Puerto Rico Water Resources Research Institute
Annual Technical Report
FY 2009

Introduction

The Puerto Rico Water Resources and Environmental Research Institute (PRWRERI) is located at the Mayagüez Campus of the University of Puerto Rico. The Institute is one of 54 water research centers established throughout the United States and its territories by Act of Congress in 1964 (P.L. 88-379) and presently operating under Section 104 of the Water Research and Development Act of 1984 (P.L. 98-242), as amended.

Originally, the Puerto Rico Water Resources Research Institute (PRWRRI) was established in April 22, 1965, as an integral division of the School of Engineering of the College of Agricultural and Mechanic Arts, the official name of the campus at that time. An agreement between the Director of the Office of the Water Resources Research Institute of the Department of the Interior and the University of Puerto Rico at Mayagüez was signed in May 25, 1965. This agreement allowed the Institute to receive funds as part of the Water Resources Act of 1964. In June 1, 1965, the Chancellor of the Mayagüez Campus appointed Dr. Antonio Santiago (Chago) Vázquez as the first director. The first annual allotment of funds for fiscal year 1965 was $52,297.29.

Since its inception, the Institute has had eight directors in nine appointment periods as shown in the table below.

Director No. Director Name Period of Appointment

1 Dr. Antonio Santiago-Vázquez 1965 - 1968

2 Eng. Ernesto F. Colón-Cordero 1968 - 1972

3 Eng. Felix H. Prieto-Hernández 1972 - 1974

4 Dr. Roberto Vázquez (acting director) 1974 - 1975

5 Dr. Rafael Ríos-Dávila 1975 - 1980

6 Dr. Rafael Muñoz-Candelario 1980 - 1986

7 Eng. Luis A. Del Valle 1987 - 1989

8 Dr. Rafael Muñoz-Candelario 1989 - 1994

9 Dr. Jorge Rivera-Santos 1995 - present

The official name of the Institute was changed in 2005 to Puerto Rico Water Resources and Environmental Research Institute.

The general objectives of the Puerto Rico Water Resources and Environmental Research Institute are (1) to conduct research aimed at resolving local and national water resources problems, (2) to train scientists and engineers through hands-on participation in research, and (3) to facilitate the incorporation of research results in the knowledge base of water resources professionals in Puerto Rico and the U.S. as a whole. To accomplish these objectives, the Institute identifies Puerto Rico's most important water resources research needs, funds the most relevant and meritorious research projects proposed by faculty from island universities, encourages and supports the participation of students in funded projects, and disseminates research results to scientists, engineers, and the general public. Since its creation, the Institute has sponsored a substantial number of research projects, supported jointly by federal, state, private, and University of Puerto Rico's funds. Through its website, the Institute's work is more widely known to the Puerto Rican and world communities and, at the same time, provides means of information transfer with regard to the reports produced through the institute's research activities.

The Institute is advised by an External Advisory Committee (EAC) composed of members from water resources related government agencies, both federal and state levels. This committee virtually convenes annually to established research priorities and to evaluate and recommend proposal for funding under the 104 program. The EAC has representation from the private sector as well. The FY2009 EAC composition was as follows.

1. Dr. Antonio Santiago Vázquez, Engineering Private Consulting Firm, former Institute's director.

2. Mr. Pedro Díaz, USGS District Chief, Puerto Rico and Caribbean Office.

3. Eng. Victor Trinidad, US Environmental Protection Agency

4. Eng. Rafael Morales, PR Planning Board

5. Eng. Angel Meléndez, PR Environmental Quality Board

6. Dr. Walter Silva, Associate Director, PRWRERI, UPRM

7. Dr. Jorge Rivera-Santos, Director, PRWRERI, UPRM

This report covers the period from March 1, 2009 to February 28, 2010. All activities relate to the base grant, National Competitive Grant Program awards for which the Institute was the lead institute, NIWR-USGS Internships, and supplemental awards funded by either the USGS or by pass-through funds from another Federal agency are summarized herein.

Research Program Introduction

Under the direct supervision of the Chancellor Office, the PRWRERI is a component of the Research and Development Center of the University of Puerto Rico at Mayaguez. As such, it acts as official liaison of the University of Puerto Rico with industry and government for all water resources related research activities. The Institute also functions as a highly recognized advisor to these two sectors on water resources and environmental issues. This role translates into multidisciplinary functions and activities that add relevance and impact to the research program the Institute supports. By virtue of the local relevance of its research and the prestige and leadership of the investigators it has supported, the Institute has become the focal point for water-related research in Puerto Rico.

Meetings, seminars, technical reports, quarterly newsletter and a web site are used by the Institute to keep the water resources community and general public informed about advances in research. Approximately once every three years, the Institute organizes a major conference on water-related research in Puerto Rico and the Caribbean Islands, in collaboration with other technical organizations in the region. All these activities facilitate the translation of the research sponsored by the Institute into practical applications of direct benefit to industry, government, and the general public.

In FY 2009, the PRWRRI submitted 5 continuing research and technical project proposals to federal and state government agencies, municipalities, and private sector. Four were approved for total funds of $546,854.59. One continuing proposal was rejected. The proposals are as follows:

1) Development of a Stormwater Management Plan for the Municipality of Mayagüez, submitted to the Municipality of Mayagüez, $160,634.98, (approved)

2) Hydrologic and Hydraulic studies appraisal for the Department of Natural and Environmental Resources of PR, PRDNER, (Part II rejected)

3) Hydrodynamic and Salinity Study for Boqueron Wildlife Refuge   Resubmission to PRDNER, $210,000, (Approved)

4) Perform an Evaluation for Heavy Metal Removal from the Miradero Water Treatment Facility   Extension to other metals, Part III, CDM, $20,000 (Approved)

5) The Northeast State & Caribbean Islands Regional Water Program, USDA, $156,219.61 (Approved).

During FY 2009 the PRWRERI administered one project funded under Section 104B, in addition to other projects funded by other agencies, as per approved proposals. Previous fiscal year continuing projects include

1. Regional Water Quality Coordination project in USEPA Region III, in collaboration with Rutgers University and Cornell University.

2. Comprehensive Integrated Management Plan for the Mayaguez Bay Watershed.

3. Perform an Evaluation for Heavy Metal Removal from the Miradero Water Treatment Facility.

4. Hydrologic and Hydraulic studies appraisal for the Department of Natural and Environmental Resources of PR.

A Call for Proposals to the research community of Puerto Rico was issued in October, 2009. Seven submissions ware received. These evaluated by the EAC and the result is as follows.

1. Outlying Groundwater Catchments Using Radar - Derived Rainfall (rejected)

2. Atmospheric Deposition of Persistent Organic Pollutants (POPs) to Jobos Bay National Research Reserve Watershed (rejected)

3. A Novel Environmental Remediation Technology - Fe(II)/02/Ligands System for Oxidization of Aqueous Organic Pollutants (rejected)

4. Water Resources Management in Rincon, Puerto Rico (rejected)

5. Polymer-Metal Nanocomposite Membranes for Water Purification (rejected)

6. Open Pit Quarry Restoration to Bio-Viable Land (continuing project). (approved)

During FY2009, Director Jorge Rivera-Santos was appointed Acting Chancellor of the University of Puerto Rico at Mayagüez. This appointment required most of Dr. Rivera-Santos time. Dr. Walter Silva, who was the Associate Director, took most of the responsabilities of the Director and jointly with the institute s staff, current research projects were managed and continued. Dr. Jorge Rivera-Santos continued function as director and looked for the progress of the research projects and continued to be a liaison between the University of Puerto Rico and other agencies including the Caribbean Office of the US Geological Survey. The director targeted other local government agencies to become directly involved with through the arrangement of Memorandums of Understanding (MOUs).

OPEN PIT QUARRY RESTORATION TO BIO-VIABLE LAND

Basic Information

Title:	OPEN PIT QUARRY RESTORATION TO BIO-VIABLE LAND
Project Number:	2008PR45B
Start Date:	3/1/2008
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	N/A
Research Category:	Engineering
Focus Category:	Water Quality, Groundwater, Hydrogeochemistry
Descriptors:	
Principal Investigators:	Sangchul Hwang

Publications

There are no publications.

Final Report of 2nd-Year Project

Open Pit Quarry Restoration to Bio-Viable Land

Project Year (2nd Year): Mar. 1, 2009 ~ Feb. 28, 2010

Submitted by:

Sangchul Hwang, PhD
Associate Professor
Department of Civil Engineering and Surveying
University of Puerto Rico at Mayaguez

Submitted to:

Puerto Rico Water Resources and Environmental Research Institute
University of Puerto Rico at Mayaguez

June 15, 2010

Table of Contents

List of Tables

List of Figures

List of Photos

Problem Statement

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 raw 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 (MDNR, 1992).

Currently, quarry restorations costs are increasing, mainly due to scarcity of natural resources, rise of material transportation costs and investments in further applications. Furthermore, environmental issues such as groundwater behavior at the end of quarrying and environmental impacts after/during the operations have to be assessed. Many sand and gravel quarries had been restored to residential areas, gulf course, industrial and commercial facilities, landfills, parks, open agriculture and horticulture sites, forestry, sport and recreation areas, car parking, and water supply reservoirs. However, a need exist to find alternate materials at lower cost and methodologies to restore quarries.

As shown in Photo 1, the site of interest is located in Santa Isabel, PR. Gravel mining has been operated by a private mining company since 1985. Its maximum extraction of the aggregates reached at 2,000 m3/day. However, its operation ceased in October 2006 resulting in approximately 420 cuerdas (~420 Acre) of the open pits at the site. Old sites have been restored to the agricultural areas with Mango trees. Organic sediment materials for the backfilling have been transported from the Coamo Lake nearby the site. Most land areas surrounding the site are being used for the agricultural purposes.

Photo 1. The location of the gravel mining site in Santa Isabel, PR.

Research Objectives

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. The site is planned to be used as an agricultural land after restoration. Therefore, this study aims to assess the potential environmental risks in relation to soil and groundwater quality associated with the use of industrial byproducts CAAs. Another objective is to evaluate bio-viability on the land after restoration. To meet this end, laboratory feasibility tests and computational modeling were proposed to perform for 3 years starting on March 1, 2008 and ending on February 28, 2011.

Methodology

Materials

The open pit site was filled with the dredged sandy sediments from the Guayama bay 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 will be used as a top soil at a depth of 1 m. In these regards, two soils were sampled on site as shown in Photo 2. After being transported, the soil samples passed a sieve size 3/8" were collected for the experiment.

Photo 2. Soil Sampling on site.

Coal ash aggregates were obtained from a local coal burning power plant in Guayama, PR. It is a solidified mixture of fly and bottom ashes with water. Main chemical components, by weight, are: 51% of (SiO_2 + Al_2O_3 + Fe_2O_3), 30% Lime (CaO), and 15% SO_3 (Pando and Hwang, 2006). The CAAs were first oven dried at 105°C overnight, crushed with a mechanical mixer, and sieved to collect the CAA sizes of 2.36 ~ 9.53 mm (Photo 3).

Photo 3. Coal ash aggregates before (left) and after (right) preparation for the experiment,

Experimental Methods

Water Quality Assessment

3-Factor, 2-Level Statistical Design and Analysis

As shown in Figure 1, initial focus was given to the volume of CAAs that can be utilized as a substitute subsoil material. For this, as shown in Photo 4, 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 fate and transport phenomena (Table 1).

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 (2.36 ~ 4.75 mm) of CAAs and the remainder to the greater particle sizes (4.75 ~ 9.53 mm). Thus, the particle size of the CAAs is another treatment factor containing two levels.

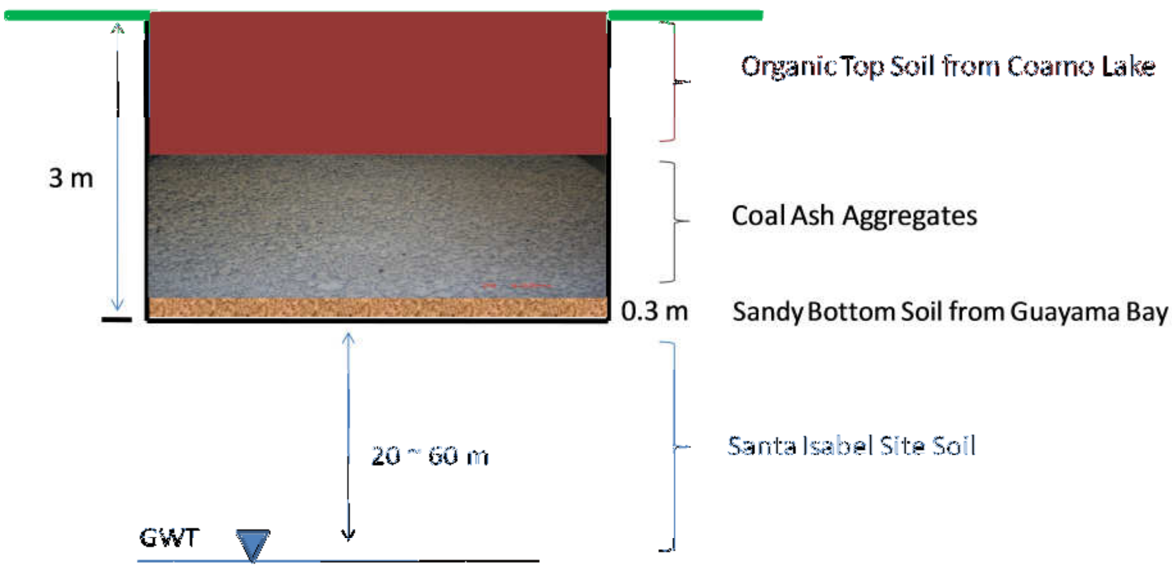


Figure 1. Schematic of backfilling of the site.

Photo 4. Column Reactors setup for water quality assessment in a statistical design and analysis.

Table 1. 3-factor, 2-level statistical design matrix.

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

Preliminary Leaching Test for Each Solid Components

Total 8 plastic reactors (2.5-in D x 6-in L) were constructed to test leaching characteristics of each solid material being used in the project as shown in Photo 5. Each component was packed at a depth of 5 inches. Table 2 shows the design matrix of leaching test. Tap water was sprayed on the top of the reactors on every Mondays, Wednesdays, and Fridays. During the first 2 watering events, 40 mL was sprayed, but the amount of water added was increased to 100 mL to collect enough amount of infiltrated water with which water quality parameters were analyzed. This experiment was done over 4 weeks.

Photo 5. Views of leaching tests of each solid material used in the project.

Table 2. Design matrix of preliminary leaching test for each solid material.

Reactor #	1	2	3	4	5	6	7	8
Component	Top soil	Bottom soil	Site soil	Sand	CAA (smaller size)	CAA (bigger size)	Gravel	Top soil (duplicate)
Bulk density (g/cm^3)	1.34	1.49	1.49	1.65	0.78	0.88	1.61	1.35

Water Quality Monitoring 1: Temperature Effect

Two identical column systems were constructed in parallel with a combination of soil and CAA distribution which had produced the worst water quality in the previous statistical experiment. The worst water quality was found when less top soil but more CAA with bigger particle sizes (4.75 ~ 9.53 mm) were used under lower rainfall intensity.

Rainfall was applied in this experiment by pumping 10 mL/min of water each weekday for 4 hours. Sampling was done weekly but analysis was done in an alternate manner. Water quality parameters of pH, turbidity, conductivity, and heavy metals (Pb and Cd) were measured from one week samples, whereas those of alkalinity, hardness and total heterotrophic bacteria (THB) counts were done from the other week samples.

One (System 1) was operated at 10 ^{o}C and the other (System 2) was at room temperature. A lower temperature set-up was to test water quality parameters in a condition similar to a field soil and groundwater environment with respect to temperature. Distribution of soils and aggregate was shown in Table 3. Schematics of column set-up and a photo are shown in Figure 2 and Photo 6, respectively.

Table 3. Soils and CAA distribution of two identical columns used for Long-Term Water Quality Monitoring 1: Temperature effect.

	Top Soil	CAA	Bottom Soil	Site Soil
Numbers of columns	1	1	1	4
Lengths of columns (inches)	6.5	13	2.5	30 each
Bulk density (g/cm^3)	1.35	0.51	1.08	1.30 -1.49

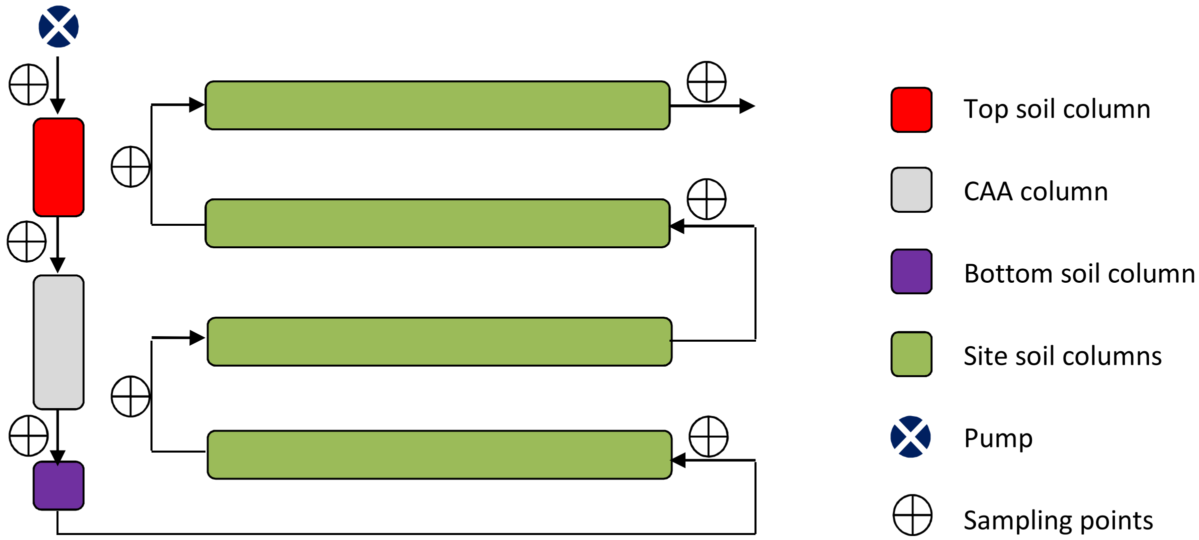


Figure 2. Schematics of column set-up for Water Quality Monitoring.

Photo 6. Column set up for the experiment of water quality assessment with the worst-case combinational refilling and temperature effect.

The System 1 was constructed in the same way as the System 2, except for the operating temperature. It was coiled with a vinyl tube and cold water (10^{o}C) was recirculated through it by a temperature controlled bath. The columns and coiled tubes were wrapped with an insulation sheet. Tap water was pumped to the Systems 1 and 2 at a rate of 10 mL/min from a reservoir by a peristaltic pump. Pumping was scheduled for 3 hours per week day at the consistent time frame using a timer. Samples were collected from the sampling ports once every two weeks and analyzed for water quality parameters.

Water Quality Monitoring 2: Amendment Effect

Another column system (System 3) was constructed with a combination of soil and CAA distribution which had produced the best water quality from the previous statistical experiment (Photo 7). The best water quality was measured when more top soil but less CAA with smaller particle sizes (2.36 ~ 4.75 mm) were tested under greater rainfall intensity (20 mL/min). The same rainfall frequency that was used for the Water Quality Monitoring 1 was used for this experiment. Sampling and analysis schemes were the same as the previous experiment. Distribution of soils and aggregate was shown in Table 4.

Table 4.Soils and CAA distribution of the column reactor used for Water Quality Monitoring 2: Amendment effect.

	Top Soil	CAA	Bottom Soil	Site Soil
Numbers of columns	1	1	1	4
Lengths of columns (inches)	13	6.5	2.5	30 each
Bulk density (g/cm^3)	1.32	0.53	1.08	1.32

Photo 7. Column set up for the experiment of water quality assessment with the best-case combinational refilling.

Water Quality Monitoring 3: Individual Columns

Additional column experiment was conducted to acquire water quality data from each soil component to understand better the contribution of each soil type to the overall water quality obtained from the Water Quality Monitoring experiment 1 and 2.

Three soils were tested: CAA, bottom soil, and site soil. Two sets of experiments were conducted as shown in Photo 8 and Table 1. Each column was stand alone and was not connected each other. System 4 was with soil and CAA distribution which had showed the worst water qualities. Each column received tap water pumped at a rate of 10 mL/min for 4 hours on each weekday. System 5 was with the cases which had produced the best water qualities and the columns were pumped at 10 mL/min for 4 hours on each week days. All columns were operated at 25^{o}C.

Photo 8. Water quality monitoring for individual soil components (left: System 4; right: System54).

Table 5. Configurastion of column set up for assessment of water quality parameters from each soil type.

		Column dia. (inch)	Column length (inch)	Bulk density (g/cm3)	Particle size (mm)	Flow rate (mL/min)
System 4	CAAs	3	13	0.51	4.75-9.53	10
	Bottom soil	3	2.5	1.08	-	10
	Site soil	3	30	1.30	-	10
System 5	CAAs	3	6.5	0.53	2.36-4.75	20
	Bottom soil	3	2.5	1.08	-	20
	Site soil	3	30	1.32	-	20

Nitrogen and Phosphorus Reduction Potential

One purpose of Santa Isabel open pit restoration is to reutilize the area for agricultural purpose. This subset of experiment intended to evaluate potential of CAAs for reduction of nitrate (NO_3^-) and phosphorous (PO_4^-) concentrations that would be from the fertilizers. Three columns were set up as shown in Photo 9 with a configuration indicated in Table 6.

Photo 9. Column setup for assessment of nitrate and phosphorus reduction by CAAs.

Table 6. Configuration of the columns set up for the experiment on nitrate and phosphorus reduction by CAAs.

Column I.D.	Column dia. (inch)	Column height (inch)	CAA size (mm)	CAA bulk density (g/cm^3)	Operating temp (^oC)	Flow rate (mL/min)
A	3	13	4.75-9.53	0.51	25	10
B	3	6.5	2.3-4.75	0.53	25	20
C	3	13	4.75-9.53	0.51	10	10
D	3	13	4.75-9.53	0.51	25	20
E	3	6.5	2.3-4.75	0.53	25	10

Influent concentrations of NO_3^- and PO_4^- were prepared at 12 and 6 mg/L, respectively. Continuous flowrate as shown in Table 6 was applied for 4 hours during weekdays. Effluent samples were taken and analyzed for the respective compounds.

In order to verify the effect of flow rate on NO_3^- and PO_4^- reduction, another set of experiment was conducted by preparing two columns D and E in the same manner for the columns A and B, respectively, as shown in Table 6. However, for this case, the column D received a flow rate of 20 mL/min, whereas the column E at 10 mL/min.

Groundwater modeling

A physical model was constructed with the best-case restoration scenario and connected to a physical aquifer model as shown in Figure 3. This experiment was to assess fate and transport of those water quality parameters (e.g., turbidity, hardness, pH) in a saturated aquifer environment. Results will be addressed in the next progress report.

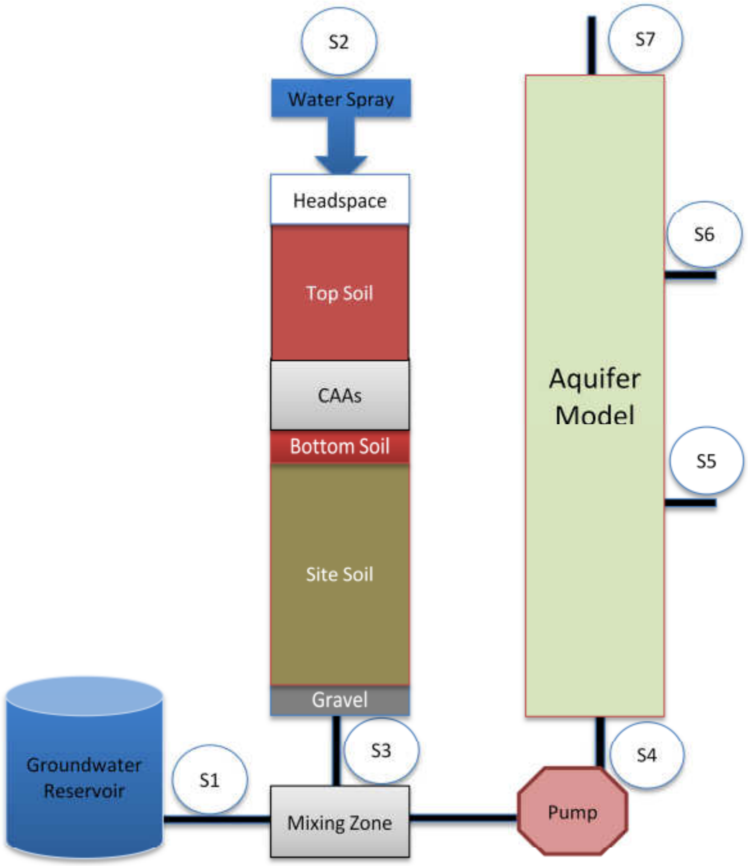


Figure 3. Aquifer model connected with restoration model.

