

**Results from a Study
of
Soil Sement®
Soil Stabilizing Emulsion:**

**Runoff Characteristics and Sediment Retention
Under Simulated Rainfall Conditions**

Prepared for

Midwest Industrial Supply, Inc.
P.O. Box 8431
Canton, OH 44711-8431
Chattanooga, TN 37421

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Tested and Reported by the

**SAN DIEGO STATE UNIVERSITY
SOIL EROSION RESEARCH LABORATORY**
5500 Campanile Drive, Industrial Technology Building #103
San Diego, CA 92182 Phone: (619) 594-3123

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1.0 SOIL STABILIZING EMULSION STUDY: Soil Sement™ Erosion Control Polymer

1.1 Introduction

There are numerous chemicals marketed to the erosion control industry that when added to water form emulsions for dust control, road stabilization and surficial slope treatment. These materials range from simple plant mucilages to complex synthetic formulations. When applied to the soil surface, with or without the benefit of fibrous mulch, these emulsions provide varying degrees of soil protection.

Soil Sement™ as manufactured by Midwest Industrial Supply, Inc. is a stabilizer that can be applied by itself for temporary erosion control lasting up to one season. Soil Sement™ can also be mixed with seed and mulch to create a hydraulic matrix.

Typical equipment used for applying a soil stabilizing emulsion includes:

- Hydroseeders
- Aerial spray
- Water trucks
- Spray rigs
- Irrigation systems

1.2 Study Objectives

There were three (3) main objectives for the RECP study:

- 1) To provide scientific, reproducible and defensible data on the effectiveness of Soil Sement™ to reduce runoff and control erosion on earthen cut or fill slopes;
- 2) To relate these tests to previous evaluations of erosion control materials and methods under similar test conditions;
- 3) To present the results of the testing in a format useful to field engineers in the design and specification of Soil Sement™ for stabilization of steep slopes.

1.3 Test Procedures

The test procedures followed for the Soil Sement™ study were adapted from portions of the testing protocols developed for the Slope Stabilization for Temporary Slopes study (Caltrans, October 1999) and the Caltrans Erosion Control Pilot Study (June 2000). The SDSU test method provides a comparative evaluation of temporary erosion control practices (including numerous types of liquid soil stabilizers) to baseline bare soil conditions under controlled and documented conditions. The SDSU test method is in general conformance with the outlined methods and scope of ASTM D6459, Standard Test Method for Determination of Erosion Control Blanket (ECB) Performance in Protecting Hillslopes from Rainfall Erosion.

Test Conditions

- The soil used was classified as a clayey sand (SC)
- The test area was 2 meters wide x 8 meters in length (6.5 feet x 26 feet)
- The storm event was a 10-year storm as predicted for the Los Angeles Basin (5 mm (0.2 inches) per hour for 30 minutes/40 mm (1.6 inches) per hour for 40 minutes/5 mm (0.2 inches) per hour for 30 minutes)
- The slope was 2H:1V
- Three replications for the bare soil (control) and three replications for the Soil Sement™ treated conditions were performed.
- In addition, following the third replication, two consecutive rainfall events were introduced (without bed rejuvenation and preparation) to gauge the difference between individual storm events, and repeated storm events.

Bed Preparation

- Prior to each replicate test, soil in the bed was removed to a depth of 8-10 cm (3-4 inches) and replaced with new, untested soil.
- The new soil was moisturized, tilled and hand-compacted to uniform consistency (See Appendix A for soil filling and compaction procedures).
- Edging and flumes were installed to differentiate a 2m x 8m (6.5-ft x 26-ft) plot.
- Prior to application of the Soil Sement™ emulsion, the surface of the compacted soil was loosely raked to a depth of approximately 1 cm (1/2 inch).

Application

- Prior to each rainfall event 9.5 liters (2.5 gallons) of Soil Sement™ was mixed with 38 liters (10 gallons) of water. The dilution rate (4:1) and application rate (670 gallons/acre) were provided by Midwest Industrial Supply, Inc.
- For most testing at SDSU, a manufacturers' representative is usually present to supervise installation or application. A representative from Midwest was not available during the study period..
- Following each testing period (except in the case of consecutive storm events), the wetted, eroded soil was removed and replaced with new soil material and a new application of Soil Sement™ was installed. A total of three (3) replications were performed
- In the case of consecutive storm events, no new application of Soil Sement™ was placed on the test bed following rainfall. A total of two (2) additional storms were introduced following the final replication of the first testing phase, effectively yielding three (3) consecutive storm events..

