Bio-viability on Restored Open Pit with Coal Ash Aggregate Amendment

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INTRODUCTION

Due to increasing demands for construction-grade sand and gravel, these row materials are heavily being exploited today and used for concrete, general fill, and road subgrade material, bridges, airports, road surfacing, and aqueduct and sewer systems. Resulting open pit, in turn, may adversely affect health and safety of human beings if not appropriately managed or restored [1].
The main goal of this study was to investigate bio-viability on the coal ash aggregates (CAA)-amended restoration of open pits. The target field site is planned to be used as an agricultural land after restoration. To this end, a lab-scale study was conducted to evaluate multiple amendment factors on their effects on the germination rate and growth of the plants.

MATERIALS AND METHODS

Soil Sampling

As shown Figure 1, the open pit site was filled with the dredged sandy sediments from the Guayama bay, PR on the bottom at a depth of 0.3 m. As the site will be eventually used as an agricultural area, an organic-rich soil from the Coamo Lake, PR will be used as a top soil at a depth of 1 m. In these regards, two soils in addition to the site soil were sampled on site. After being transported, the soil samples passed a sieve size 3/8" were collected for the experiment.

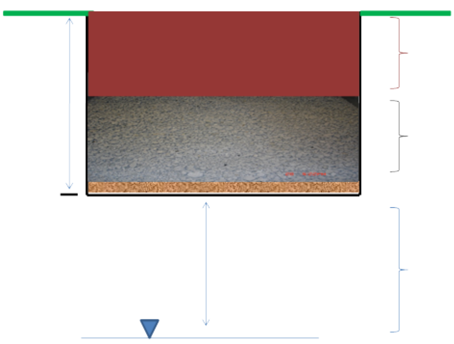

Figure 1. Schematics of backfilling of the site.

Coal Ash Aggregates

Coal ash aggregates (or commonly called manufactured aggregates) are solidified mixture of fly (FA) and bottom ashes (BA). This material gains strength with time due to cementitious reactions and physiochemical properties of the CAAs can be found in a previous study [2]. Briefly, main chemical components, by weight, are: 51% of (SiO_2 + Al_2O_3 + Fe_2O_3), 30% Lime (CaO), and 15% SO_3 [2]. Bulk CAAs were sampled at a local coal burning power plant in Puerto Rico (PR). Since the particle sizes are in a wide range, they were crushed and sieved in the laboratory. The CAAs were first oven dried at 105^{o}C overnight, crushed with a mechanical mixer, and sieved to collect the CAA sizes of 2.36 ~ 9.53 mm.

Germination of Beans and Pumpkins with Different Backfilling Methods

A germination experiment was conducted to assess various factors which could affect the germination rate and growth of the plants from the restored land. The parameter monitored was the product of the germination rate and shoot growth. First factor evaluated was a backfilling mode with a mixed or a layered application of the top soils and CAAs. Second factor was the type of seeds, bean or pumpkin. Third factor assessed was the ratio of the top soil to the CAAs. Lastly, the type of water sprayed to the systems was tested with natural rain water collected and tap water.

Sixteen treatments and 4 control reactors were constructed as shown in Table 1. Plastic reactors were dimensioned with 2.5-in dia. and 6-in long. Five seeds were placed to each reactor at a depth of 1.5 inches below surface. The reactors were put in the environmental chamber at 30^{o}C. Corresponding to the actual local maximum average precipitation, 40 mL of water (rain water or tap water) was sprayed on every other day for 2 weeks.

Table 1. Design matrix to assess the effects of multiple factors on the germination.

Reactors	Mixed/Layered	Seed	Distribution	Water*
R1	Layered	beans	4" top soil+2" aggregate	RW
R2	Layered	beans	2" top soil+4" aggregate	TW
R3	Mixed	beans	66.7% top soil+ 33.3% aggregate	RW
R4	Mixed	beans	33.3% top soil+ 66.7% aggregate	TW
R5	Layered	beans	4" top soil+2" aggregate	TW
R6	Layered	beans	2" top soil+4" aggregate	RW
R7	Mixed	beans	66.7% top soil+ 33.3% aggregate	TW
R8	Mixed	beans	33.3% top soil+ 66.7% aggregate	RW
R9	Layered	pumpkin	4" top soil+2" aggregate	RW
R10	Layered	pumpkin	2" top soil+4" aggregate	TW
R11	Mixed	pumpkin	66.7% top soil+ 33.3% aggregate	RW
R12	Mixed	pumpkin	33.3% top soil+ 66.7% aggregate	TW
R13	Layered	pumpkin	4" top soil+2" aggregate	TW
R14	Layered	pumpkin	2" top soil+4" aggregate	RW
R15	Mixed	pumpkin	66.7% top soil+ 33.3% aggregate	TW
R16	Mixed	pumpkin	33.3% top soil+ 66.7% aggregate	RW
*RW: rainwater, TW: tapwater				

