Feasibility of Open Pit Restoration with Coal Ash Aggregates: Ground Water Quality Assessment

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KEYWORDS: restoration, statistical design, water quality

INTRODUCTION

As the magnitude of civil, transportation and construction infrastructure has expanded since the industrial revolution, demands for construction-grade sand and gravel has subsequently increased. These row materials are heavily being exploited in PR 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 is to investigate the feasibility of coal combustion ash aggregates (CAA)-based refill for the open pits in Santa Isabel. Therefore, this study aims to assess quality of groundwater resulting from use of CAAs as backfilling amendments for open pit quarry restoration.

MATERIALS AND METHODS

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^oC overnight, crushed with a mechanical mixer, and sieved to collect the CAA sizes of 2.36 ~ 9.53 mm.

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.

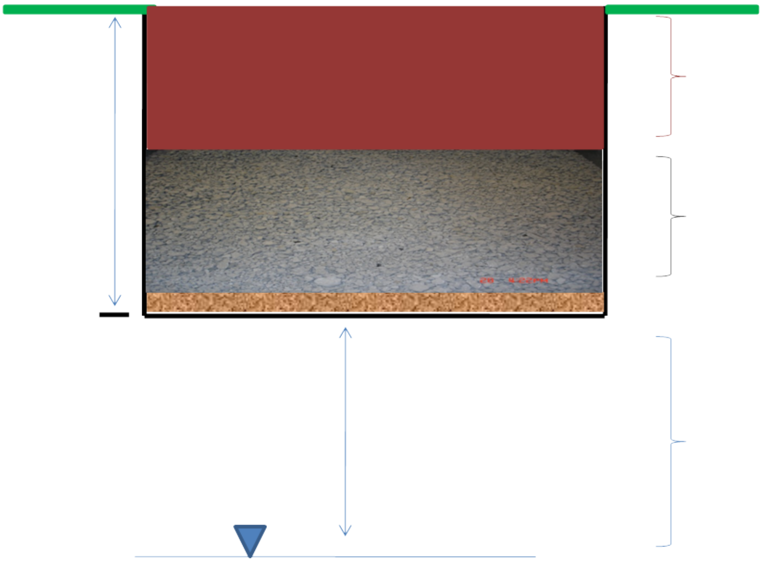

Figure 1. Schematics of backfilling of the site.

3-Factor, 2-Level Statistical Design and Analysis

Focus was given to the volume of CAAs that can be utilized as a substitute subsoil material. For this, PVC column reactors (3-in dia. and 30-in long) were designed, performed, and analyzed by a statistical design with three factors containing two levels each for the assessment of the unsaturated-zone transport phenomena (Table 1).

Table1. Design matrix of 3-factor, 2-level statistical experiment.

Reactors	Top Soil (in)	CCPs (in)	Bottom Soil (in)	Site Soil (in)	CCPs Size	Rain Intensity
R_1	8	4	4	10	A	High
R_2	8	4	4	10	A	High
R_3	8	4	4	10	A	Low
R_4	8	4	4	10	A	Low
R_5	8	4	4	10	B	High
R_6	8	4	4	10	B	High
R_7	8	4	4	10	B	Low
R_8	8	4	4	10	B	Low
R_9	4	8	4	10	A	High
R_{10}	4	8	4	10	A	High
R_{11}	4	8	4	10	A	Low
R_{12}	4	8	4	10	A	Low
R_{13}	4	8	4	10	B	High
R_{14}	4	8	4	10	B	High
R_{15}	4	8	4	10	B	Low
R_{16}	4	8	4	10	B	Low

The volumetric ratio of the CAAs to the organic top soil is a treatment factor with two levels of 8:4 and 4:8, which was the ratio of the depth of the top soil to the CAAs. Simulated precipitation was made three times a week by spraying tap water on the top of the reactors. Precipitation rates are another treatment factor with two different levels:

high rainfall 60 mL each application, low rainfall 30 mL each application. Two rainfall amounts were calculated according to the actual maximum and minimum average precipitation in Santa Isabel. Half of the reactors were assigned to the smaller particle sizes (“A” type in Table 1, 2.36 ~ 4.75 mm) of CAAs and the remainder to the greater particle sizes (“B” type in Table 1, 4.75 ~ 9.53 mm). Thus, the particle size of the CAAs is another treatment factor containing two levels.

