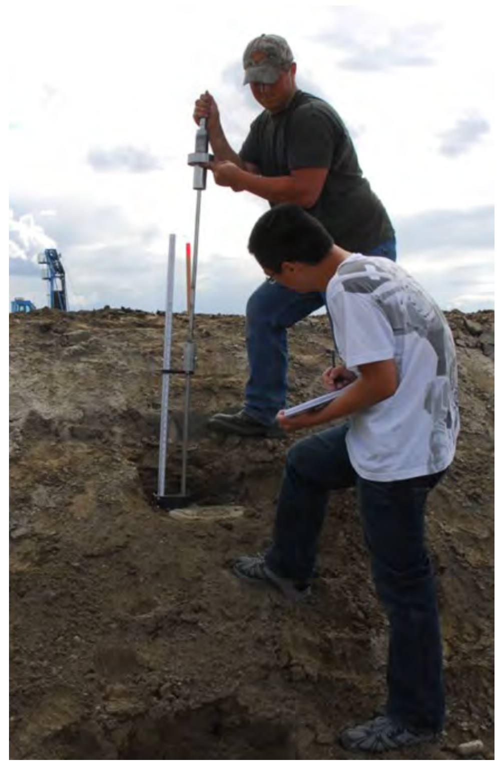
Alaska Department of Transportation & Public Facilities
Alaska University Transportation Center

Stabilization of Erodible Slopes with Geofibers and Nontraditional Liquid Additives



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13. ABSTRACT (Maximum 200 words)

Instability of erodible slopes due to extreme climate events and of permafrost slopes due degradation and thawing is a significant engineering problem for northern transportation infrastructure. Engineers continually look for mitigation alternatives to stabilize erodible slopes and reduce thaw instability and related hazards in permafrost areas. Traditional stabilization techniques tend to be costly as they require specialized skills and equipment to ensure adequate performance. Additionally, the effectiveness of traditional slope stabilization methods becomes limited in cold climatic conditions. Recently, geofibers and synthetic fluid have been used to improve very loose sandy soils. The projects propose is to conduct a large-scale field investigation to study the feasibility of stabilizing erodible and thawing permafrost slopes with geofibers and synthetic fluid. The proposed research will greatly help minimize the problems and risks posed by thawing permafrost slopes instability in cold regions. The outcome of this research will be useful in ensuring a reliable, safe and economic design. The followings are expected to be accomplished: (1) large-scale testing of the proposed technology on an in-situ slope, 2) development of design guidelines for producing plans and specifications for geofiber/synthetic fluid reinforced slopes, 3) a guidance manual for construction installation and maintenance of the constructed slope

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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Acknowledgment

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Special thanks need to be made to Dr. Thomas Ravens and Samuel McAlpine at the University of Alaska Anchorage. Dr. Ravens provided the flume and methodology to conduct the critical shear stress testing discussed in this research. Samuel McAlpine deserves thanks for repairing the flume and providing help while work was conducted in Anchorage.

Executive Summary

The original proposal called for construction of an embankment with five test sections, each containing a different combination of treatment methods. These treatments included:

- 6% water + 0.5% geofibers + 4% EnviroKleen®
- 6% water + 0.5% geofibers + 1.5% Soil-Sement®
- 6% water + 2% Soil-Sement
- 0.5% geofibers only
- A control section

The soil used in these tests was sandy silt which is known to be highly erodible.

The objective was to provide treatments that would limit erosion until perennial grasses were rooted. To help evaluate the effectiveness of these treatments, several measurements were taken. These measurements included using the Field California Bearing Ratio (CBR), a Humboldt GeoGauge™ (soil stiffness), and a Dynamic Cone Penetrometer (DCP). Measurements were taken periodically until the embankment surface froze. In addition to field tests, photographic documentation was collected.

The bearing capacity results collected in the initial phase of the research proved to be ineffective in determining which of the treatments were most effective. To determine the effect of the treatment, additional techniques to validate performance were added to the study. A three-pronged approach was adopted to evaluate treatments. The first feature in the new study plan used the University of Alaska Fairbanks (UAF) School of Natural Resources to evaluate erosion at the field site, and determine soil properties associated with the treatments. These methods included installation of a silt fence at the bottom of each test strip. The silt fence was used to collect the runoff material and measure the total lost material. Soil and plant samples were collected and subjected to chemical and physical property tests. A plant survey determined the plant coverage for each treatment section. The results showed that all treatments had a vegetation coverage of >92% for the treated area except EnviroKleen which only had 29% coverage. No measurable amount of sediment collected following each rain event at the bottom of the field site even with the low vegetation coverage of the EnviroKleen treatment, indicating that the additive can effectively hold soil from erosion. The soil analysis indicated that both EnviroKleen and Soil-Sement can reduce soil negative

surface charge. However, this reduction was achieved differently by each additive. For EnviroKleen, the surface charge reduction was achieved through altering soil solution chemistry. But for Soil-Sement, it was through altering soil solid phase. Based on the results, possible erosion control mechanisms for the two additives were proposed.

The second feature of the adjusted study plan involved developing a methodology to determine critical shear stress for treated and untreated soils using a Sedflume apparatus. Critical shear stress is defined as the shear stress at which a small, but accurately measurable rate of erosion occurs. The Sedflume consists of a rectangular flume with a space cut out of the bottom where a soil sample can be placed. The critical shear stress was determined using a relationship between the flow rate of the water pulled over the sample and the geometry of the soil sample. The results of testing showed that for sandy silt (ML), the addition of geofibers in all cases caused a decrease in the critical shear stress when compared with the untreated soil. The soil treated with only Soil-Sement received a modest increase in critical shear stress.

The third feature of the adjusted study plan was to build a laboratory-scale model of the embankment to simulate an extreme erosion environment. Tests using this model were used to evaluate erosion potential of the treated soils prior to the onset of grass growth. The laboratory scale model was built to one-third scale of the embankment at the field site. A uniform flow of water was placed over the sample, and the runoff material was collected and measured. The results show that some improvement was gained with all the samples that contained geofibers.

The collection of runoff material was inconclusive because no material eroded from any of the slopes. The critical shear stress determination showed that treatments reduced the shear stress of samples. This could be attributed to geofibers being pulled out of the sample and reducing the density of the sample, which results in increased erosion. The laboratory erosion slope showed that geofibers increased the erosion resistance of the sandy silt tested. The greatest overall reduction in erosion was achieved through the addition of 2% Soil-Sement and 0.5% geofibers.

Based on these tests, the use of geofibers and polymer soil stabilizers such as Soil-Sement can hold slopes in sandy silt until grass can be established. However Soil-Sement alone also proved effective. Because grass did not grow on the site treated with EnviroKleen, that product would not be recommended.

CHAPTER I

GENERAL

Interior Alaska has large amounts of fine-grained soils, typically used as surfacing for embankments. However, fine-grained soils are very erodible (State of Alaska 2005). These fine-grained soils often erode until the seeded grass has established roots. Erosion of surface material affects the stability of the embankment and causes drainage issues. Typical stabilization techniques can be expensive due to the specialized skills and equipment needed to ensure adequate performance. The use of geofibers and nontraditional liquid additives has been shown to provide stabilization of fine-grained soils. These findings have been reported by several investigators including Hazirbaba and Gullu (2010) and Collins (2011).

In Alaska, road construction often extends into areas of permafrost. Removal of vegetation and the organic layer on the soil surface can cause thawing of the permafrost layer, resulting in collapse of a roadside. The surface soil organic layer insulates and thereby reduces heat transfer from solar radiation due to its low bulk density and high porosity when dry and its high heat capacity (because of water) when wet (O'Donnell et al. 2009). Vegetation shields the soil surface from direct solar radiation and thus preserves the permafrost layer from thawing. In addition, the plant roots from vegetation in the active layer hold soil together, which helps prevent erosion.

Stabilization of soil on newly constructed roadsides has been studied in several states. Using bioengineer technology, Lewis et al. (2001) demonstrated that bioengineering is an effective way to stabilize an erodible roadside. As an aid to structural construction (e.g., live crib wall/willow wall, branch packing, bender board fencing), the establishment of vegetation (both canopy and roots) stabilizes the erodible roadside immediately after construction, which becomes stronger as the vegetation grows larger.

For soil erosion at a construction site, the ultimate goal is to have vegetation established even when geofibers and additives are needed. With this goal, soil properties, especially the chemical properties after these soil treatments, need to be known. One of the objectives of this research was to investigate if chemical and biological properties were changed in an in situ test site with treatments of geofibers or geofibers plus chemical additives.

A research plan was developed to determine if using geofibers and nontraditional liquid additives could protect slopes containing fine-grained soils. A test slope was constructed and treated with different combinations of geofibers and nontraditional liquid additives. This site was monitored using a silt fence to collect eroded soil, and treated samples were collected to provide analysis of soil properties related to the growth of grass.

The critical shear stress of the treated soils was determined using a flume developed by Ravens and Sindelar (2008). The critical shear stress of each treated material was compared with the original untreated sample to analyze the microscale mechanics of the treatments.

Finally, a laboratory slope constructed at one-third-scale size was constructed to determine the percentage of material loss for separate treatment configurations.

PROBLEM STATEMENT

Embankment top soil is easily erodible until grass grows. Traditional stabilization techniques are expensive due to the specialized skills and equipment needed to ensure adequate performance.

OBJECTIVE

The overall objective of this project is to evaluate several combinations of geofibers and nontraditional liquid additives, and determine if they are useful as erosion-control products. The treatments were:

- 0.5% (by dry soil weight) geofibers
- 2% Soil-Sement®
- 2% Soil-Sement and 0.5% geofibers
- 4% EnviroKleen® and 0.5% geofibers

RESEARCH METHODOLOGY

The research was divided into the following tasks:

Task 1: Literature review

A survey of existing literature on current methods of evaluating erosion resistance of treated soils and critical shear stress of soils was conducted. This literature review was used to evaluate testing methodology and help with the evaluation of results. This task is presented in Chapter II.

Task 2: Experimental design

A three-pronged experimental approach was developed to evaluate the effectiveness of soil treated with (1) Soil-Sement, (2) Soil-Sement and Geofibers, (3) Geofibers, and (4) EnviroKleen and Geofibers. Along with these four treatments, there were two control sections. Construction and monitoring of a field site was used to monitor the treatment methods in natural conditions. A laboratory flume was used to compare the critical shear stress of treated soils with untreated soils. Finally, a one-third-scale slope was constructed to compare soil loss of treated soils with untreated soils. This task is presented in Chapter III. Testing conducted by the UAF School of Natural Resources is presented in Chapter IV.

Task 5: Data processing and analyses

The data and field performance information was processed and analyzed. Analysis of variance was conducted among treatments. Least significant differences (LSD) at 5% probability was used to compare treatment mean differences. Recommendations for the most effective treatment type are based on the analysis.

Task 6: Project summary and recommendations

Based on the above tasks, a final recommendation is made based on results and analysis. A plan for further study is included based on the results of the project. This task is presented in Chapter VI.

CHAPTER II

LITERATURE REVIEW

Erosion occurs when soil materials detach and are transported from one location and deposited in another due to rainfall and runoff (State of Alaska 2005). The erosion potential of any area is determined by four principal factors: soil characteristics, vegetative cover, topography, and climate (State of Alaska 2005). Several primary controls slow erosion, including vegetative cover, special grading methods, and diversion of surface runoff (State of Alaska 2005). In addition, use of chemical additives in soil can also prevent soil erosion.

Based on the literature, it appears that there is no standard method for measuring the performance of erosion-control products. Several methods have been used by various researchers, but no consensus has been reached on which method produces the most reliable results.

Ament (2011) evaluated a method of erosion control called steep cut slope composting. His evaluation methods included:

- Randomized quadrants used to measure the percentage of live vegetation cover, compost, plant litter, rock, and bare ground.
- Ocular estimation used for early measurement of compost to evaluate retention after plot construction and before vegetation growth in the first year.
- Erosion measurement using the Bureau of Land Management (BLM) numerical scoring system.
- Photographs of each plot.

Wan and Fell (2004) thought the two most relevant test methods for slope erosion purposes are flume tests and rotation cylinder tests. The flume test measures erosion of soils in channels/canals. The rotating cylinder test, which determines the critical shear stress and erosion rate, can be used to study the relationship between erosion characteristics and fundamental soil properties.

There are many examples of researchers using soil stabilization techniques to prevent erosion. Soil stabilization usually consists of mechanical or chemical methods to reduce the amount of erosion. There are no examples in the literature of researchers using mechanical and chemical stabilization to prevent erosion.

Orts et al. (2001) used biopolymer additives to reduce erosion. The authors used a lab-scale furrow test to compare several additives. The findings showed that starch xanthate, cellulose xanthate, and acid hydrolyzed cellulose microfibrils have the ability to reduce soil runoff significantly.

Foltz and Copland (2009) used wood shreds to minimize erosion in construction sites. The wood shreds were spread on a laboratory slope and subjected to simulated rainfall. Foltz and Copland find that a 50% coverage rate is optimal; however, a more appropriate coverage rate could be determined based on known conditions at the site of interest.

Liu et al. (2011) treated a clay material with organic polymer soil stabilizer. A surface erosion test was performed using simulated rainfall. The organic polymer was sprayed on the surface of the test slope and allowed to dry for 48 hours. Tests showed that the organic polymer was effective for improving the erosion resistance of slope topsoil.

Sariosseiri et al. (2011) used Portland cement and cement kiln dust (CKD) to stabilize silty sand and silt materials. Sariosseiri et al. looked at the effectiveness of using the combination on a slope for erosion control. Cement kiln dust in amounts of 5%, 10%, and 15% by dry weight was mixed with soil in field and lab conditions. A rainfall simulator was used in the laboratory. Soil loss results in both the lab and field showed that increasing amounts of CKD led to a decrease in soil loss. The samples mixed with 10% and 15% gave the highest reduction in soil loss.

Ekwue et al. (2011) used Soiltac® to treat clay soil slopes (Soiltac is referenced in Collins 2011, and is similar in nature to Soil-Sement®, used in this study). A specialized lab slope was used to measure the effectiveness of Soiltac as an erosion-control method. The results of testing showed that soils treated with Soiltac performed better than untreated soils.

No literature was found regarding measurement of the critical shear stress of soils treated with erosion-control methods. There are several examples of methods used to determine the critical shear stress of fined-grained soils.

Kamphuis and Hall (1983) observed that critical shear stress increased as compressive strength, vane shear strength, plasticity index, clay content, and consolidation pressure increased. Kamphuis and Hall also observed that once the critical shear stress for a soil is reached, erosion progresses immediately, and any alteration to the surface of the sample causes increased erosion due to the change in roughness.

Mallison (2008) compared an in situ submerged jet testing device with a laboratory flume to estimate erosion characteristics of cohesive soil. The flume, built by Mallison, did not have sufficient power to cause erosion on the surface of the soil.

Ravens and Sindelar (2008) evaluated the difference in test section lengths in sediment erodibility measures. Ravens and Sindelar concluded that the difference in length of the test sections is negligible. A smaller, more economical test section was used to determine critical shear stress in their study.

CHAPTER III

EXPERIMENTAL DETAILS

Overview

This chapter provides details of the experiments used in this research. Details such as products used and standards followed are provided, and the methodology behind the test method is described.

Materials

The soil used in this research is sandy silt that was collected at Great Northwest, Inc. in Fairbanks, Alaska (64.8378° N, 147.7164° W). The embankment was constructed using sandy silt (ML), which is shown in Figure 3-1. The soil was extracted from the pond shown in Figure 3-2. After being extracted from the pond, the soil was stockpiled to drain the free water.

