order for the ground reclaimed with dredged soil to be used as vegetation soils, it should be covered with at least 30 cm of outside soil, causing huge economic and environmental losses.

Bringing in the outside soil creates environmental problems in the processes of collecting, transporting, and applying the soil and thus increases indirect expenses such as transportation costs and land compensation costs in securing the soil. Excessive efforts for securing the soil may result in secondary environmental damage (Yoon and Bae [1], Park et al. [2]).

The objective of the study is to come up with reasonable ways of improving the dredged soils in the Saemangeum area so that they can be used for vegetation of land plants. Untreated dredged soils and dredged soils treated with mountain soil (0% and 30%), sawdust fertilizer (0% and 6%), bioameliorant (0% and 6%), and coffee sludge (3%, 6% and 9%) were compared in the laboratory test. Based on the laboratory test results, a field test was carried out to verify the effects of the dredged soil on vegetation.

(2) Previous Studies. Much interest has been given to dredged soil recycling since the 2000s and several studies have been conducted by some researchers (Koo et al. [3], Kim [4], Ryu [5], and Ann [6]). However, the study of recycling dredged soil is at the very basic stage, and most of the research for developing vegetation soils is based on the use of sewage sludge and aggregate byproducts (Kim [7]). For the domestic dredged soil in Korea, about 80% is dumped to the dumping ground and 9% is dumped to offshore dumping grounds, leaving only 10% for landfills or other usages.

Table 1: Physical properties of soils used in the study.

Classification	G_s	W_n (%)	# 200 (%)	$r_{d\max}$ (g/cm^3)	OMC (%)	LL	PL	PI	U.S.C.S
Sample A (dredged soil)	2.583	19.3	27.47	1.505	18.07	NP	NP	NP	SM
Sample B (dredged soil)	2.607	23.05	27.85	1.548	19.01	NP	NP	NP	SM
Loess (mountain soil)	2.845	14.60	40.82	1.795	15.97	31.11	25.35	5.76	ML

For other countries, various dredged soil improvement methods have been developed and used for the marine environment restoration projects (Teal and Weishar [8], Chiellini et al. [9], Derbyshire and Mellors [10], Ruiz Diaz et al. [11], and Mulligan et al. [12]). Regardless of the dredged soil utilization, habitat development projects have been actively promoted and recently recycling of the dredged soil has been carried out as well (Yoon and Cho [13]). Also, in terms of utilization of the dredged soil, other countries' ratio of coastal or foreign offshore dumping is only 60% while approximately 40% is used for the land or wetlands in their countries, which is about 30% higher than Korea's dredged soil utilization ratio.

Lee et al. [14] claimed that plant growth is influenced by the soil texture (physical composition of the soil) as it is related to breathability, water holding capacity, nutrient absorption capacity, void volume, moisture content, and cohesiveness. As soil is a general product that is affected by climate, topography, vegetation, time, water, and anthropogenic interferences, it is possible to understand the vegetation characteristic of an area by examining the soil environment of the area.

According to the previous studies (Yoon and Cho [13], Lee et al. [14]), when typical vegetation is planted in the soil with a good degree of ventilation and water holding capacity, its growth is affected by the moisture content and the organic matter contained in the soil. However, when it is planted in the soil with a poor texture, it is difficult to form a good vegetation community. Therefore, the types of plants grown should be changed depending on the soil properties.

Yoon [15] claimed loess as the best soil for vegetation of plants among 60 types of soils on the Earth's surface, because it has fine particles, contains a lot of oxygen for excellent purification capacity, and contains about 200 million live microorganisms per spoon that can stimulate a large variety of enzymes to purify the soil.

2. Properties of the Materials Used

2.1. Material Used in the Test

2.1.1. Properties of Saemangeum Dredged Soils and Mountain Soil. Figure 1 exhibits the location of Saemangeum where the dredged soils used in the study were collected. As shown in Figure 1, Saemangeum is located on the west coast of Korea. Saemangeum Project is a national project in Korea to develop a new area as the next economic hub of North Asia. According to the Saemangeum Development and Investment Agency (SDIA), through this project, 283 km^2 of new land is to be reclaimed and 118 km^2 of lake was created after the construction of the world's longest 33.9 km sea dike connecting Saemangeum and Buan on the west coast of Korea. Since a lot of soil is needed for reclamation for this project, a new method of utilizing of the dredged soil is necessary.

Figure 1: Location of Saemangeum in Korea.