ANALYSIS

Heavy metals, lead (Pb) and cadmium (Cd), were monitored with the Leadtrak (HACH) and an ion specific electrode (Orion), respectively. The value of pH was measured with an Orion pH meter. Specific conductivity was analyzed with Orion Specific Conductivity Meter Model 162. Turbidity was measured with LaMotte 2020 Turbidimeter. Hardness was analyzed with an ion specific electrode (Orion).

EXPERIMENTAL RESULTS

The water volume infiltrated in each reactor weekly is shown in Figure 2 (top). Apparently, it seems the rainfall intensity influenced greatly on the infiltrated water volume. The infiltrated water from each reactor containing the CAAs had a slightly basic pH (~8.5) throughout the experiment, as shown in Figure 2 (bottom). A higher pH of the control reactors was attributed to the characteristics of the sand used for the system.

For Pb, the HACH LeadTrak testing methods can detect Pb as low as 5 µg/L as Pb. For ensuring quality of the measurement, a Cole-Parmer Pb ion selective electrode was also used for Pb analysis. Its lower limit was 0.2 mg/L. For Cd, a Cole-Parmer Cd ion selective electrode with a lower limit of 0.2 mg/L was used for the analysis. However, heavy metal analysis showed no concentrations of Pb and Cd.

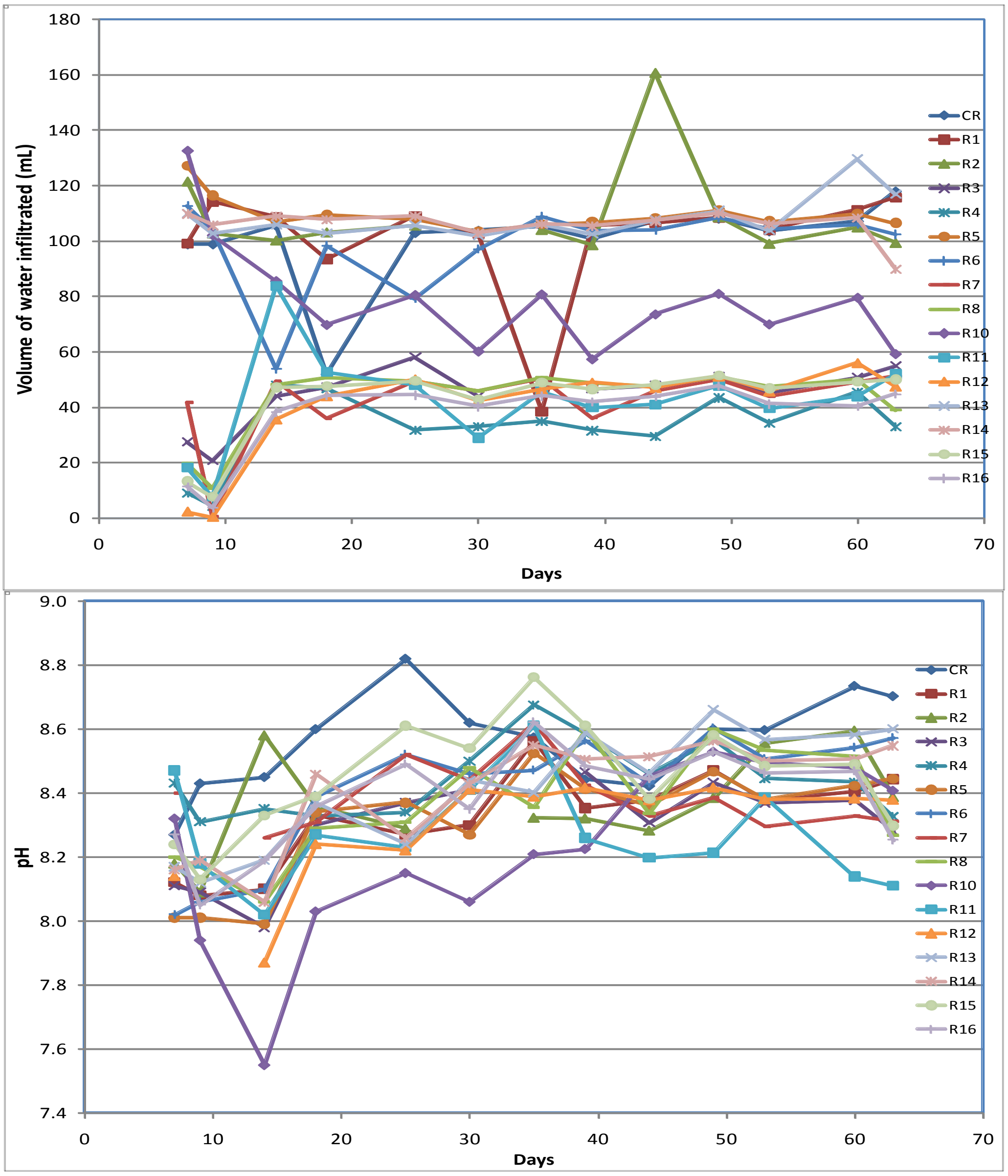

Figure 2. Trend of the amount of infiltrated water (top) and pH values (bottom).

Turbidity was monitored in the range between 0.5 and 1 NTU, except for a couple of outliers, in the beginning of the experiment. However, it reduced to a value less than 0.5 NTU as shown in Figure 3 (top). Specific conductivity showed higher strengths in all treatment columns compared to that in the control reactor as shown Figure 3 (bottom). A similar trend was observed for the hardness concentrations.