Bio-viability Assessment

Germination with CAA Water

Germination of bean and pumpkin seeds was assessed in a worst case scenario that the plants might get experienced due to the presence of the CAAs. A hypothesis was that no toxic chemicals from the CAAs, if any, would be taken up by the plants so that seeds would germinate and grow. For this, water infiltrated from the CAAs was collected from a separate column system. In the flat-bottom, porcelain funnel (6-in dia. and 8-in long), 1,080 g of CAAs were layered on the top of 835 g of gravels. 1,500 g of sand covered the CAAs layer. Both clean gravels and sands were used as supporting layers to facilitate the hydraulics of water. Total 3 L of tap water was poured to the column and infiltrated water was collected and used for spraying to the reactors prepared as shown in Table 7.

Table 7. Initial germination experiment matrix where water infiltrated from the CAAs column was sprayed to the reactors.

Reactors	Gravel (grams) Nominal depth: 2.5 inches	Top Soil (grams) Nominal depth: 6.5 inches	Seeds
1	201	1262	Beans
2	202	1264	Beans
3	200	1270	Pumpkin
4	196	1262	Pumpkin

Four reactors (4-in dia. and 11-in length) were put in an environmental chamber which controlled temperature at 30 ^{o}C with a refrigerated and heating bath circulator (Thermo NESLAB RTE-10 Digital One). The chamber was also equipped with a 20 W lighting system (GRO-LUX, Sylvania) which was scheduled to turn on from 1 pm to 10 pm with a timer. The infiltrated water collected from the CAA column was sprayed on every other day at an amount of 105 mL which was calculated according to the actual maximum average precipitation in Santa Isabel. This germination experiment was performed for 2 weeks.

Multifactor Assessment on Germination and Growth

Another germination experiment was conducted after the first germination experiment aforementioned. This time, multiple factors were assessed on their effects on the germination rate and growth. The parameter monitored is 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 8. 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. Like the previous germination experiments, the reactors were put in the environmental chamber. Corresponding to the actual maximum average precipitation in Santa Isabel, 40 mL of water (rain water or tap water) was sprayed on every other day for 2 weeks.

Table 8. Design matrix to assess the effects of multiple factors on the germination rate and growth.

Reactors	Mixed/Layered	Type of seed	Distribution	Type of water	Top Soil (g)	Aggregate (g)
R1	Layered	Beans	4" top soil+2" aggregate	RW	440.1	134.3
R2	Layered	Beans	2" top soil+4" aggregate	TW	225.1	254.3
R3	Mixed	Beans	66.7% top soil+ 33.3% aggregate	RW	445.2	127.7
R4	Mixed	Beans	33.3% top soil+ 66.7% aggregate	TW	222.7	258.6
R5	Layered	Beans	4" top soil+2" aggregate	TW	439.6	134.5
R6	Layered	Beans	2" top soil+4" aggregate	RW	227.5	254.5
R7	Mixed	Beans	66.7% top soil+ 33.3% aggregate	TW	444.5	129.5
R8	Mixed	Beans	33.3% top soil+ 66.7% aggregate	RW	222.5	259.5
R9	Layered	Pumpkin	4" top soil+2" aggregate	RW	439.4	134.5
R10	Layered	Pumpkin	2" top soil+4" aggregate	TW	227.5	254.5
R11	Mixed	Pumpkin	66.7% top soil+ 33.3% aggregate	RW	444.4	129.5
R12	Mixed	Pumpkin	33.3% top soil+ 66.7% aggregate	TW	222.3	256.5
R13	Layered	Pumpkin	4" top soil+2" aggregate	TW	439.6	134.5
R14	Layered	Pumpkin	2" top soil+4" aggregate	RW	227.5	254.5
R15	Mixed	Pumpkin	66.7% top soil+ 33.3% aggregate	TW	447.2	129.5
R16	Mixed	Pumpkin	33.3% top soil+ 66.7% aggregate	RW	222.9	262.5

Reactors	Mixed/Layered	Type of seed	Distribution	Type of water	Top Soil (g)	Aggregate (g)
CR1	N/A	beans	6" top soil	RW	664.9	/
CR2	N/A	beans	6" top soil	TW	674	/
CR3	N/A	pumpkin	6" top soil	RW	657.6	/
CR4	N/A	pumpkin	6" top soil	TW	677.3	/

Potential Effect of Physical Hindrance by CAA Layer

An experiment was conducted to assess potential physical hindrance of the CAAs against seeds germination and growth. 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 the following Table 9 and Figure 4.

Table 9. Specifications of the reactors run 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

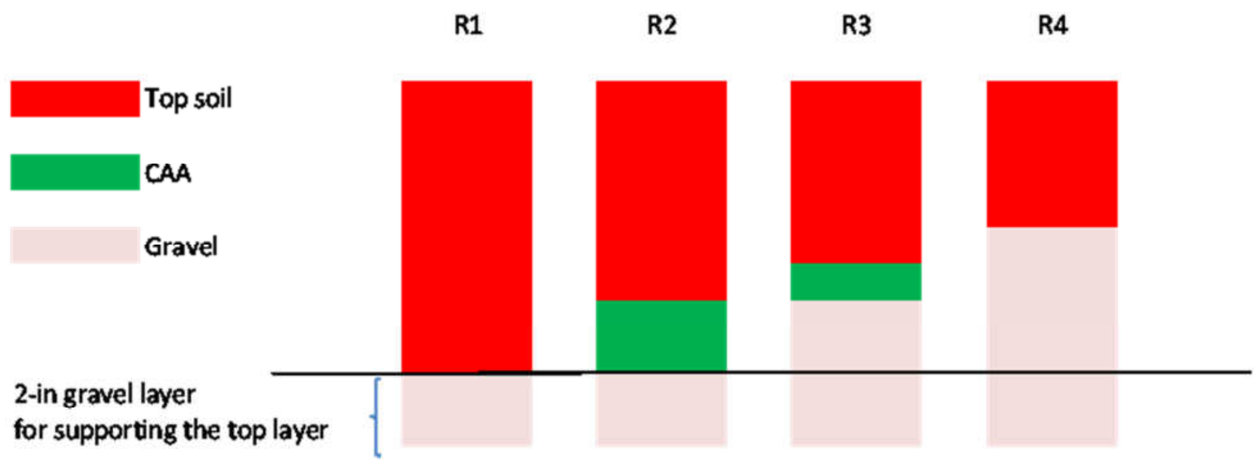


Figure 4. Schematics of the reactors run for testing physical hindrance of the CAA against germination and growth.

Six bean seeds were planted in each reactor at a depth of 1.5 inches. Corresponding to the actual maximum average precipitation in Santa Isabel, 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.

Effect of Hardness in Water

An experiment was conducted to elucidate potential contribution of hardness to germination and growth. This experiment was initiated based on the results from the multiple factor germination experiments where the tap water (64.4 mg/L Hardness as $CaCO_3$) spraying showed better germination and growth compared to the rain water (6.3 mg/L Hardness as $CaCO_3$) spraying. Plastic reactors used for the multiple factor experiments (2.5-in dia. and 6-in long.) were filled with the organic top soil at a depth of 5 inches. Two seeds were placed to each reactor at a depth of 1.5 inches below surface. Each system was run in duplicate. Corresponding to the actual maximum average precipitation in Santa Isabel, 40 mL of hardness water (0 to 80 mg/L Hardness as $CaCO_3$) was sprayed on every other day for a month. Table 10 shows the design of the experiment.

Table 10. Design of the experiment to assess the effect of hardness on germination and growth.

Reactor	A	B	C	D	E
Hardness in the water sprayed (mg/L as $CaCO_3$)	0	4	20	40	80

Expansion of Assessment of Physical Hindrance with Various Plants

After completing Physical Hindrance experiment, all beans were removed from the reactors and the configurations of the reactors were slightly modified as shown Figure 5. This experiment was to assess potential contribution of the CAAs as nutrient source for the plants. Four different plants were tested: botellas, beans, papayas, and pumpkins. Baby botellas and papayas were obtained from a nursery farm at the site and planted in the reactors #1 and #2, and #3 and #4, respectively. Beans were seeded directly to the reactors #3 and #4. Pumpkins were later seeded to the reactors #3 and #4 after the beans were completed with the experiment and removed from the reactors. Due to deeper and bigger roots, the reactors #1 and #2 had deeper top soils by 40% than the reactor #3 and #4. Like the Physical Hindrance experiment, 840 mL of tap water was evenly sprayed on the top of the reactors every other day during the experiment. Germination and growth monitoring was done every Mondays and Fridays.

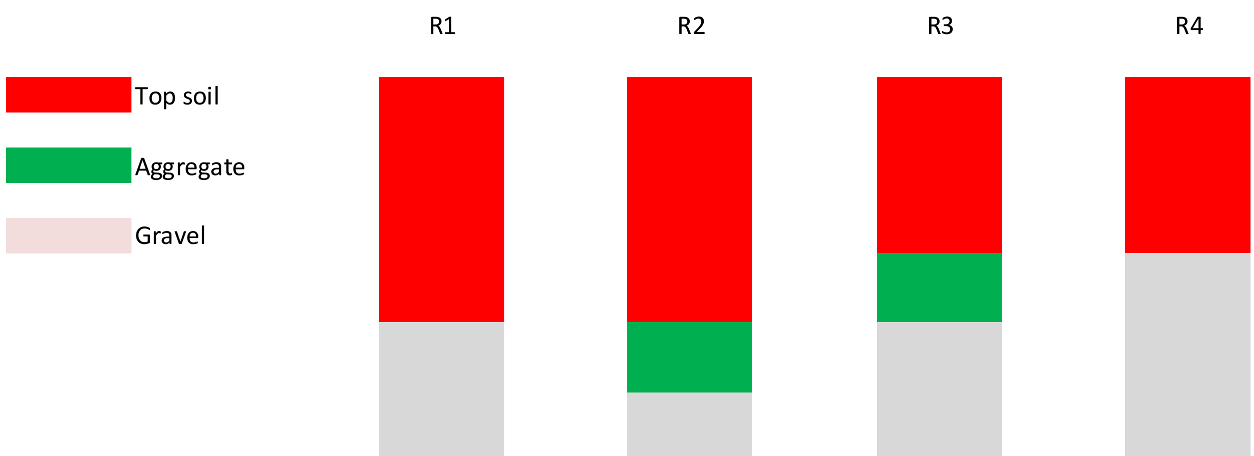


Figure 5. Assessment of CAAs as a nutrient source for the various plants: botellas, papayas, beans and pumpkins.

Soil Microbiology and Plant Growth

To test phyto-viability and evaluate consequent rhizospheric biochemical changes, an experiment was designed as shown in Figure 6. Two pots with a width of 2 inches, a length of 15 inches and a depth of 15 inches were constructed. Narrow width allowed observing the shape and conditions of roots. On the side wall, there were 9 evenly distributed sampling ports for soil microbial analysis: 3 in the top layer, 3 in the middle layer, and 3 in the bottom layer (Photo 10). CAAs were applied in 5 thimbles on the top of the top soils. A bean seed was planted between CAA thimbles. A control pot was also constricted in the same manner but with gravels in the thimbles. Microbial activity in rhizosphere in terms of total heterotrophic bacteria (THB) and soil dehydrogenase activity, growth rate and extent, and shape/conditions of the roots were analyzed.

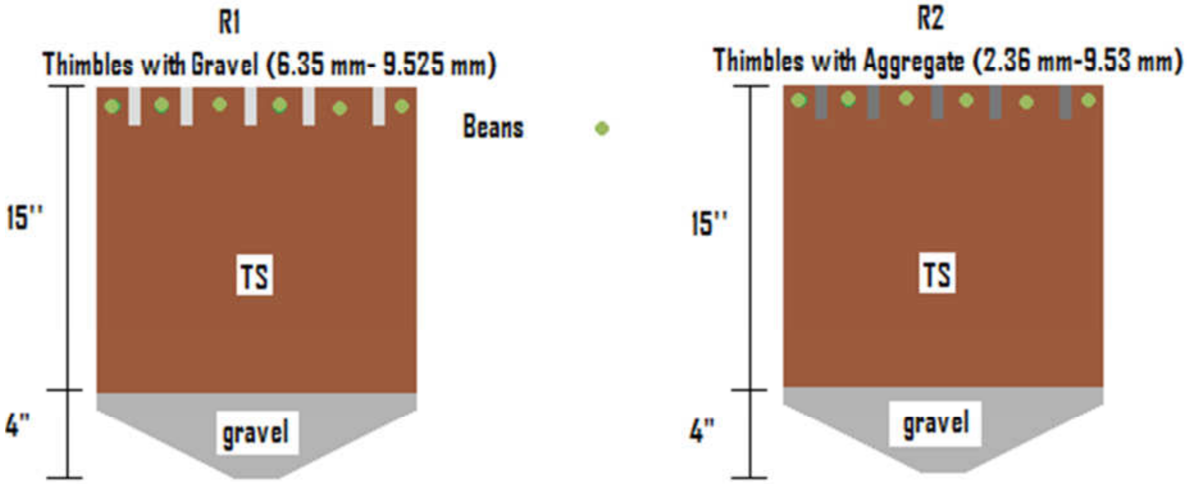


Figure 6. Design of 2 reactors for assessment of soil microbiology and plant growth with addition of CAAs (left: control pot; right: CAA pot).

Photo 10. Side views of two pots with 9 sampling ports on the side wall (top 2 photos) and top view of the arrangement of CAAs in the thimble (bottom).

Outdoor plant experiment

Outdoor plant growth and healthiness was preliminarily tested in the systems with and without influence of the CAAs on rhizosphere. The system was set up in the field experiment area of the Department of Civil Engineering and Surveying, UPRM.

Two identical pots were used (13”W × 8”L × 8”D). Each pot had three perforated troughs where the CAAs and gravels were placed for the treatment and control pots, respectively. The dimension of trough was 1”W × 8”L × 1”D. 1.84 lbs of gravels were evenly placed to three troughs in the control pot, whereas 0.94 lbs of the CAAs were to three troughs in the treatment pot. Six inches of top soil was placed at a bulk density of 1.53 g/cm^3. Eight been sees were placed at a depth of 1.5”, as shown in Figure 7.

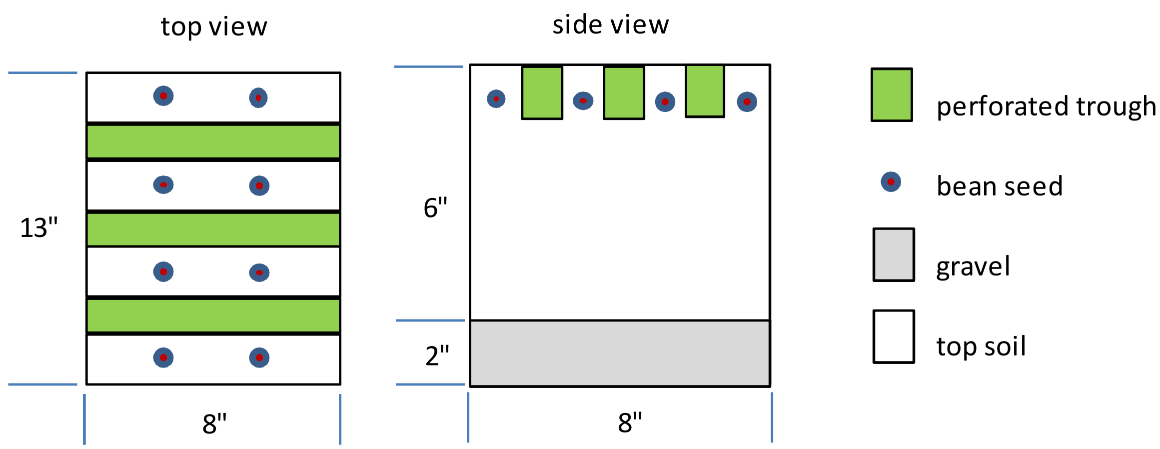


Figure 7. Schematics of outdoor plant growth pots.

Subject to natural weather environments (e.g., precipitation, wind, evapotranspiration, sunlight, etc), survival, physiology, and growth dynamics of the beans were assessed for 16 days. Natural weather environments were monitored via a weather station located in the experiment area.

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). THB was done by the standard plate count using tryptic soy broth as the growth media and then counted after incubation at 30^{o}C for 72 hrs. Soil dehydrogenase activity was quantified according to Methods of Soil Analysis (1994).

For bio-viability assessment, beans and pumpkins were initially selected as the target plants. Their germination rates and shoot growth were monitored. The former is defined as the ratio of the germination to the numbers of the seeds planted. The latter is defined as the physical height of the shoots above the ground. Two target heavy metals, Pb and Cd, in the plants were also analyzed after the Digesdahl digestion (HACH). For the healthiness observations, chlorophyll intensity of plant leaves was monitored using the Chlorophyll Meter SPAD-502.

Principal Findings and Significance

Water Quality Assessment

The water volume infiltrated in each reactor weekly is shown in Figure 8. Apparently, the rainfall intensity influenced greatly on the infiltrated water volume.

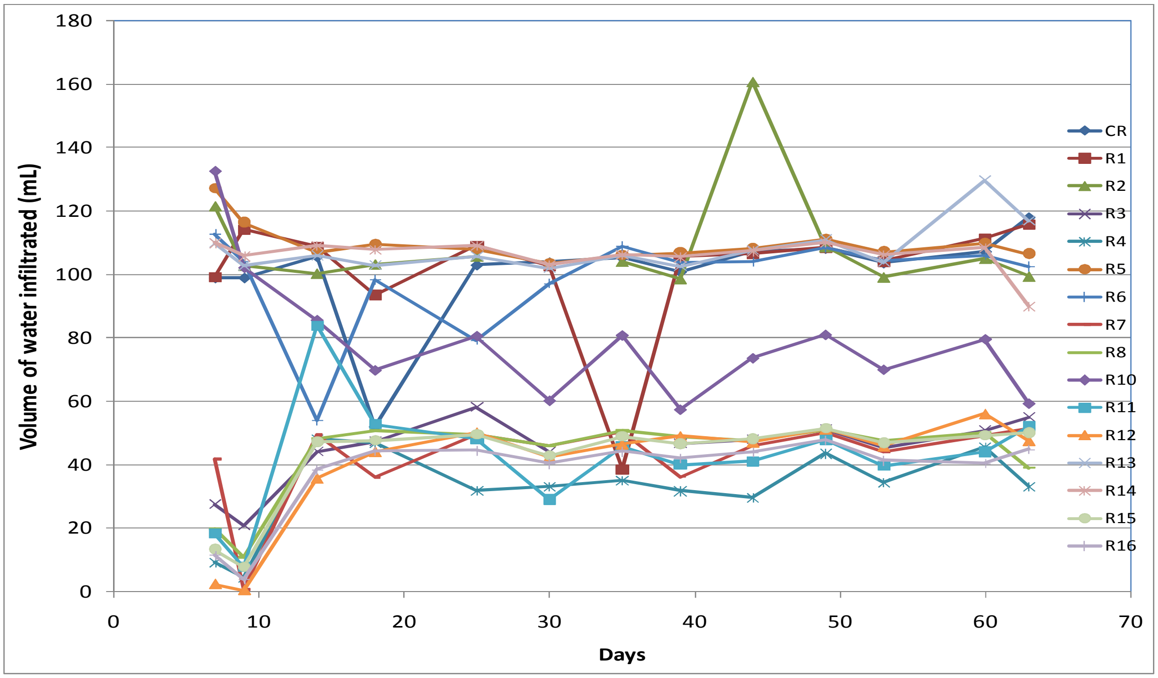


Figure 8. Volume of water infiltrated weekly in each reactor.

The infiltrated water from each reactor containing the CAAs had a slightly basic pH (~8.5) throughout the experiment, as shown in Figure 9. A higher pH of the control reactors was attributed to the characteristics of the sand used for the system.

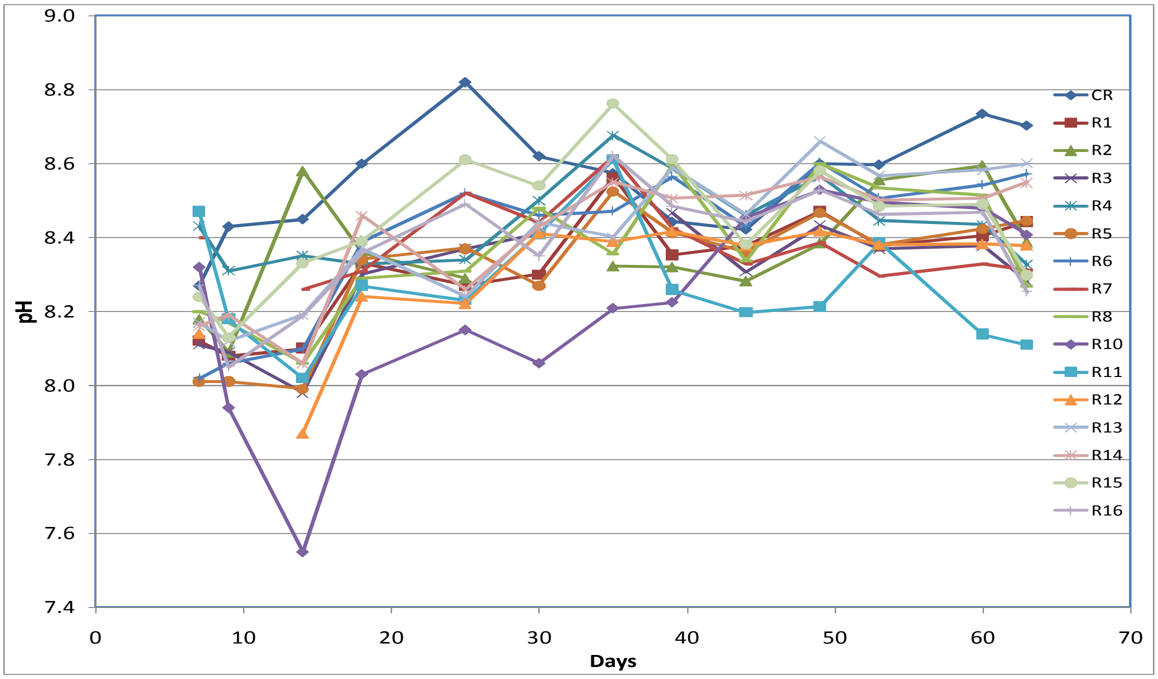


Figure 9. Value of pH in the water infiltrated weekly in each reactor.

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 10.

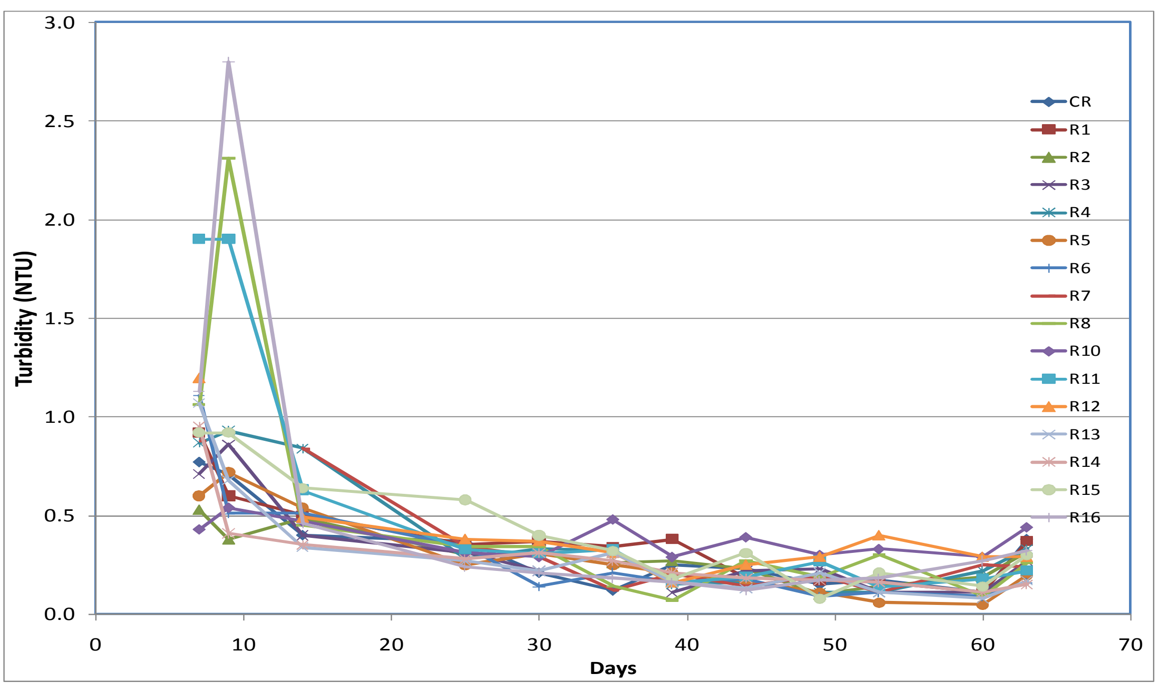


Figure 10. Turbidity in the water infiltrated weekly from each reactor.

Specific conductivity showed higher strengths in all treatment columns compared to that in the control reactor as shown in Figure 11. A similar trend was observed for the hardness concentrations.