In order to examine the chemical and physical properties of the dredged soils sampled at Saemangeum Section 3 and those of mountain soil, the following tests were conducted in accordance with Korea standard tests: the particle size test (KS F 2302), the moisture content test (KS F 2305), the hydrometer test (KS F 2302), the specific gravity test (KS F 2308), and the liquid/plastic limit test (KS F 2303, 4). Table 1 shows physical properties of the Saemangeum dredged soils (Samples A and B) and the mountain soil. Both Samples A and B were classified as SM (silty sand), and the mountain soil was classified as ML (low compressible silt), according to the Unified Soil Classification System (USCS).

2.2. Analysis of the Chemical and Physical Properties of Saemangeum Dredged Soils and Coffee Sludge. As the dredged soil from the sea contains generally excessive salt concentration for the growth of land plants, it should be generally used for embankment construction after being left untreated in nature for a certain period of time. For this reason, in order to investigate the differences in plant germination characteristics depending on the period that the dredged soil was left untreated, the dredged soil left untreated about a year after dredging was taken as Sample A, and the dredged soil collected right at the field (immediately after dredging) was used as Sample B for laboratory tests.

Table 2: Physical and chemical characteristics of the Saemangeum dredged soils and coffee sludge.

Classification	pH	Organic content (%)	Available phosphate (mg/kg)	Salt concentration (%)	Electric conductivity (dS/m)
Sample A	7.55	1.220	12.732	0.070	1.099
Sample B	7.28	0.468	10.171	0.747	11.669
Coffee sludge	6.59	37.007	246.597	0.711	11.102
Arboreal Growth Condition	5.5–6.5	3.00 more	100 more	0.05 less	0.4 less

Table 3: Mixing ratios of the typical materials for improving the dredged soil.

Sample	Classification	Seed	Soil conditions				
			Dredged soil (%)	Loess (%)	Bio ameliorant (%)	AC ameliorant (%)	Sawdust (%)
Saemangeum Sample A Sample B	Untreated	Grass	100	0	0	0	0
	Bio 6%		100	0	6	0	0
	AC 6%		100	0	0	6	0
	Sawdust 6%		100	0	0	0	6
	Mountain soil 50%		50	50	0	0	0
	Mountain soil 50% + bio 6%		50	50	6	0	0
	Mountain soil 50% + AC 6%		50	50	0	6	0
	Mountain soil 50% + sawdust 6%		50	50	0	0	6

Table 2 presents the physical and chemical characteristics of the Saemangeum dredged soils and coffee sludge. As shown in Table 2, the physical and chemical characteristics of the dredged soils do not meet the standard values (suggested by Korean National Institute of Forest Science) for the arboreal growth condition, implying that the dredged soils should be improved. Note that the salt concentration of Sample A is about 10 times lower than that of Sample B. This indicates that it takes about a year for the dredged soil to be used as a vegetation soil.

Over the past years, coffee has remarkably gained its popularity in Korea. About 225 tons of coffee sludge generated from coffee shops every day in Korea is commissioned to be treated as general waste (Yoo [16]). Therefore, the need for research for utilizing the coffee sludge has been increasing. Several studies on the use of coffee sludge for heavy metal control reported that the dredged soil containing a large amount of chrome and cadmium could be efficiently controlled with the coffee sludge (Kim and Shin [17], Lee et al. [18]). In addition, they also investigated the possibility of controlling the potential releaching of heavy metals from the mixture of sewage sludge and quicklime due to a high pH, using the coffee sludge.

In this study, as the beneficial use of coffee sludge has been increasingly needed, coffee sludge was used to improve growth conditions of the dredged soils that are not suitable for the growth of land plants. As shown in Table 2, the results of its physical and chemical properties confirm that it meets several items in arboreal growth conditions and thus could be used as an organic material for arboreal growth. In particular, it is noteworthy that coffee sludge has high percentage of organic content and available phosphate.

3. Laboratory Experiment

Due to the lack of studies of plant growth characteristics using typical land plants, the focus was placed on improving the physical and physicochemical properties of the dredged soils. Also, considering the anticipated timing of field test, grass was selected as the test seed as it could germinate even in late fall (October-November).

Since limited research data are available on Saemangeum dredged soils, different mixing ratios of the materials were used to evaluate the effect of mixing ratios on the germination of the dredged soils. The amount of samples was determined based on dry unit weight (r_d) in a pot with the dimension of D5 (cm) × H5 (cm), with a relative density (D_r) of 60%. While the dredged soil was being left alone in nature, the samples were watered once after being set and completely dried for two days and then the same process was repeated one more time to simulate the change in the salt concentration in the field caused by rain, snow, and wind. Seeds were soaked in water for 24 hours before being sown and 20 seeds were used for each case.