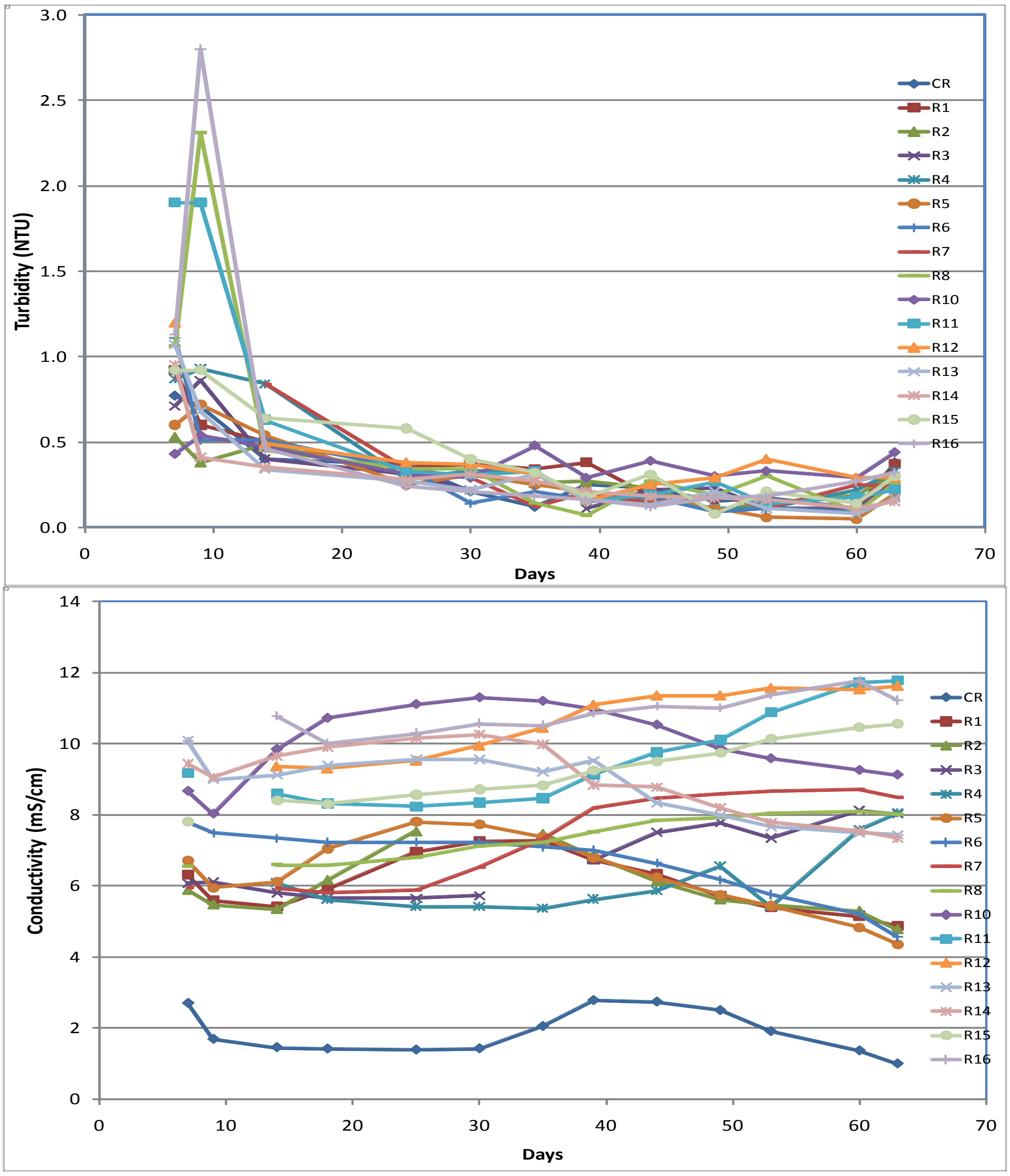

Figure 3. Trend of turbidity (top) and conductivity (bottom) in the infiltrated water.

For better understanding of statistically significant effects that were produced by the main factors in a simpler way, plots containing only the main effects and causes were constructed as shown in Figures 4 and 5. The rainfall intensity undoubtedly significantly influenced on the amount of the infiltrated water as shown in Figure 4 (top). The difference in the amount of the infiltrated water was all statistically different, with the greater rainfall intensity being produced more amount of the infiltrated water. For the values of pH, significantly higher pH values were observed for the reactors with low-level rainfall intensities and small-sized CAAs (Figure 4 (bottom)).