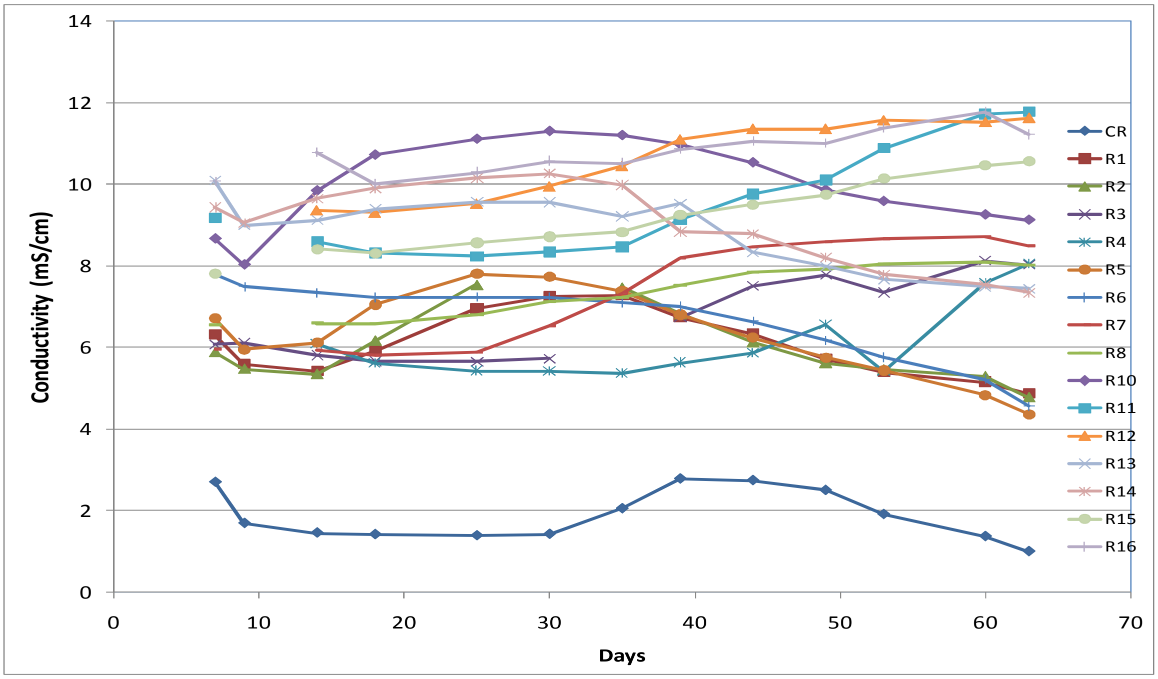


Figure 11. Specific conductivity in the water infiltrated weekly from each reactor.

Heavy metal analysis showed no concentrations of Pb and Cd. 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, both an AA spectrometer and a Cole-Parmer Cd ion selective electrode with a lower limit of 0.2 mg/L were used for the analysis.

3-Factor, 2-Level Statistical Analysis

To evaluate the causes and effects produced by the factors aforementioned in the Method section, 3-factor, 2-level statistical analysis was conducted based on the corresponding the statistical design. For this purpose, the latest version of the Minitab software was used. Example plots are shown in Figure 12.

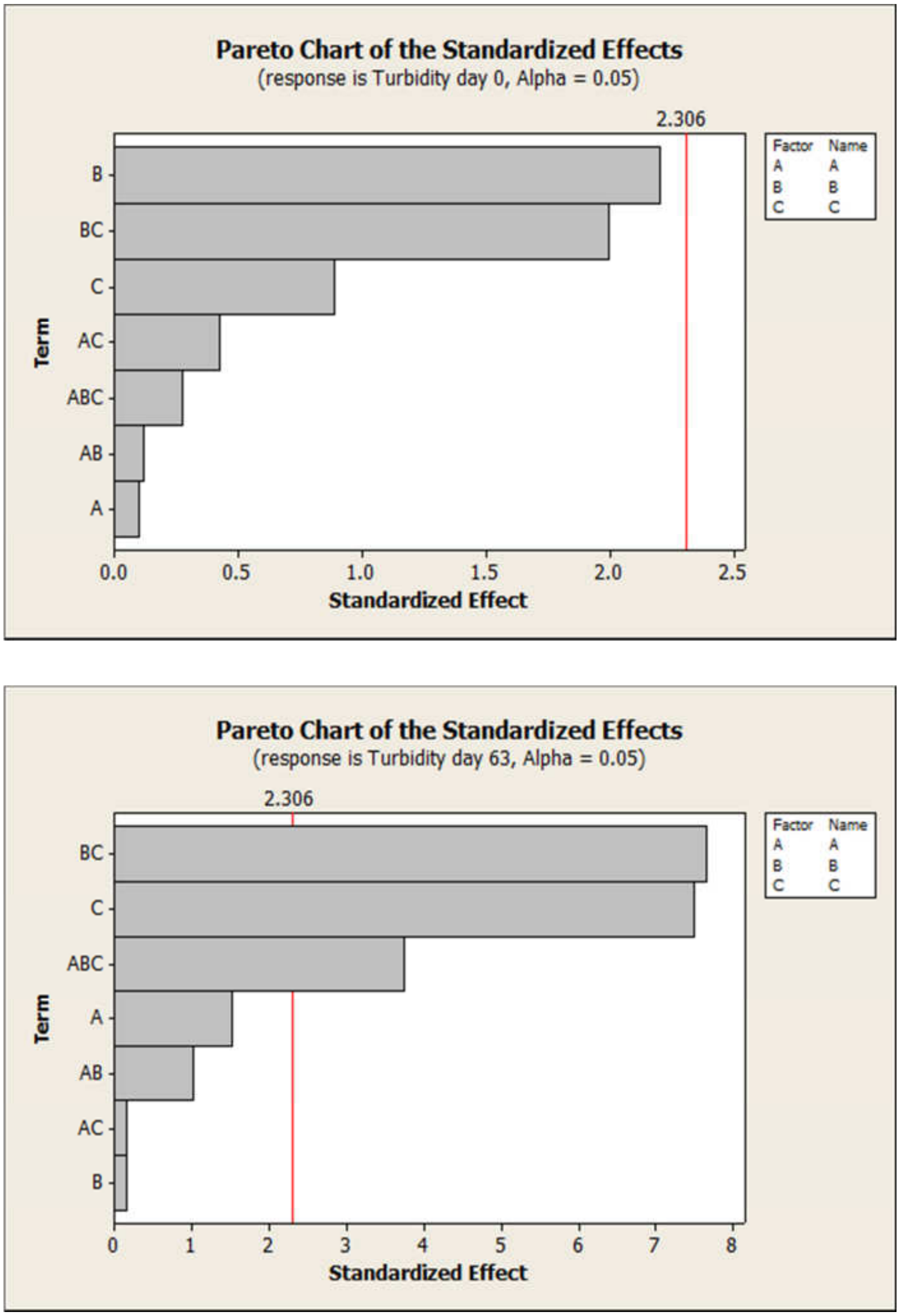


Figure 12. Examples of the statistical analysis using the Minitab software.

As shown in Figure 12 above, the factors produced different effects on the monitored parameters throughout the experiment (i.e., temporal effects). In this regard, those factors which produced statistically significant difference in the monitored parameters were selected and plotted in order to compare temporal effects of the factors. Figure 13 and Figure 14 show temporally significant factors which produced a statistical difference in pH values (top) and turbidity (bottom,) and hardness, respectively.

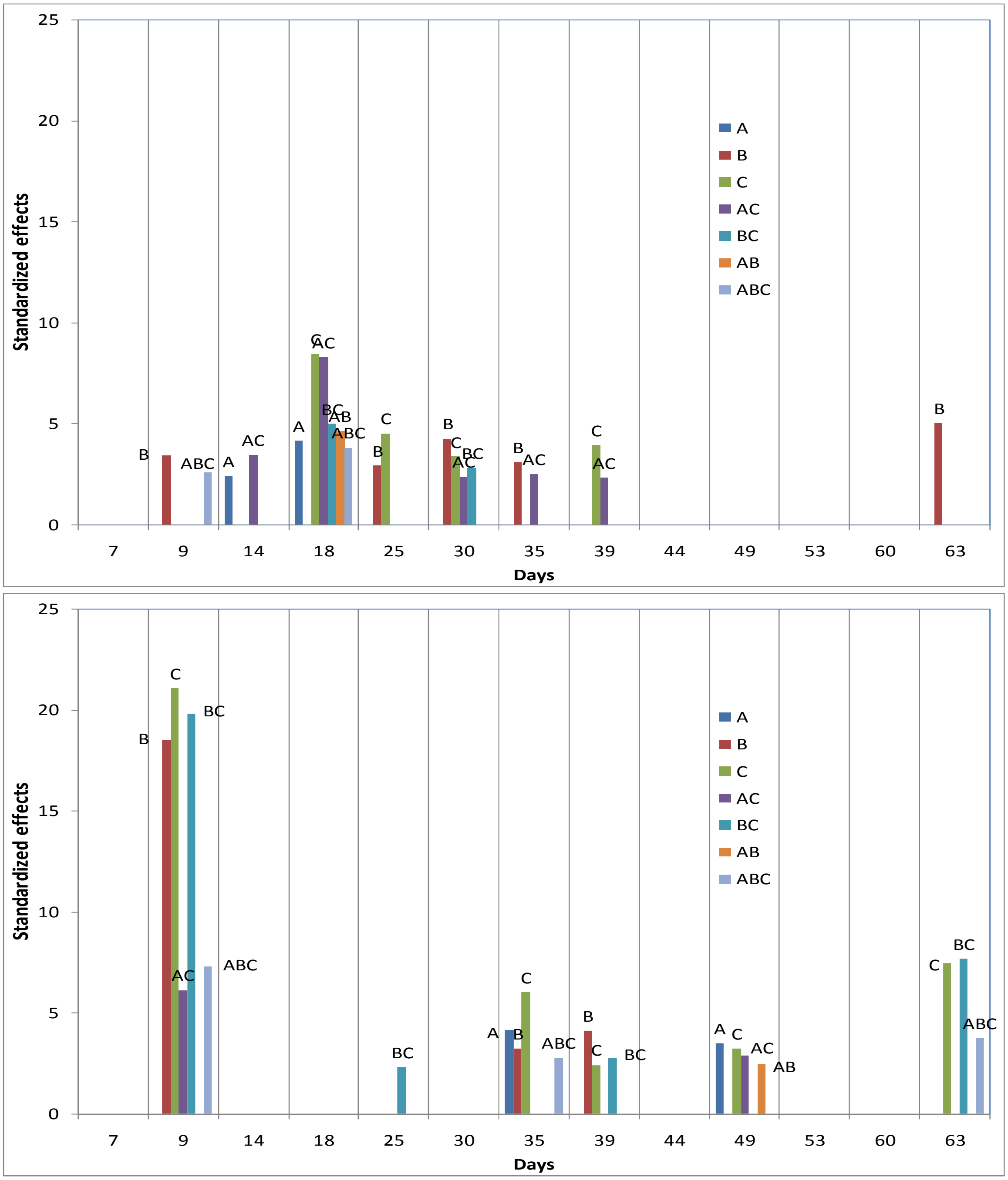


Figure 13. Factors and their extent to have produced a statistically significant difference in pH values (top) and turbidity (bottom).

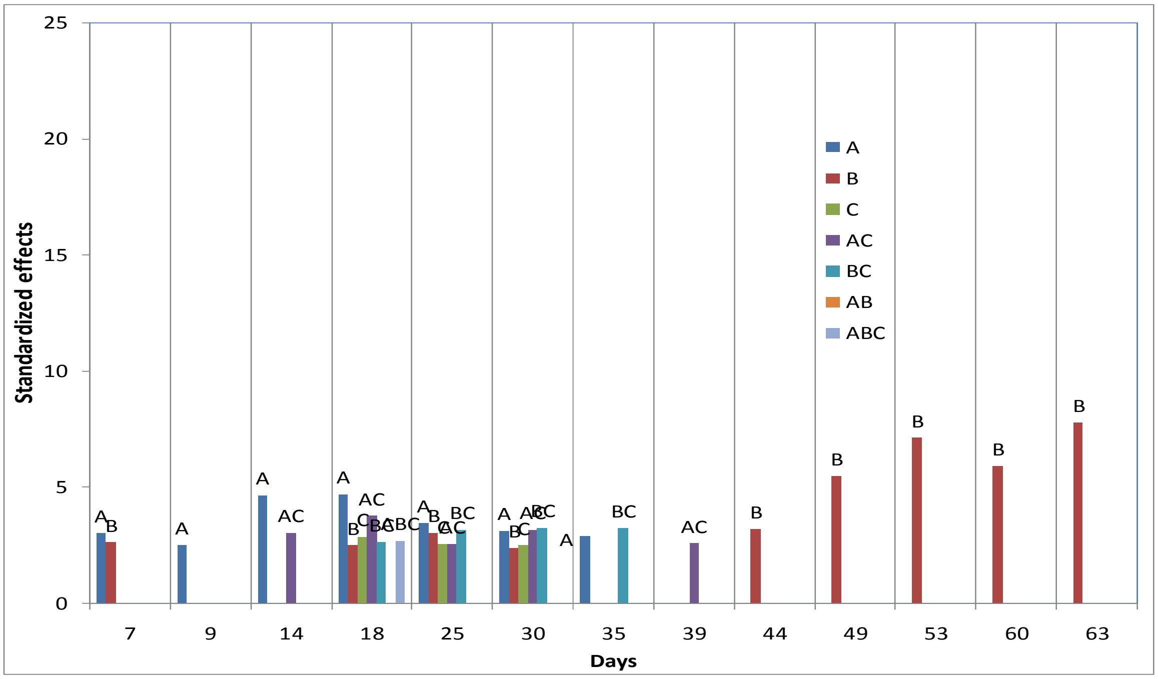


Figure 14. Factors and their extent to have produced a statistically significant difference in hardness.

For better understanding of statistically significant effects that were produced by the main factors, plots containing only the main effects and causes were constructed as shown in Figure 15 and Figure 16. The rainfall intensity undoubtedly significantly influenced on the amount of the infiltrated water as shown in Figure 15. 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.

As shown in Figure 16, 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. However, low-level rainfall intensity dominantly produced significantly higher concentrations of hardness in the later experiment.

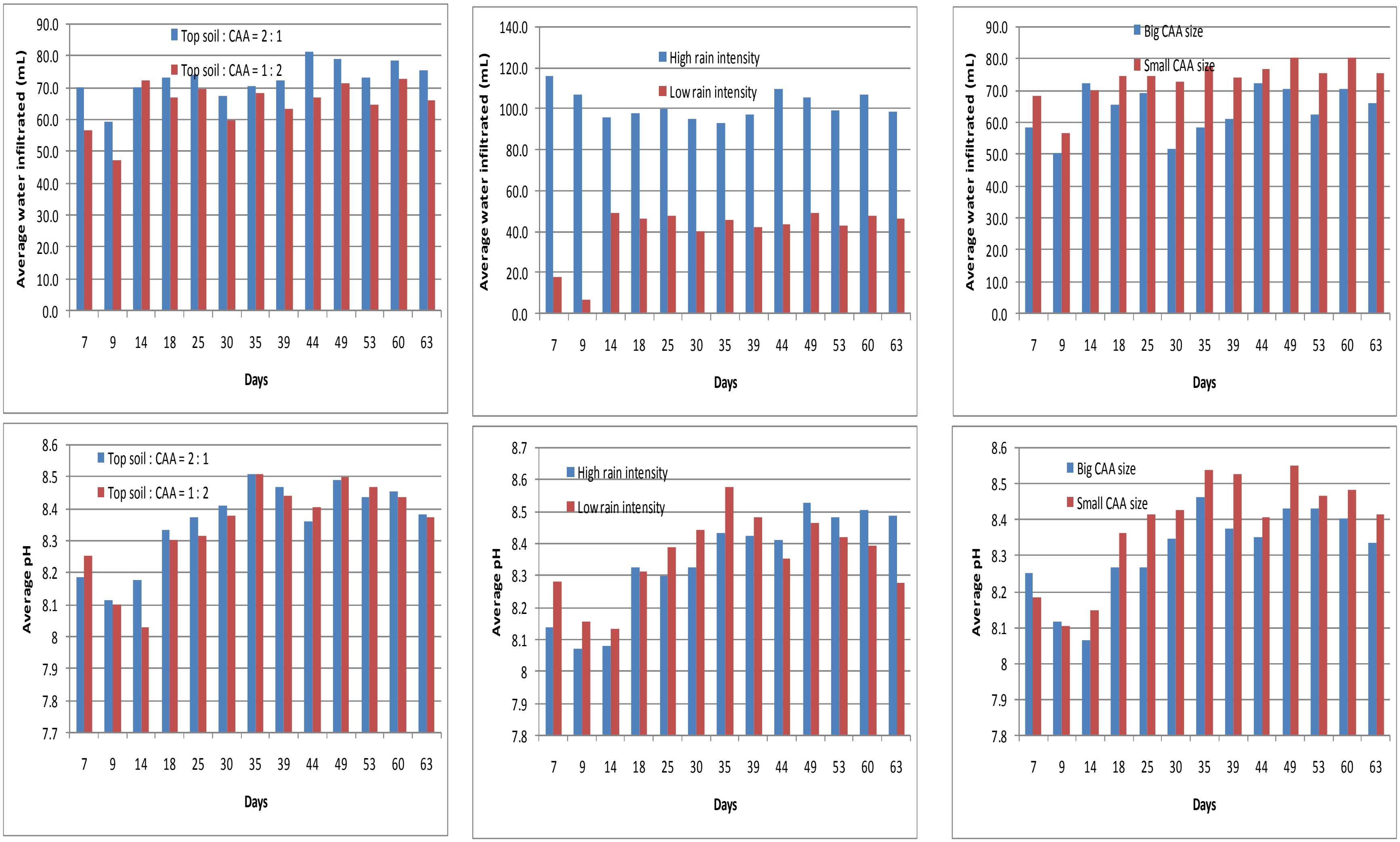


Figure 15. Plots of the main effects on the amount of infiltrated water (top row) and pH values (bottom row).

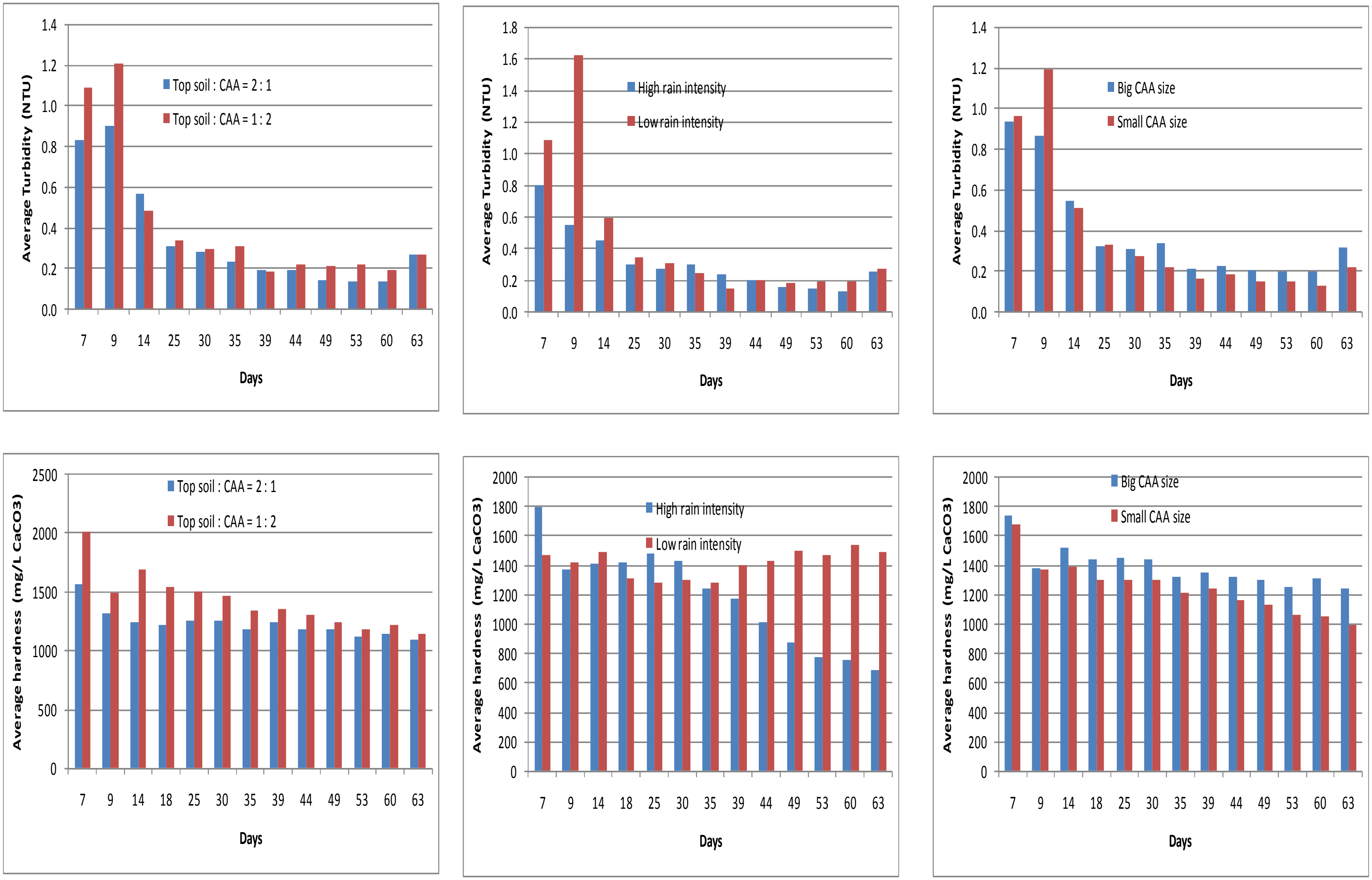


Figure 16. Plots of the main effects on the amount of turbidity (top row) and hardness (bottom row).

Preliminary Leaching Test for Individual Solid Components

Figure 17 shows the trends of water infiltration for each column packed with the different solid materials (i.e., top soil, bottom soil, site soil, sand, small CAA, big CAA, and gravel). A steady-state water infiltration was calculated by using infiltration volume data after total 120 mL was added to each column. After that event, the infiltration trend reached a pseudo plateau producing a constant amount of water. Results are sown in Table 11. With those infiltration ratio data, water retention capacity at a steady-state was calculated per grams of solid materials tested.

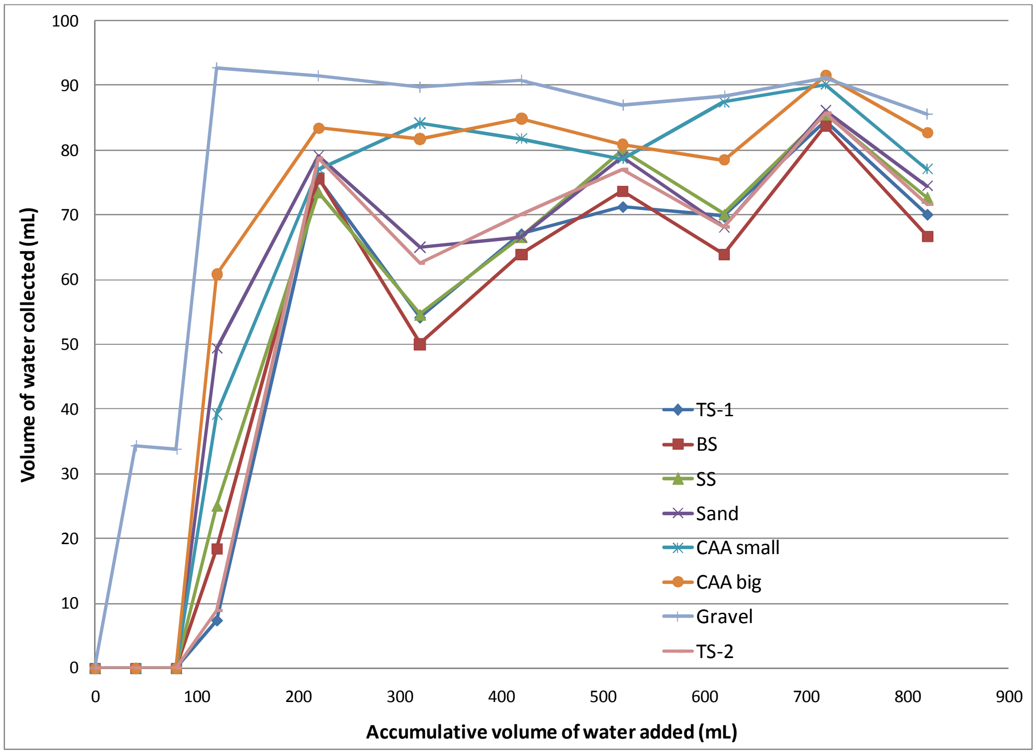


Figure 17. Volume of water collected from each reactor.

Table 11. Water infiltration ratio and water retention capacity of each column packed with different solid materials.

Solid Type	Top soil 1	Bottom soil	Site soil	Sand	CAA small	CAA big	Gravel	Top soil 2
Steady-state Water Infiltration Ratio (%)	70.6	68.4	72.9	73.7	83.5	83.2	88.9	73.3
Water Retention (mL H_2O/g solid)	0.131	0.114	0.121	0.111	0.267	0.236	0.137	0.135

In addition, several water quality parameters were monitored. The values of pH were ranged between 7.5 and 8.5 as shown in Figure 18 (top). Turbidity was also monitored. Interestingly, the bottom and site soils were the most influencing solids which exerted abnormally high turbidity during the infiltration test as shown in Figure 18 (bottom). Further sophisticated experiment is warranted to assess the contribution extent of each solid material to overall water quality parameters.