Fig. 3-1: Sandy silt shown in the field

Fig. 3-2: Source of soil used for embankment construction

Sieve and hydrometer analysis was performed in accordance with ASTM D422. The grain-size distribution is presented as Figure 3-3. The measured specific gravity of the soil was 2.76 according to ASTM D854. The optimum moisture content was determined according to ASTM D1557. The moisture density curve is presented as Figure 3-4.

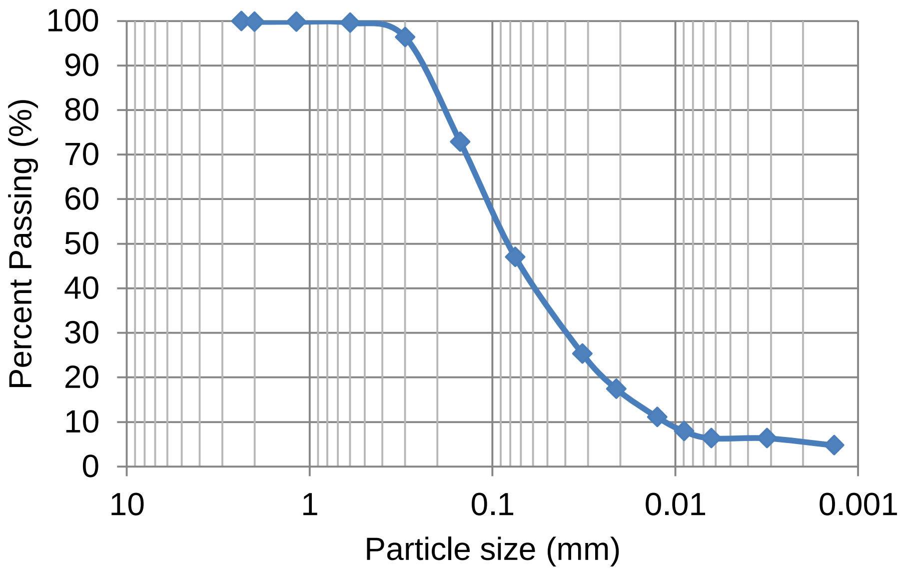

Fig. 3-3: Particle-size distribution for sandy silt

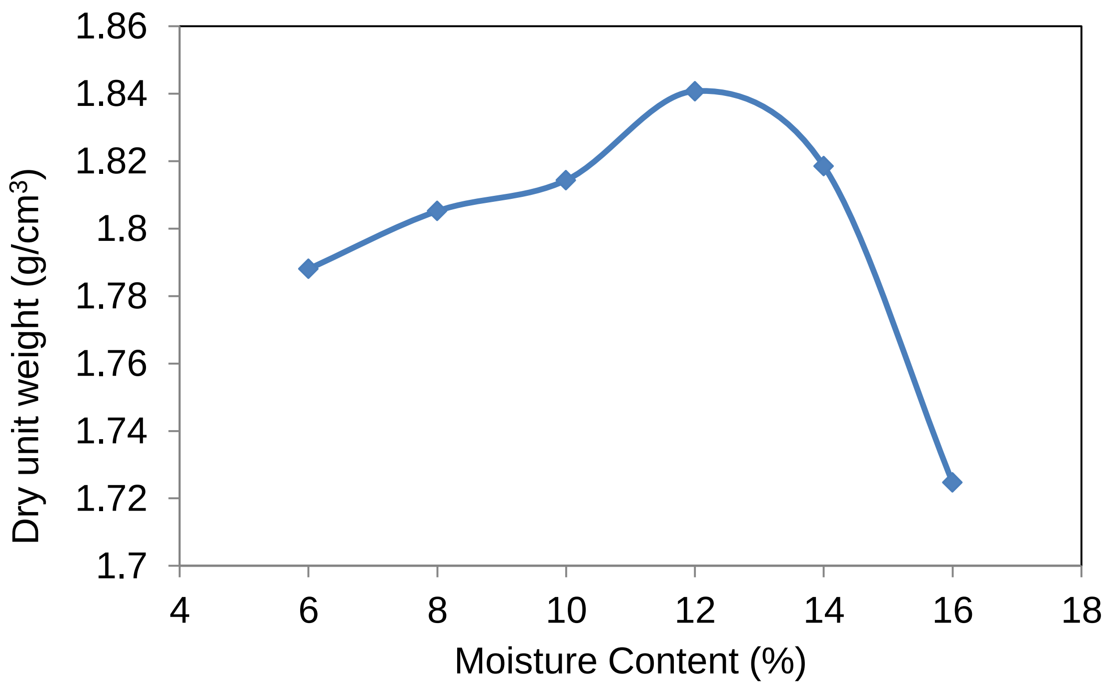

Fig. 3-4: Moisture density curve for sandy silt

The geofibers used in this project were 70 mm long and fibrillated.

The nontraditional soil stabilization fluids used in this research included EnviroKleen® and Soil-Sement®, two products produced by Midwest Industrial Supply, Inc. Soil-Sement is a polymer emulsion-type stabilizer that increases cohesion of treated soils. EnviroKleen is classified as a synthetic fluid; its main function is to increase density and cohesion of treated soils. Geofibers and the nontraditional liquid additives are described in more detail by Collins (2011).

Construction of the Field Site

An idealized picture of the field site with treatment sections is presented as Figure 3-5. To be consistent with real-world road embankment, the slope used for the trapezoid-shaped cross section was 1:1.5. This picture shows the width of each test section, which was 12 feet. The width of the test sections was chosen to match the width of the bulldozer blade used in construction. The embankment measured 6 feet in height. The top of the embankment measured 15.6 feet across; the base measured 33.6 feet across. A picture of the embankment prior to installation of the treated sections is presented as Figure 3-6. Six test strips were prepared. The test strips consisted of control sections and treatments, as follows:

- Two control sections on each end of the embankment
- 0.5% (by dry soil weight) geofibers
- 2% Soil-Sement
- 2% Soil-Sement and 0.5% geofibers
- 4% EnviroKleen and 0.5% geofibers

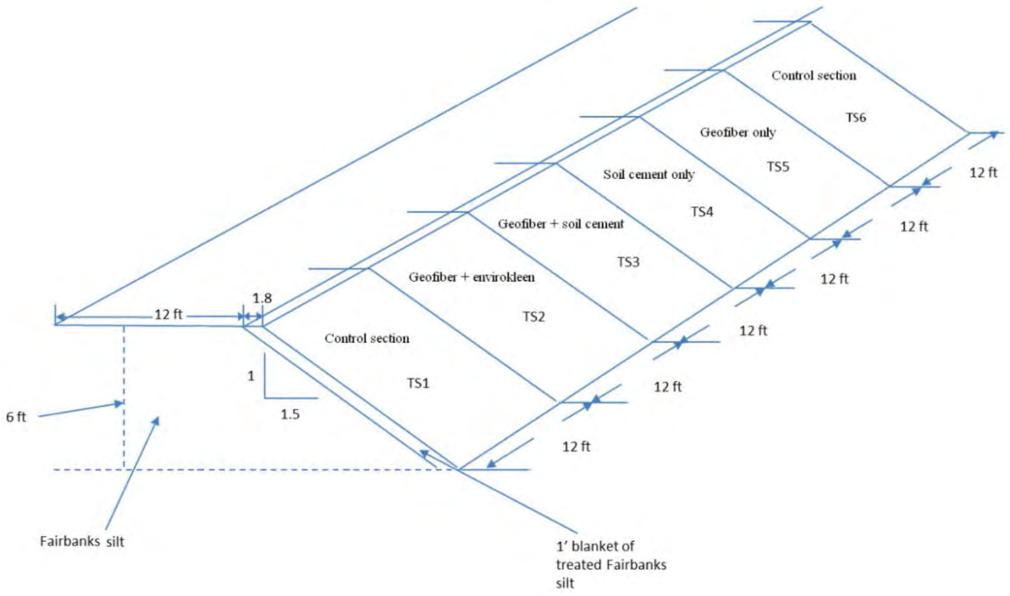

Fig. 3-5: Idealize image of field site (TS1=0.5% Geofibers + 4% EnviroKleen, TS2=0.5% Geofibers + 1.5% Soil-Sement, TS3=2% Soil-Sement, TS4= 0.5% Geofibers, and TS5=Control.)

Fig. 3-6: Embankment prior to installation of test strips

Test sections were prepared in the following manner:

- Before treatment, on July 29, 2011, the south slope was recompacted and labled as shown in Figure 3-7.

- Figure 3-8 is a picture of the north side of the embankment without recompaction; rills from erosion can easily be seen in this figure.
- Soil was stockpiled at the base of the slope, and fluid and geofibers were added based on the estimated weight of the soil. (A picture of the treatments being added to the stockpiled soils is presented in Figures 3-9 and 3-10.)
- The soil was blended with a rototiller until the treatment appeared to be uniformly blended. (The rototiller used on the soil is shown in Figure 3-11.)
- The treated soil was pushed onto the side of the embankment using a loader (pictured in Figure 3-12.)
- A bulldozer was driven over the side of the embankment to provide compaction (pictured in Figure 3-13).
- The site was then hydroseeded using a blend typical for Fairbanks (the hydroseeded slope is shown in Figure 3-14. The hydroseed blend used was Actared red creeping fescue (*Festuca rubra L.*) (45%), Park Kentucky blue grass (*Poa praensis L.*) (45%), and annual ryegrass (*Lolium multiforum L.*) (10%). The hydroseeding mixture contained chemical fertilizer (8(N)-32(P_2O_5)-16(K_2O)) at 488 kg/ha (10 lb/1000 ft^2) and EcoFiber Plus at 4878 kg/ha (100 lb/1000 ft^2).

Fig. 3-7: Embankment compaction before treatment (south slope)

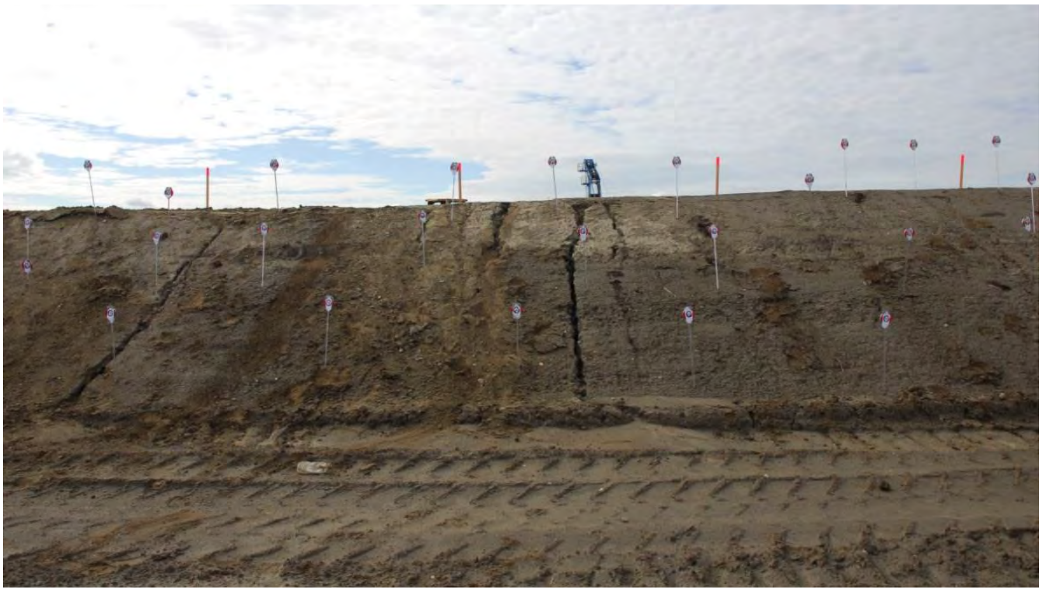

Fig. 3-8: Embankment before treatment (north slope)

Fig. 3-9: Addition of liquid additive

Fig. 3-10: Geofibers added to stockpiled soil

Fig. 3-11: Rototiller blending geofibers with stockpiled soils

Fig. 3-12: Treated soil pushed onto side of slope

Fig. 3-13: Bulldozer running over side of slope to provide compaction

Fig. 3-14: Slope after hydroseeding

Initial Monitoring of Field Site

The original plan to measure the effectiveness of erosion control involved measuring bearing capacity and stiffness using Field California Bearing Ratio (CBR) testing, a GeoGauge™, and a Dynamic Cone Penetrometer (DCP).

Field CBR testing was abandoned because it was not practical to perform the test on the side of an embankment. The DCP and GeoGauge measurements were taken by shoveling out a flat section on the side of the slope and performing the tests. Pictures of GeoGauge and DCP testing are shown in Figures 3-15 and 3-16, respectively.

Based on a study conducted by the Louisiana Department of Transportation (Midwest standard designation H-4140-01), the GeoGauge can be used as an alternative for in situ CBR, following the procedure produced by Midwest Industrial Supply, Inc. All stiffness values were converted to the CBR for this study. To get an accurate measure of stiffness using the GeoGauge, a flat section was carved into the side of the slope using a shovel.

In a similar manner to the GeoGauge, DCP measurements can be used to determine CBR following ASTM 6951. Therefore, all DCP measurements were converted and reported as CBR values. The DCP measurements were taken on the same carved-out section of slope used to take the GeoGauge measurements.

Measurements of stiffness and DCP were taken at the top, middle, and bottom of each test section.

Fig. 3-15: GeoGauge testing at the field site

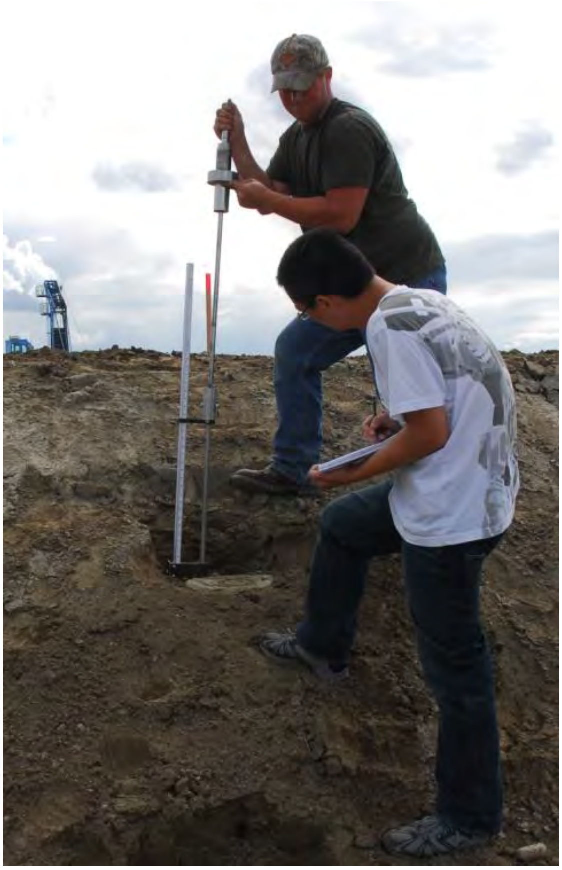

Fig. 3-16: DCP testing at the field site

Installation of Silt Fence

One year after the construction of the embankment, a silt fence was installed at the field site to collect runoff material. A continuous fence with stakes pre-attached was installed at the bottom of the slope. The silt fence was placed in a “V” shape. For each slope, the ends were placed 36 inches above the base of the slope, with the middle placed at the base of the slope. To install the fence, a trench was dug using a flat-headed shovel and the claw end of a masonry hammer. The trench dug was 6 inches deep and approximately 6 inches wide to ensure adequate placement of the silt fence. Each side of the silt fence was backfilled and compacted to hold it firmly in place. An image of the silt fence is presented as Figure 3-17; the image shows the clearly visible “V” shape. Fluorescent orange dots were painted at the base of the silt fence on the upslope side. Runoff material will cover the dots, making it easy to identify and remove. The dots are shown in Figure 3-18.