Figure 2 shows a view of the laboratory experiment and Figure 3 shows a view of the greenhouse made for the experiment. As shown in Section 3, the experiment was conducted outdoors after the samples were set to create an environment similar to the field test. In addition, a greenhouse was made with plastic film to maintain temperature and moisture and protect the cases from environmental harms, shown in Figure 3.

Table 3 presents the mixing ratios of typical materials such as mountain soil, sawdust fertilizer, and bioameliorant for improving the dredged soil. The mixing ratios of these materials were determined based on the weight of dredged

Figure 2: View of laboratory experiment.

Figure 3: Making of a greenhouse with plastic film.

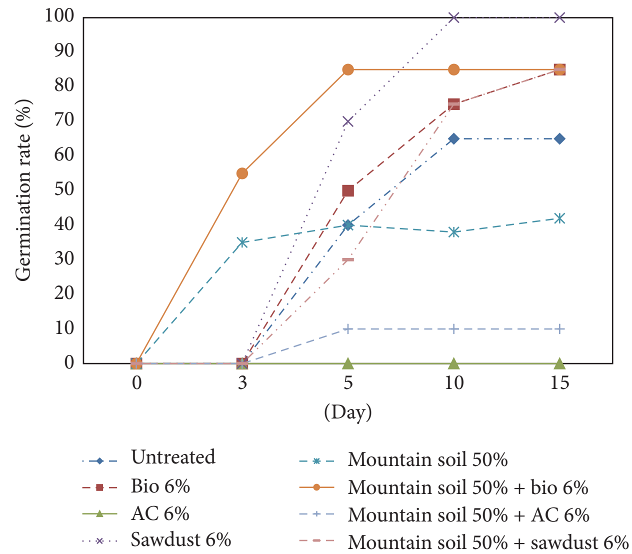

Figure 4: Grass germination rate measured from Saemangeum Sample A for typical materials.

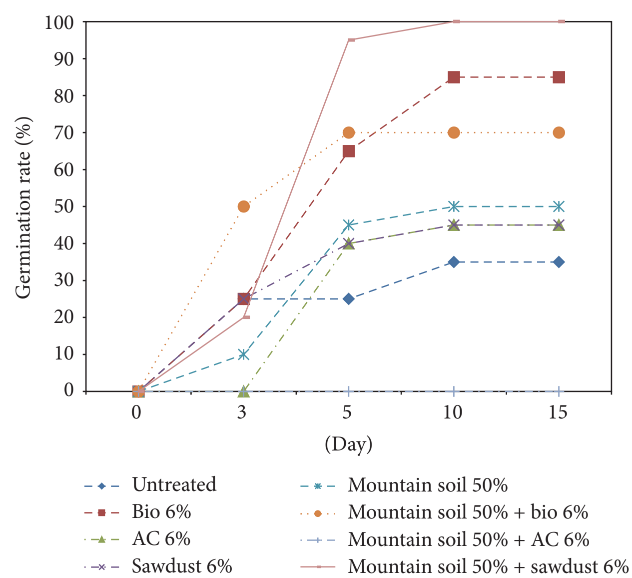

Figure 5: Grass germination rate measured from Saemangeum Sample B for typical materials.

soil + mountain soil as 100% for the convenience of determining the weight of mixture for future field tests. Bioameliorant (patent ameliorant) is generally used in Korea for improving the dredged soil with high salt concentration for vegetation purpose. Sawdust fertilizer is usually used for better seeding for slope stabilization. Table 4 shows the mixing ratios of coffee sludge for improving the dredged soil. In order to ensure the reliability of the result of laboratory tests, four specimens were made for each mixing ratio.

4. Results of the Dredged Soil Ameliorator Test

4.1. Germination Rate Test. Germination rate can be defined as the ratio of the number of the seeds that germinate to the number of the total seeds. Figures 4 and 5 show the germination rates of Samples A and B with various mixing ratios, respectively. As shown in Figures 4 and 5, the germination rates of the grass seeds were about 30–50% higher in the cases using both bioameliorant and sawdust fertilizer compared to that for the untreated case. When the 50% mountain soil was mixed with the 50% dredged soil, the germination rates generally increased compared to those with 100% dredged soil for most of the cases. This is because the mountain soil, loess, offers a favorable condition for plants to grow well, as reported by Yoon [15].