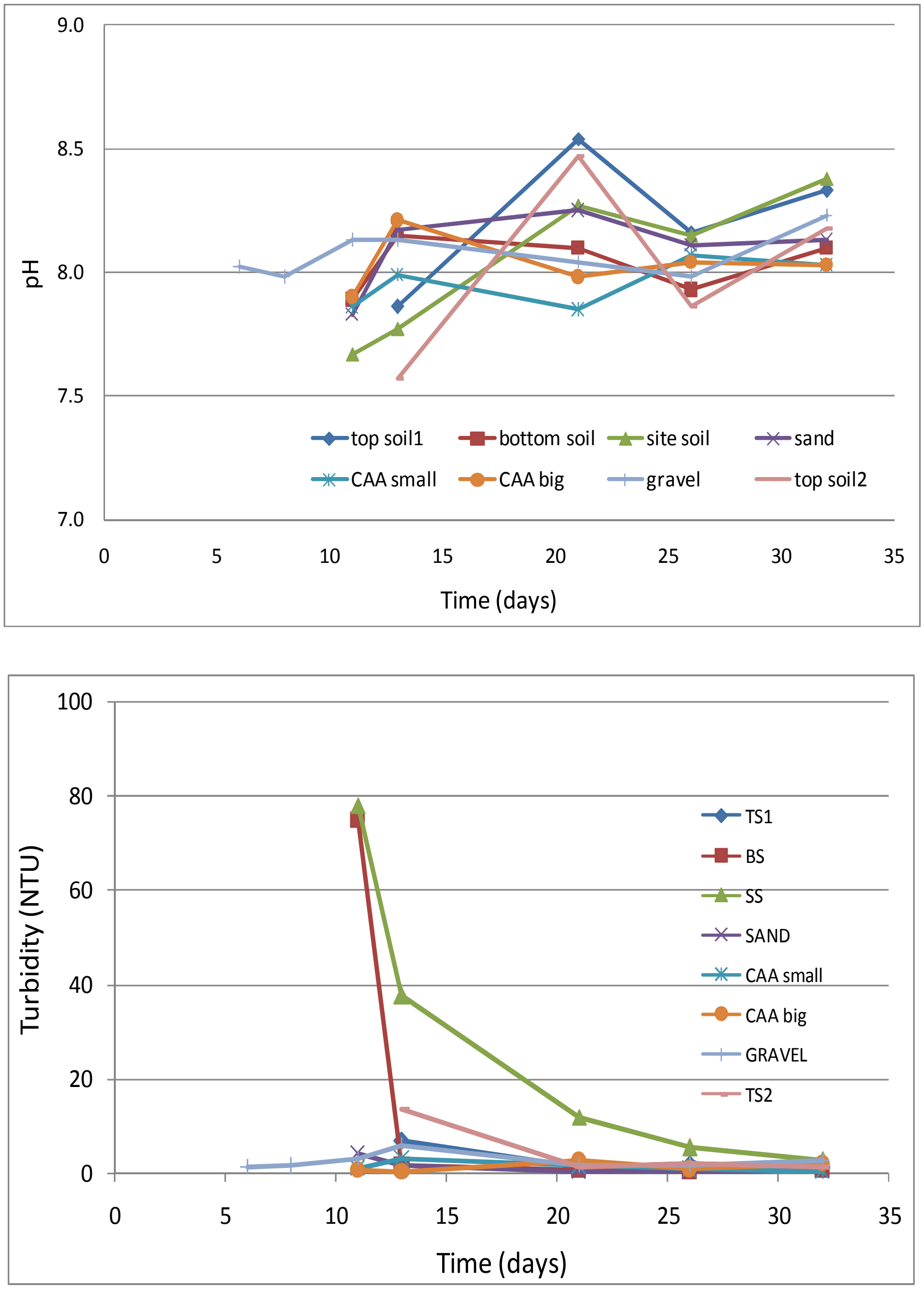


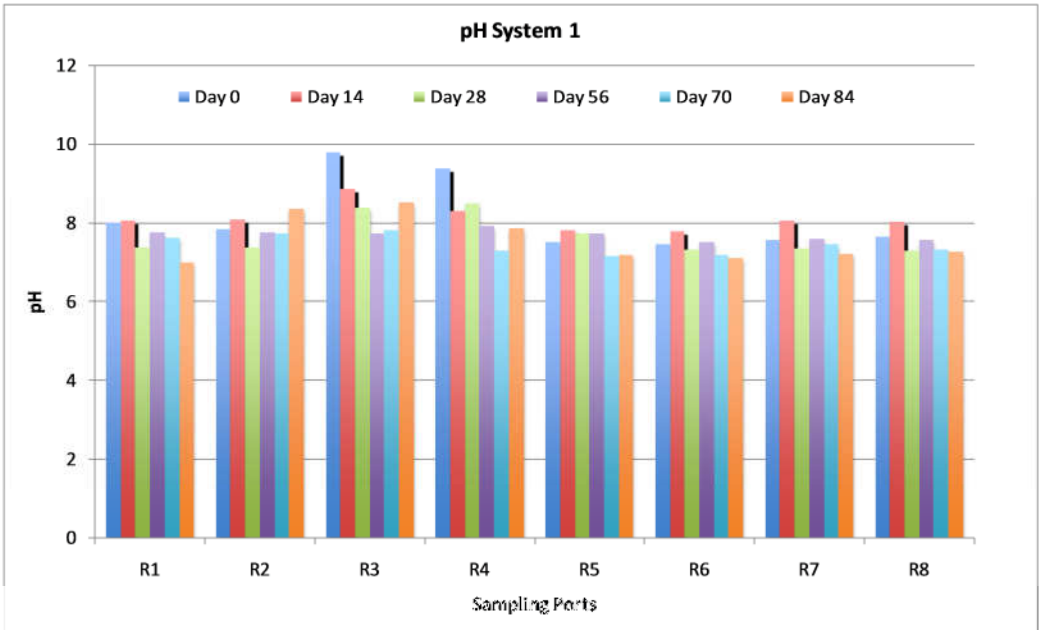
Figure 18. Trends of pH (top) and turbidity (bottom) in the infiltrated water collected.

Water Quality Monitoring 1: Temperature Effect

Two identical column systems were constructed in parallel with a combination of soil and CAA distribution which had produced the worst water quality in the previous statistical experiment. The System 1 was operated at 10 ^oC and the System 2 was at room temperature. A lower temperature set-up was to test water quality parameters in a condition similar to a field soil and groundwater environment with respect to temperature.

Interpretation of the data obtained from this experiment is still on-going. Additionally, a statistical comparison using the Student's t-test will be performed on the data so as to compare the results statistically.

The values of pH were similar for two systems as shown in Figure 19.This implies that the temperatures tested (i.e., 10 ^oC vs. 25^oC) sis not affect pHs exerted by the soils of the serial columns.



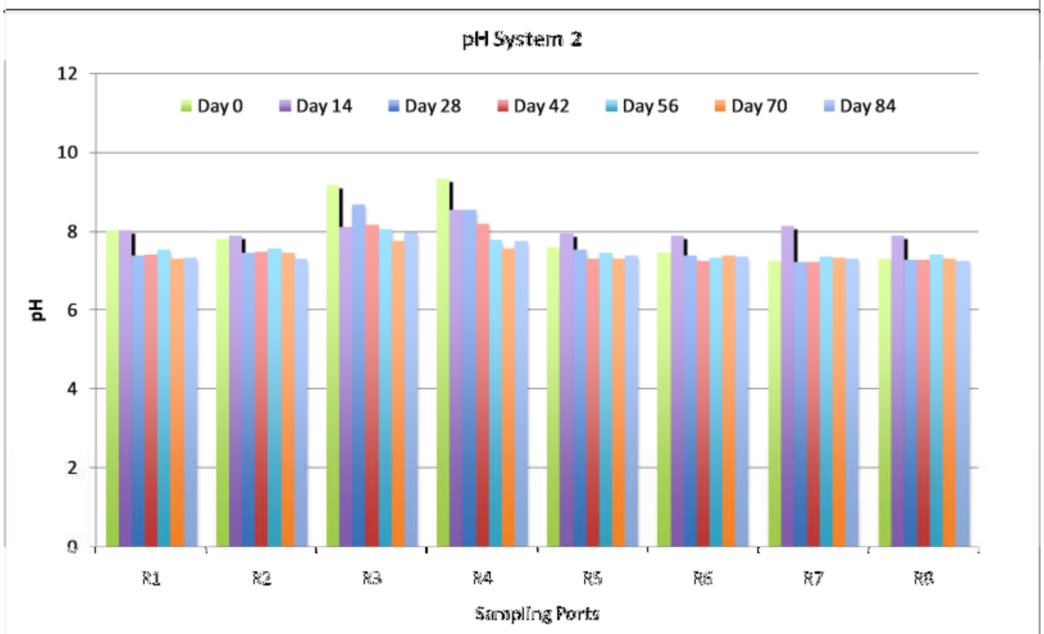


Figure 19. Values of pH from the samples collected at various sampling ports of Systems 1 and 2.

The trend of conductivity was shown in Figure 20. The samples collected for the columns of site soil (i.e., R5~R8) showed much higher conductivity for the System 1 run at 10oC than the System 2 run at 25oC. Possible answers for this phenomenon are currently seeking.

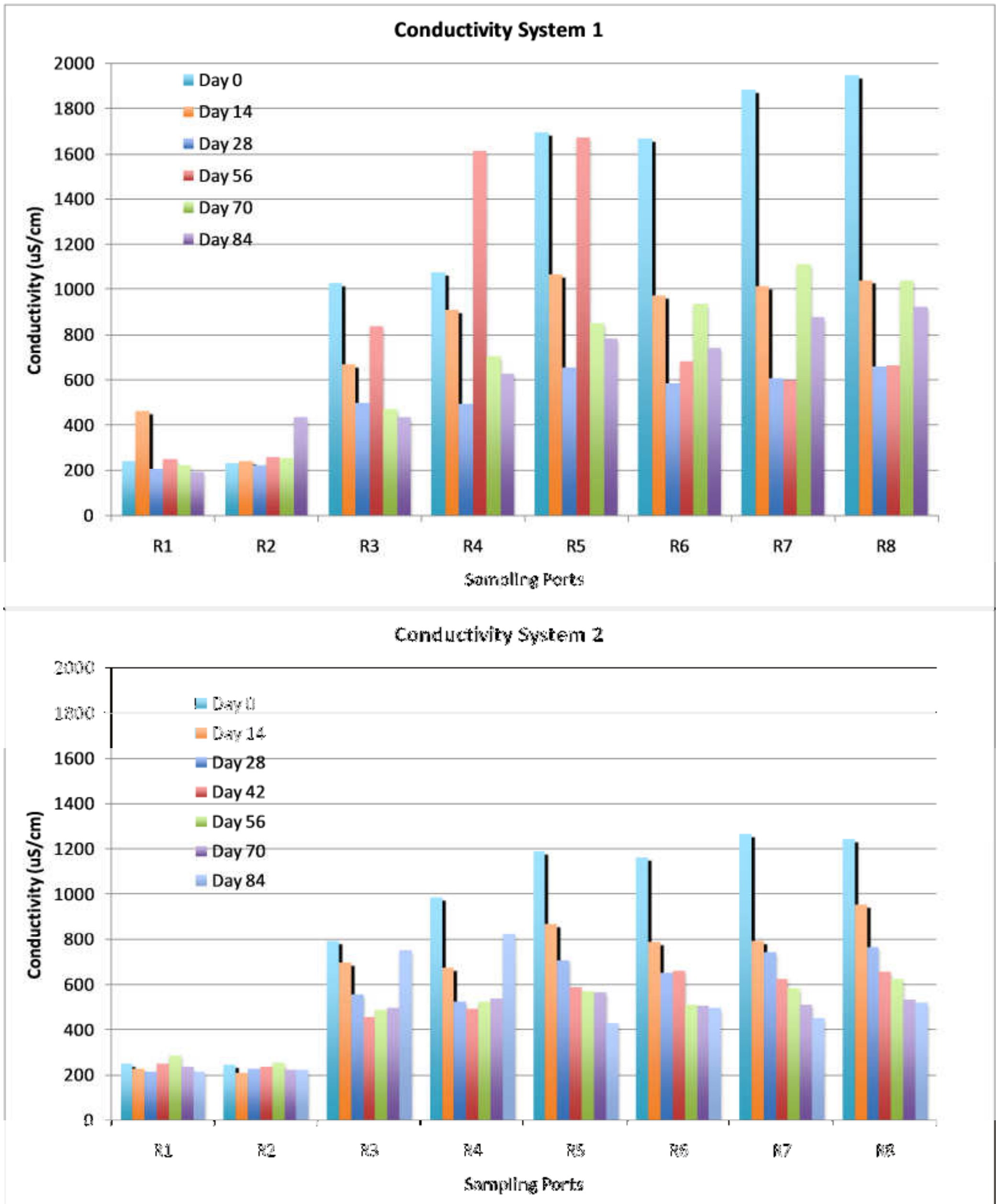


Figure 20. Trend of conductivity from the samples collected at various sampling ports of Systems 1 and 2.

Turbidity measurements were not successful due to the coincident equipment malfunctioning. Unless the turbidity meter is repaired or a new one is acquired, particle size counter will replace turbidity measurement for the next experiment. The concentrations of target heavy metals, lead and cadmium, were not greater than the lower limit of each respective analytical method. For lead analysis, a lower detection limit was 5 ug/L and, for cadmium, it was 0.2 mg/L.

Figure 21 shows the trends of alkalinity between the Systems 1 and 2. Hardness trends are shown in Figure 22.

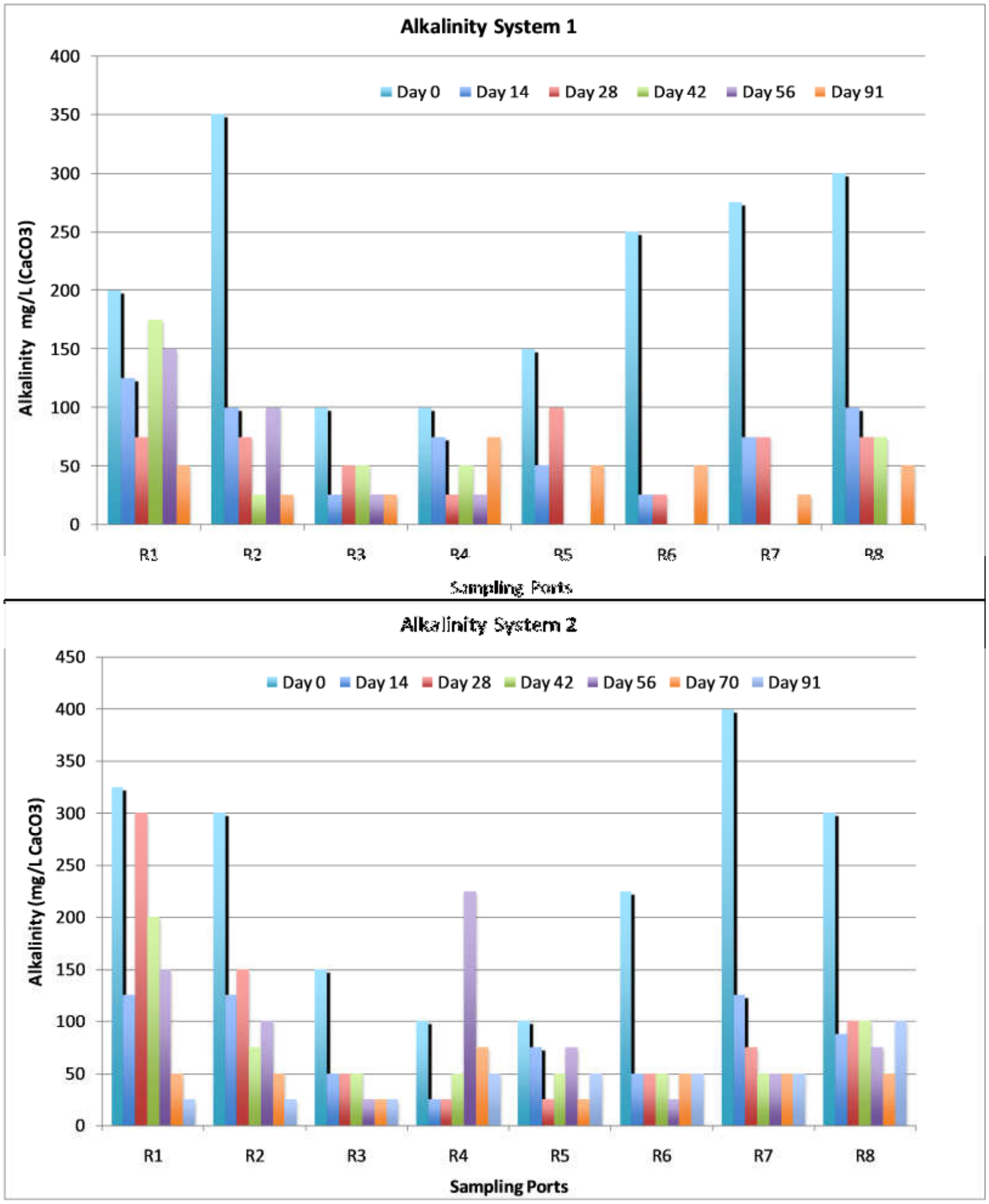


Figure 21. Trend of alkalinity from the samples collected at various sampling ports of Systems 1 and 2.

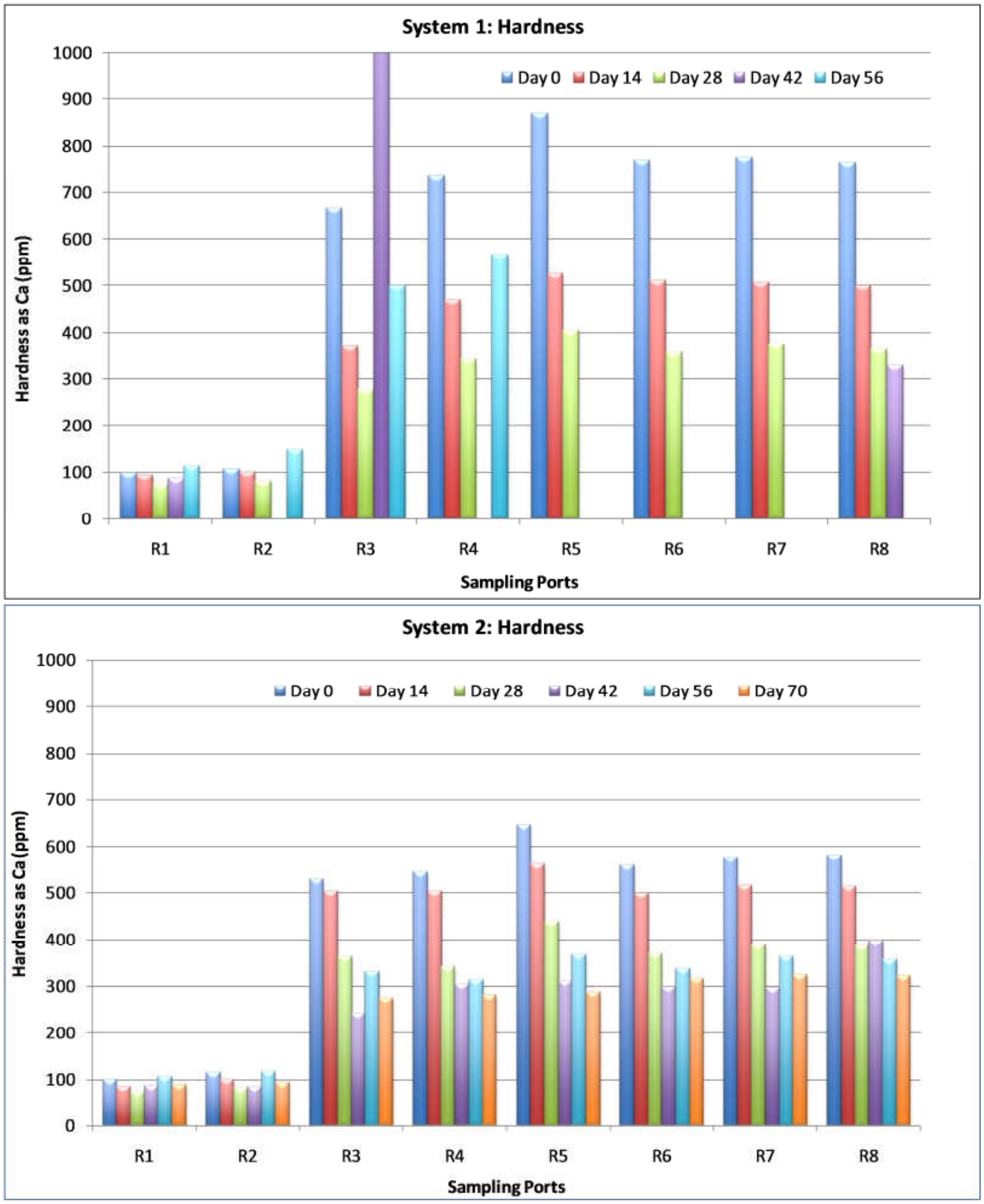


Figure 22. Trend of hardness from the samples collected at various sampling ports of Systems 1 and 2.

Water Quality Monitoring 2: Amendment Effect

Another set of columns (System 3) were constructed to assess water quality parameters for the case when backfilling is done with the parameters produced better water quality form the statistically designed and analyzed experiment: the deeper top soil layer, shallower CAA layer with smaller particle sizes and greater rainfall intensity. Comparisons between the Systems and 2 and 3 were made with water quality data monitored. As aforementioned, more sophisticated data interpretation is still being conducted currently and the Student's t-test will also be utilized for data comparisons between the Systems 2 and 3.

Figure 23 shows the results of pH and conductivity analyses. The values of pH were very similar to those from the System 2, whereas much lower conductivity was observed from the System 3 than the System 2.

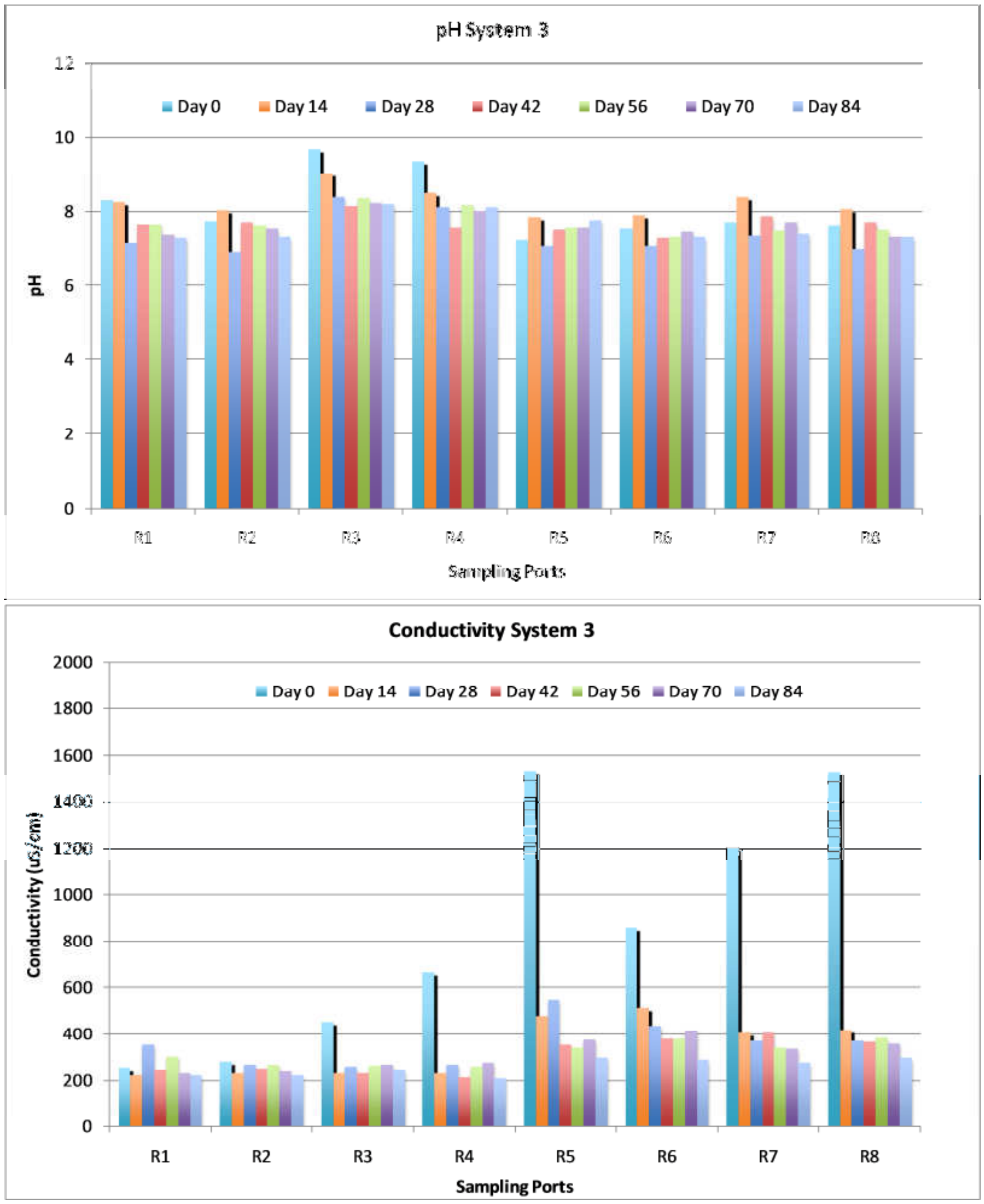


Figure 23. Trend of pH (top) and conductivity (bottom) from the samples collected at various sampling ports of System 3.