Fig. 3-17: Installed silt fence

Fig. 3-18: Dots painted below base of silt fence allow for identification of runoff material from the slope

Determination of Critical Shear Stress

The critical shear stress was determined by a method developed by Ravens and Gschwend (1999) and with a flume described by Ravens and Sindelar (2008). A diagram of the flume is presented in Figure 3-19. Ravens and Sindelar (2008) compared two different-sized test sections; the smaller of the test sections was used (0.15 m long × 0.13 m wide). The sample depth used was 0.06 m. An image of the flume is shown in the appendix (Fig. A-27). The sample is shown near the center of the flume bolted in. The white pipe above the flume carries return water after it has run over the sample. The test samples were prepared in the following manner:

- The soil was oven-dried, and all material retained on a #4 sieve was removed.
- Water was added to the dry soil to bring the soil to the desired moisture content. Water was blended with Soil-Sement before being added to the dry soil. EnviroKleen was added after the water was blended with the dry soil. Geofibers were added after the soil was wetted.
- Soil was placed in the mold and compacted by tamping.
- The top of the sample was smoothed.
- The sample was placed in the flume and water was slowly introduced until air bubbles no longer escaped from the sample.

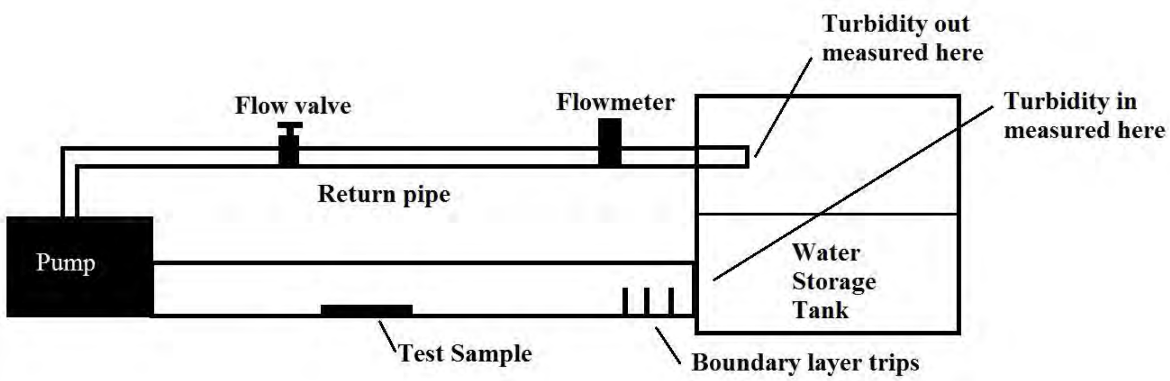

Fig. 3-19: Diagram of flume used for critical shear stress measurement

After the sample was placed in the flume, water was pumped over the sample at increasing flow rates. The flow rate was slowly increased to 10 gpm, and turbidity measurements were started. Turbidity was measured at the inlet to the flume and at the end of the return pipe at 40-second intervals. A small pump was used to pump water from the inlet of the flume to measure turbidity. Water was collected directly from the outlet pipe for the return pipe turbidity measurement. Turbidity measurements were taken for 20 minutes at each flow rate, for a total duration of 2 hours. The flow rate was increased in either 10 or 20 gpm increments depending on the visible amount of erosion occurring. In the appendix, the graphs in Figures A-2 through A-11 show the flow rate used during testing as well as the differential turbidity measured during the test. The differential turbidity was calculated as the turbidity at the flume inlet subtracted from the turbidity at the flume outlet. The graphs also show that at relatively low flow rates there is very little differential turbidity. The differential turbidity does not begin to really increase until the critical shear stress is reached.

Laboratory Slope Testing

To simulate intense erosion prior to the onset of grass growth, a slope was built to match a single treatment section from the field site at one-third scale. The laboratory slope was built using timber with hinges at the bottom to allow the slope to be put in a horizontal position for sample preparation, and then moved to a slope position for the test. The sandy silt (ML) available at the field site was collected and brought back to the laboratory. The soil was passed through a #4 sieve and all material retained was discarded, as it mostly contained wood and other non-soil material. Soil was then dried and placed in buckets in preparation for testing.

Test samples were prepared using the four previously mentioned treatment configurations. Dry soil was placed in a box large enough to contain the total amount of soil that would be used for the test. Water was added to the soil to achieve the desired moisture content. The water was mixed into the sample by hand until homogenous conditions were observed. Liquid additives were added and blended by hand until uniformly mixed into the soil. Geofibers were then added and mixed by hand mimicking rototiller motion to ensure adequate distribution.

The test slope had hinges on one end to allow for compaction and soil placement to take place in a horizontal position. The soil was placed in the box in three layers and compacted using a 15.8 kg tamper. The soil was scarified between layers to ensure uniformity throughout the section. After the prepared soil was placed in the test box, the top of the soil was screened and the remaining material was collected and dried. The remaining soil was subtracted from the weight of the dry soil known to be in the box.

A large box was placed at the bottom end of the slope to collect all of the runoff soil and water from a test. Except for one case, tests were run for 1 minute and 5 seconds. In the one exception, the test was run for only 45 seconds, because a considerable amount of erosion had taken place. The time used for running the test was determined based on several practice tests, allowing significant erosion to take place.

After the elapsed time allowing the soil to erode, the material in the box was moved to a large pan and placed in an oven to measure the mass of the eroded soil. In all cases, the mass of the treatment material (either fibers or nontraditional liquid) was neglected in the measurement of the eroded material. The percent of material loss was calculated as the mass of eroded material divided by the mass of the material placed in the test box.

CHAPTER IV

TESTING CONDUCTED BY SCHOOL OF NATURAL RESOURCES

Experimental Details

Three replicated soil samples were taken on June 4 and on September 1, 2012, from each treatment. Each replicated soil sample was a composite of three subsoil samples. Because of the existence of geofibers, it was difficult to penetrate the surface of the embankment to collect soil samples; therefore, a small shovel was used for soil sampling. During the June soil sampling, two depths of soil samples were taken: 0–15 and 15–30 cm. In September, only 0–15 cm soil samples were taken for assessing the change in soil properties as affected by erosion-control treatments. Soil samples were dried at room temperature, sieved (<2 mm), and saved for chemical analysis.

Plant shoot and root samples were taken by digging a 0.093 m^2 area to a depth that included a majority of the roots. From the area, plant shoots were cut, and plant roots were separated from the soil and washed. Both the plant shoots and plant roots were dried at 65°C for two days, and the dried biomass was weighed. In the treatments where geofibers were used, it was difficult to separate the geofibers from the plant roots. Because geofibers are light in mass, their mass was not taken into consideration when calculating the root biomass. Representative subsamples were taken from plant shoots and roots, which were ground to pass a 2 mm sieve. This sieve was used to retrieve samples to conduct carbon and nitrogen concentration analysis.

Soil total organic carbon (C) and nitrogen (N) were determined with a LECO 1000 analyzer (St. Joseph, MI, USA). Soil pH and electrical conductivity were determined with deionized water with a soil:solution ratio of 1:1. The amount of available nitrogen (NH_4-N + NO_3-N) was extracted with a 2 M KCl solution, followed by the determination with an Alpkem continuous flow analyzer (Pulse Instrumentation, Milwaukee, WI, USA). Soil cation exchange capacity (CEC) was determined by ammonium acetate autoextraction methods at pH 7.0 (Soil Conservation Service, USDA, 1982). Available plant nutrients other than N were extracted using a Mehlich-3 solution (1.5 M NH_4F + 0.1 MEDTA) (Mehlich 1984), and P, K, Ca, Mg, Zn, Cu, Na, and Mn in the extractant were determined with ICP-AES. Soil bulk density was determined in situ gradually by pushing a core (104 mm in diameter × 60 mm in height) into soil. Because of the presence of geofibers, a knife was used to aid penetration of the core into the soil. Soil particle-size distribution was determined using the hydrometer method (Gee and Or 2002). The total C and N in shoots and roots were determined using a LECO 1000 analyzer. Weather data (temperature and precipitation) were collected from January 1 to September 30, 2012. For comparison, weather data were gathered for years 2000 to 2011 from the National Climate Data Center at the NOAA website (www.ncdc.noaa.gov)

Image analysis for plant cover in fall 2011 was evaluated using ImageJ software. The percentage of plant cover was determined using a Color Inspector 3D analysis.

Data for treatment effect were analyzed for ANOVA using a complete randomized design, and a mean comparison was made using Duncan's least significant difference at 5%.

Precipitation in 2012

The average cumulative monthly precipitation for 2012 was slightly below the average for the past 12 years (2000 to 2011) (Fig. 4-1). For daily precipitation, the frequency of above >2 mm/day precipitation in the past 12 years is a high of 92%, most of which was in the month of July in contrast to August (26th) of 2012 (Fig. 4-2). Samples were taken on September 1, after the big rain event in August, yet no sediments were found at the bottom of the hill from each treatment, indicating that with normal rain frequency, all treatments prevent a major erosion event, in particular the EnviroKleen® treatment where little grass was established (Fig. 4-3).

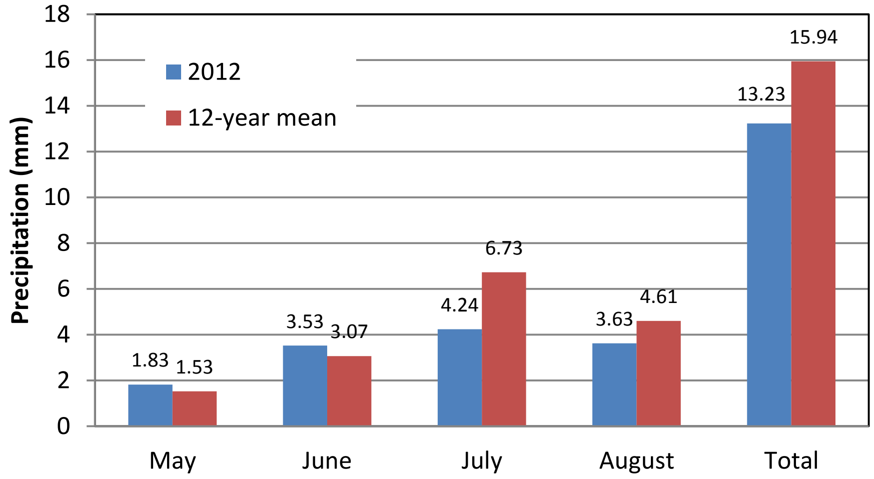

Fig. 4-1: Comparison of monthly (May to August) precipitation in 2012, with average cumulative monthly precipitation from May 2001 to 2011

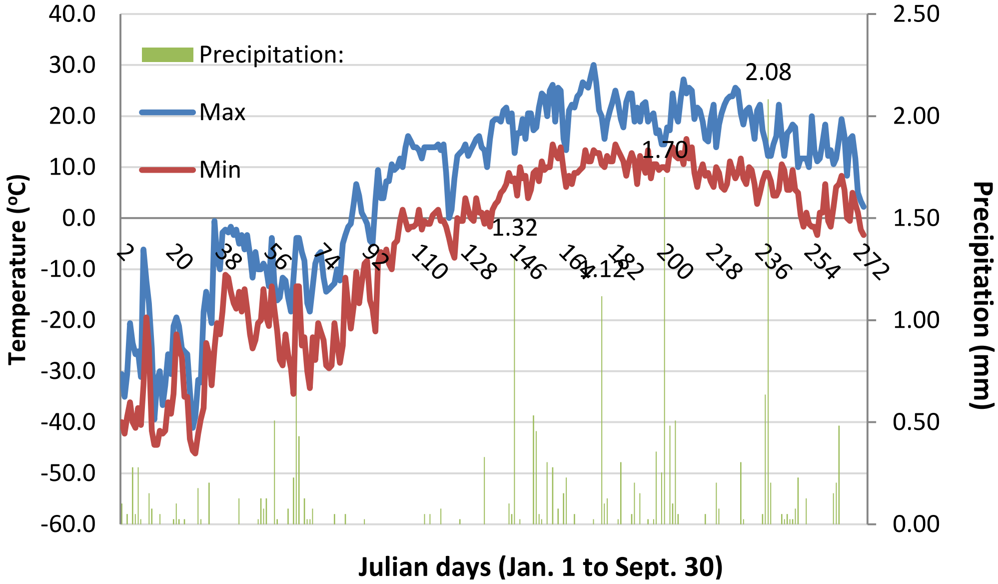

Fig. 4-2: Minimum and maximum temperature and daily precipitation from Jan. 1 to Sept. 30, 2012

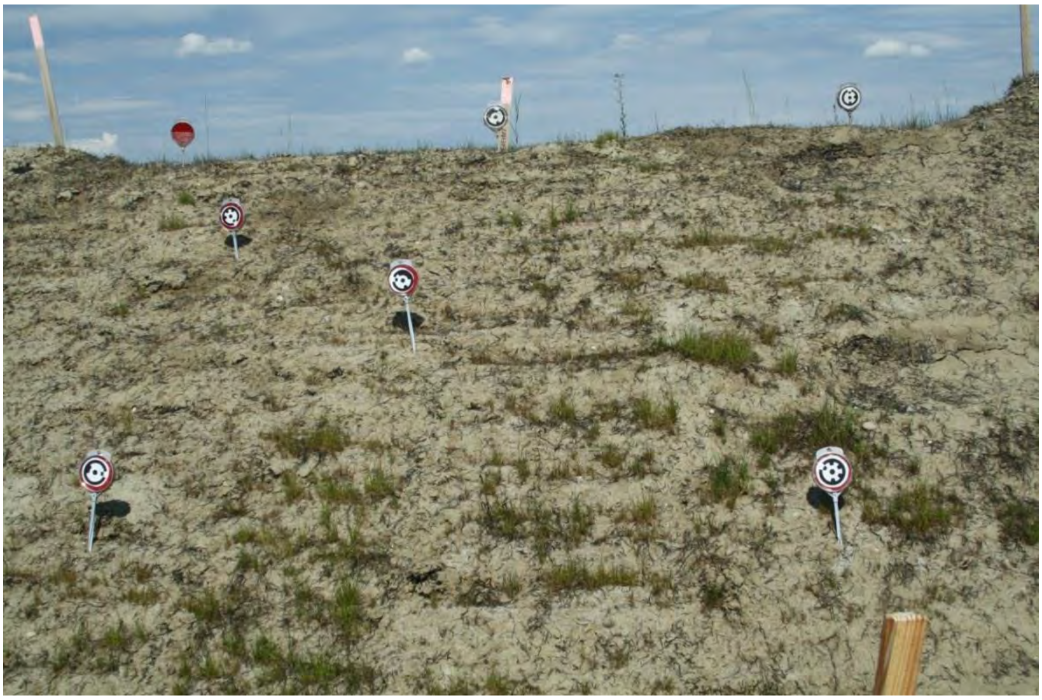

Fig. 4-3: Geofibers + EnviroKleen treatment for erosion control (photo taken June 22, 2012)

Plant Cover and Biomass Production

Seed mixture was planted for each treatment in August 3, 2011. One month after seeding, all test sections indicated relatively good germination and plant appearance including those treated with Geofibers + EnviroKleen (Fig. 4-4), indicating that added materials did not impede seed germination. However, the Geofibers + EnviroKleen treatment appeared to have less plant coverage as compared with other treatments, especially for the lower slope areas (Fig. 4-4). Analysis of Figure 4-4 using ImageJ indicated that the green color in the area of the Geofibers + EnviroKleen treatment occupied <10% in contrast to >50% for the test section treated with Soil-Sement® only (Fig. 4-5). The plant coverage survey for June 1, 2012, showed a distinct difference among treatments, with the lowest coverage from a Geofibers + EnviroKleen treatment and the highest coverage from the control section (Table 4-1). In comparing the plant coverage of the Geofibers + EnviroKleen treatment with its adjacent treatment of Geofibers + Soil-Sement, the difference between the two in plant coverage was not as dramatic in September 2011 as the survey result on June 1, 2012. In the Fairbanks area, grass growth slows in September and stops in October. As such, the lack of grass growth in the treatment of Geofibers + EnviroKleen seemed to occur in spring 2012, rather than in fall 2011.