Interestingly, the germination rate of the case with sawdust 6% was higher than that with mountain soil 50% + sawdust 6%. Although the 100% dredged soil was used with the 6% sawdust, the germination rates of both Samples A and B were the highest among all the cases. This finding is very encouraging in improving the dredged soil. The germination rate in the AC ameliorator was similar to that of the untreated soil or lower than that of the untreated soil. This is due to the fact that AC ameliorator's extremely small particles reduced voids in the dredged soil and its high strong base (pH 9–11) inhibited germination.

Figure 6 shows the germination rates for Sample A with coffee sludge. As shown in Figure 6, the germination rate increased with an increase in the ratio of coffee sludge. When the 30% mountain soil was used instead of the 30% dredged soil, the maximum germination rate increased significantly. It is observed that when compared to the untreated case, the germination rate of the case with coffee sludge increased by at least 20% or more. Also, as shown in Figure 7, it is confirmed

Table 4: Mixing ratio of coffee sludge for improving the dredged soil.

Sample	Classification	Seed	Soil conditions Dredged soil (%)	Loess (%)	AC ameliorant (%)	Coffee Sludge (%)	Sawdust (%)
Saemangeum Sample A	Coffee sludge 3% + Sawdust 6%	Grass	100	0	0	3	6
	Coffee sludge 6% + Sawdust 6%		100	0	0	6	6
	Coffee sludge 9% + Sawdust 6%		100	0	0	9	6
	AC 6% + Coffee sludge 9%		100	0	6	9	0
	Mountain soil 30% + Coffee sludge 3% + Sawdust 6%		70	30	0	3	6
	Mountain soil 30% + Coffee sludge 6% + Sawdust 6%		70	30	0	6	6
	Mountain soil 30% + Coffee sludge 9% + Sawdust 6%		70	30	0	9	6
	Mountain soil 30% + AC 6% + Coffee sludge 9%		70	30	6	9	0

Table 5: Result of chemical and physical analysis of Saemangeum Sample A after the test.

Classification	pH	Organism (mg/kg)	Available phosphate (mg/kg)	Salt concentration (%)	Electric Conductivity (ds/m)	Total nitrogen
Sample A	8.48	0.755	11.618	0.085	1.328	92.459
Bio ameliorant 6%	7.19	1.030	187.316	0.445	6.960	152.654
Sawdust 6%	7.80	2.022	110.932	0.029	0.455	216.547
Mountain soil 30%	8.04	3.935	9.283	0.017	0.266	485.264
Mountain soil 30% + bioameliorant 6%	6.95	3.267	93.352	0.544	8.501	359.495
Mountain soil 30% + sawdust 6%	7.55	3.845	52.968	0.027	0.426	492.661
Mountain soil 30% + sawdust 6% + Coffee sludge 9%	7.65	11.532	78.381	0.037	0.581	1829.117
Arboreal growth condition	5.5–6.5	3.00 more	100 more	0.05 less	0.4 less	200 more

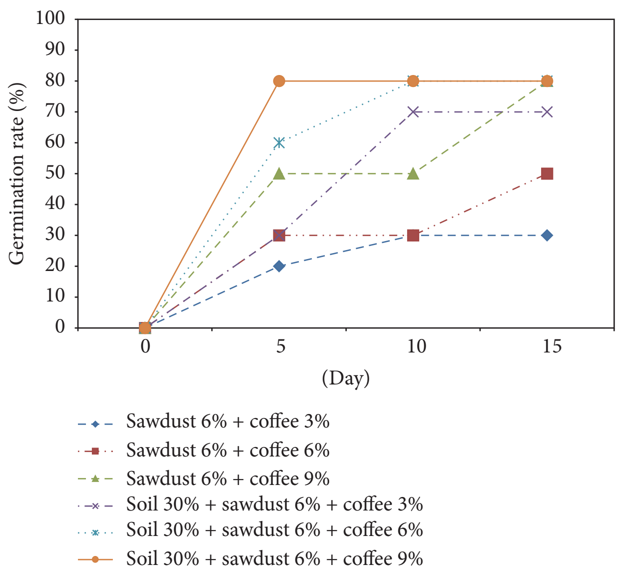

Figure 6: Grass germination rate measured from Saemangeum Sample A for coffee sludge.