Rainfall event

- Rainfall consisted of a 10-year storm event as modeled from Los Angeles Basin hydrologic data, consistent with those values of the Caltrans SSTS Study (October 1999) and the Caltrans ECPS Study (June 2000).
- The intensity and duration of the storm were as follows:
 - Period 1: 5 millimeters (0.2 in) / hour rain for 30 minutes
 - Period 2: 40 millimeters (1.6 in) / hour rain for 40 minutes
 - Period 3: 5 millimeters (0.2 in) / hour rain for 30 minutes
- Settings on the rainfall simulators to achieve these intensities were based on previous calibrations conducted at the laboratory.

Sample Collection and Analysis

- Water and sediment were collected at the downstream (toe) end of the flume in polyethylene lined, 133 liter (35 gallon) containers.
- At the end of each rainfall event, 500 grams (18 ounces) of gypsum was added to each collection barrel to aid in settling out the fine sediments.
- The samples were allowed to settle overnight (24 hours)
- The supernatant, or clear water, was siphoned from each container, and its weight and volume recorded.
- The weight of the remaining wet sediment was recorded.
- A sample of the remaining wet sediment was taken and placed in an oven overnight to determine moisture content of the wet sediment.
- The moisture content of the wet sediment sample was used to determine the total dry sediment weight of the collected sediment.

2.0 TEST FACILITY

The San Diego State University Soil Erosion Laboratory (SDSU/SERL) integrates beneficial features from some of the primary soil erosion research facilities in the United States. Funding for the facility was provided by Caltrans, (California State Department of Transportation) as part of a 1998-2000 erosion control pilot study, in which design, construction and operation of the SERL was supervised by URS Greiner Woodward Clyde and SDSU faculty. Actual modification of Industrial Technology Building Room #103 and construction of the soil test bed was carried out by the SDSU Physical Plant.

In designing the SDSU laboratory, members of the Caltrans pilot study team studied the physical layout, testing protocols, and past research activities of the following soil erosion laboratories:

- Utah Water Research Laboratory (UWRL) at Utah State University, Logan, Utah;
- USDA-Agricultural Research Service National Soil Erosion Research Laboratory (NSERL) at Purdue University, West Lafayette, Indiana; and
- Texas DOT/Texas Transportation Institute (TTI) Hydraulics and Erosion Control Laboratory at Texas A & M, College Station, Texas.

Aspects of the SDSU Soil Erosion Laboratory design that resulted from examination of these facilities include the following:

Table 2.1

Design Features of Soil Erosion Laboratories

Design Feature	Erosion Facility
Norton Ladder Rainfall Simulator	NSERL
Hydraulically-lifted soil bed	UWRL
12-inch soil depth placed on porous, open-grid system for drainage	UWRL, NSERL
Procedures for collection of runoff and sediment samples	UWRL, NSERL, TTI
Confirmation of test plot size	UWRL, NSERL
Number of replicates for each test	UWRL, NSERL

The SDSU laboratory is primarily used to provide comparative evaluations of temporary erosion control practices (including erosion control blankets) to baseline bare soil conditions under controlled and documented conditions. The SDSU Soil Erosion Research Laboratory is in general conformance with the outlined methods and scope of ASTM D6459, Standard Test

Method for Determination of Erosion Control Blanket (ECB) Performance in Protecting Hillslopes from Rainfall Erosion.

2.1 Norton Ladder Rainfall Simulator

The rainfall simulation device selected for the SDSU Soil Erosion Laboratory is the Norton Ladder Rainfall Simulator, which was developed at the USDA-ARS National Soil Erosion Research Laboratory by Dr. Darrell Norton. This apparatus has been used worldwide, is reasonably inexpensive, and is easily transported and operated.

For testing in the indoor laboratory, multiple simulators (4) have been installed in parallel above the soil test bed to uniformly apply precipitation over the entire test plot area. The pre-fabricated rainfall devices were purchased from Advanced Design & Machine (Clarks Hill, Indiana), an experienced manufacturer specializing in production of the Norton simulator.

Physical Characteristics

The basic unit of the simulator is an aluminum frame 5.3 meters (17 feet) long, 0.32 meters (12 inches) wide, and 0.25 meters (10 inches) deep. Each frame is a self-contained unit that includes nozzles, oscillating mechanism, drive motor, pump, float valve, piping, and sump.