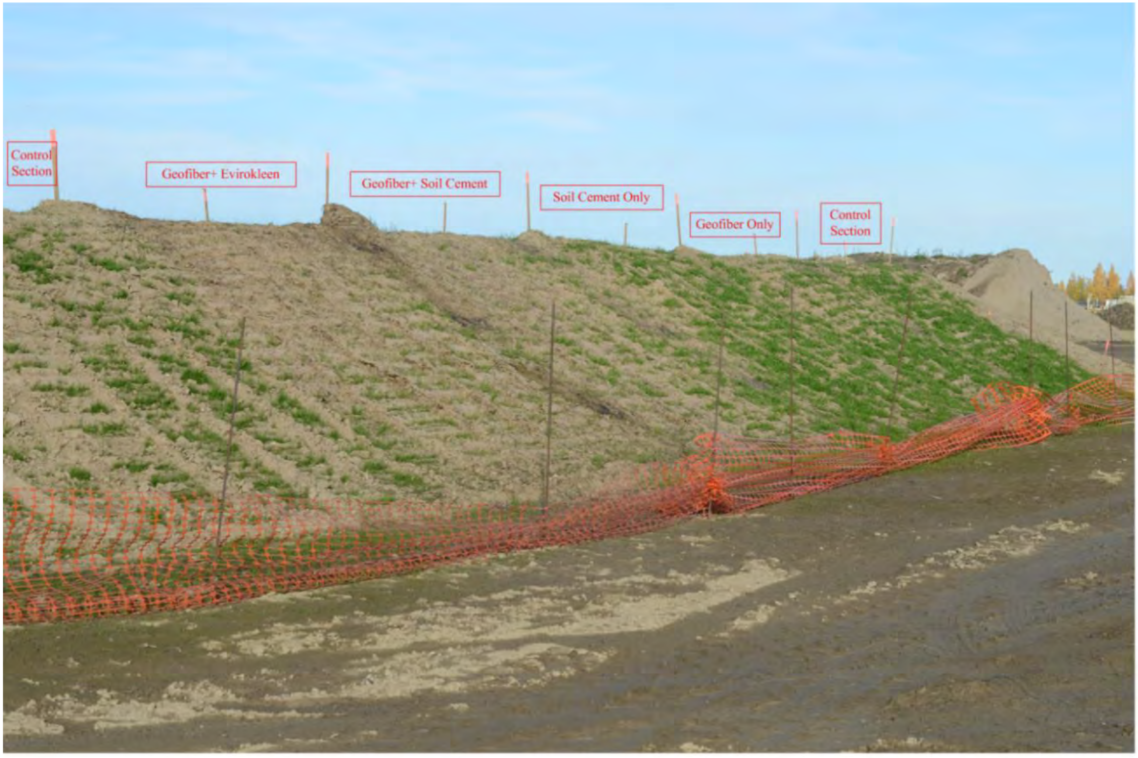

Fig. 4- 1 : Plant coverage for each treatment one month after seeding (date of photo: Sept. 12, 2011).

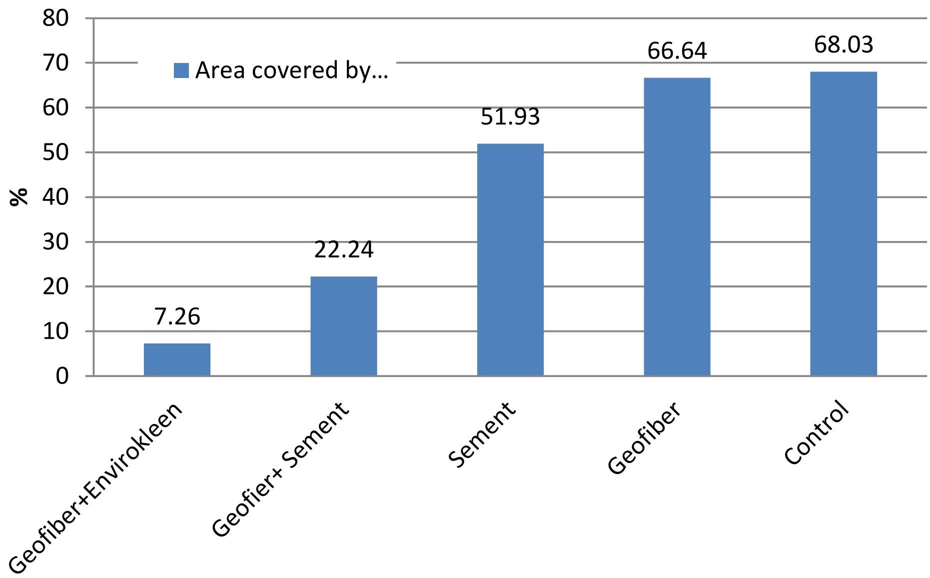

Fig. 4-5: Percentage of area covered by plants from each treatment based on color analysis of Fig. 4-4

Table 4-1: Performance of plants as affected by the erosion-control treatments (GF: Geofiber, EVK: EnviroKleen, SS: Soil-Sement)

Treatment	June 1, 2012		Sept. 1, 2012		Composite sample of plant biomass			Shoot C and N concentration		
	Plant cover	Species	Plant cover	Species	Shoot	Root	Shoot/ root ratio	C	N	C:N ratio
	%		%		kg/m^2			(g/kg)		
GF+ EVK	29a	Fescue	29a	Fescue	0.086	0.392	0.2	22.02	0.54	40.8
GF+ SS	84b	Fescue + Lambsquarters	95b	Fescue	1.299	5.886	0.2	35.36	1.27	27.8
SS	84b	Fescue	95b	Fescue	1.889	3.966	0.5	37.25	1.79	20.8
GF	78c	Fescue + Tansy mustard	95b	Fescue	1.310	5.004	0.3	37.08	1.43	25.9
-	90d	Fescue	95b	Fescue	1.786	3.151	0.6	27.71	1.57	17.6
F test (0.05)	<0.001		<0.001							

When seeds were planted in August 2011, the seed mixture consisted of 45% red fescue, 45% Kentucky blue, and 10% annual rye grass. No species survey data was obtained in 2011 after germination, but the survey taken on June 1, 2012, indicated that only the red fescue survived in all treatments. In general, Park Kentucky blue grass is very winter hardy, and survives the tough winters of Interior Alaska. The lack of Kentucky blue grass in all treatments certainly indicated that some unidentified variables other than treatments prevented grass growth at the sites.

The lack of growth in the treatment of Geofibers + EnviroKleen persisted, and the plant coverage for the rest of the treatments reached 95% in contrast to 29% for the Geofibers + EnviroKleen treatment (Table 4-1). This finding further indicated some ingredients in the treatment that prevented grass growth. The biomass sample taken from each treatment apparently showed that all treatments but Geofibers + EnviroKleen had >1 kg of aboveground biomass and >5 kg of root biomass per square meter (Table 4-1). In addition, carbon and nitrogen concentrations in the shoots showed that the plants from Geofibers + EnviroKleen were low in nitrogen. Tissue samples had a C:N ratio of 41:1 in contrast to normal grass, which has a C:N ratio of 12 to 25:1 (Starbuck 2003), and to the C:N ratio of the other treatments (18 to 28:1). Carbon and nitrogen ratios reflect the use of nitrogen from soil by plants. All treatments received the same amount of nutrient application (8(N)-32(P_2O_5)-16(K_2O)) at 488 kg/ha. However, the plants in the Geofibers + EnviroKleen treatment had low N concentration, which may have been caused by the inability of plant roots to take up nitrogen from soil or by there being little available nitrogen left in the soil for plant roots to use.

Soil Properties

All soil properties in Table 4-2 were related to a soil solution phase except cation exchange capacity (CEC). Soil pH in the solution phase was based on active pH. Treatments with either EnviroKleen or Soil-Sement application with geofibers appeared to have a higher pH than the soil without these ingredients. However, when Soil-Sement was applied alone, it did not affect the soil pH. Apparently, EnviroKleen and Soil-Sement in combination with geofibers affect H^+ concentration in the solution phase. The major constituents of these two products (Midwest Industrial Supply, Inc., www.midwestind.com) are not clear, but the increase in pH in the soil treated with either product + geofibers can probably be attributed to (1) the release of OH^- from these products or (2) the H^+ being tied up in solution when the products were applied to the soil.

Electrical conductivity (EC) measures the total soluble salts in the solution phase. All soils except the soil from Geofibers + EnviroKleen had a similar EC (Table 4-2). The EC from Geofibers + EnviroKleen was significantly lower than the rest of the treatments for both sampling times. The CEC was lower for Geofibers + Soil-Sement and Geofibers + EnviroKleen as compared with the soils without the addition of these amendments. Cation exchange capacity is a measurement for the number of negative charges on the soil particles. Since the use of the two amendments is for erosion or dust reduction in construction sites, according to the product description from the manufacture (Midwest Industrial Supply, Inc., www.midwestind.com), it might be possible that the amendments possess positive charges that bridge small clay particles together to reduce the concentration of small particles, hence, depressing the dust. Alternatively, perhaps the amendments serve as glue to combine the small particles. As such, the exposed surface negative charges for small particles are shielded and lose their negative charge functions. There were no statistical differences between the two sampling times for CEC for all treatments (Table 4-2).

Table 4-2: Impact of erosion-control treatments and sampling times (May 4 and Sept. 1) on soil pH, EC[1], CEC, DOC and DON in 2012 at 0–15 cm sampling depth

Treatment	May 4	Sept.1	May 4	Sept.1	May 4	Sept.1	May 4	Sept.1	May 4	Sept.1
	pH	pH	EC	EC	CEC	CEC	SOC	SOC	SON	SON
	(1:1 H_2O)		dS/m		Cmol kg^{-1} soil		mg C L^{-1}		mg N L^{-1}	
Geofiber+EnviroKleen®	6.27a[2]	6.49a	0.36b	0.38c	8.87c	8.84c	34.8a	30.9a	2.7	2.5b
Geofiber+Soil-sement®	6.40a	6.38ab	1.60a	1.63a	6.86d	6.91d	16.5b	18.4b	9.9	7.3a
Soil-sement®	6.03ab	6.07c	1.28a	1.30b	9.52bc	9.93b	21.8b	19.9b	9.9	9.4a
Geofiber	5.81b	6.06c	1.45a	1.43ab	10.82a	11.40a	23.9b	23.4b	13.9	10.0a
Control	6.06ab	6.23bc	1.58a	1.63a	10.31ab	10.80a	25.2b	24.0b	13.9	7.5a
F test (prob.)	0.05	0.006	<0.001	<0.001	<0.001	<0.001	0.02	0.01	0.2	0.04
Contrast of May 4 vs. Sept.1	NS[3] (p = 0.17)		NS (p = 0.90)		NS (p = 0.61)		NS (p = 0.65)		NS (p = 0.19)	

[1]EC – electric conductivity, CEC – cation exchange capacity, DOC – dissolved organic C in water, DON – dissolved organic N in water.
[2]Different letters indicate the statistical difference at $p \leq 0.05$.
[3]NS – not significant.

Soluble organic C and organic N are good indicators of plant nutrient availability in soil; they also indicate a level of active C in soil solution. Soluble organic C and N are derived from the solubility of soil organic matter and intermediate products from the microorganism metabolic process of using the organic matter as substrates. As such, the level of soluble organic carbon in soil also reflect microorganism activity. However, if a soluble polymeric carbon is added to soil, it becomes a part of soluble organic C. The soil soluble organic C and N in between both sampling times (May 4 vs. Sept.) did not change significantly (Table 4-2), but in both sampling times, soluble organic C was significantly higher in the Geofibers + EnviroKleen treatment than in other treatments. In contrast, the soluble organic N in the same treatment was lower ($p < 0.05$) than in others. The C:N ratio for soluble organic matter in Geofibers + EnviroKleen was 12.9:1 for the May sampling, as compared with 1.8:1 for other control treatments sampled at the same time. High soluble organic C and low soluble organic N in the Geofibers + EnviroKleen treatment indicated that soluble organic C might be from the external addition rather than the internal soil process. From the product description of EnviroKleen, it is certain that the high soluble organic C came from the product, since it is a synthetic organic product (Midwest Industrial Supply, Inc., www.midwestind.com). Whatman #42 filter paper was used to filter the soil/water mixture for soluble organic C and N analysis. The filter paper retained particles >2.5 µm, and experienced difficulty filtering samples taken from soil treated with Geofibers + EnviroKleen. This difficulty indicated that the additive may form colloids larger than the appropriate size of 2.5 µm, which were soluble and plugged the pores of the filter paper. The Geofibers + EnviroKleen treatment impact on soil properties was limited not in the surface 0–15 cm soil depth, but in the 15–30 cm soil depth (Table 4-3), and the trend was similar when compared with the surface depth in the tested parameters for treatments.

Table 4-3: Impact of erosion-control treatments (GF: Geofiber, EVK: EnviroKleen, SS: Soil-Sement) and sampling times (May 4 and Sept. 1) on soil pH, EC[1], CEC, DOC and DON in 2012 at 15–30 cm sampling depth

Treatment	4-May	Sept.1	4-May	Sept.1	4-May	Sept.1	4-May	Sept.1	4-May	Sept.1
	pH		EC		CEC		SOC		SON	
	(1:1 H_2O)		dS/m		$cmol_c\ kg^{-1}$ soil		mg C L^{-1}		mg N L^{-1}	
GF+EVK	6.43	6.54a[2]	0.34c	0.36c	8.46c	8.24c	25.0a	25.1a	1.7	2.2
GF+SS	6.64	6.52a	0.81b	0.84b	6.75d	7.02d	13.2b	13.4b	5.1	4.2
SS	6.25	6.18b	0.75b	0.76b	9.47b	9.68b	14.4b	13.7b	4.6	4.a
GF	6.17	6.13b	0.68b	0.71b	10.12ab	10.91a	15.5b	14.4b	5.3	4.5
Control	6.18	6.22b	1.34a	1.35a	10.44a	10.58ab	15.7b	14.2b	4.9	4
F test (prob.)	0.06	0.001	0.001	<0.001	<0.001	<0.001	0.015	<0.001	0.23	0.32
Contrast of May 4 vs. Sept.1	NS[3] (p = 0.87)		NS (p = 0.85)		NS (p = 0.68)		NS (p = 0.99)		NS (p = 0.42)	

[1]EC – electric conductivity, CEC – cation exchange capacity, DOC – dissolved organic C in water, DON – dissolved organic N in water.