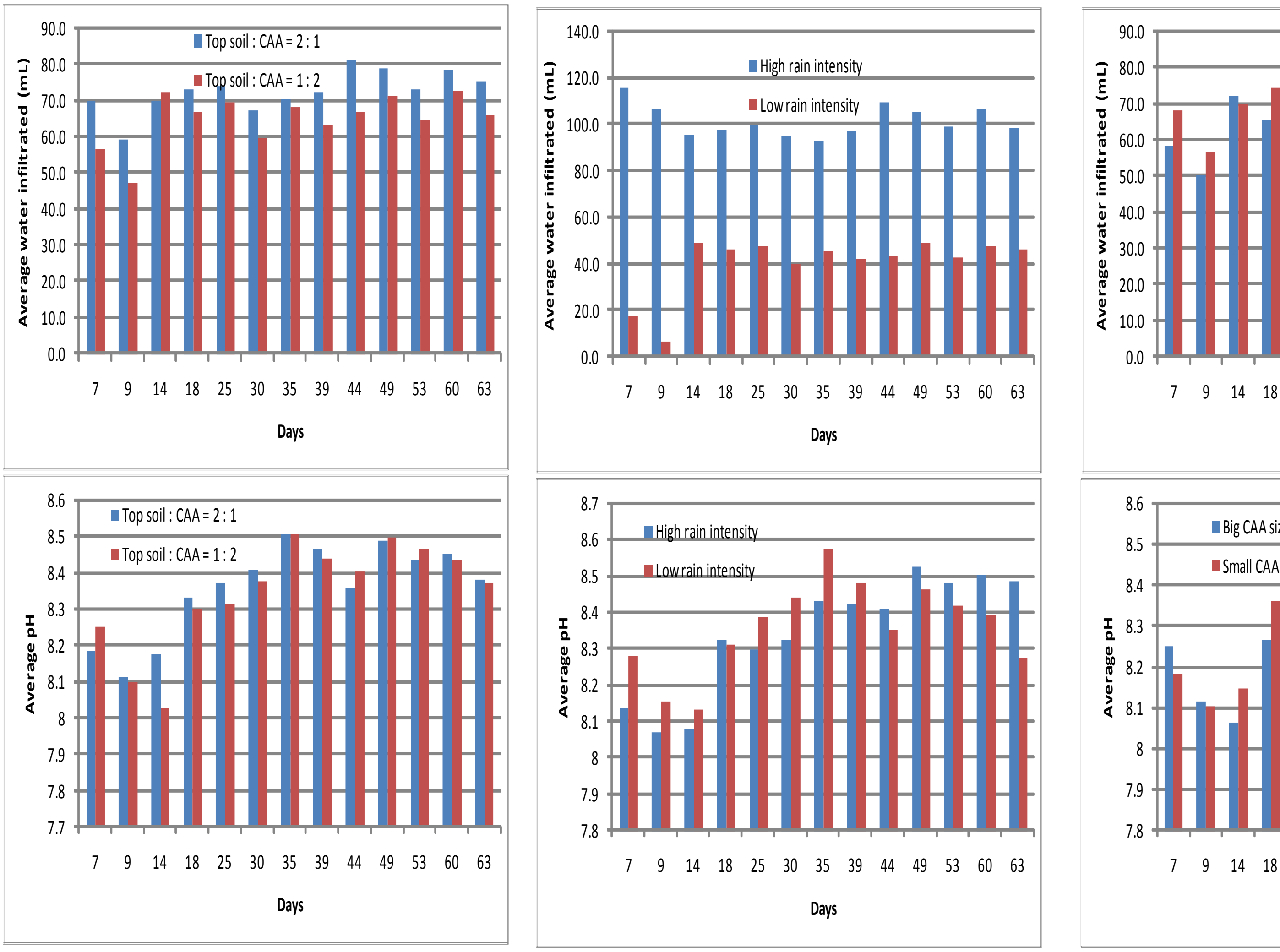

Figure 4. Plots of the main effects on the amount of infiltrated water (top row) and pH value

As shown in Figure 5 (top), turbidity was statistically higher for the reactors with low-level rainfall intensities, more CAAs ratio, and smaller size CAAs. However, in the later part of the experiment, the infiltrated water from the bigger size CAAs produced significantly higher turbidity. Statistically higher hardness concentrations were monitored for the reactors with more CAAs ratio up to the middle of the experiment (Figure 5 (bottom)). However, low-level rainfall intensity dominantly produced significantly higher concentrations of hardness in the later experiment.

CONCLUSIONS

Coal ash aggregates were tested if they can be used as amendments for restoration of disturbed land. Results from a 3-factor, 2-level statistical experiments showed that temporally varying trend of main effects on water quality parameters (pH, turbidity, conductivity, and hardness). Despite temporal variations, values of pH were found near 8.5, turbidity near 0.5 NTU, and conductivity ranging 4 to 12 mS/cm in the infiltrated water. A long-term water quality monitoring experiment is currently ongoing to assess spatial and temporal changes of water quality parameters.

ACKNOWLEDGMENTS

The authors would like to express sincere appreciation to the AES Puerto Rico and US Geological Survey Water Resources Research Grant State Program for their financial support for the project.