Physical Hindrance

An experiment was conducted to assess potential physical hindrance of the CAAs against seeds germination and growth. For this experiment, only beans were used. In order to accommodate more numbers of the seeds (bean), 4 rectangular reactors were constructed of acrylic plates with effective volume of 800 in^3 (13 W x 8 L x 8 D). All 4 reactors had a supporting gravel layer of 2 in on the bottom. The reactors were packed as shown in Table 2. Six bean seeds were planted in each reactor at a depth of 1.5 inches. Corresponding to the actual local maximum average precipitation, 840 mL of tap water was evenly sprayed on the top of the reactors every other day for over 5 weeks. Germination and growth monitoring was done every Mondays and Fridays.

Table 2. Reactor design for testing physical hindrance of the CAA against germination and growth.

Layers		**Reactor 1**	**Reactor 2**	**Reactor 3**	**Reactor 4**
Top soil layer	Depth (in)	8	6	5	4
	Bulk density (g/cm^3)	1.51	1.56	1.23	1.56
Hindrance Layer	CAA, depth (in)	-	2	1	-
	Bulk density (g/cm^3)	-	0.80	0.91	-
	Gravel, depth (in)	-	-	2	6
	Bulk density (g/cm^3)			1.77	1.40

RESULTS AND DISCUSSION

Effects of Backfilling Methods on Germination and Growth

Generally, beans germinated and grew much better than pumpkins during the period of the experiment (2 weeks) as shown in Figure 2. Between two backfilling modes, a layered mode showed better results than a mixed mode. It was suspected that a physical hindrance due to the presence of the CAAs had occurred, thereby poorer germination and growth patterns for the mixed backfilling mode and the more CAA ratio in the layered mode. Additional experiment was conducted to disclose this suspicion. Regardless of the seed type, better results were observed with a greater depth of the top soil for a layered backfilling mode and a higher ratio of the top soil to the CAAs for a mixed mode. Both plants also showed better results when their seeds were planted into the system that had more top soils than the CAAs.

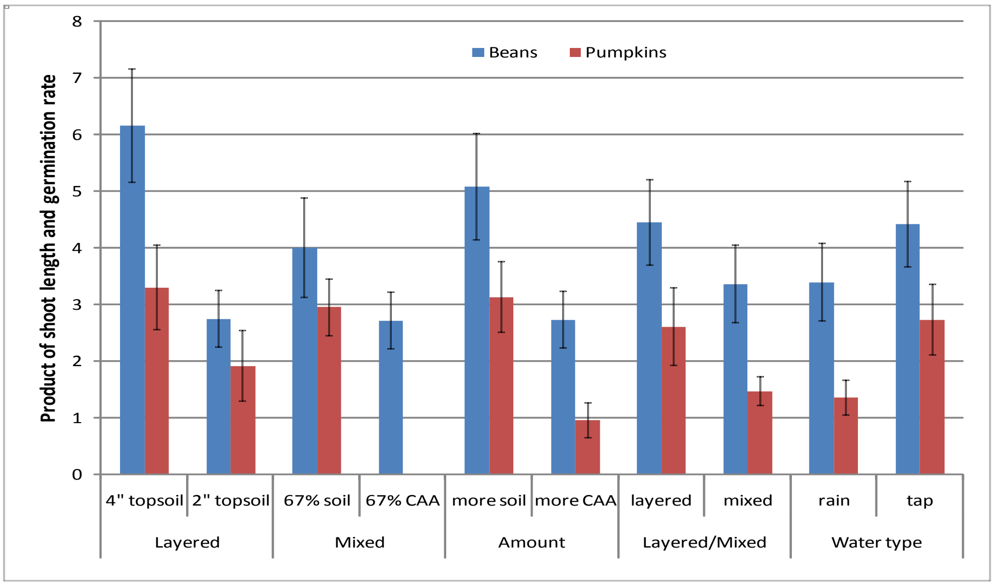

Figure 2. Effects of backfilling methods on germination and growth of beans and pumpkins.