[2]Different letters indicate the statistical difference at $p \leq 0.05$.

[3]NS – not significant.

Plant-Available Nutrients in Soil

Erosion-control treatment test sections as compared with the control section did not differ ($p > 0.05$) in plant-available nutrient concentration for both soil sampling depths (Tables 4-4 and 4-5). The plant available nutrients in soil are a sensitive parameter with soil erosion, because these nutrients are associated with soil organic matter and fine clay particles. With eroded soils, the plant nutrient concentrations are usually lower due to losses of fine particles in soil. For all treatments, the plant available nutrients except mineral N were not affected, even with the less plant coverage of the Geofibers + EnviroKleen treatment. Results showed that these dust-suppressing materials, especially EnviroKleen, appear to hold soil particles together, preventing them from eroding away.

Table 4-4: Plant-available nutrients as affected by erosion-control treatments (GF: Geofiber, EVK: EnviroKleen, SS: Soil-Sement) for soil sampling depth 0–15 cm.

Treatment	4-May	Sept.1	4-May	1-Sep	4-May	Sept.	4-May	Sept.	4-May	1-Sep
	Mineral N		Available P		Extractable K		Extractable Ca		Extractable Mg	
GF+EVK	4	2.3	129.7	131.7	197.7	201	2000	2071	278	283.7
GF+SS	95.2	67	155.3	158.3	210.3	216.3	2005	2005	308.3	308.3
SS	111.1	79.1	146	144.3	205.7	204	1963	1893	305	308
GF	11.3	104.8	184.7	190.3	245.7	236	2044	2061	299.7	304.3
Control	99.6	67.3	188	192.7	271.3	272	2048	2035	313.3	311
F test (prob.)	0.08	0.09	0.74	0.7	0.56	0.52	0.37	0.27	0.89	0.96
Contrast of May 4 vs. Sept.1	NS[1] (p =0.36)		NS (p = 0.91)		NS (p = 0.99)		NS (p = 0.30)		NS (p = 0.88)	

[1]NS – not significant.

Table 4-5: Plant-available nutrients as affected by erosion-control treatments (GF: Geofiber, EVK: EnviroKleen, SS: Soil-Sement) for soil sampling depth 15–30 cm.

Treatment	4-May	Sept.1	4-May	1-Sep	4-May	Sept.	4-May	Sept.	4-May	1-Sep
	Mineral N		Available P		Extractable K		Extractable Ca		Extractable Mg	
GF+EVK	2.2b[1]	1.5c	48	46.7a	111.7	107.7	1972	2011	259	266
GF+SS	48.3a	38.7ab	44	41.7b	107.7	107.3	1957	1995	300.7	304.7
SS	44.3a	42.9ab	30.7	29.0c	97	97.7	2010	2003	315	318.3
GF	44.8a	45.2a	72.3	73.0a	133.7	135	1981	1984	283.3	281.3
Control	21.9ab	13.9bc	63	64.3a	118.3	121	1908	2000	286.7	298
F test (prob.)	0.03	0.04	0.11	0.05	0.14	0.13	0.78	0.95	0.6	0.66
Contrast of May 4 vs. Sept.1	NS[1] (p =0.64)		NS (p = 0.94)		NS (p = 0.99)		NS (p = 0.19)		NS (p = 0.73)	

[1]Different letters indicate the statistical difference at $p \leq 0.05$.

[2]NS – not significant.

Soil samples taken from each treatment showed that the mineral N concentration in Geofibers + EnviroKleen treatment was marginally lower statistically (p = 0.08 for May samples, and p = 0.09 for Sept. samples) than other treatments for the 0–15 cm depth (Table 4-4). For the 15–30 cm sampling depth, the difference in mineral N concentration between the Geofibers + EnviroKleen and other treatments was statistically different (p = 0.03 and p =

0.04 for May and Sept. samples, respectively) (Table 4-5). The amount of mineral N in Geofibers + EnviroKleen was at least 20 times lower for the 0–15 cm sampling depth and 10 times lower for the 15–30 cm sampling depth than the rest of the treatments. Nitrate nitrogen possesses negative charges and is very mobile in soil. Comparing the May soil samples with the September ones, apparently some losses of mineral N occurred in the 2012 growing season, but most of these losses were not significant (Tables 4-4 and 4-5, Figs. 4-6a and 4-6b). Likely, the mineral N losses occurred in fall 2011 and in early spring 2012, when the ground started to thaw. Soil mineral N includes NH_4-N and NO_3-N. In an aerobic soil environment, NH_4-N has a short life in soil; it is quickly oxidized to NO_3-N. Because of this, in upland soils, the majority of mineral N extracted from soil is NO_3-N. In waterlogged conditions, NO_3-N can be easily lost through the denitrification process. For the treatment site, NO_3-N loss in spring runoff or the spring perched water table could be a cause for mineral N loss from the Geofibers + EnviroKleen treatment. A deep rill that formed in the back slope of the test site demonstrated the runoff problem at the site when the surface was not covered by grasses (Fig. 4-7).

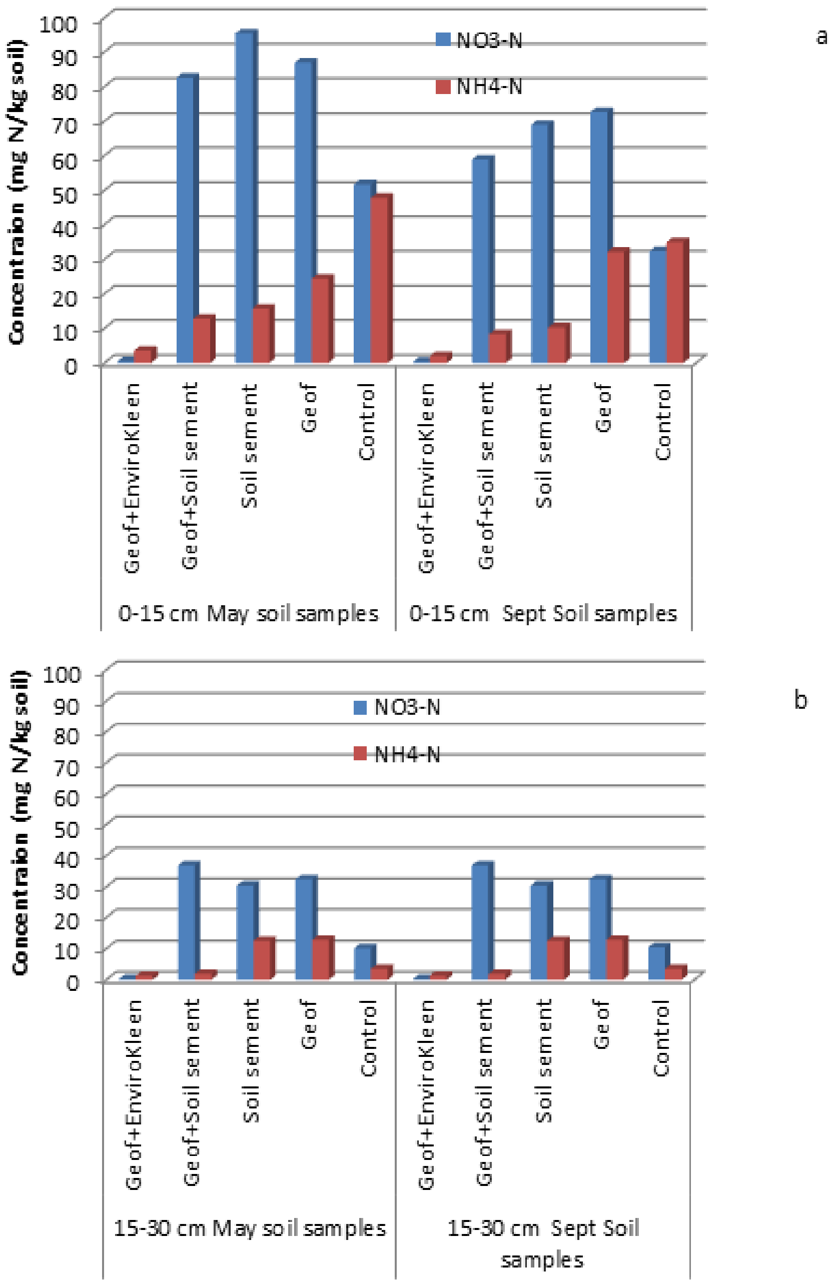

Fig. 4-6: Nitrate and ammonium in soil between May and September samples of 0–15 cm (a) and 15–30 cm (b).

Fig. 4-7: Erosion on the backside of the constructed test site. An illustration of erosion when soil was not covered by plants or addition of dust-depressing materials (photo taken June 28, 2012)

Bulk Density, Total Elements Composition, and Soil Particle-Size Distribution

Soil bulk density was not statistically different among treatments (Fig. 4-8). As discussed earlier, no sediment was collected from each treatment after the major rain event in August. Another important contributor for soil bulk density is soil organic matter. The total organic C content collected from May and September 2012 indicated little change in soil organic C (Tables 4-6 and 4-7).

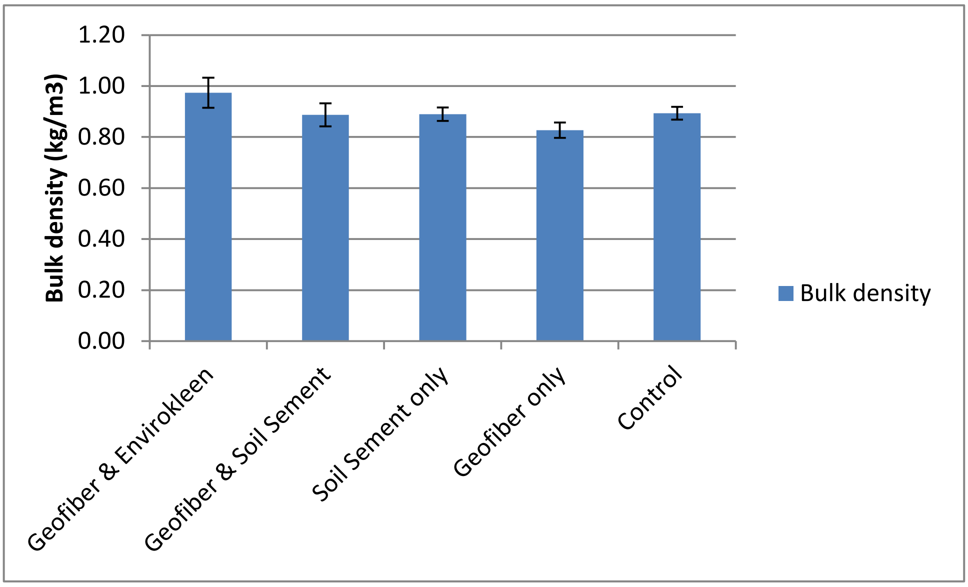

Fig. 4-8: Bulk density of soil from different treatments measured in May 4, 2012

Table 4-6: Total N, C, P, and K in soil and particle-size distribution for soils of 0–15 cm depth (GF: Geofiber, EVK: EnviroKleen, SS: Soil-Sement)

Treatment	4-May	1-Sep	4-May	1-Sep	Particle size distribution		
	Total N		Total C		Sand	Silt	Clay
	%		%		%		
GF+EVK	0.12	0.11	2.31	2.23	31.8b[1]	54.6	14.1
GF+SS	0.17	0.1	2.51	2.54	32.5b	53.9	15.5
SS	0.12	0.1	2.44	2.43	33.10ab	53.6	13.3
GF	0.08	0.08	1.63	1.64	34.60ab	53.1	12.7
Control	0.1	0.07	1.58	1.6	36.30a	52.3	11.4
F test (prob.)	0.75	0.91	0.79	0.81	0.1	0.87	0.34
Contrast of May 4 vs. Sept.1	NS[2] (p = 0.14)		NS (p = 0.75)				

[1]Different letters indicate the statistical difference at $p \leq 0.05$.

[2]NS – not significant.

Table 4-7: Total N, C, P, and K in soil and particle-size distribution for soils of 15–30 cm depth (GF: Geofiber, EVK: EnviroKleen, SS: Soil-Sement)

Treatment	4-May	1-Sep	4-May	1-Sep	Particle size distribution		
	Total N		Total C		Sand	Silt	Clay
	%		%		%		
GF+EVK	0.07	0.07	2.21	2.15	23.1b[1]	52	18.9a
GF+SS	0.09	0.07	2.48	2.43	34.2a	53.7	12.7b
SS	0.07	0.07	2.54	2.71	32.9ab	53.3	13.8b
GF	0.06	0.07	1.63	1.58	36.0a	51.4	12.6b
Control	0.05	0.07	1.6	1.51	33.8a	51.5	14.7b
F test (prob.)	0.79	0.99	0.83	0.68	0.08	0.4	0.004
Contrast of May 4 vs. Sept.1	NS[2] (p = 0.77)		NS (p = 0.64)				

[1]Different letters indicate the statistical difference at $p \leq 0.05$.

[2]NS – not significant.

Soil total organic C and organic N were not significantly different statistically among all treatments in the May as well as the September soil samplings. Apparently, the soil organic C concentration in the treatments that received either geofibers or Soil-Sement was 0.12, 0.17 and 0.12% in contrast to the use of geofibers alone or a control treatment, which only had soil organic C concentration of 0.08 and 0.10%, respectively (Table 4-6) for a sampling depth of 0–15 cm. Similarly, this trend was also reflected in soil organic N (Table 4-6). Soil organic matter (mostly organic C and N) is a major constituent of soil, which holds soil particles together to form good structure. In the early stage of erosion (i.e., sheet erosion), soil organic matter is lost, resulting in disintegration of soil structure (Brady and Weil 2007). With such losses, the erosion process accelerates. The little change of total soil organic C and N from May to September 2012 in the 0–15 cm sampling depth indicated that all treatments were effective in holding soil from erosion. But this was only based on the results of one year. Whether the treatments can prevent soil particles from being eroded away may require multiple-year results for validation, especially for the treatments in which little grass has grown. There was little change in soil organic C and N in soil sampled from 15–30 cm depth (Table 4-7).

Soil particle analysis indicated that there was more sand relative to clay in the control treatment as compared with the treatment that received EnviroKleen or Soil-Sement in the surface layer soil samples (Table 4-6). In soil science, particle size is classified as clay <0.002 mm, silt < 0.02 mm, and sand <2 mm, and the unit for distribution is percentage, meaning the percentage share of each particle in a 100-unit sample. The relatively low percentage in sand resulted in an increase of percentage of clay particles in the 0–15 cm sampling depth, even though the percentage of clay particles among different treatments was not statistically significant (Table 4-6). In the soil sampling depth of 15–30 cm, the percentage of clay particles in EnviroKleen was statistically ($p = 0.004$) higher, but the percentage of sand was marginally statistically ($p = 0.08$) lower than the rest of the treatments (Table 4-7).