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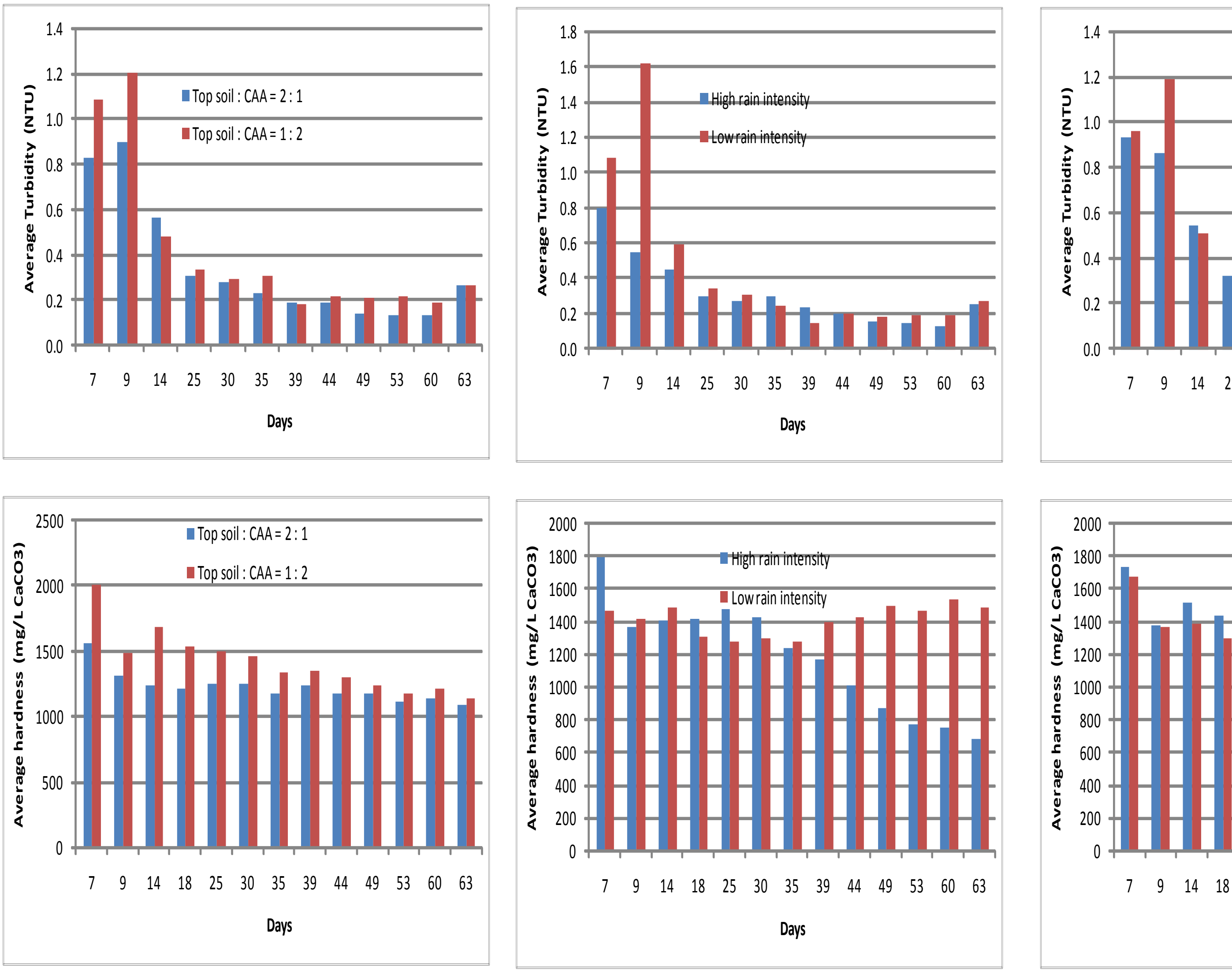

Figure 5. Plots of the main effects on turbidity (top row) and hardness (bottom r