The drop former used for the Norton simulator is the Spraying Systems Veejet 80100 nozzle, and the nozzles are spaced 1.1 meters (3.6 feet) apart. For uniform intensity across the plot, the center of spray patterns from two laterally adjacent nozzles meet at the plot surface. This gives a 2.25 mm (.09 in) median drop size, a nozzle exit velocity of 6.8 meter per second (22.3 feet per second), and a spherical drop.

The impact velocities of almost all drops from the Veejet nozzle are nearly equal to the impact velocities of those from natural rainstorms when the nozzle is at least 2.4 meters (7.9 feet) above the soil surface. For this reason, the rainfall simulators used in the SDSU Soil Erosion Laboratory have been installed such that the nozzles are a minimum of 2.5 meters (8.2 feet) above the soil surface. Rainfall intensity can be changed instantaneously with the simulator in operation, and the maximum intensity produced is 135 mm/hr (5.3 in/hr).

Design of Simulated Rainfall

Prior to testing, the Norton ladder-type simulators are placed into position above the soil test bed. Calibration is achieved by conducting rainfall tests and measuring rainfall volumes in collection devices placed at precise intervals within the 2 meters x 8 meters (6.5 feet x 26 feet) test plot. A full range of rainfall intensities can be achieved by adjusting either one, or both of the following parameters:

- The number of sweeps per minute (spm) of the spray nozzles, ranging from 25 to 125 spm.

- Adjusting the water pressure within the supply system. Each simulator has a system of valves that allow internal water pressure to be adjusted from a low of 2 psi to a high of 6 psi. Gauges atop each simulator allow for accurate, manual adjustment.

Simulated rainstorm events utilized for most of the current testing at the SDSU/SERL have an initial period (Part 1) of low intensity rainfall, followed by a period (Part 2) of relatively high intensity rainfall, and ending with a period (Part 3) of relatively low intensity rainfall.

2.2 Soil Test Bed

The soil test bed is a 3-meter wide by 10-meter long (323 square feet) metal frame which rests on a series of pivots located at the lower end of the bed, and is supported by two hydraulic cylinders near the upper end of the bed. These telescopic cylinders extend to tilt the test bed from its horizontal position to a maximum 2H:1V slope gradient.

The test bed is designed to support a 30.5-cm (1-foot) depth of soil. The depth is sufficient to allow placement and compaction of soil and the application of various surface erosion control practices to evaluate their effect on erosion rates.

The sides and ends of the soil test bed are constructed of steel frame-supported 1.0-cm (0.4-in) thick Plexiglas that allows ambient light onto the soil surface, and facilitates viewing of the effects of rainfall impact and runoff. The total usable surface area of the soil bed is 3 meters (10 feet) wide by 10 meters (33 feet) long, but during testing only a portion of the treated bed, 2 (6.5 feet) meters wide by 8 meters (26 feet) long, is generally delineated for evaluation by the use of plastic edging. Runoff and sediment are collected at the toe of the slope by a metal flume.

Drainage grates have been installed in the floor underneath and at the front of the soil bed, and all runoff not collected is directed to a sanitary sewer. As a safety precaution, stationary steel support posts are placed beneath the bed when it is raised for rainfall simulations.

2.3 Hydraulic System

The soil test bed was designed to be lifted hydraulically to the desired slope inclination for testing. Two 5-stage, single-acting, telescopic cylinders are positioned approximately 3.0 meters (10 feet) from the top of test bed. The cylinders, which weigh 230 kilograms (505 pounds) each, have a 20.3-cm (8-inch) diameter as the largest moving stage.

The complete hydraulic system consists of the cylinders, a 227-liter (60-gallon) hydraulic fluid reservoir, a 114 lpm (30 gpm) hydraulic pump, and a 50 hp electric motor with motor starter. Also included are a suction strainer, return oil filter, pressure relief valve, and a directional control valve.

2.4 Sediment Collection System

Water and soil runoff from the test bed is collected by plastic edging, flume, and collection containers. The components of the sediment collection system on the test bed are installed prior to each rainfall simulation. For most erosion control treatment evaluations, the plastic edging is installed prior to application of the erosion control treatment.

2.5 Water Treatment and Storage

In order to obtain accurate results from the rainfall simulation/erosion rate evaluations, the municipal water supply is treated by reverse osmosis and softened to remove minerals. This treatment process produces “softer” water that is more similar in quality to natural rainfall. Using municipal water without treatment would cause a decrease in sediment load, because minerals in the water serve to decrease erosion.