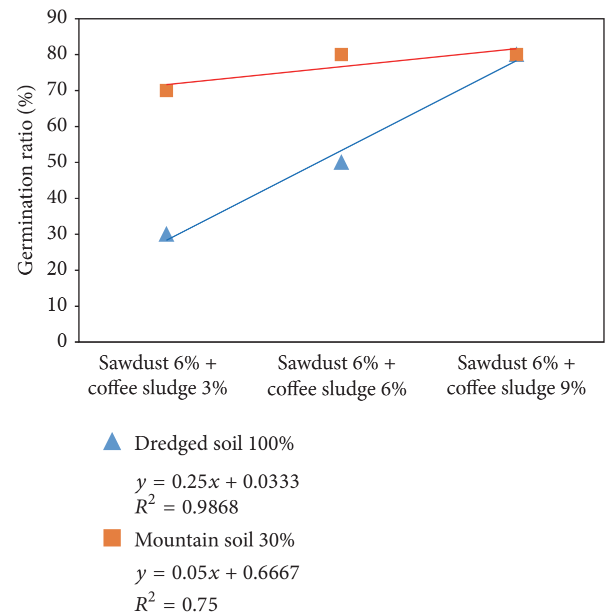

Figure 7: Comparison of germination rates between coffee sludge and mountain soil.

that the increase rate of the germination rate was much higher by using coffee sludge compared to that by using mountain soil.

4.2. Weight Measurement. Figures 8 and 9 display the plant growth for Samples A and B depending on different materials, respectively, and clearly show that adding ameliorators to the dredged soils allows better growing of the plants. When the weights of plants were measured 15 days after seeding, they varied with the ameliorators used for treatment in both Saemangeum Samples A and B, as shown in Figures 10 and 11. Plants grown in the soil treated with bioameliorant and sawdust fertilizer appeared to be 1.5–3 times heavier than those grown in the untreated soil. However, the difference between the weights of plants grown in these two ameliorators was not significant. Plants grown in the soil treated with AC ameliorator appeared to be lighter than those grown in the untreated soil.

4.3. Results of the Posttest Chemical and Physical Analysis of Sample A. Table 5 shows the result of chemical and physical analysis of Saemangeum Sample A after the soil conditioning test. The samples were taken from the case in dry condition after the test was completed (15 days after seeding) and analyzed for chemical and physical properties. The result showed that the samples from the sawdust fertilizer + coffee sludge mixture case had very similar properties to the arboreal growth condition. This implies that the dredged soil can be suitable for arboreal growth if its soil salinity is controlled through irrigation and drying processes and coffee sludge and sawdust fertilizer are mixed into it.

It was observed that when coffee sludge took 9% or more of the mixture, light and fine particles drifted up during irrigation and covered the case surface. Oil contained in the coffee sludge helped extend the moisture retention inside the sample. But when covering the surface of the case, it blocked

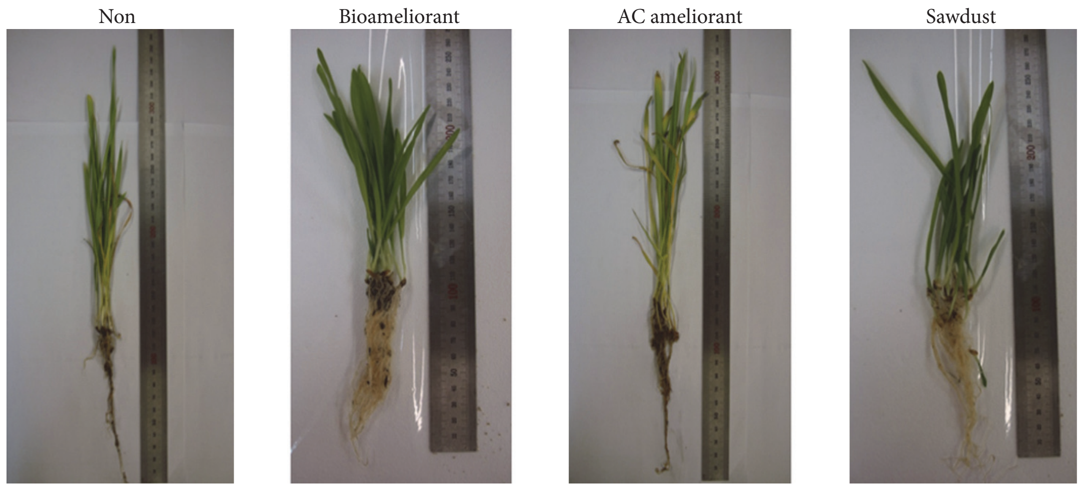

Figure 8: Plant growth for Sample A.