Alkalinity and hardness profiles are shown in Figure 24. Compared to its counterpart data from the System 2, data from the System 3 showed similar trend for alkalinity but much lower concentrations of hardness.

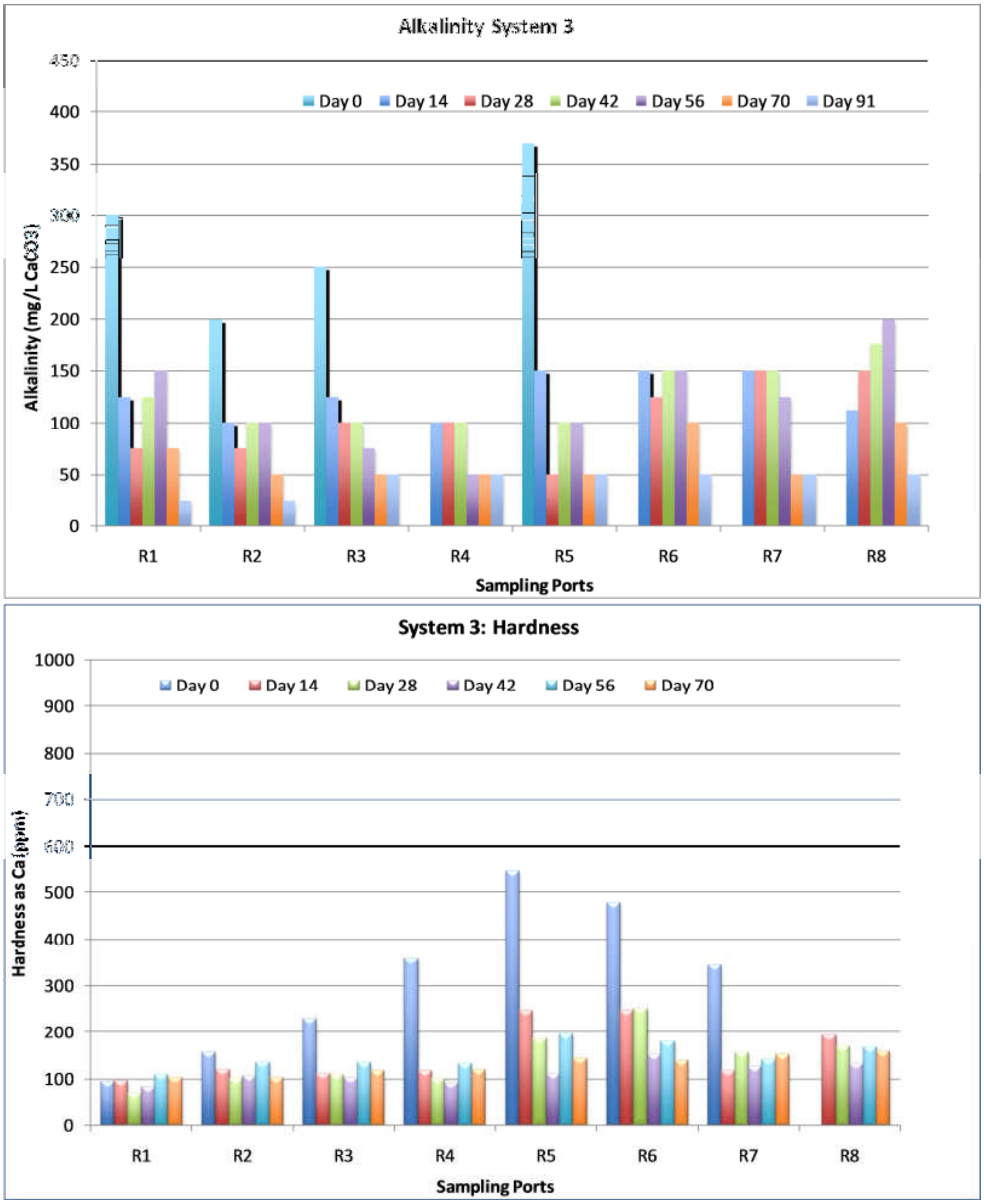


Figure 24. Trend of alkalinity (top) and hardness (bottom) from the samples collected at various sampling ports of System 3.

Water Quality Monitoring 3: Individual Columns

Additional column experiment was conducted to understand contribution of each soil types to overall water quality trends observed from the previous experiments (Systems 2 and 3). Figures 24, 25, 26, and 27 show the trends of pH, conductivity, alkalinity, and hardness, respectively from the Systems 4 and 5. Results will be discussed in the next report, in conjunction with the results from the Systems 2 and 3.

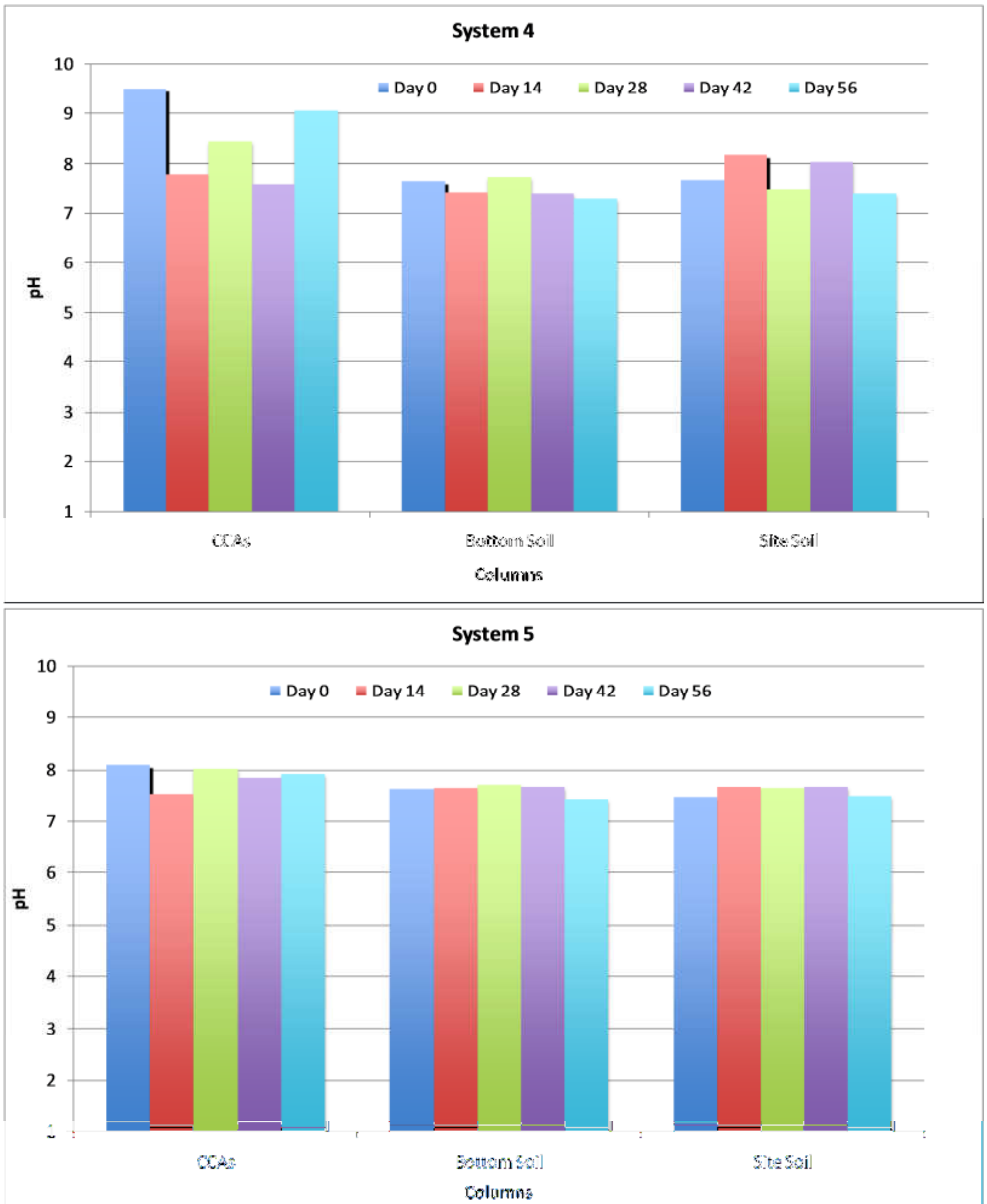


Figure 25. Results of pH measurement from the Systems 4 (top) and 5 (bottom).

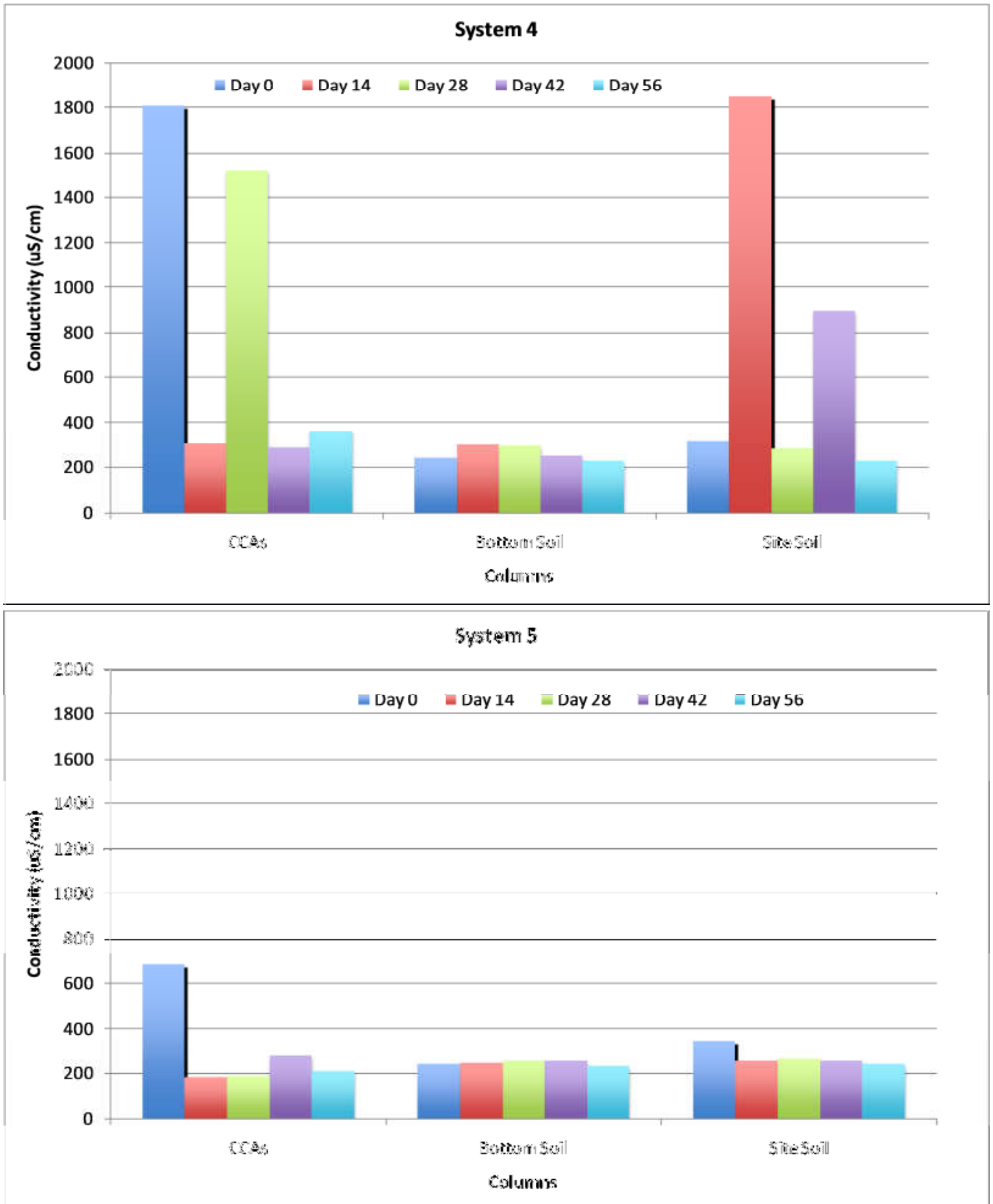


Figure 26. Results of conductivity measurement from the Systems 4 (top) and 5 (bottom).

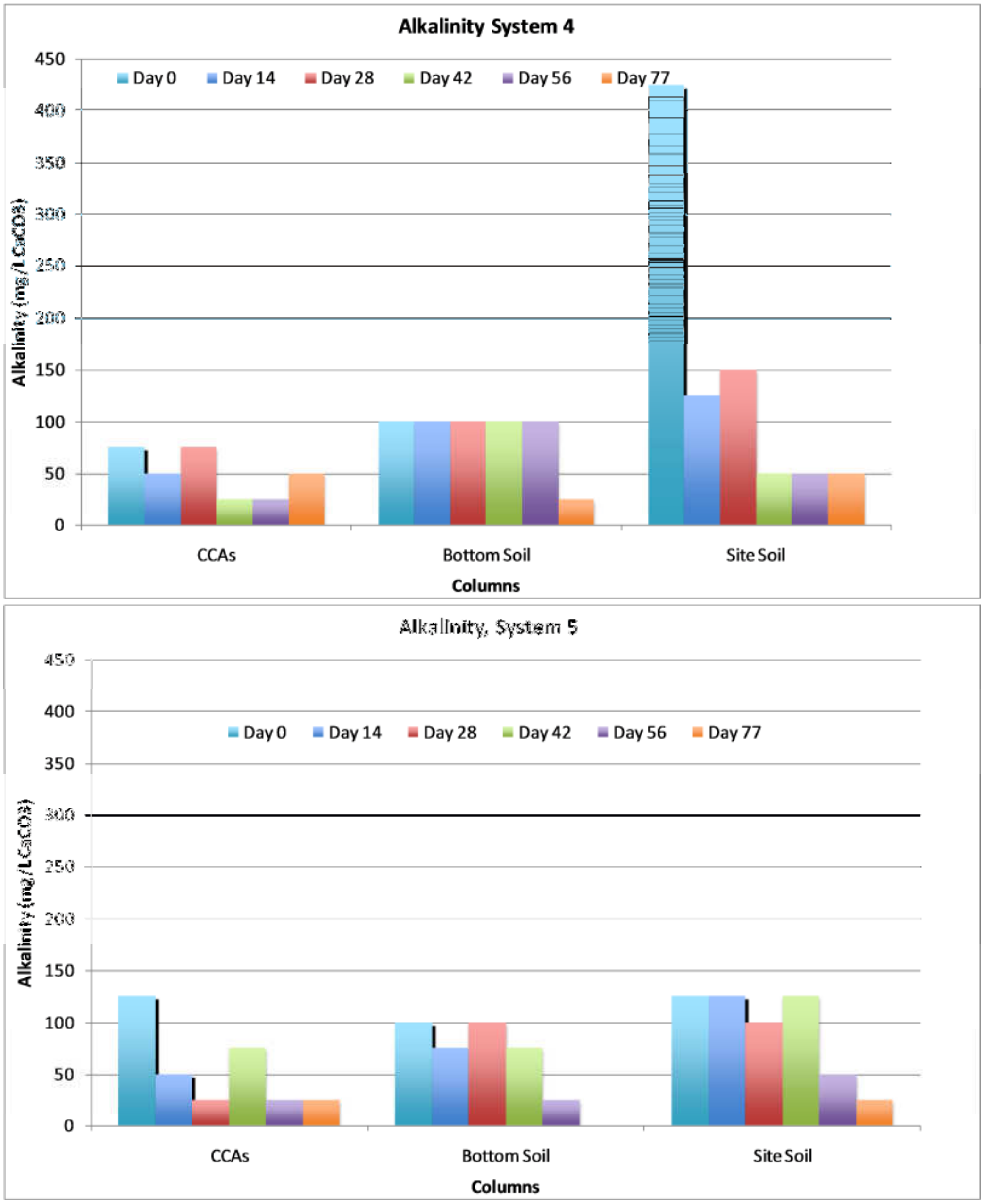


Figure 27. Results of alkalinity measurement from the Systems 4 (top) and 5 (bottom).

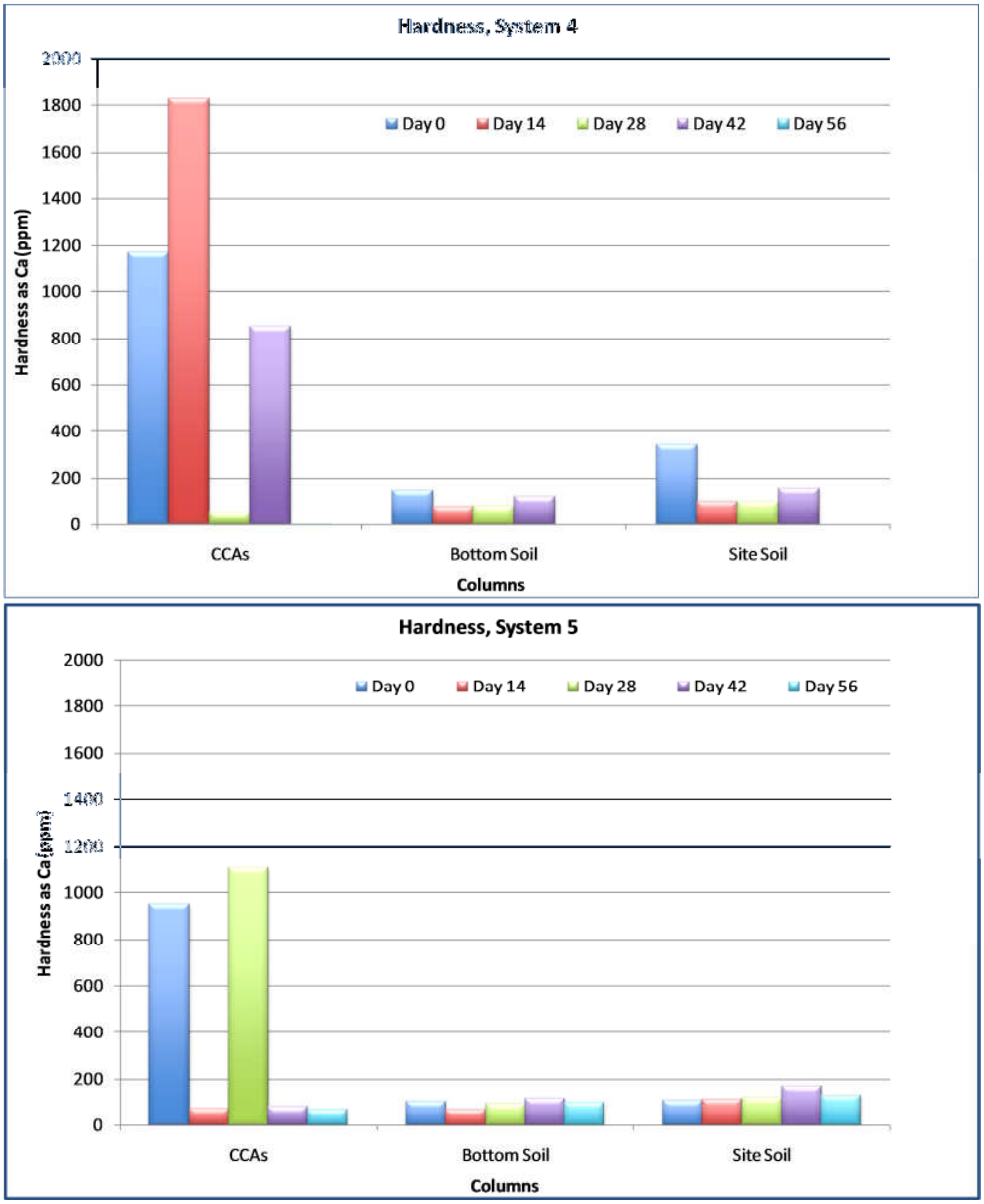


Figure 28. Results of hardness measurement from the Systems 4 (top) and 5 (bottom).

Nitrate and Phosphorus Reduction Potential

There was no reduction of nitrate in the effluent from the CCA columns A, B, and C when influent solution containing ~12 mg/L nitrate was applied at a flow rate of 10 and 20 mL/min for the CCA columns A and c, and B, respectively. Unlike nitrate, phosphorus reduction was achieved in all CCA columns A, B, and C, as shown in Figure 29.

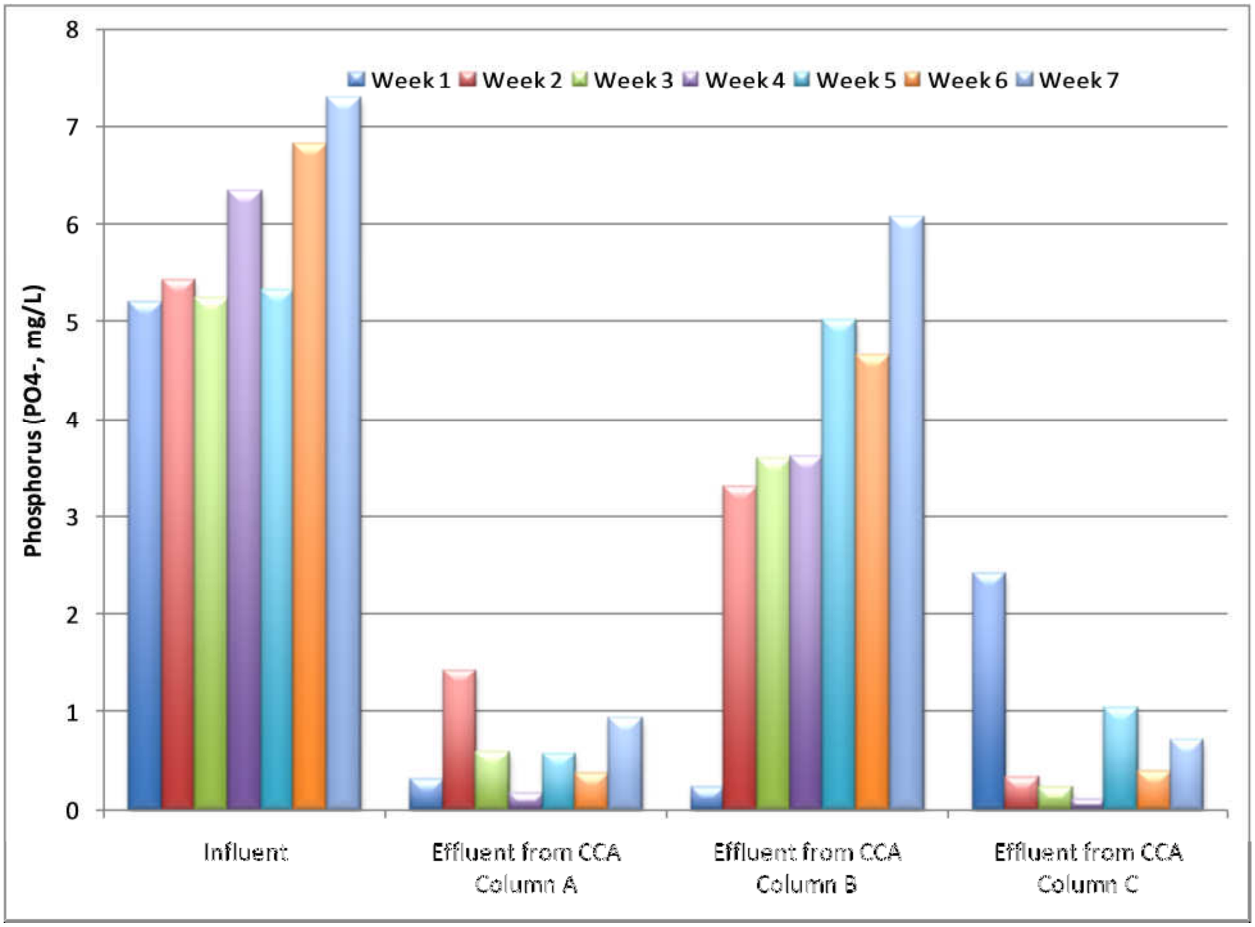


Figure 29. Phosphorus reductions in Columns A, B, and C.

As shown, the CCA Column B did not show such significant phosphorus reduction as the Column A and C did. One main operating difference between the Columns B and C was the pumping rate of the influent: 10 mL/min for the Column C vs. 20 mL/min for the Column B. Another main difference was in the configuration of the column setup: 13 inches long and bigger size CAAs for the Column C vs. 6.5 inches long and smaller size CAAs for the Column B.