Water Treatment System

The water treatment system consists of a reverse osmosis unit, preceded by one activated carbon vessel and two softening vessels arranged in series (i.e. carbon/softener/softener). The system, which is capable of producing 1,140-2,270 liters per day (300-600 gallons per day), also includes a pre-filter to remove particulates greater than 5 microns in size that may escape the service vessels. The system is serviced monthly by a local U.S. Filter representative.

Delivery of water to the rainfall simulators positioned above the soil test bed is by a pump attached to hard plumbing and flexible hoses. A key aspect of the Norton design is that unused water from within the simulators is returned to the holding tank and available for reuse. Flexible plumbing is installed to accommodate this return flow.

Treated Water Storage

Treated water is stored in a 3,785-liter (1,000-gallon) polyethylene storage tank for use in the laboratory simulations. For outdoor test plots, two 757-liter (200-gallon) tanks are truck or trailer-mounted to deliver treated water to the field for rainfall simulations.

3.0 RESULTS

Tables 3.1 through 3.6 show the results of the laboratory analysis of sediment weight and runoff volumes for each test condition:

- Table 3.1 represents the runoff and sediment yield for bare soil (control)
- Table 3.2 presents the runoff and sediment yield for Soil Sement™
- Table 3.3 presents the runoff and sediment yield for the three (3) consecutive storm events on bare soil
- Table 3.4 presents the runoff and sediment yield for the three (3) consecutive storm events on Soil Sement™

Table 3.1
Runoff and Sediment Yield for Bare Soil (control)

soil loss(kg)	rep #1	rep #2	rep #3	Total(Kg)
Period 1	0.10	0.45	2.33	0.96
Period 2	54.46	44.19	50.36	49.67
Period 3	2.20	2.59	4.75	3.18
total (1,2,3 periods)				53.81
Runoff(L)	rep #1	rep #2	rep #3	Total(L)
Period 1	11.43	20.34	19.32	17.03
Period 2	375.25	336.82	354.87	355.65
Period 3	57.22	63.75	62.92	61.30
total (1,2,3 periods)				433.97

Table 3.2
Runoff and Sediment Yield for Soil Sement™

soil loss(kg)	rep #1	rep #2	rep #3	Total(Kg)
Period 1	0.02	0.00	0.07	0.03
Period 2	17.11	11.64	40.64	23.13
Period 3	1.16	1.56	3.70	2.14
total (1,2,3 periods)				25.30
Runoff(L)	rep #1	rep #2	rep #3	Total(L)
Period 1	6.99	6.06	18.51	10.52
Period 2	266.78	240.83	370.20	292.60
Period 3	60.96	54.33	68.70	61.33
total (1,2,3 periods)				364.45

Table 3.3
Runoff and Sediment Yield for Three Consecutive
Storm Events on Bare Soil (control)

soil loss(kg)	rep #1	rep #2	rep #3	Total(Kg)
Period 1	0.47	0.47	0.47	1.41
Period 2	52.54	31.33	26.96	110.83
Period 3	7.07	8.28	7.98	23.33
total (1,2,3 periods)				135.57
Runoff(L)	rep #1	rep #2	rep #3	Total(L)
Period 1	18.19	52.25	54.14	124.58
Period 2	360.72	363.85	359.79	1084.36
Period 3	62.06	61.29	72.22	195.57
total (1,2,3 periods)				1404.51

Table 3.4
Runoff and Sediment Yield for Three Consecutive Storm Events
on a Soil Sement™ Application

soil loss(kg)	rep #1	rep #2	Rep #3	total(Kg)
Period 1	0.07	4.42	2.66	7.15
Period 2	40.64	95.28	82.29	218.21
Period 3	3.70	9.14	4.41	17.25
total (1,2,3 periods)				242.61
Runoff(L)	rep #1	rep #2	Rep #3	total(L)
Period 1	18.51	58.85	63.79	141.15
Period 2	370.20	411.70	414.63	1196.53
Period 3	68.70	79.84	69.17	217.71
total (1,2,3 periods)				1555.39

3.1 Relative “C” Factor Determinations

Relative cover, or “C” factors, can be determined for each tested material by utilizing the Universal Soil Loss Equation (USLE):

$$A = R \times K \times LS \times C \times P$$

where:

- A = gross erosion rate
- R = rainfall
- K = soil erodibility
- L = length and steepness of slope
- C = cover
- P = soil conservation practice

With all other factors being held constant (R, K, LS, and P) and assigning a “C” factor of 1.0 to the baseline, bare soil condition, Table 3.4 provides a mathematical interpretation of relative “C” values for each product tested:

Table 3.4
Relative “C” Factors for Products

Treatment	Relative “C” Factor
Bare soil (control)	1.00
Soil Sement™	0.47

Relative “C” factors based on test conditions, i.e. 2H:1V slope, clayey sand (SC) soil, 10-year storm, 8 meter (26 feet) test bed length, uniform bed preparation and material installation procedures.

Figure 3.5 and Figure 3.6 provide relative comparisons of sediment weights and runoff volumes for each Soil Sement™ treated slope condition. When compared to the untreated bare soil condition, the data illustrates that the use of Soil Sement™:

- Reduced erosion and sediment delivery by an average of 53% for three replicate storms
- Reduced runoff by an average of 16% for three consecutive storms

Figure 3.5
Relative Sediment Weights for a 10-year Storm Event
on a Soil Sement™ Application

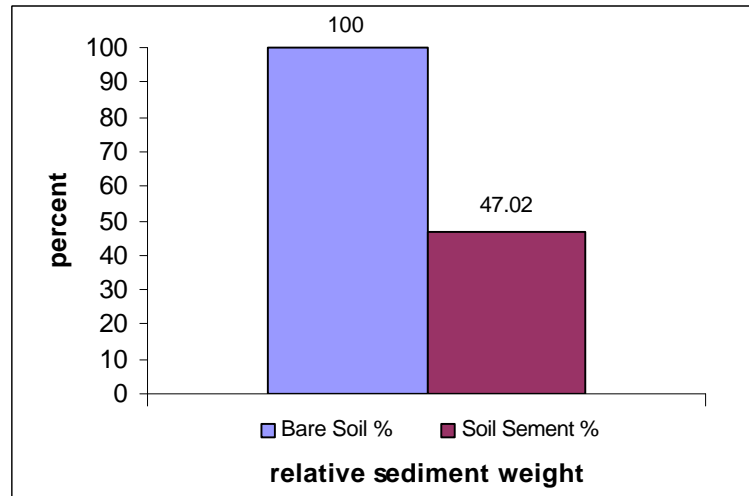


Figure 3.6
Relative Runoff Percentage for a 10-year Storm Event
On a Soil Sement™ Application

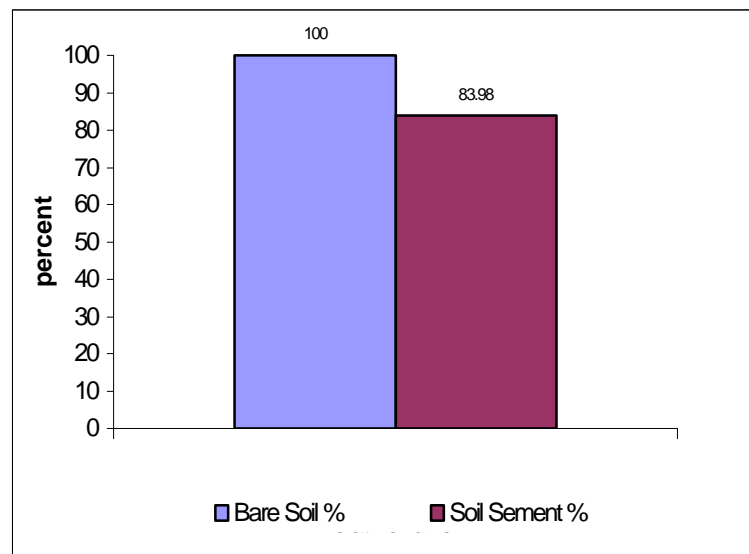


Figure 3.7
Relative Sediment Weights for 3 Consecutive 10-year Storm Events
On a Soil Sement™ Application