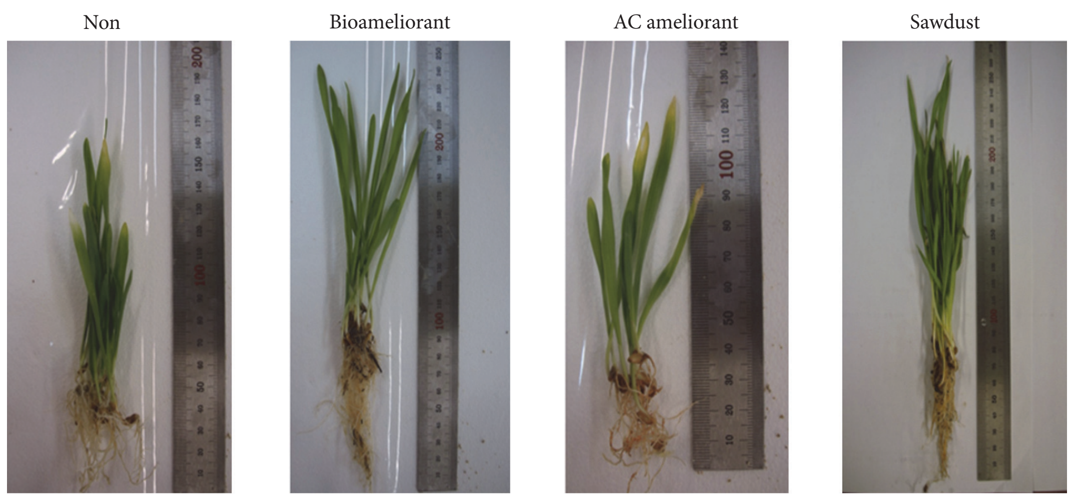

Figure 9: Plant growth for Sample B.

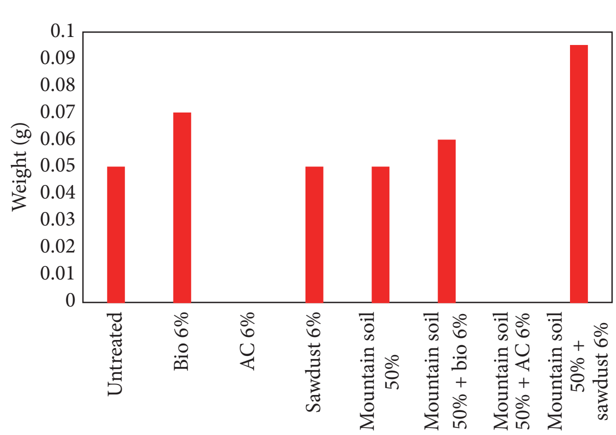

Figure 10: Weights of the grasses of Saemangeum Sample A.

oxygen that needed to be transmitted into the case, resulting in the delay of germination.

5. Field Test

5.1. Preparation for the Field Test. The field test was set up in Saemangeum Section 3. Total area of the test site was 284 m^2, where two 10 m × 10 m sections were set up and 21 m × 7 m L-shaped 1 : 1 slope was made. Bent grass (western grass) seeds, the same kind used for the laboratory test, were used. A total of 10 thousand seeds were sprayed in a 3 mm thickness using the seed spraying method. An artificial slope was formed before the field test and 25 tons of dredged soil was placed on the slope right before the test so that the effects of dredged soil could be properly reflected.

The field test was originally planned to spray the dredged soil after mixing it with 3%-crushed straws to prevent the dredged soil from being blown away by wind. However, due to the field conditions, instead of the crushed straws, straw mats were placed on top of the dredged soil. Figure 12 shows a view of pasting seeds by spraying after the surface was prepared, and Figure 13 shows a sheet of plastic film applied to maintain

Table 6: Mixing ratios for the field test.

Classification	Seed	Soil conditions				
		Dredged soil (%)	Loess (%)	Coffee sludge (%)	Straw (%)	Sawdust (%)
1	Grass	100	0	0	0	0
2		100	0	6	3	0
3		100	0	6	3	4
4		100	0	6	3	4
5		80	20	0	0	0
6		80	20	6	3	0
7		80	20	6	3	4
8		80	20	6	3	4

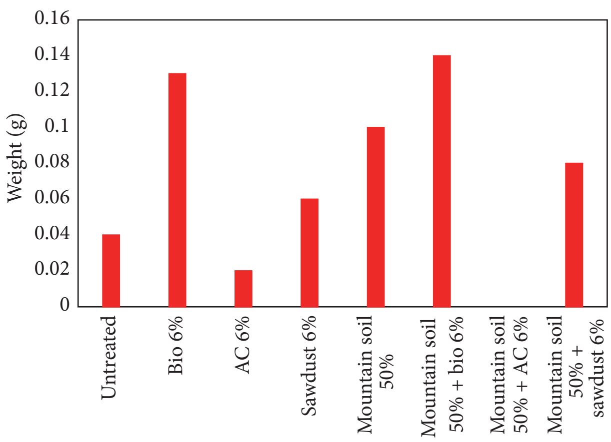

Figure 11: Weights of the grasses of Saemangeum Sample B.