Possible Mechanisms for the Chemical Additives Functioning in Soil

There are many publications on the subject of using additives, either traditional or nontraditional, to stabilize fugitive soil particles on unpaved roads or disturbed sites. The traditional compounds include cement, lime, fly ash, and bituminous products. Extensive research has been conducted on how these materials work in soil to capture and consolidate soil particles and release less fugitive particles (Birst and Hough 1999; Meyers et al. 1976; Transportation Research Board Committee 1987; American Concrete Institute Committee 230 1990; Soil Stabilization for Pavement 1994). The nontraditional chemical additives consist of a diverse group of chemicals, and are basically classified as ionic, enzymes, lignosulfonate, salt, petroleum resin, polymer, and tree resins (Tingle et al. 2007). Nevertheless, research on the mechanisms of how these additives function in soil is very limited. In the published research papers about using nontraditional chemical additive, little testing has been done with respect to soil chemical properties. In our research, we determined a variety of chemical properties, even though we did not have detailed information from the manufacturer about how these two chemical additives function in soil. Through our experiments, however, we knew what the possible mechanisms were for each additive.

Both additives reduced the surface charges of soil particles reflected by the reduction of CEC (Table 4-3). Reduction of surface charge can result in shrinking of hydrous layers of soil particles, especially clay particles. Clay particles have a large surface area and are the major contributor for soil surface charges. Around the clay particles is a hydrous layer that consists of water and exchangeable cations (i.e., diffusion double layer). The thickness of the layers is related to surface charge density. The higher the density, the thicker the diffusion double layer will be. Reduction in the thickness of the hydrous layer in clay particles makes these clay particles easier to be flocculated when the particles bounce into each other. Since most soil particles possess negatives charges, the two additives must possess positive charges in order to cancel out the negative charges on the clay surface. But by examining other tested soil parameters, these two additives appeared to act differently in neutralizing particle surface charges. The EnviroKleen had more impact on soil-solution chemistry; it increased soil pH and soluble organic C, but decreased soil solution EC and soluble organic N as compared with the control treatment at the 0–15 cm sampling depth. In contrast, Soil-Sement was similar to the control treatments in all these soil-solution parameters. Based on these findings, we hypothesize that the additive Soil-Sement might precipitate on the surface of soil particles so that the amount of surface charge of the soil particles is reduced, thus shrinking the hydrous layer around the soil particles and increasing the chance of forming large particles (Fig. 4-9).

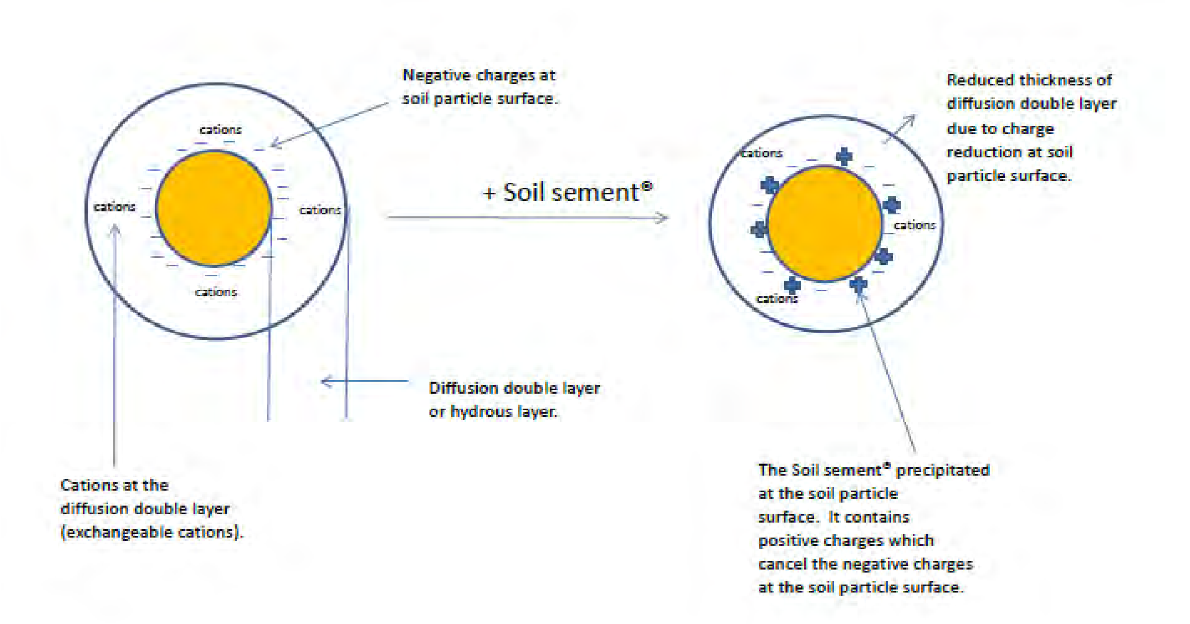

Fig. 4-9: The illustration of how Soil-Sement functions in soil for dust depression and erosion control. The additive directly precipitated on the surface of the soil particle due to its positive charges. As such, the soil particle surface charges reduced, along with reduction of the thickness of the diffusion double layer.

As for EnviroKleen, based on the product description, the additive is a polymer. As such it is not surprising to see the increase in soluble organic C in solution. But the importance is that the polymer can be used by soil microorganisms as an energy source, resulting in immobilization of soluble organic N and mineral N in soil. If a biological method of erosion control is used (i.e., establishment of vegetation in disturbed soil), immobilization of mineral and soluble organic N in the soil may delay plant growth and thus decrease the effectiveness of erosion-control measures (engineering + biological means of erosion control). The polymer appeared to chelate metals in soil solution, which resulted in charges cancelling in the metals, causing a reduction in solution electrical conductivity (decreased about 1.22–1.25 dS/m for surface soil of both sampling times). At the same time, the solution pH increased, meaning further reduction of positive charge (i.e., H^+) in soil solution.

In comparison with the control treatment, the addition of EnviroKleen resulted in a decrease of 3.39×10^{-7} moles/L H^+ (or an increase of 3.39×10^{-7} moles/L of OH^-) for spring sampling and 2.65×10^{-7} moles/L H^+ for fall sampling in the 0–15 cm depth. Similar patterns can be found for the 15–30 cm soil samples. Based on these observations, we think that the additive EnviroKleen possesses both positive and negative charges, and its role in suppression of the negative charges in soil particles may be in two steps. First, negative charges in the additive chelate the cations in the diffusion double layers at the soil particle surface. Second, the positive charges react with the negative charges at the soil particle surface, resulting in suppression of soil particle surface negative charges (Fig. 4-10). The alternative mechanistic reaction of EnviroKleen reacting with soil particles is to form a coating around soil particles (Fig. 4-11). The coating chelates the cations on the diffusion double layer, and the positive charges point outward to form a layer of coating (Fig. 4-10). How well this coating forms depends on the size of the positive functional groups and the repelling forces of the positive charges. Either way, EnviroKleen may be more effective at making soil fine particles become larger by flocculating. The effectiveness of EnviroKleen was strongly reflected by an increase in the clay fraction and a decrease in the sand fraction in soil samples, especially the 15–30 cm sampling depth (Tables 4-6 and 4-7). This particle-size distribution was not observed for Soil-Sement in the 15–30 cm, but at the surface sampling layer, indicating that environmental factors such as moisture and temperature can enhance the Soil-Sement reaction in soil.

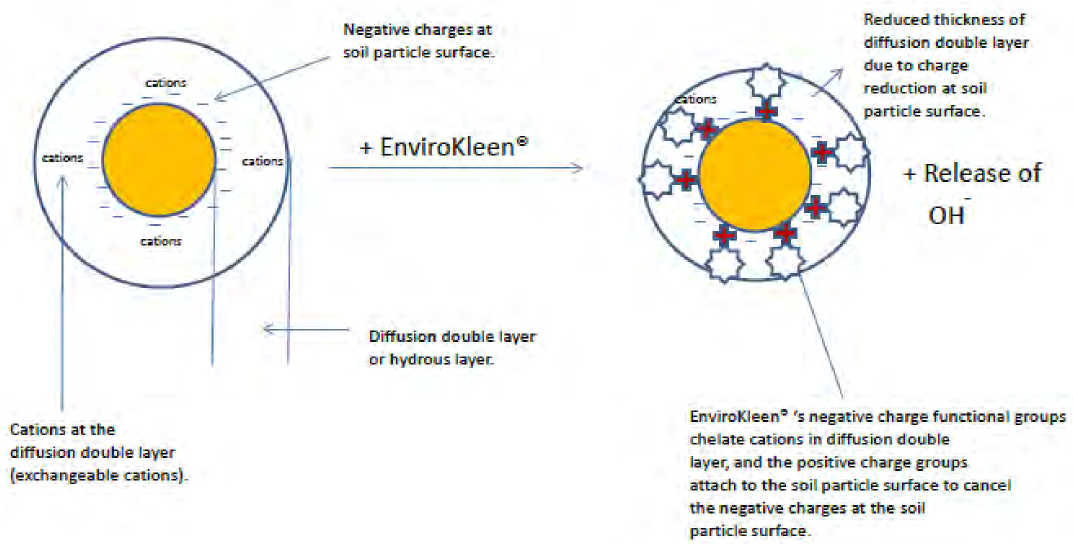

Fig. 4-10: The illustration of how EnviroKleen, functions in soil for dust depression and erosion control. The additive possesses negative and positive charges. The negative charge functional groups chelate the cations in the diffusion double layers, and the positive functional groups are attached on the surface of the soil particles. As such, the soil particle surface charges are reduced, resulting in a reduction of the thickness of the diffusion double layer and reduction of soluble cations in the soil solution.

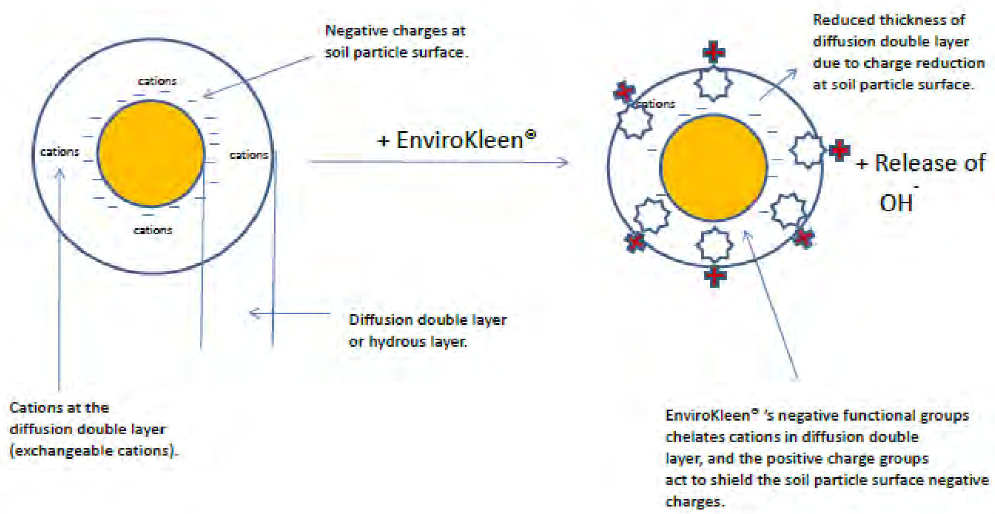

Fig. 4-4: Another possible model of how EnviroKleen functions in soil for dust depression and erosion control. The additive possesses negative and positive charges. The negative charge functional groups chelate the cations in the diffusion double layers, and the positive functional groups point outward to shield the negative charges at the surface of the soil particle. As such, the soil particle surface negative charges are reduced, resulting in a reduction of the thickness of the diffusion double layer and reduction of soluble cations in the soil solution.

Soils receiving both additives appeared to have poor plant coverage as compared with the control treatment in fall 2011, after implementation of the treatments (Fig. 4-3, Fig. 4-4). This result indicates that there might be an interaction of additives with geofibers in preventing good seed germination and seedling growth, since the treatments using Soil-Sement or geofibers alone had high plant coverage. However, in the plant coverage survey in June 2012 (Table 4-1), plant coverage for Geofibers + Soil-Sement increased to 84%, while plant coverage for Geofibers + EnviroKleen was 29%, the lowest among all treatments. This 29% remained nearly the same in the September plant survey, which suggests that the impediment of germination and growth from the combination of Geofibers + Soil-Sement was temporary, but it was permanent for Geofibers + EnviroKleen. Grass growth from May to September 2012 was poor (Fig. 4-3, Table 4-1), indicating that the soil after treatment was harder for plant growth. We think this hardness was caused by a shortage of plant-available water in the soil. This shortage may be attributed to

(1) less water infiltration after rain because the small pores were plugged by flocculated small particles (the experience we had for filtrating the soil/water mixture from the soil samples taken from EnviroKleen showed such evidence), and
(2) a high osmotic potential for preventing seeds from imbibing water for germination and for preventing roots from taking soil water for growth.

Even though we did not measure the osmotic potential of soil solution from the treatment, high soil organic C could be an indicator for that activity. A reduction of the application rate might overcome high soil organic C in soil when using EnviroKleen. This possibility needs validation in further research.

CHAPTER V

RESULTS AND ANALYSIS

Field Site Analysis

Measurements of stiffness using the GeoGauge™ and bearing capacity using the Dynamic Cone Penetrometer (DCP) were taken. Photographs were also taken until the first snowfall of 2011. These results showed that DCP and GeoGauge measurements may not be a good indicator of what is occurring at the field site as it relates to erosion.

The first set of stiffness measurements were taken at the beginning of August 2011. Subsequent measurements were taken weekly in August and biweekly in September, and the final measurement was taken in mid-October prior to snowfall. Although measurements were taken at the top, middle, and bottom of each section, all results compared closely, so only the middle results are reported.

The results of the GeoGauge stiffness measurements converted to the CBR are presented in Figure 5-1. These results show very little change in the CBR value over the total duration of the recorded measurements. Measurements show that the behavior has an upward trend, though the amount of increase is small. Treated sections had CBR values similar to the control section. It is worth noting that all the CBR values shown fall in the poor-to-fair general rating range (from Bowles 1978).