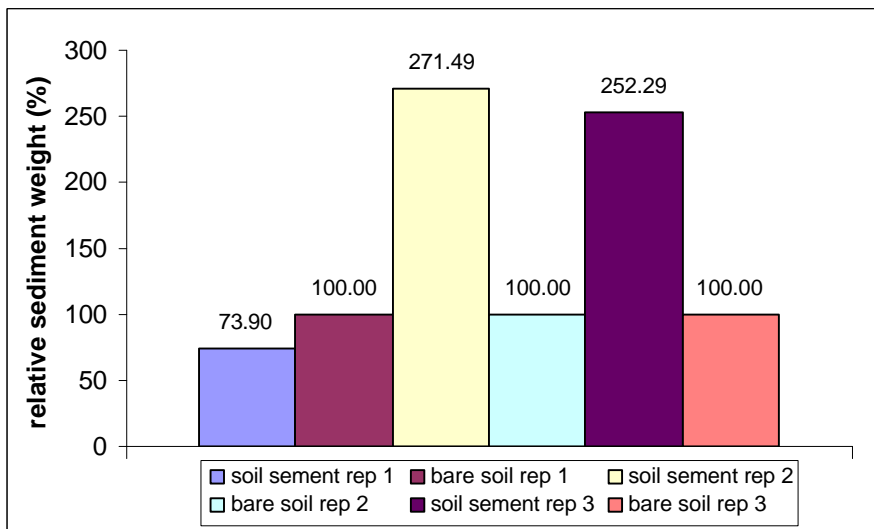
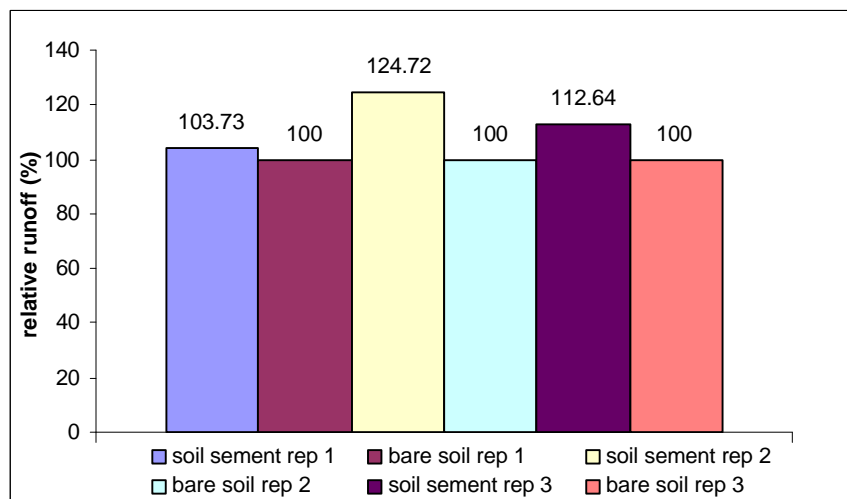


Figure 3.8
Relative Runoff Percentage for 3 Consecutive 10-year Storm Events
On a Soil Sement™ Application



Figures 3.9 through 3.12 illustrate the cumulative sediment delivery and runoff over the duration of the test (1 hour and 30 minutes).