Figure 12: View of pasting seeds by spraying.

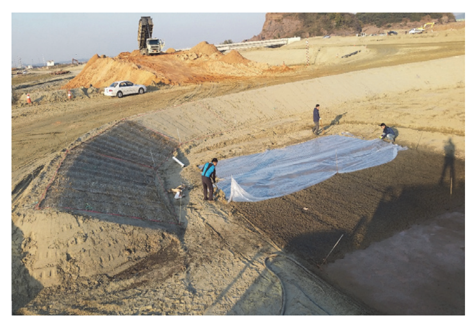

Figure 13: Plastic film application for the field test.

temperature and moisture. Table 6 presents the mixing ratios for the field test.

5.2. Field Test Results. Figure 14 is a view after the snow-removal work. On December 1, 2014 (21st day of the field test), 30 cm of snow fell and thus snow-removal work was carried out the next day. At that time, it was confirmed that sample populations had decreased drastically. Figure 15 is a view of the test field on February 27, 2015 (110th day of the field test): (1) is a view of the untreated section and (2) is the section treated with coffee sludge.

Figure 16 is a view of the untreated section on the 180th day of the field test, and Figure 17 is the section treated with coffee sludge.

5.3. Evaluation of the Germination Rate. There was limitation in counting the number of germinated plants. So, sections of 50 cm × 50 cm size were selected for each sample in the part where the highest germination rate occurred, and the coverage of those sections was measured with the same concept as the germination rate at an interval of two weeks. Figure 18 shows the grass coverage measured. For the sections treated with coffee sludge, the initial germination rate (on the 14th day of the field test) was measured as 50% but the coverage measured after the second interval (28th day of the test) was as high as 90%. After a heavy snow fall of 30 cm in Saemangeum area on the 30th day of the field test, many samples in the untreated section were lost and their population decreased drastically. The surface in the untreated section might have been removed by natural phenomena (rain, snow, wind, etc.) between the first measurement (14th day of the test) and the second measurement. However, when coffee sludge was added to the untreated section and then the section was covered with straw mats, the decrease of populations became slower.

5.4. Weight Measurement. Samples of grass in the dimension of 25 cm × 15 cm were taken from the slope on the 117th day of test. After being washed to get rid of the soil and other remnants, only plants were collected and measured for weight after seven days of natural drying. As shown in Figure 19, the weight of the sample in which only sawdust fertilizer was mixed was not significantly different from that of the untreated sample. However, the weight of the sample in which

Figure 14: View of the field test site on the 21st day of test.

Figure 15: View of the field test site on the 110th day of the field test.

coffee sludge was mixed was three times heavier than that of the untreated sample.

When coffee sludge was mixed into the dredged soil, oil contained in the coffee sludge helped the mixture retain moisture even during the dry winter season, causing the delay in growth rate. But, at the same time, it helped the grass sown in the coffee sludge and dredged soil mixture grow for a longer period compared to those in other cases.

5.5. Analysis of Chemical and Physical Properties. Samples of grass in the dimension of 25 cm × 15 cm were taken from each treated soil mixture and were analyzed for their chemical and physical properties. Table 7 shows a result of the analysis of chemical and physical properties of samples after the field test. For the untreated dredged soil, it was confirmed that there was rarely any organic content (0.277%) and remarkably low cation exchange capacity (CEC), electrical conductivity (EC), and total nitrogen (TN). The reason why salt concentration was low compared to what had been expected was natural phenomena like frequent rains and snows during the test. Therefore, it was determined as results of two times' watering and completed dry.

For the samples with the dredged soil mixed with coffee sludge, it was confirmed through the field test that pH was reduced due to slightly acidic nature of the coffee sludge. Due to the coffee sludge's own salinity, the salt concentration became higher than the untreated samples. Except for that, all other items appeared to be higher than the required condition.

Figure 16: View of the untreated section on the 180th day of test.

Figure 17: View of the section treated with coffee sludge on the 180th day of the field test.