To assess potential effects of such operating and setup differences of the Columns B and C, additional experiment was conducted. For this, the Column D made in the same manner as the Column C was received the influent at a flowrate of 20 mL/min, whereas the Column E made in the same manner as the Column B was received the influent at a flowrate of 10 mL/min.

As shown in Figure 30, in comparison of the column A to the column D, a better removal of phosphorus was achieved when the system received a lower flow rate (i.e., Column D). The same phenomenon was also found for comparison of the column B and the column E, where the column E at a lower flow rate produced greater phosphorus removal. A better phosphorus removal was achieved when more CAAs were utilized (i.e., column A vs. column E, and column B vs. column D). But, in this case, a different size of CAAs was used. To clarify these issues, a follow-up experiment will be designed and run (Table 12):

Table 12. Additional experimental set-up for phosphorus removal by CAAs.

Column I.D.	Column dia. (inch)	Column height (inch)	CAA size (mm)	CAA bulk density (g/cm^3)	Operating temp (^oC)	Flow rate (mL/min)
F	3	6.5	4.75-9.53	0.53	25	10
G	3	13	2.3-4.75	0.51	25	10
H	3	6.5	-	-	25	10

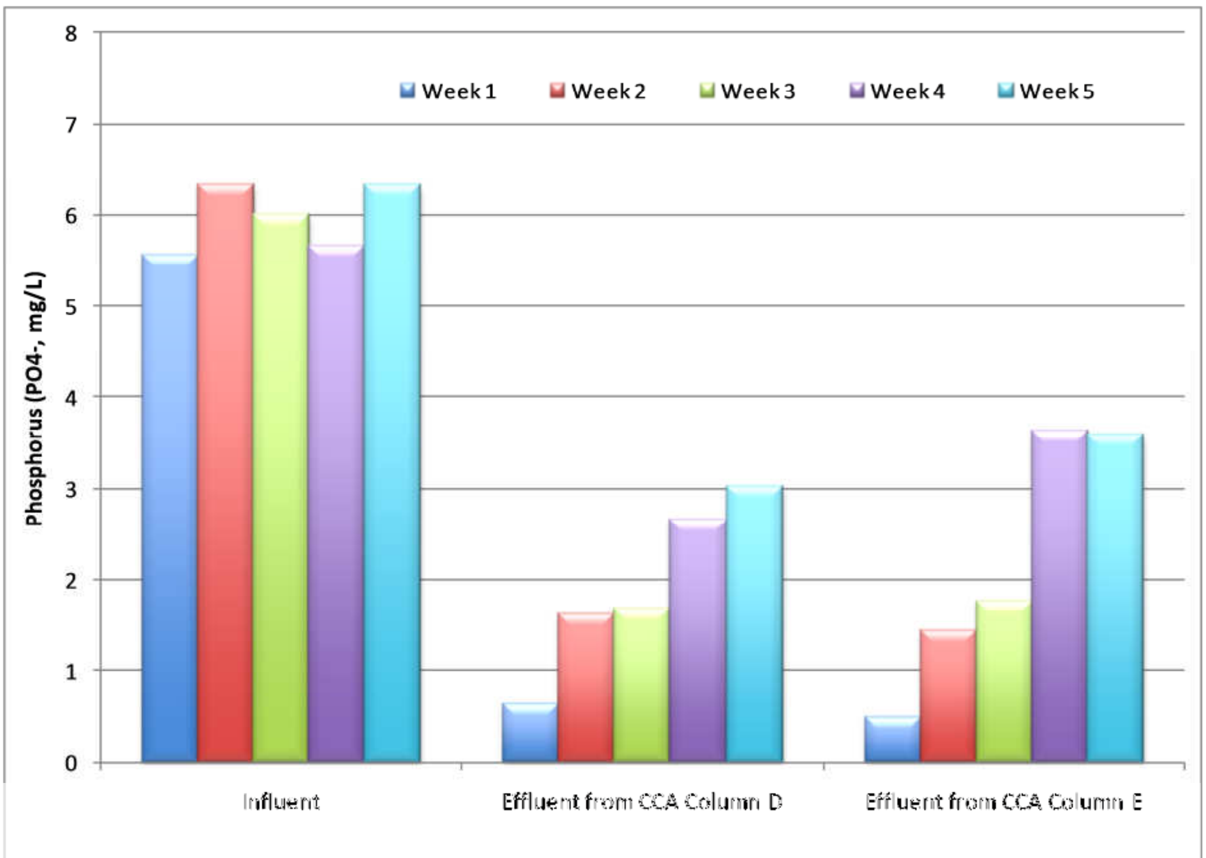


Figure 30. Phosphorus reductions in Columns D and E.

Groundwater modeling

Results will be presented in the next progress report.

Bio-viability Assessment

Germination in a Worst Case Scenario

It was hypothesized that neither toxic chemicals would be leached out of the CAAs nor the plants would take up them, if any, so that the seeds would germinate and the plants would grow. To test this hypothesis, water collected form a column filled with the CAAs was sprayed to the seeds as a worst case scenario and their germination was monitored. As shown in Photo 11, both beans and pumpkins germinated and grew in a good shape. After 2 weeks, roots, leaves and stems of both plants were analyzed with respect to the target heavy metals, Pb and Cd. Both heavy metals were not detected.

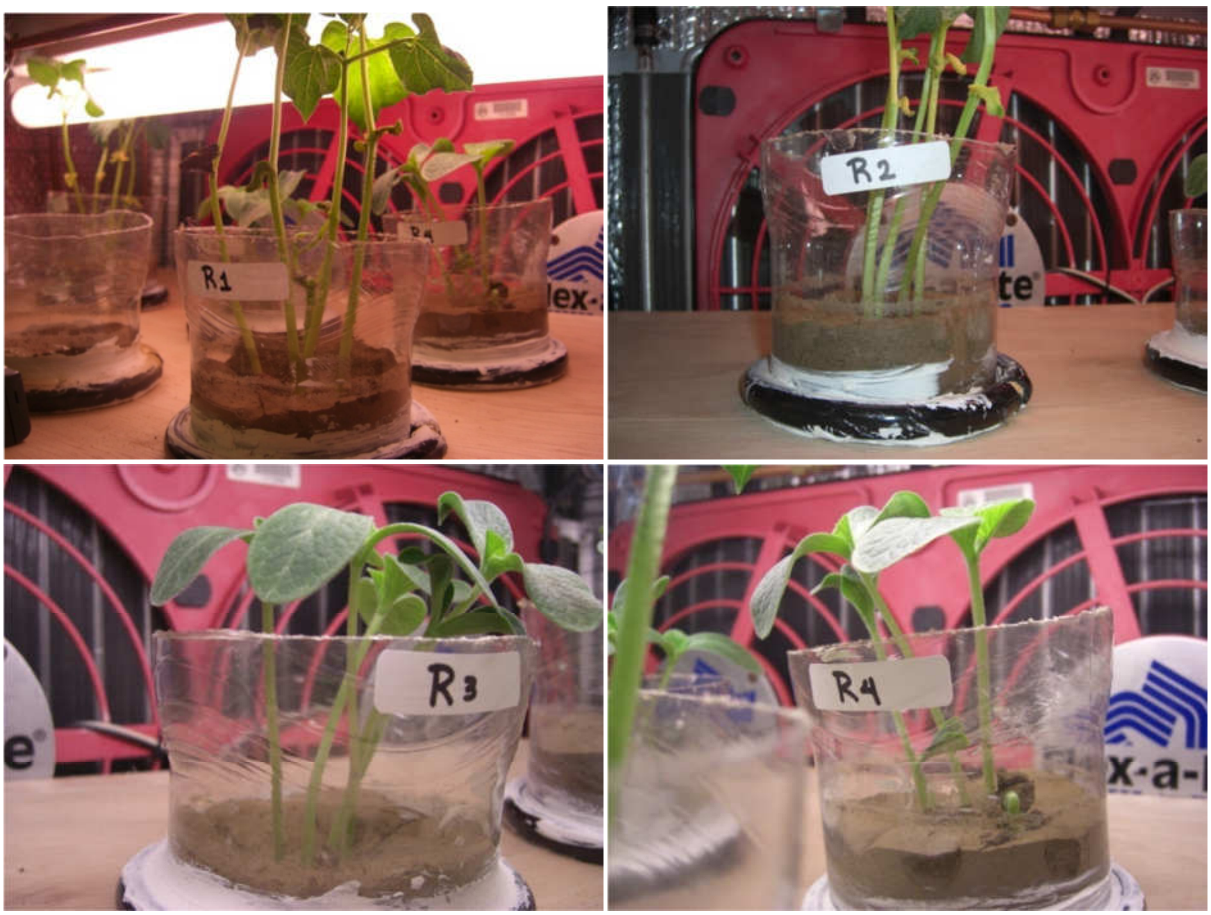


Photo 11. Germination results of bean (top row) and pumpkin (bottom row) seeds.

Germination and Growth Assessment with Multiple Factors

Generally, beans germinated and grew much better than pumpkins during the period of the experiment (2 weeks) as shown in Photo 12 and Figure 31. Between two backfilling modes, a layered mode showed better results than a mixed mode. 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.

It was suspected that a physical hindrane due to the presence of the CAAs 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.

Photo 12. Beans and pumpkins growing in various reactors which were designed to assess the effects of multiple factors on the germination rate and shoot growth.

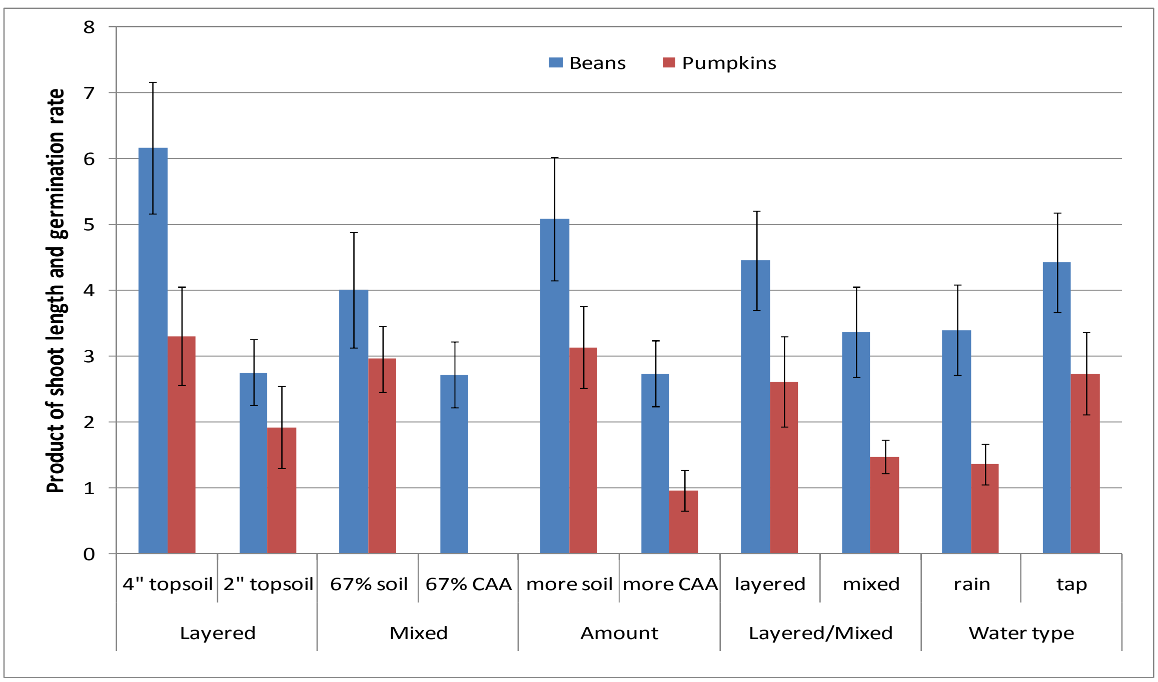


Figure 31. Results of the effects of multiple factors on the product of germination rate and shoot length.

When sprayed with the tap water, better germination and growth were observed in comparison to the rain water application. Water quality analysis was done with respect to specific conductivity, pH, and hardness of both waters (Table 13).

Table 13. Results of analysis on pH, specific conductivity and hardness of rain and tap waters (two samples each).

	pH	Specific Conductivity (µS/cm)	Hardness (mg/L as $CaCO_3$)
Tap water	7.9 ± 0.1	42.6 ± 0.2	64.4 ± 4.0
Rain water	7.5 ± 0.1	37.5 ± 28.1	6.3 ± 0.6

As shown, a major difference between two waters was found in the concentration of hardness, with the tap water being greater 10 times. Additional experiment was performing to elucidate potential contribution of hardness in the tap water which showed better germination and growth compared to the rain water.

Physical Hindrance

As shown in Photo 13 and Figure 32, all of 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).

Photo 13. Scene of the 1st day (left) and the 20th day (right) of the reactors to assess physical hindrance of the CAAs.

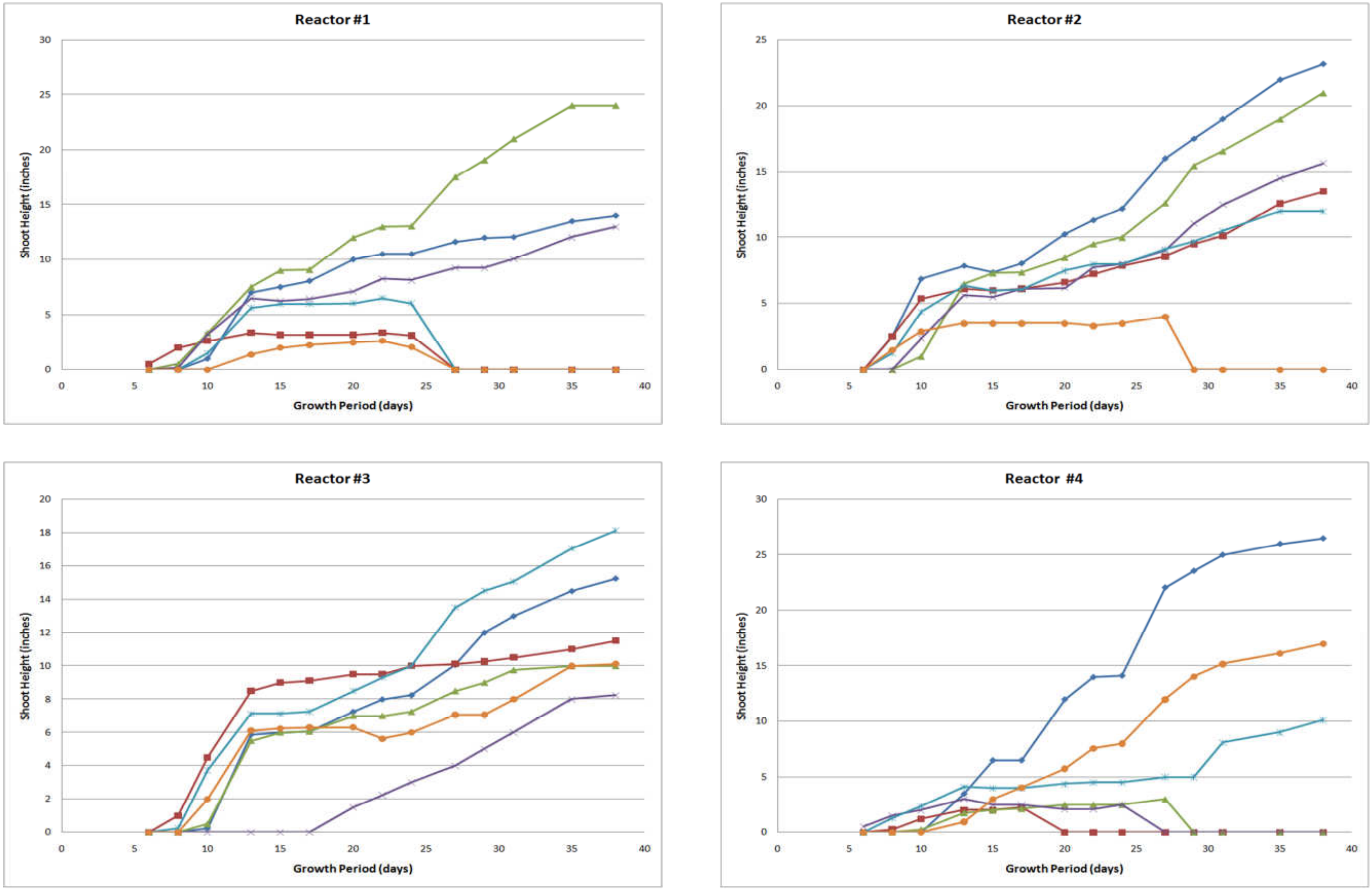


Figure 32. Height of 6 shoots germinated from each pot. 3 shoots, 1 shoot and 3 shoots did not survive after about a month of growth in the Reactor 1, 2 and 4, respectively.

Generally, the Reactor 2 had the best shoot growth as shown Figure 33, 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 limited.

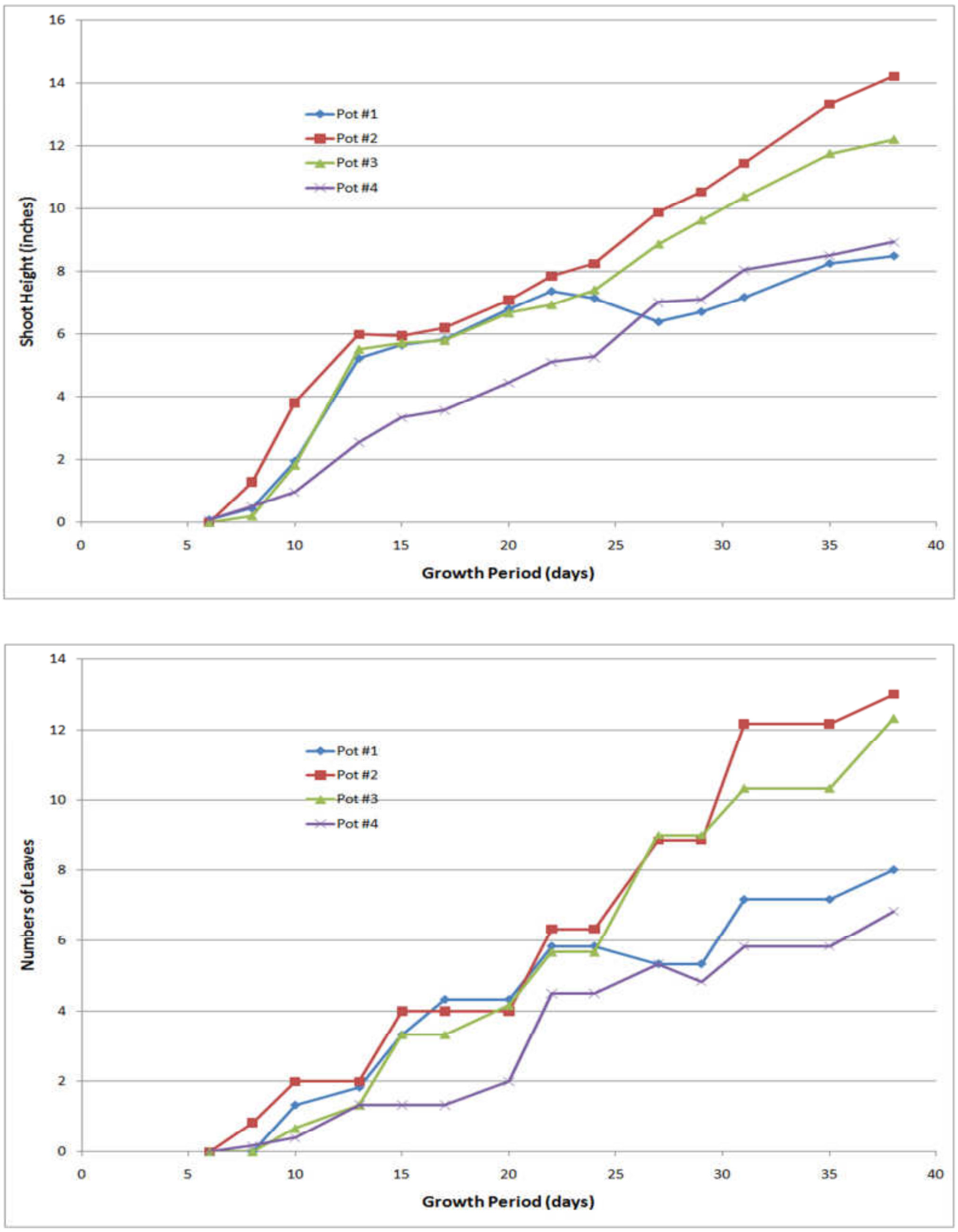


Figure 33. Results of the study which aimed to assess effect of physical hindrance on germination and growth.

Effect of Hardness

Reactors in duplicate were sprayed with water having different hardness concentrations (0 ~ 80 mg/L as $CaCO_3$). The Reactors having received the highest hardness water made 100% germination (i.e., 4 germinations out of 4 seeds planted). Other Reactors made 75% (i.e., 3 out 4) germination. As shown in Photo 14 and Figure 34, the highest growth of the beans was achieved in Reactor D which has been sprayed with water at a hardness concentration of 80 mg/L as $CaCO_3$. In general, the numbers of leaves were not significantly different among the reactors (Figure 35).

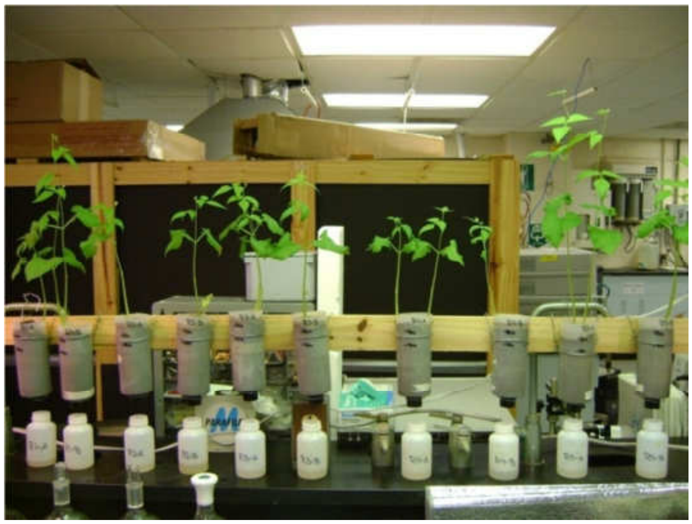


Photo 14. Resulting view of the experiment to assess the effect of hardness on germination and growth.

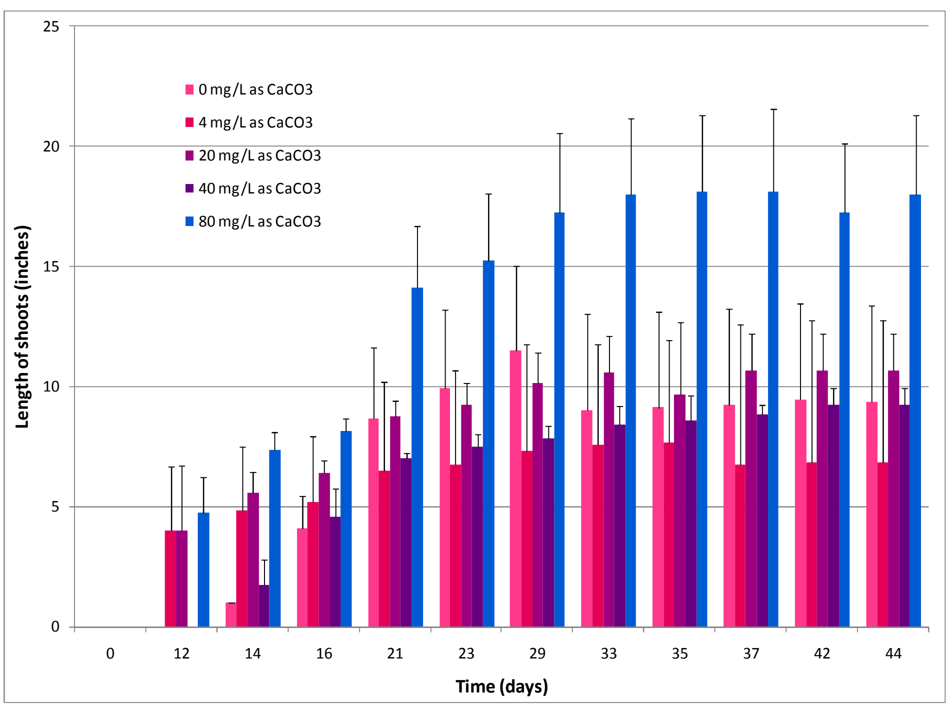


Figure 34. Length of bean shoots when receiving water at different hardness concentrations. Bars indicate standard deviations: n=3 for the reactors receiving 0, 4, 20, and 40 mg/L hardness as $CaCO_3$, whereas n=4 for 80 mg/L case.