Figure 3.9
Cumulative Sediment Delivery for
Soil Sement™ vs. Bare Soil Over Time

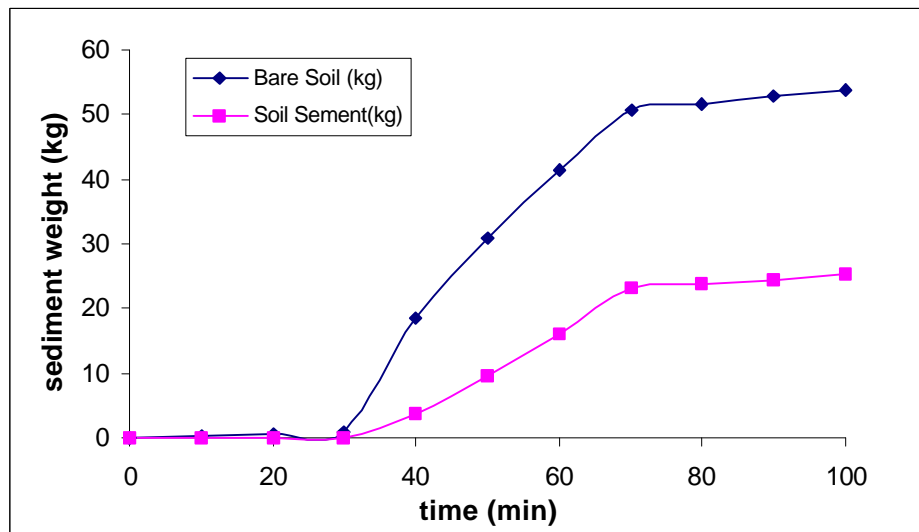


Figure 3.10
Cumulative Runoff for
Soil Sement™ vs. Bare Soil Over Time

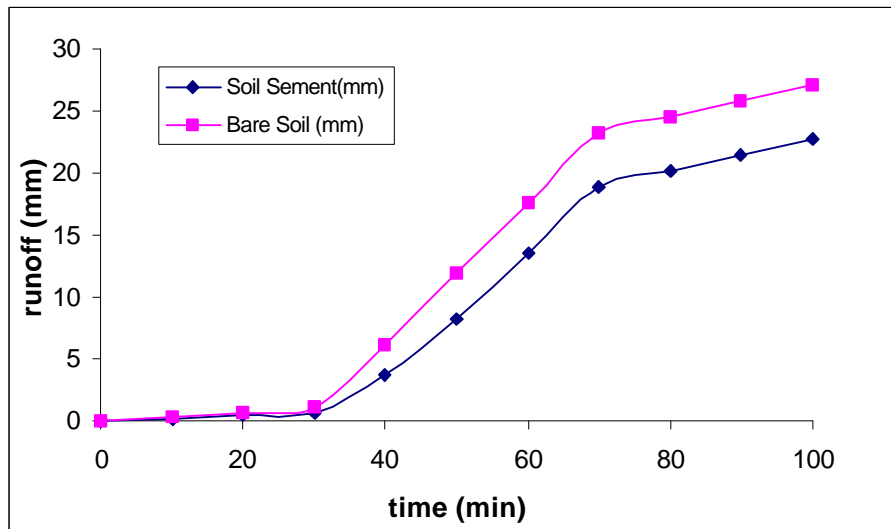


Figure 3.11
Cumulative Sediment Delivery for Three Consecutive
Soil Sement™ Applications vs. Bare Soil Over Time

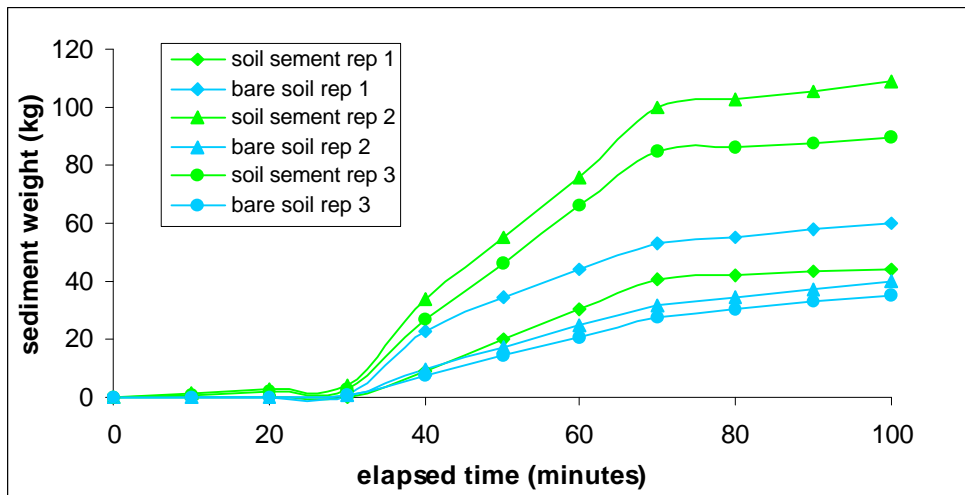
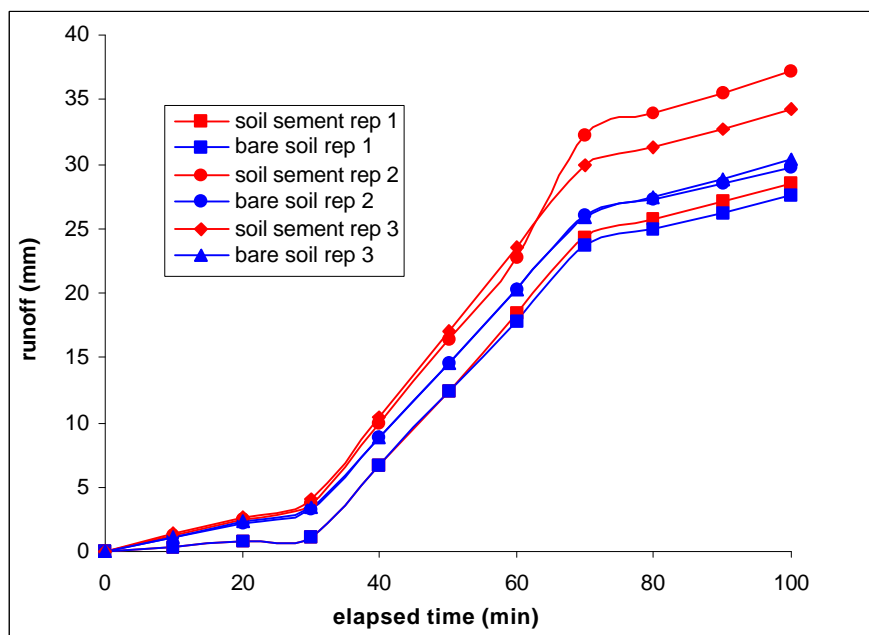