6. Summary and Conclusions

This study aimed at improving the Saemangeum dredged soils that can be used for vegetation purpose, and the following conclusions can be drawn:

(1) The Saemangeum dredged soils were classified as SM. However, the results of chemical and physical analysis showed that all items were significantly below the arboreal growth conditions. This implies that the dredged soil must be improved through conditioning with appropriate materials.

(2) The test result showed that the case treated with bioameliorator and sawdust fertilizer had about 30–50% higher germination rate than that of the untreated case. As the cases treated with sawdust 6% had a higher germination rate than those of the cases treated with loess. This implies that it is possible to increase the recycling of the amount of the dredged soils using some ameliorators, leading to cost savings.

(3) The maximum germination rate of the dredged soil in which the 30% mountain soil was added decreased, but as the amount of coffee sludge was added to the dredged soil, the germination rate significantly increased. This means that coffee sludge is more efficient in improving the dredged soil compared to the one using loess.

(4) Based on the analysis of chemical and physical properties for the samples from the field test, it was confirmed that meteorological phenomena (snow, rain, wind, etc.) played a similar role in the field to what irrigation and complete drying processes did for

Table 7: Result of the analysis of chemical and physical properties of samples after the field test.

Classification	pH	Organism (mg/kg)	Available phosphate (mg/kg)	Salt concentration (%)	Electric conductivity (ds/m)	Total nitrogen
Saemangeum field sample	8.37	0.789	14.390	0.034	0.537	235.82
Untreated	7.37	0.277	11.328	0.040	0.633	71.26
Sawdust fertilizer 4%	7.23	5.680	14.161	0.148	2.314	350.48
Sawdust fertilizer 4% + Coffee sludge 6%	6.93	22.213	16.976	0.091	1.424	1518.51
Arboreal growth condition	5.5–6.5	3.00 more	100 more	0.05 less	0.4 less	200 more

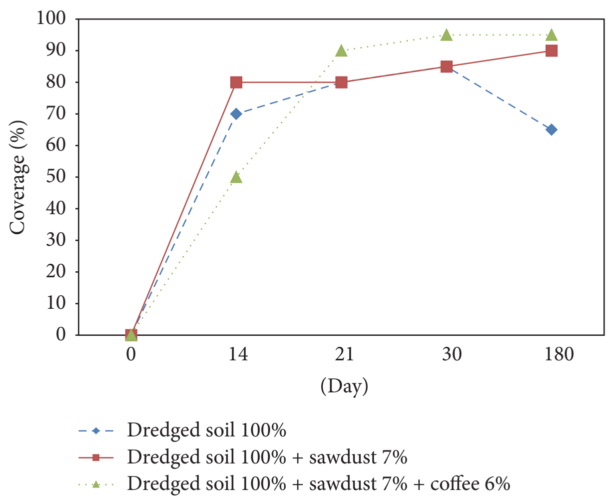

Figure 18: Coverage measured during the field tests.

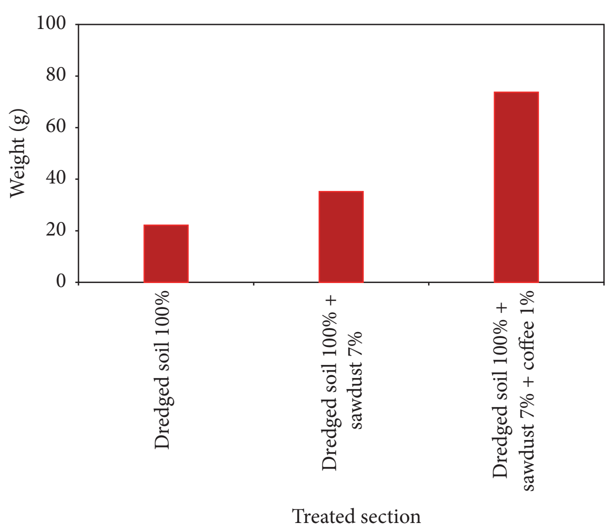

Figure 19: Weights of grass measured during the field test.

salt concentration in the laboratory test. Therefore, the possibility of the reduction in salt concentration through irrigation, drying, and being left alone in nature was confirmed through the tests.

(5) Light and fine particles of coffee sludge prevented oxygen permeation by covering the surface and thus were found to be a factor in inhibiting plant growth. Though the samples in the field test to which coffee sludge was added showed a slow initial germination, frequent snows and rains removed the surface. When the samples were dried for a long period of time, it was hard to remove the surface and the salt contained in the coffee sludge itself could be an inhibiting element for plant growth. For this reason, effective measures to control this problem are required.

Competing Interests

The authors declare no conflict of interests.

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