Potential Physical Hindrance of CAAs

All 6 bean seeds germinated from each reactor. However, after about a month of growth, 3 shoots died from the Reactors 1 and 4 (i.e., 50% survivability), and 1 shoot died from the Reactor 2 (i.e., 83% survivability). No shoot death was observed from the Reactor 3, resulting in 100% survivability). Therefore, greater survivability was observed for the systems (Reactors 2 and 3) which had a CAA layer below the top soil.

Generally, the Reactor 2 had the best shoot growth, as shown Figure 3, followed by the Reactor 3. Both Reactors had the CAA layers: 2-inch CAA layer below 6-inch top soil for the Reactor 2, whereas 1- inch CAA layer below 5-inch top soil for the Reactor 3. The shoots in the Reactor 1 which had only 8-in top soil grew a similar manner that those in the Reactors 2 and 3 which had the CAA layers up to 3 weeks of growth. However, its growth was getting limited after 3 weeks.

Therefore, the hypothesis that there would be a physical hindrance against plant growth was not met. Rather, it was construed that as long as enough top soil layer was provided, a layer of the CAAs could play a role as a nutrient sources.

After ~40 days, bean sacks were developed. Bean seed in the sacks were harvested at the end of experiment and extracted for Pb analysis by a HACH Digestion method. Extracted liquids were measured for Pb with an ion selective electrode and the results showed no Pb in the extractant.

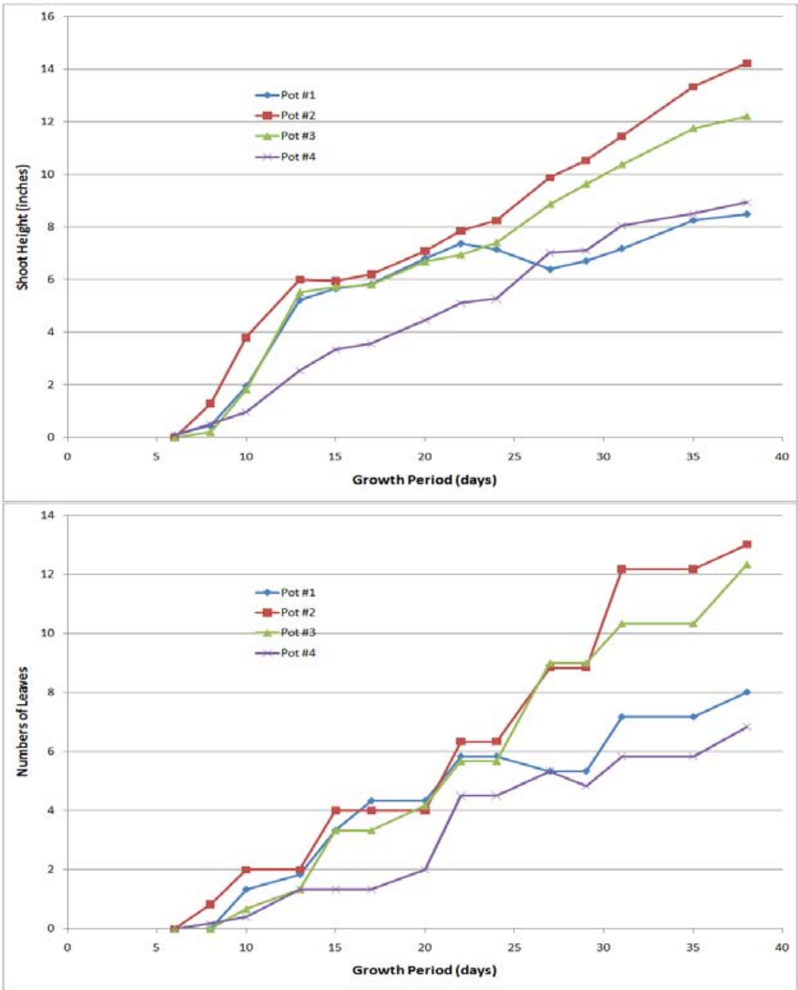

Figure 3. Shoot height and leaf numbers of beans.

CONCLUSIONS

Bio-viability was assessed on the land restored with CAAs as a backfilling amendment. Preliminary results showed that the presence of CAAs below the top soil did not exert a negative impact on the germination and growth of plants tested (beans and pumpkins). Rather, it produced better germination and growth when layered as an amendment below the top soils. Further study is warranted to draw a more concrete conclusion of feasibility of utilization of CAAs as a backfilling amendment for the land to be restored and used for agricultural purposes.

ACKNOWLEDGMENTS

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