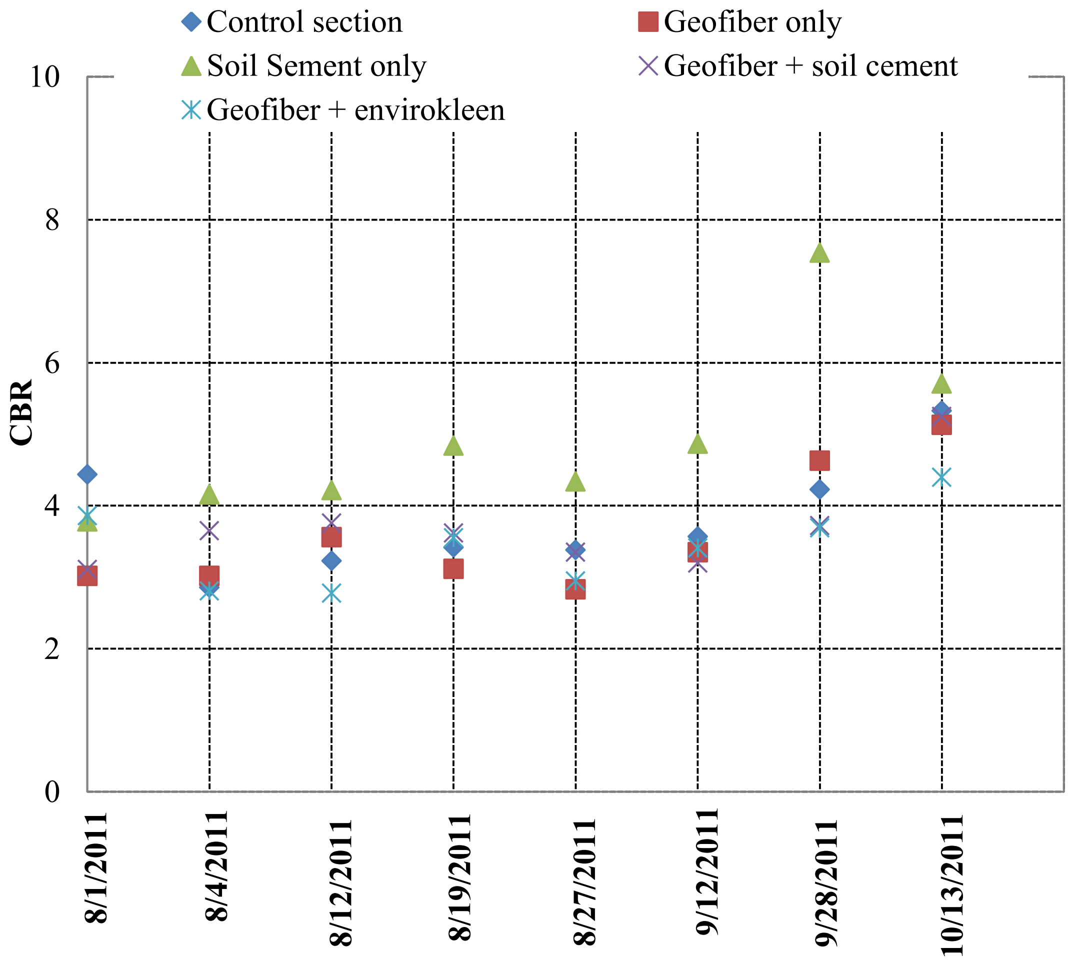

Fig. 5-1: CBR values determined from GeoGauge measurements taken at the middle of the field slope

The DCP tests were converted to the CBR. The results of the DCP tests performed on the middle test section are presented in Figure 5-2. The results show that there is not much variation in the CBR value through the dates measured. Values fall in the poor-to-fair rating range for all measurements. The lone exception is the measurement recorded on August 19, 2011, with samples treated with geofibers and Soil-Sement®. This is likely an aberration, because in the following weeks, the data are closer to the other measurements.

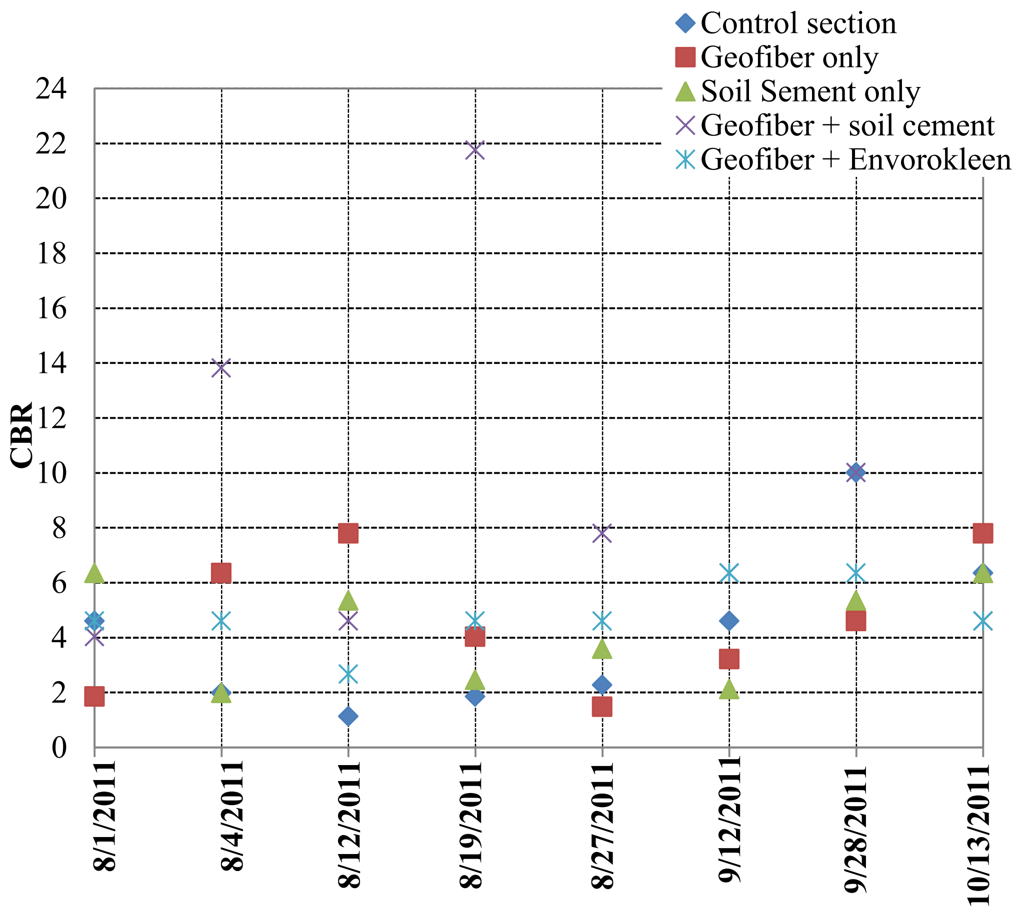

Fig. 5-2: CBR values determined from DCP measurements taken at the middle of the field slope

By simply looking at the DCP and stiffness measurements, it is impossible to make any determination as to which of the treatments provided the best improvement in erosion resistance. Therefore, it is necessary to consider other options for determining the most effective treatment. The determination by School of Natural Resources and Agricultural Sciences in the Chapter IV clearly indicated that with the EnviroKleen application, soil chemical properties were altered resulting poor grass growth in the tested section.

Determination of Critical Shear Stress

Critical shear stress was determined for each of the treatment configurations. Results were found by plotting the erosion rate (g/m^{2}s) versus the bottom stress measured at the surface of the soil sample, then plotting a linear "best fit" line through the area in the curve where the erosion rate begins to increase. The graphs used to determine critical shear stress are provided in the appendix.

Two tests were performed for each treatment configuration. The average shear stress (τ_{crit}) for the tests is presented in Table 5-1. The results show that all treatment configurations reduce the critical shear stress of the soil. The samples treated with geofibers showed a severe reduction in critical shear stress. This is likely attributed to geofibers being pulled out of the sample, which caused a loss in density and increased the erosion rate. The treatment with only Soil-Sement caused a slight decrease in critical shear stress. This is likely attributed to increased cohesion in the soil particles, which causes larger clumps of soil to erode.

Table 5-1: Critical shear stress results (w=moisture content, SS = Soil-Sement, GF = Geofibers, EVK = EnviroKleen)

Sample Configuration	Average τ_{crit} (pa)
6% w	27.5
6% w + 2% SS	22.5
6% w + 0.5% GF	9.5
6% w + 2% SS + 0.5% GF	10
6% w + 4% EVK + 0.5% GF	7

Laboratory Slope Erosion Analysis

The laboratory erosion slope testing provided results that are critical in evaluating the performance of erosion-control methods prior to the onset orillf grass growth. Two samples were prepared for each treatment configuration, including two untreated samples. The results show a reduction in percentage of loss for treated samples when compared with untreated samples.

Table 5-2 provides the results of the laboratory slope testing. Note that the 6% water-Test 1 (shown in Fig. A-17) was abandoned after only 45 seconds due to the severe erosion that was taking place. If the test had been allowed to run for another 20 seconds, it would have shown similar erosion to that indicated in Figure A-18. All other tests were run for a total time of 1 minute and 5 seconds, which was found based on experimentation. The 6% water-Test 2 is comparable to the other results. The results show that, in general, treatment causes a reduction in percentage of material loss. The greatest overall reduction in percentage of loss came from the sample treated with 2% Soil-Sement and 0.5% geofibers. The samples with geofibers caused greater reduction in percentage of loss than the sample without. The effectiveness of geofibers is likely due to a root-like structure that forms and tends to hold the sample together.

Table 5-2: Lab slope % loss results (w=moisture content, SS = Soil-Sement, GF = Geofibers, EVK = EnviroKleen)

Sample Name	% Loss
6% w-Test 1 (45 seconds)	9.9
6% w-Test 2	18.6
6% w + 2% SS-Test 1	16.2
6% w + 2% SS-Test 2	15.9
6% w + 0.5% GF-Test 1	15.1
6% w + 0.5% GF-Test 2	13.0
6% w + 2% SS + 0.5% GF-Test 1	12.6
6% w + 2% SS + 0.5% GF-Test 2	11.0
6% w + 4% EVK + 0.5% GF-Test 1	14.3
6% w + 4% EVK + 0.5% GF-Test 2	13.2

Pictures of all of the tests conducted taken before and after testing are shown in the appendix. The samples treated with water and Soil-Sement, shown in Figures A-19 and A-20, are very similar to the control samples. Tests samples treated with only 0.5% geofibers are shown in Figures A-21 and A-22. These images show a slight reduction in the severity of the rills that form. The geofibers tend to hold the sample together much better than just the addition of Soil-Sement, which did not contribute much to erosion resistance. The samples treated with Soil-Sement + Geofibers are shown in Figures A-23 and A-24. Rills formed in these tests, which usually led to severe erosion. However, due to the presence of the geofibers and the enhanced cohesion with the addition of Soil-Sement, the sample held together and major erosion did not occur. The tests where geofibers were mixed with EnviroKleen are presented in Figures A-25 and A-26. These tests show less rill formation than those that formed with the combination of geofibers and Soil-Sement; however, more material was lost. The increase in loss of material with EnviroKleen likely occurred because the product does not increase the cohesion of soil. Once erosion starts, the soil does not hold together, resulting in increased erosion.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The addition of geofibers and nontraditional additives was investigated for sandy silt. Combinations of field and laboratory studies were used to evaluate the effectiveness of several combinations of geofibers and nontraditional additives. This plan consisted of determining critical shear stress for the treated soils, evaluating the effect of additives on grass growth at the field and the additives impact on soil chemical and physical properties, and constructing a laboratory-scale slope to measure loss after a significant erosion event.

In the laboratory erosion test, all treatments experienced certain degree of soil loss. However, with grass coverage (except the treatment where EnviroKleen was added), all treatments resulted in no loss of sediments at the field site with a slope of 1:1.5 even with a rain intensity of 2.08 mm/day. The combination of the use of erosion-control material and grass vegetation was an effective way to control erosion at disturbed sites, especially for materials such as geofibers and Soil-Sement®. The use of EnviroKleen® resulted in poor grass establishment. The poor grass growth is possibly caused by adverse soil solution chemistry altered due to the addition of the additive. The erosion control by the two additives was achieved by decreasing negative charges at soil particle surface. However, the two additives had different mechanisms in soil negative charge suppression. The erosion control mechanism from this research fill the information in this area. Even EnviroKleen can act alone in soil erosion control, further study on this product with respect to plant seed germination is still needed especially when vegetation and the additive are used together.

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APPENDIX

Calibration of Turbidity for Critical Shear Stress Determination

In order to use turbidity to measure the amount of solids suspended in water during the test, it was necessary to perform a calibration between turbidity and mass concentration. To do this, an untreated soil sample was compacted and placed in the flume and the flow was gradually increased. Water samples were collected at various intervals throughout the test. The turbidity of these samples was measured. Then the samples were placed under vacuum suction, and the soil remaining on a piece of filter paper was weighed. The results are plotted in Fig. A-1. A linear line was fitted to the data, and the equation derived was used to determine the amount of suspended solids for each turbidity measurement.

During the critical shear stress testing, plots were made of elapsed time of the test versus the measured turbidity and flow rate. The graphs are shown as Figs. A-2–A-11.

The graphs showing bottom stress versus erosion rate are shown in Figs. A-12–A-16. Linear lines are drawn through the points where the erosion rate starts to significantly increase. The equations found for the lines were set equal to zero in order to solve for the critical shear stress.