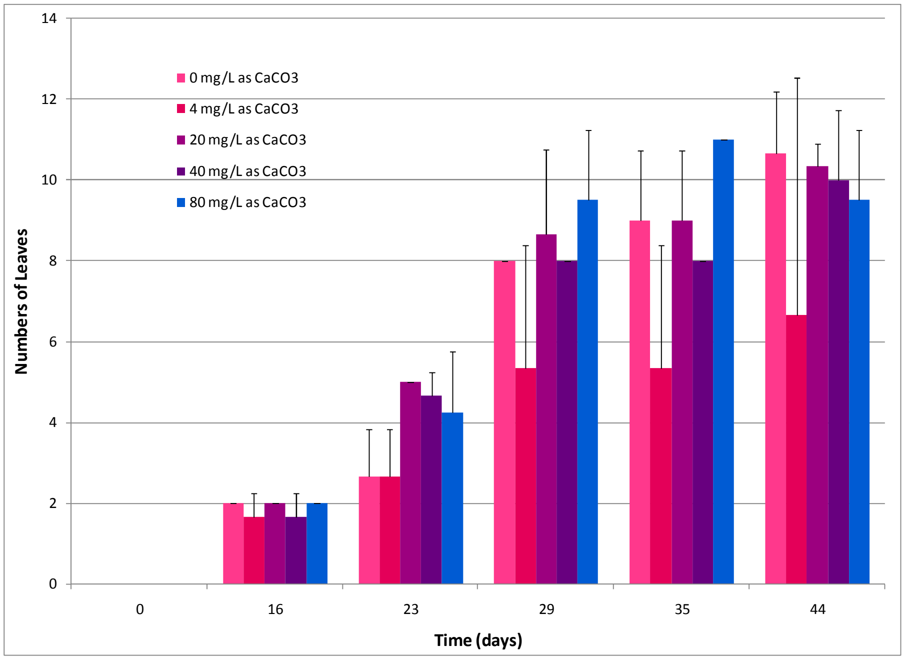


Figure 35. The numbers of bean leaves when receiving water at different hardness concentrations. Bars indicate standard deviations: n=3 for the reactors receiving 0, 4, 20, and 40 mg/L hardness as $CaCO_3$, whereas n=4 for 80 mg/L case.

Expansion of Physical Hindrance Experiment with Various Plants

As shown in Photo 15, botellas, papayas, beans and later pumpkins were tested with respect to physical hindrance that the CAA layer might exert for their roots and consequently their growth. Baby botellas (~8 inches) and papayas (~5 inches) were planted directly to the Reactors, whereas beans and pumpkins were seeded to the Reactors.

Photo 15. Various plants (botellas, beans, papayas, and pumpkins) tested for potential physical hindrance.

Botellas: Two identical baby botellas were planted in the Reactor 1 and 2 (Photo 16). Due to the physical characteristics of their leaves, no specific measurements have done with them. However, regardless of the amendments (CAAs vs. gravel) below 7-in top soil, both botellas have grown well so far up to more than 4 months.

Photo 16. Comparison of the growth of botellas between the initial day (left) and 160th day later (right).

Papayas: Initially, one papaya was planted to each Reactor (Reactors 3 and 4). However, those two baby papayas died after one month due to parasites developed on the leaves. Four new baby papayas were obtained from a nursery farm and two were planted again to one reactor. This time, a commercial pesticide (VEL 4283) was diluted 130 times as instructed and the leaves were gently swabbed with it. Results are shown in Figure 36.

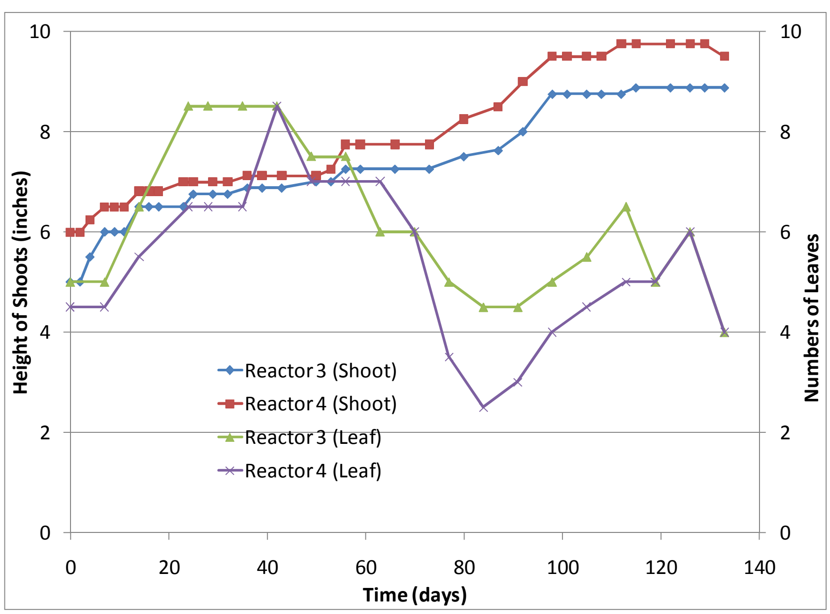


Figure 36. Height of shoots and the numbers of leaves of papayas.

As shown, shorter shoots but more leaves were found from the papayas planted in Reactor 3 which had the CAAs layer five inches below the top soil. However, it is not sure at the moment whether or not the initial physical conditions have influenced the results. That is, four identical baby papayas were obtained and planted to the Reactors but the Reactor 3 started with shorter shoot and more leaves in the beginning.

A chlorophyll meter (SPAD-502, Konica Minolta) was acquired in the middle of the experiment and the chlorophyll intensity was monitored on the leaves of papayas. Monitoring results showed a healthier growth of papayas in the Reactor 3 which had a CAAs layer than in the Reactor 4 which had a gravel layer (Figure 37).

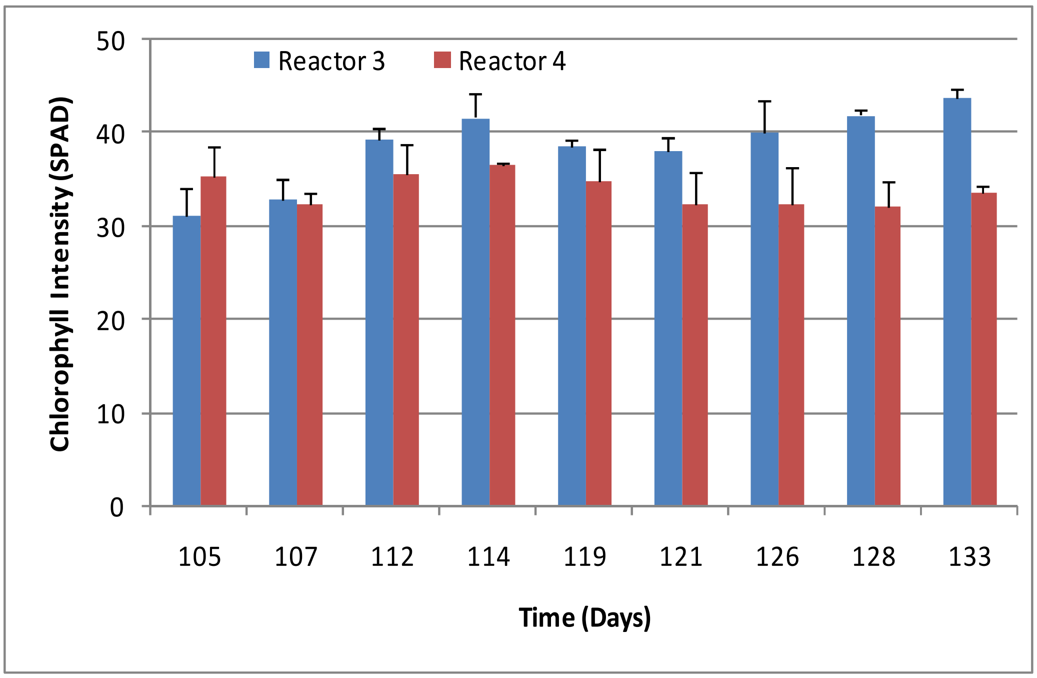
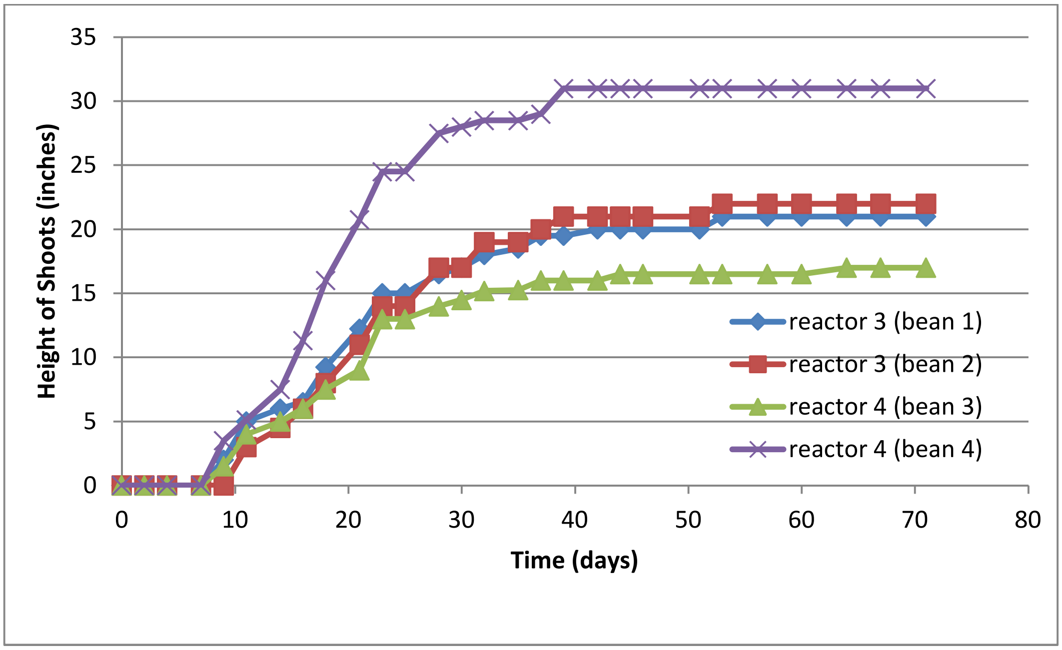


Figure 37. Chlorophyll intensity in the papaya leaves.

<u>Beans</u>: Beans were germinated almost the same time. Fist cotyledon was observed after 8 ~ 10 days. Likely, they started blossoming 29 ~ 31 days after seeding. The heights of shoots of the beans grown in the Reactor 4 were very dissimilar between two bean plants. The numbers of bean leaves were found very similar except for a bean grown in the Reactor 4 (Figure 38).



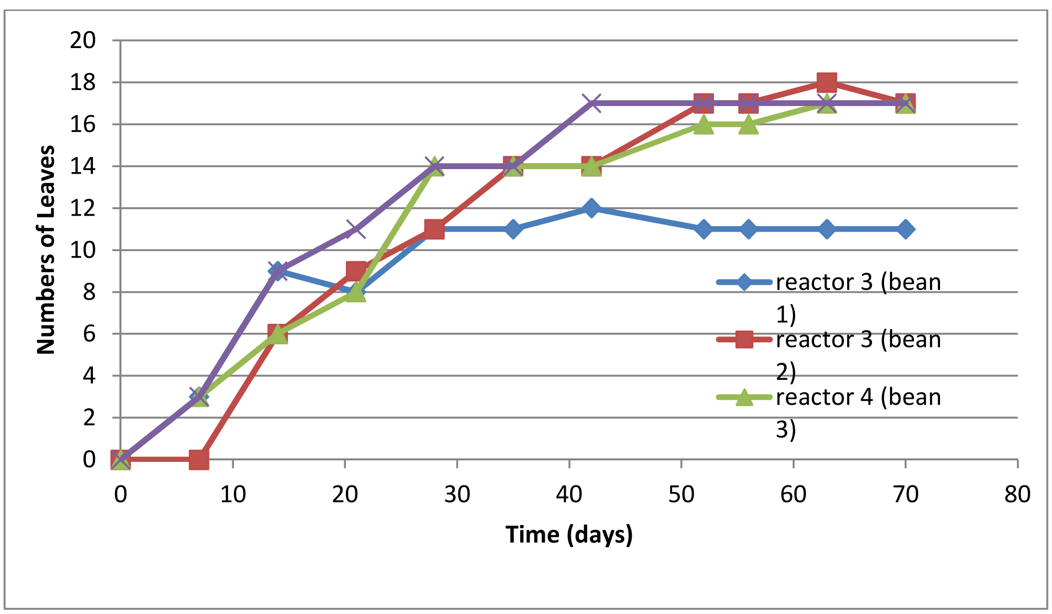
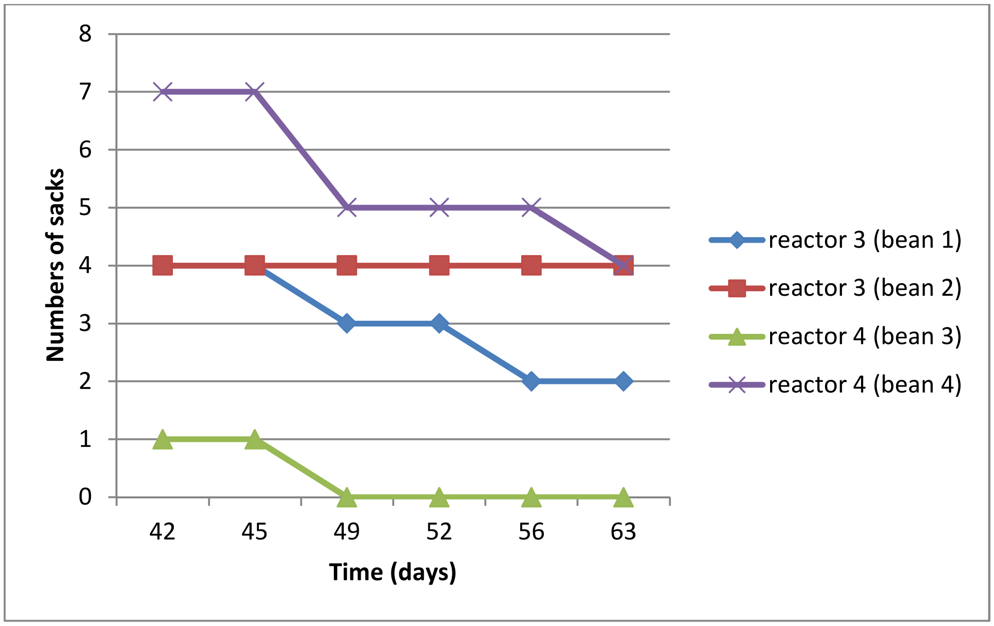


Figure 38. Height of shoots (top) and the numbers of leaves (bottom) of the beans.

After ~40 days, bean sacks were developed and their numbers and lengths were monitored (Figure 39). Data were varying much and did not show any significant trends. However, two beans grown in the Reactor 3 showed closer data points than those in the Reactor 4. 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.



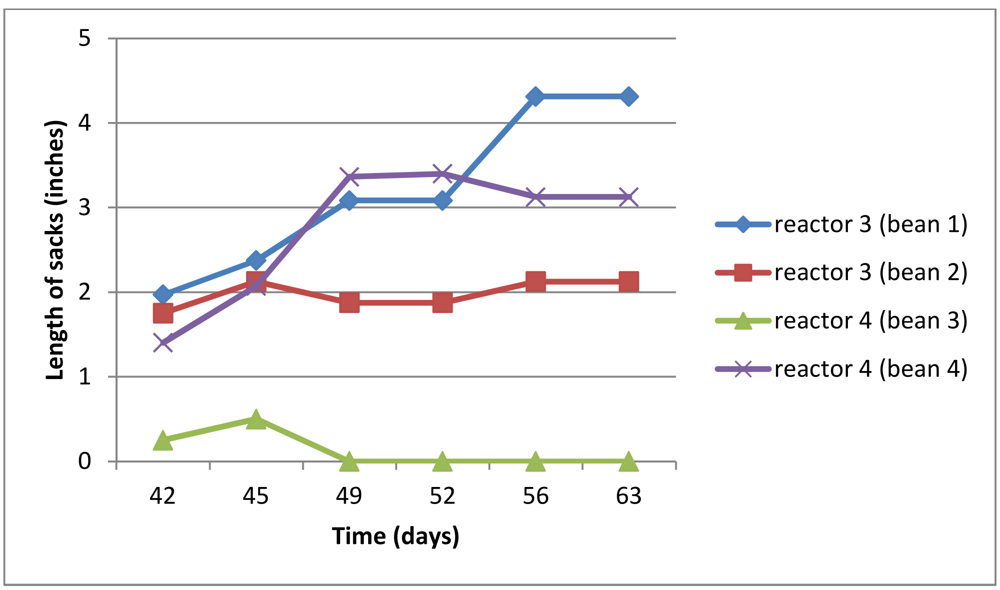


Figure 39. The numbers (top) and length (bottom) of bean sacks.

Pumpkins: Bean stalks were cut close to the roots after completion of the experiment. Then, two pumpkin seeds were planted in the same reactor (Reactors 3 and 4). In the Reactor 4 which had a gravel layer as a physical barrier 5 inches below the top soil, one seed did not germinate at all and the other one died after a month of growth. However, pumpkins germinated in the Reactor 3 have grown well (Figure 40).

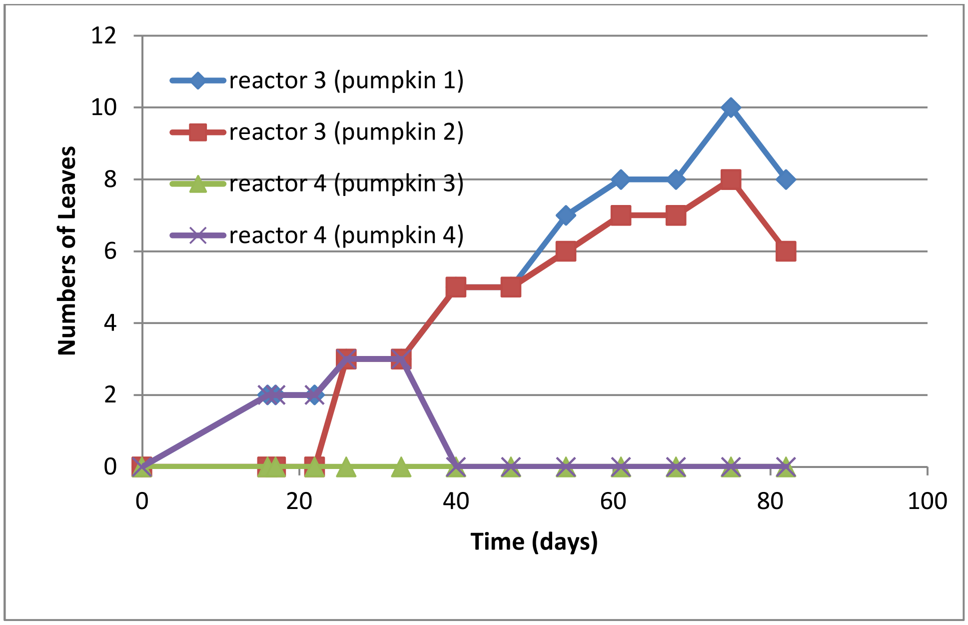


Figure 40. The numbers of pumpkin leaves.

Soil Microbiology and Plant Growth

Figure 41 shows trends of bean growth in terms of their height. It should be noted that 3 bean seeds and 3 pumpkin seeds were planted in the pots. However, pumpkin seeds did not germinated so that 3 additional bean seeds were planted (B4, B5 and B6). The B4 bean in the Control Pot was spoiled due to unknown reasons. A new bean seed was planted later time in the B4 spot. The B1, B3, and B6 beans in the CAA Pot were damaged during the transport of the systems to another location due to local electricity shut-down. This resulted in losses of the heights and leaves of the beans B1 and B3 as shown in Figure 41. No further efforts were provided for the B1 and B3 but a new beam seed was planted to replace the dead B6 bean.

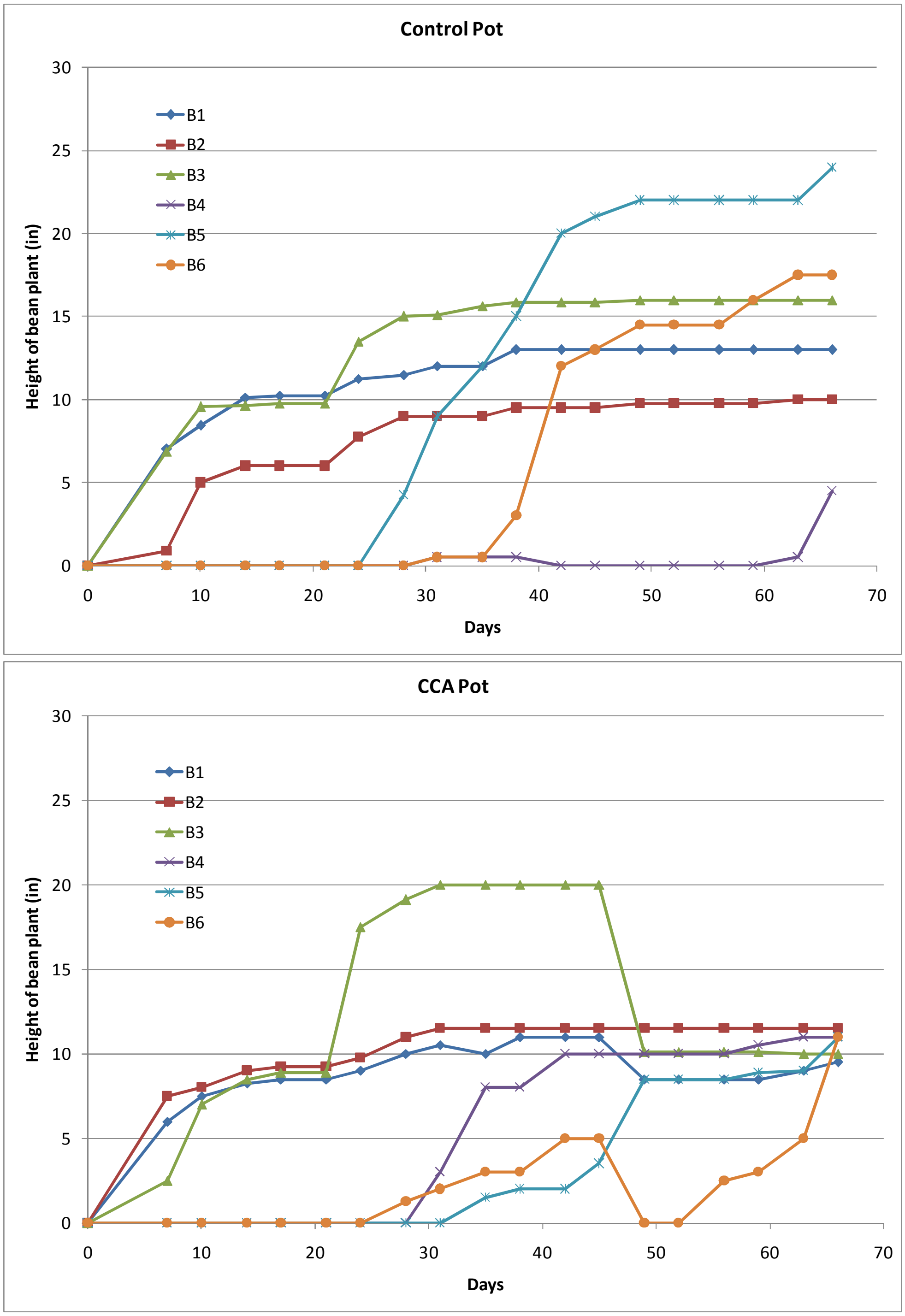


Figure 41. Height of beans from a study on plant growth and soil microbiology results from the addition of CAAs.

Due to the same reason as for the heights, monitoring of the numbers of the bean leaves was also affected. Taking into consideration of the numbers of bean leaves only during the first stage of the experiment (up to 40th days), the results of physical parameters (i.e., heights in Figure 41 and leaf numbers in Figure 42) from the CAA Pot were not much different from those from the Control Pot.