Figure 3.12
Cumulative Runoff for Three Consecutive
Soil Sement™ Applications vs. Bare Soil Over Time



4.0 CONCLUSIONS

The data from this series of tests appear to support the use of Soil Sement™ to reduce soil erosion and off-site delivery of sediment from steep slopes. A reduction of 53% in off-site sediment delivery is an acceptable level of performance on many sites, particularly when the Soil Sement™ practice complements permanent vegetation establishment techniques such as seeding or inter-planting with trees or shrubs.

The performance level of Soil Sement™ is consistent with previous studies conducted on similar products at the Utah State University Water Research Laboratory, Texas Transportation Institute, and numerous manufacturer-sponsored evaluations. Erosion control effectiveness of this magnitude appears to support the current use and specification of these types of products on critical slopes, particularly in the Southern California where soils are similar to those used at the SDSU laboratory.

Figures 3.8 and 3.9 seem to support a conclusion that once saturated, soils treated with Soil Sement™ appear to erode and release water at a steady rate, particularly in the heavy portions of a storm event. The same can be said for the bare soil control plots and this characteristic can, in some cases, be considered as beneficial from a slope stability standpoint. These results are consistent with previous testing of various soil stabilizing materials and methods at the SDSU Soil Erosion Research Laboratory.

APPENDIX A: Compaction of Soil Within the Test Bed

Compaction Procedures:

The placement and preparation of soil in the test bed can be divided into two distinct activities: 1) the initial “filling” of the test bed with a base layer of compacted soil 30-40 cm (12-16 inches) in depth, and 2) the creation of a second 10 cm (4 inches) “testing” layer of soil on top of the fill layer.

1) The “fill layer” of soil is placed in the bed in 10 cm (4 inches) lifts. Each lift is moistened to optimum moisture content as determined by an initial series of Modified Proctor tests (ASTM D1557) for the soil being evaluated. A mechanical wacker is used to compact each lift. Following compaction, eight randomly positioned sand cone tests are performed (ASTM D1556) to verify 95% relative compaction of the fill layer.

2) After placement of the fill layer and compaction as described, the top 10 cm (4 inches) of compacted soil is loosened using a rotor-tiller. After tilling, the soil is then re-compacted by hand using an 20 cm x 20 cm (8 inch x 8 inch) hand tamp weighing 5 kg (11 pounds). Following hand-tamping, the soil is lightly raked perpendicular to the length of the test plot and is considered ready for testing.

Following each rainfall simulation test, the eroded soil is removed to a depth of 5-10 cm (2-4 inches) depending on saturation and replaced with new untested soil from storage bins located inside the laboratory. The rotor-tilling and hand compaction steps are then repeated in preparation for the next test.

Sand Cone Testing Procedures (ASTM D1556):

1. Prepare a level surface in the fill and dig a cylindrical hole about 5in. (125 mm) in diameter and about 5in. (125 mm) deep. Save all of the soil that comes out of the hole and determine its weight.
2. Fill the sand cone apparatus with a special free-flowing SP sand, of a known density, similar to that found in an hourglass. Then determine the weight of the cone and the sand.
3. Place the sand cone over the hole. Then open the valve and allow the sand to fill the hole and the cone.
4. Close the valve, remove the sand cone from the hole, and determine its new weight.
5. Through comparing the weight of the sand used in the test with the weight of the soil removed from the hole the density of the soil can be determined.

Nuclear Density Testing is performed in accordance with **ASTM D2922**.