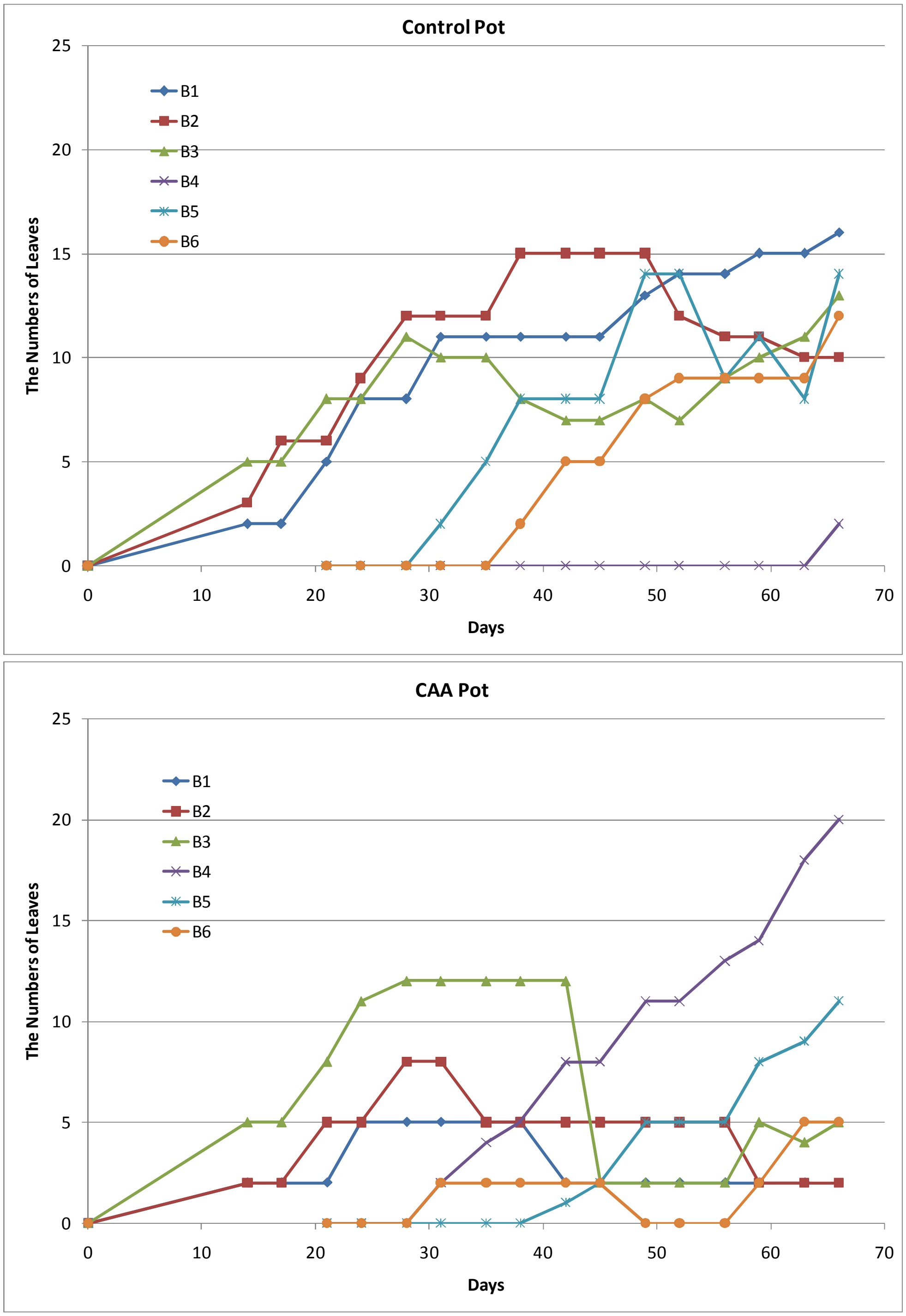


Figure 42. The numbers of bean leaves from a study on plant growth and soil microbiology results from the addition of CAAs.

Results from the Chlorophyll intensity measurement (Figure 43) showed very similar trends between the Control and CAA Pots. The data point shown in Figure 40 was an average of Chlorophyll intensity measure on the leaves. The value of zero Chlorophyll intensity means no leaves available for the analysis at the respective times.

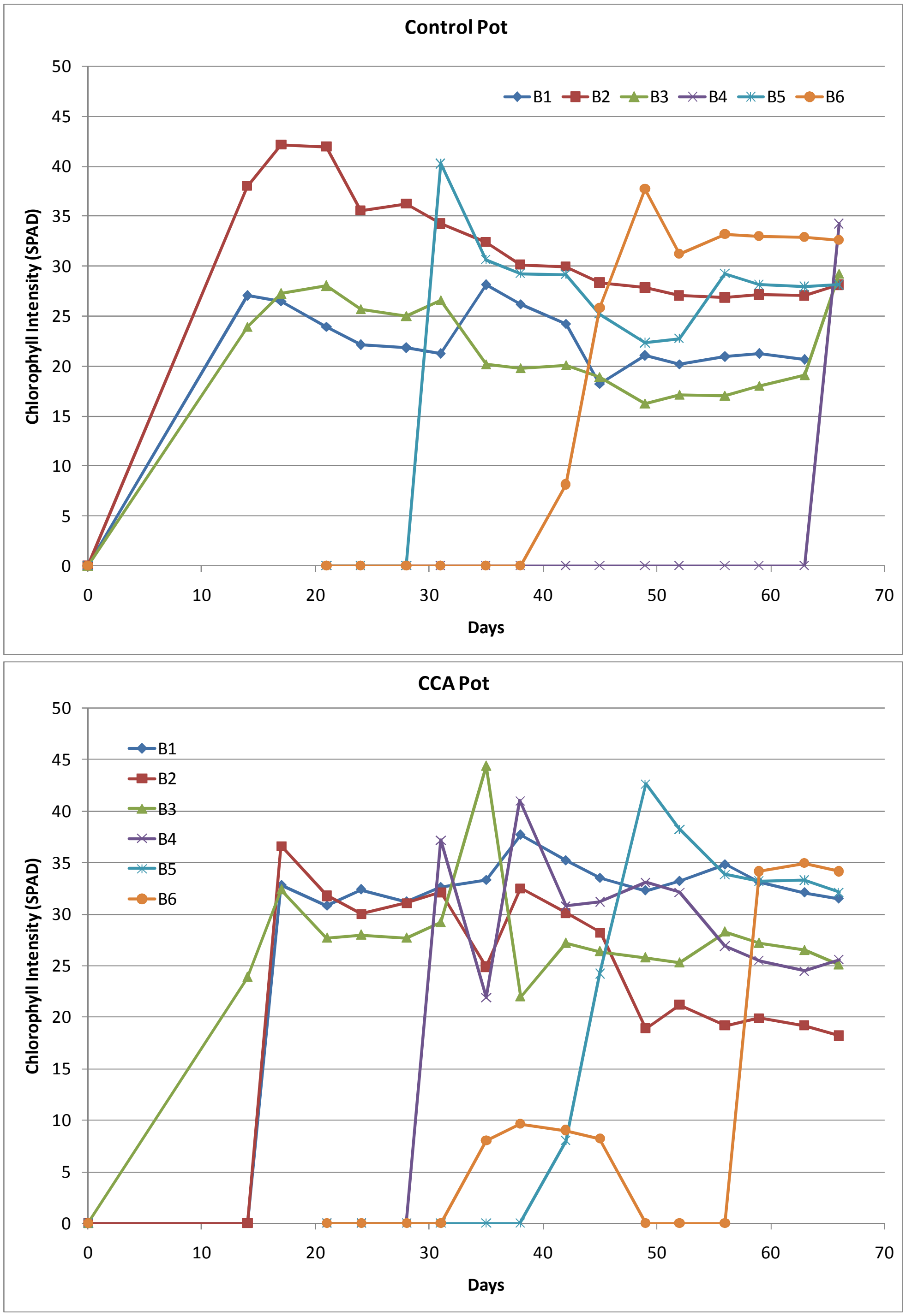


Figure 43. Trend of Chlorophyll intensity from a study on plant growth and soil microbiology results from the addition of CAAs.

Figure 44 shows the results of soil dehydrogenase analysis at 3 intervals during the experiment. A slightly greater soil dehydrogenase activity was observed from the Control Pot than the CAA Pot. Possible reasons of this phenomenon will be addressed in the next report.

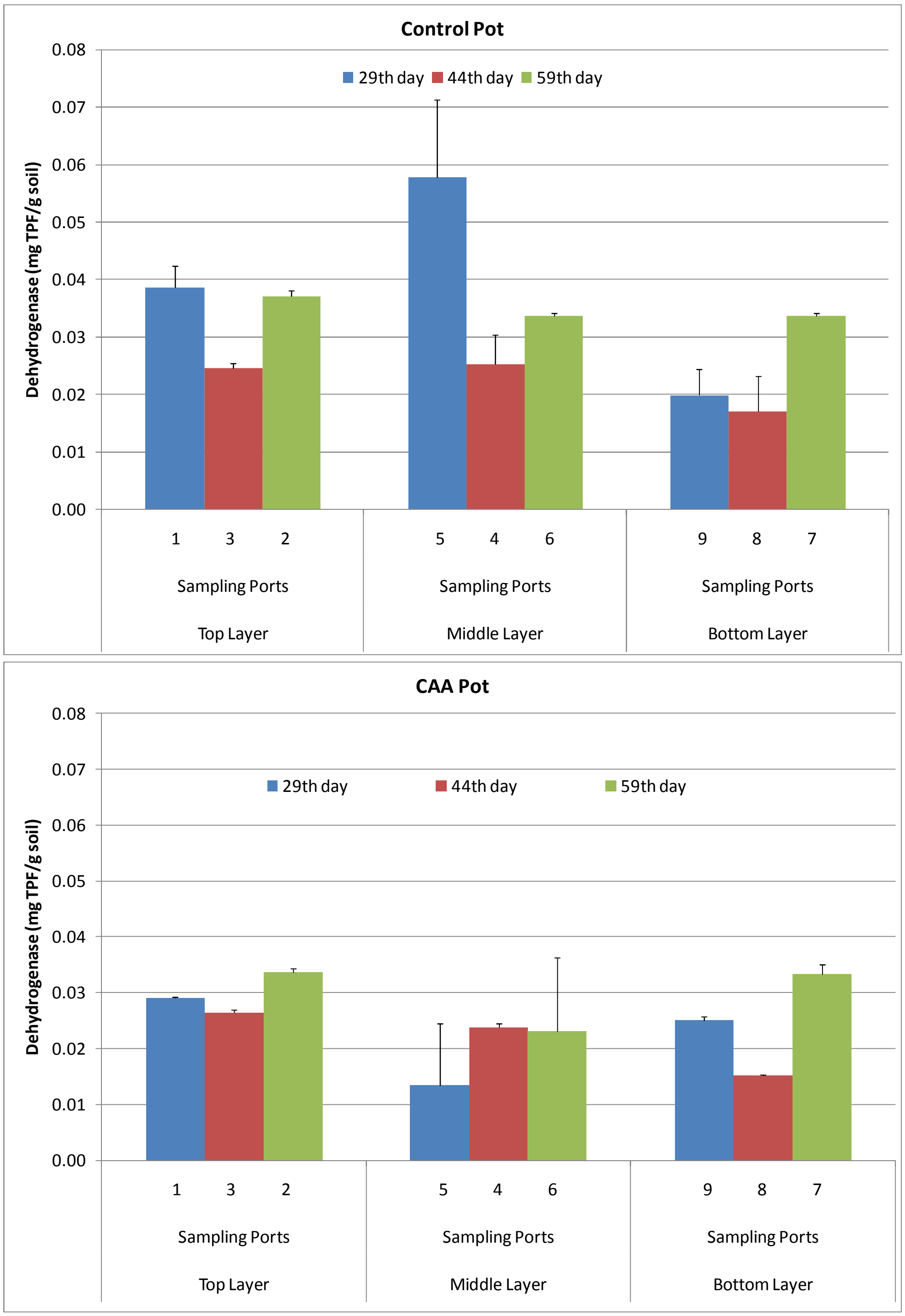


Figure 44. Soil dehydrogenase concentrations from a study on plant growth and soil microbiology results from the addition of CAAs.

THB was also quantified to support the results of soil dehydrogenase analysis, or vice versa for understanding of effect of CAAs on the plant growth and soil microbiology. Table 14 shows large numbers of THB in all three layers regardless of the amendment.

Table 14. Total heterotrophic bacteria counts from a study on plant growth and soil microbiology results from the addition of CAAs.

Layer	Sampling Port	Day	CFU/g soil	
			Control Pot	CAA Pot
Top	1	29th	TMTC	TMTC
	3	44th	TMTC	TMTC
	2	59th	3.80E+06	2.00E+06
Middle	5	29th	TMTC	1.18E+07
	4	44th	8.10E+06	5.10E+06
	6	59th	3.20E+06	4.00E+06
Bottom	9	29th	TMTC	TMTC
	8	44th	TMTC	4.80E+06
	7	59th	5.40E+06	3.20E+06

* TMTC: too many to count

Outdoor plant experiment

As shown in Photo 17, two identical pots were set up in the outdoor experimental area. Weather information was collected with a weather station located in the same experimental area (Figure 45).

Photo 17. A view of outdoor plant growth experiment.

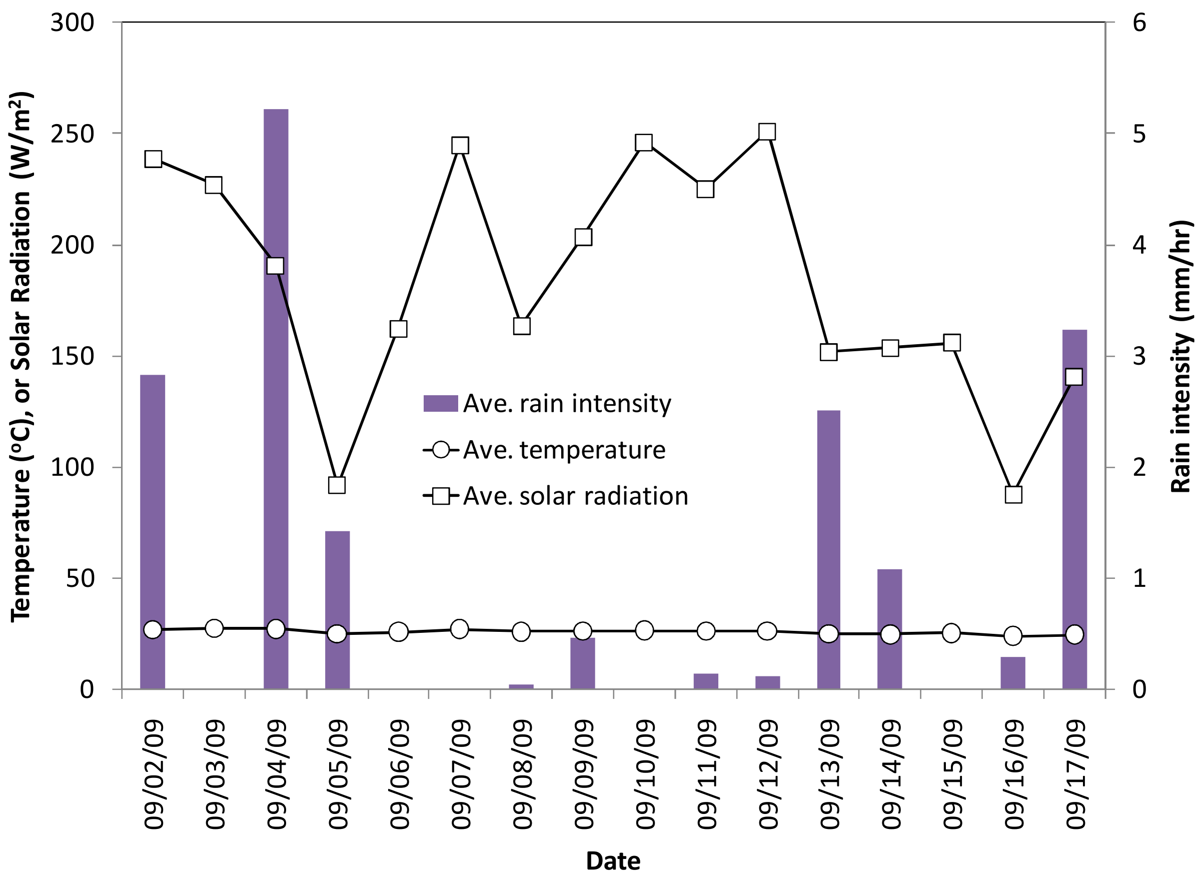


Figure 45. Weather information during outdoor plant growth experiment (Sep. 2~17, 2009).

Beans grown in the treatment pot with the CAAs were taller (Figure 46), had more leaves (Figure 47), and had healthier leaves in terms of Chlorophyll a (Figure 48). These findings are consistent with those obtained from the indoor experiment.

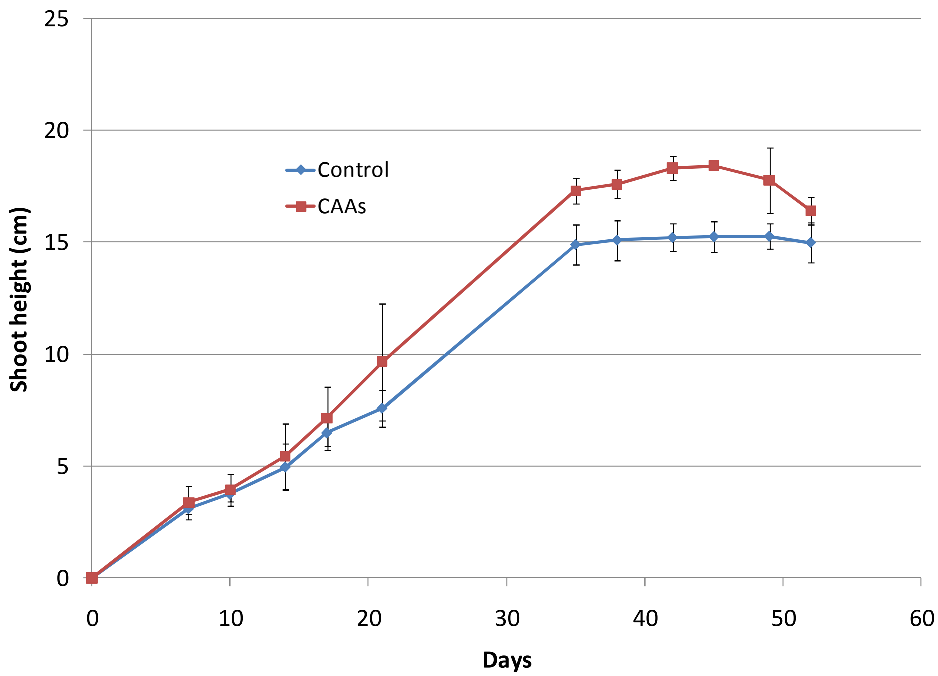


Figure 46. The height of bean shoot in the outdoor pots.

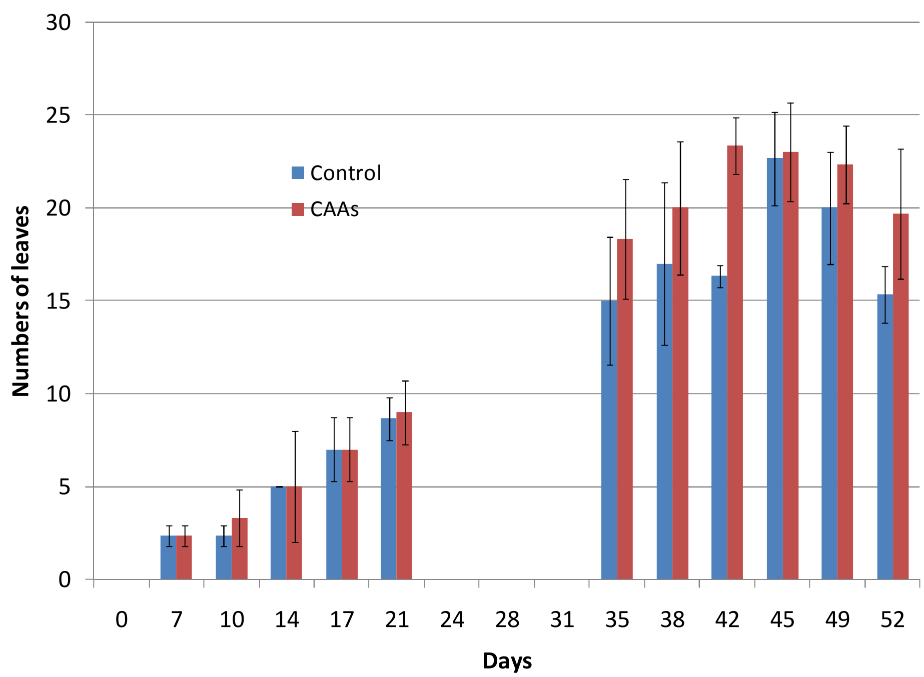


Figure 47. The numbers of leaves in the outdoor pots.

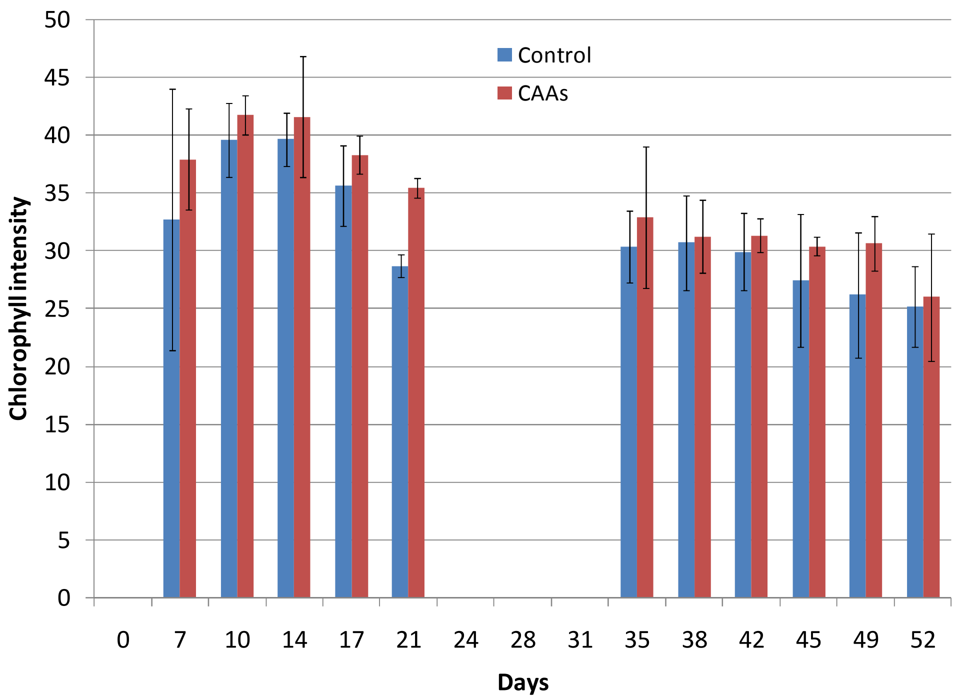


Figure 48. The intensity of Chlorophyll a in the outdoor pots.

Future Studies

A detailed statistical comparison of data obtained from Water Quality Monitoring will be made. Nitrate and phosphorus reduction experiment will be finalized and data will be analyzed. A physical restoration model with the best case backfilling scenario in combination with an aquifer system is under investigation. A numerical simulation will be made using soil and CAAs characterization data in order to compare experimental results obtained from the groundwater quality assessment experiment with the responses from numerical model studies.

Extensive soil characterizations will be conducted to assess physicochemical characteristics such as hydraulic conductivity, carbon, nitrogen and phosphorus contents, soil types, and particle distributions.

Pots will be set up in the outdoor experimental area of the Department of Civil Engineering and Surveying, UPRM. Subject to natural weather environments, survival, physiology, and growth dynamics of other types of plants will be assessed.

Result Disseminations

Preliminary results obtained from the current research were presented at the local and international conferences as follows:

Hwang, S., Escobar, Z., Hernandez, V., Latorre, I., Hernandez, I., Fonseca, A., Del Moral, A. "Environmental Engineering Applications of Coal Combustion Byproducts Aggregates", 2008

International Conference on Environmental Science and Technology (ICEST), Houston, TX, Jul 28-31, 2008.

Latorre, I., Hernandez, I., Fonseca, A., Hwang, S. "Restoration of Open-Pit Quarry to Bio-viable Land: Resource Recovery Approach", XIII Sigma Xi, University of Puerto Rico, Mayagüez, PR, April 10, 2008.

Hernandez, I., Feliciano, I., Hwang, S. "Bio-viability on Restored Open Pit with Coal Ash Aggregate Amendment", 2009 World Of Coal Ash Conference, Lexington, KY, May 4-7, 2009.

Latorre, I., Roman, D., Hwang, S. "Feasibility of Open Pit Restoration with Coal Ash Aggregates: Ground Water Quality Assessment", 2009 World of Coal Ash Conference, Lexington, KY, May 4-7, 2009.

Hwang, S., Latorre, I., Hernandez, I. "Groundwater Quality and Phyto-Viability from Restored Open Pit", 2009 AWWA Annual Conference & Exposition, San Diego, CA, June 14-18, 2009.

A graduate student Imiraily Hernandez who has been working on the bio-viability component of the project had her defense for a Master degree in December 2009. Her thesis title is "Phyto-viability on Restored Land with Coal Ash Aggregates as Backfilling Amendments".

Acknowledgments

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References

Feliciano, I., Hwang, S., Padilla, I. "Distribution of Explosives TNT and DNT with Surface Vegetation Fimbristylis Cymosa", 2008 AIChE Annual Meeting, Philadelphia, Pennsylvania, November 16 – 21, 2008.

MDNR. (1992). A Handbook for Reclaiming Sand and Gravel Pits in Minnesota, Minnesota Department of Natural Resources, USA.

Pando M., Hwang S. (2006) "Possible Applications for Circulating Fluidized Bed Coal Combustion By-products from the Guayama AES Power Plant". Technical Report. Civil Infrastructure Research Center, University of Puerto Rico at Mayagüez, PR

Information Transfer Program Introduction

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USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	0	1
Masters	5	0	0	0	5
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	7	0	0	0	7

Notable Awards and Achievements

None in this reporting period.

Publications from Prior Years