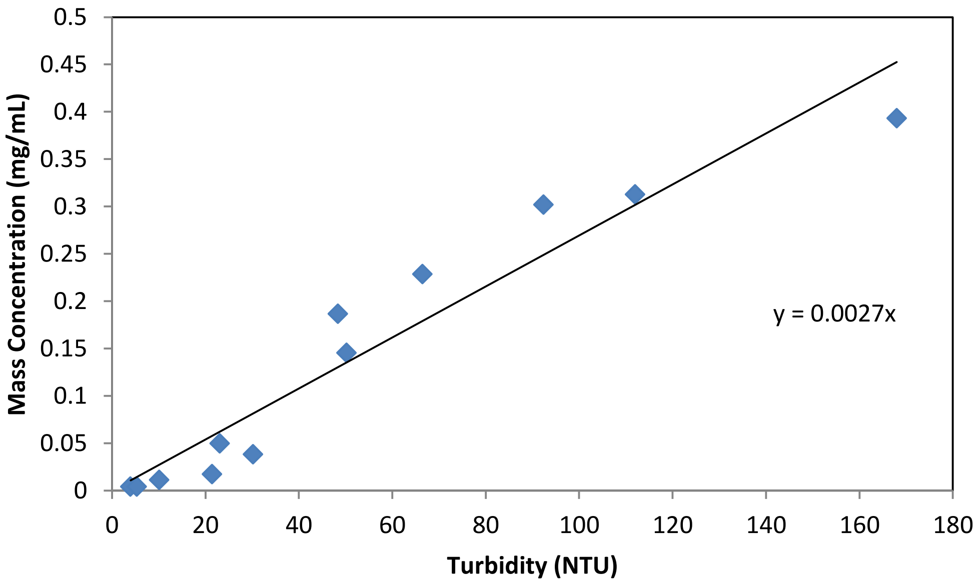

Fig. A-1: Calibration of Turbidity to Mass Concentration

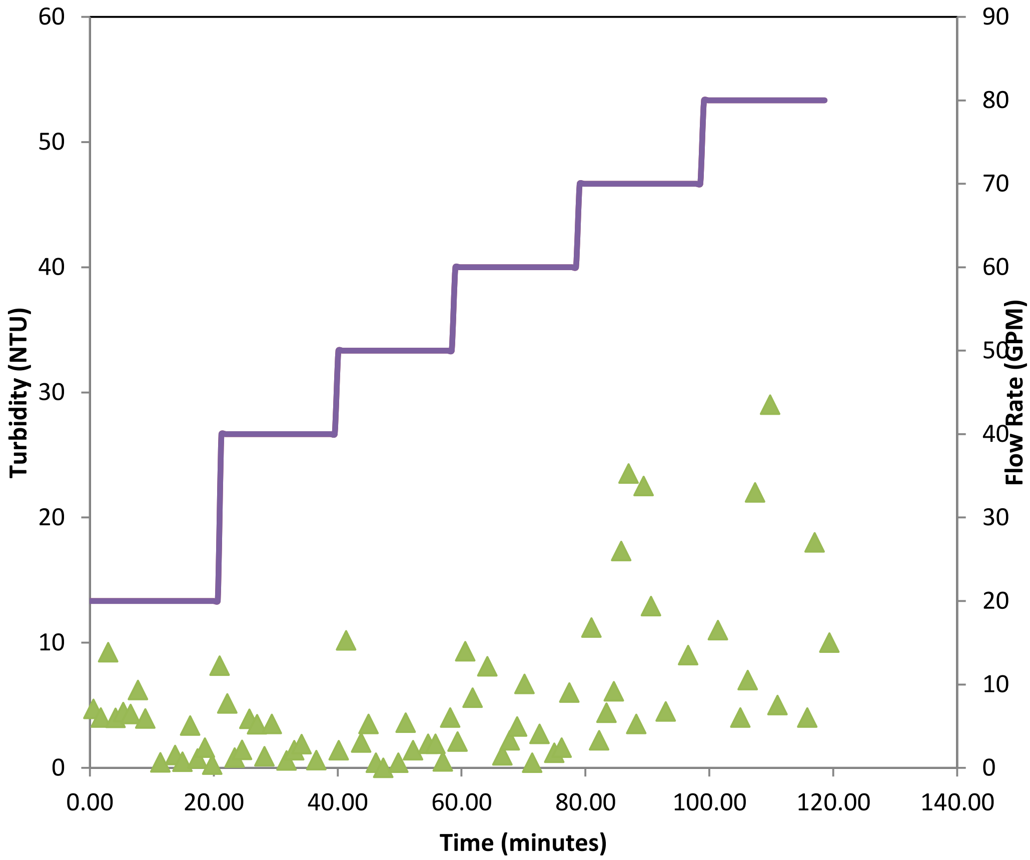

Fig. A-2: 6% water test one

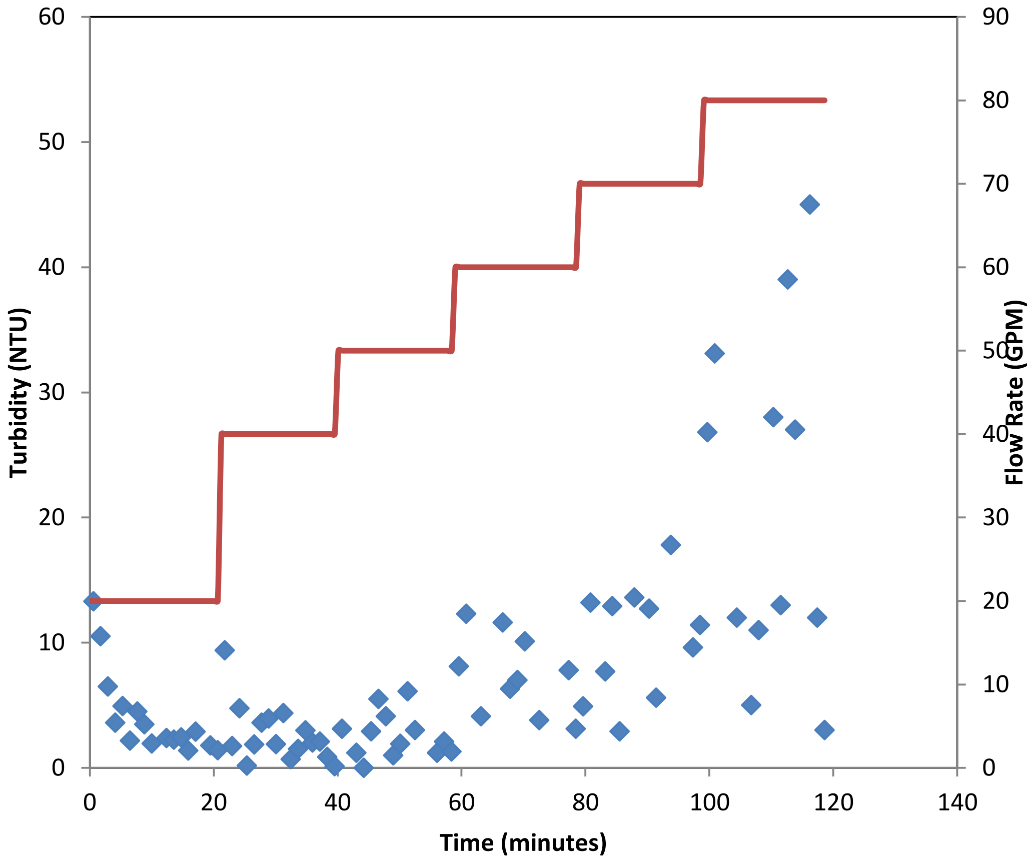

Fig. A-3: 6% water test two

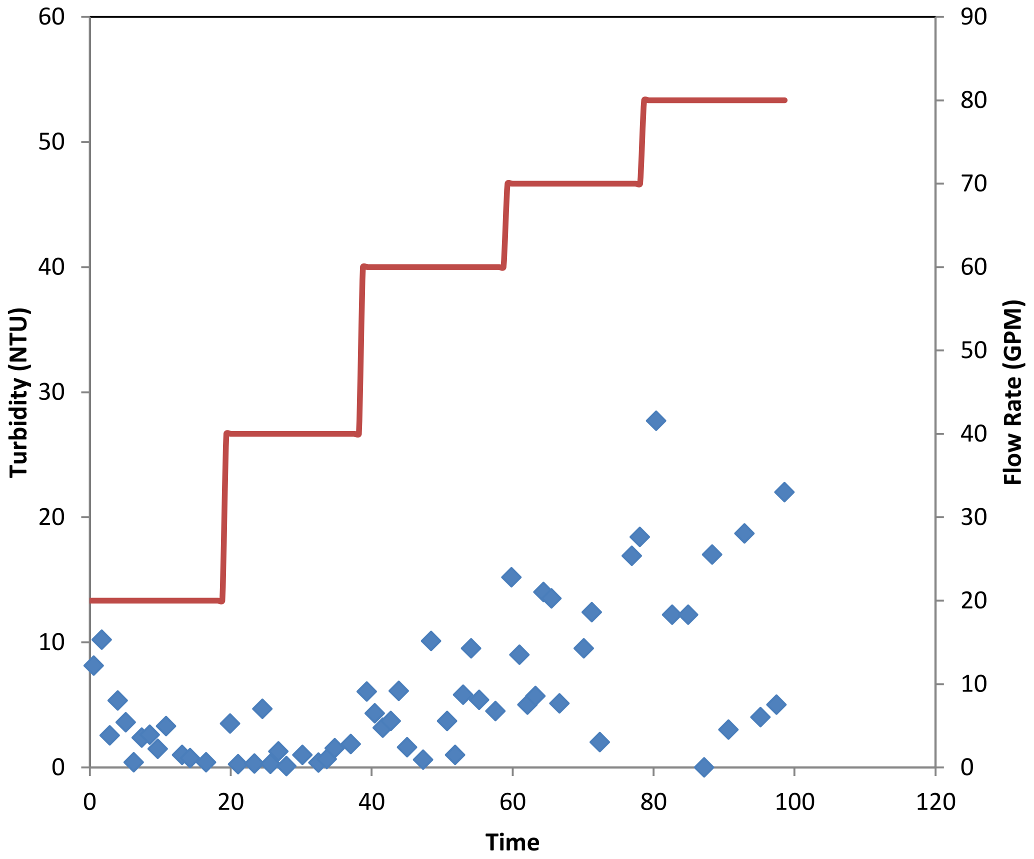

Fig. A-4 2% Soil-Sement test one

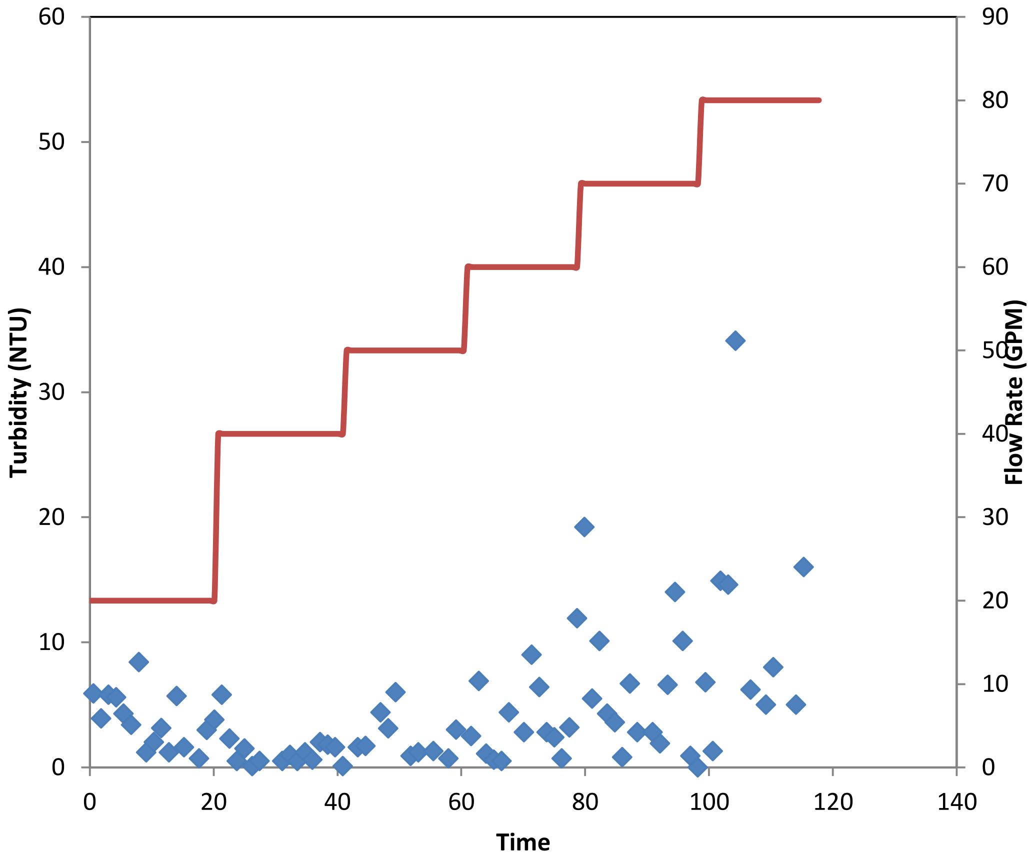

Fig. A-5: Soil-Sement test two

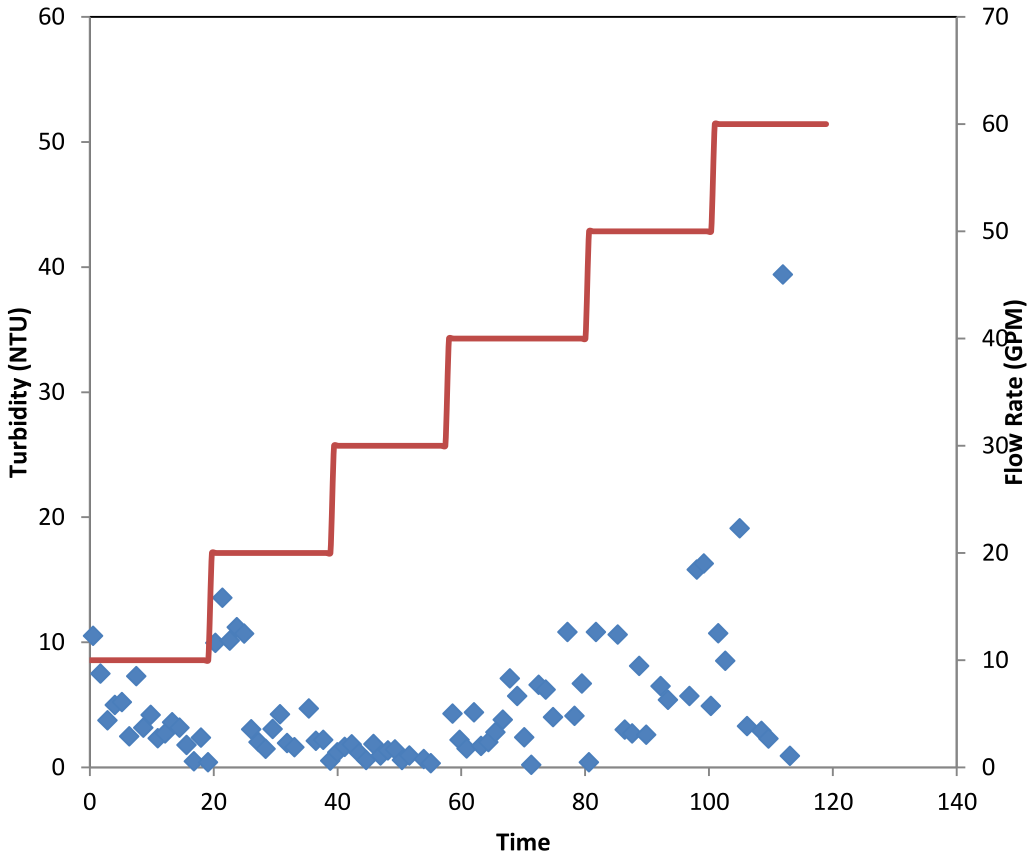

Fig. A-6: 0.5% Geofibers test one

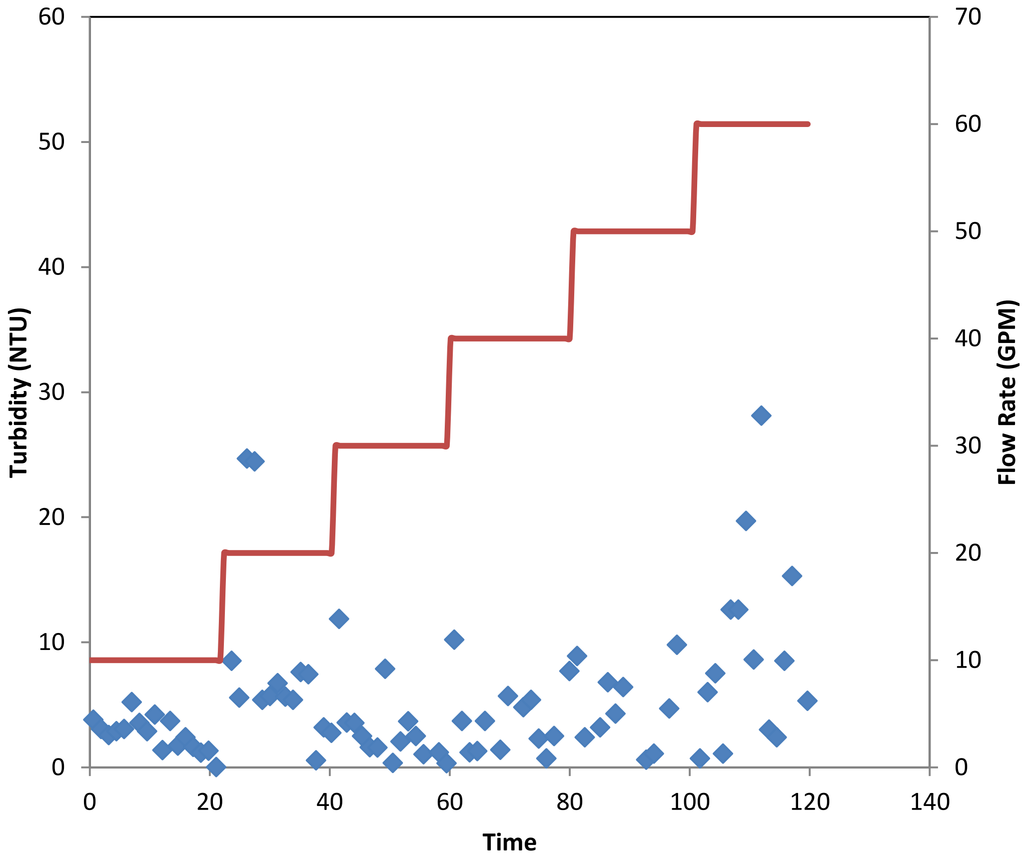

Fig. A-7: 0.5% Geofibers test two

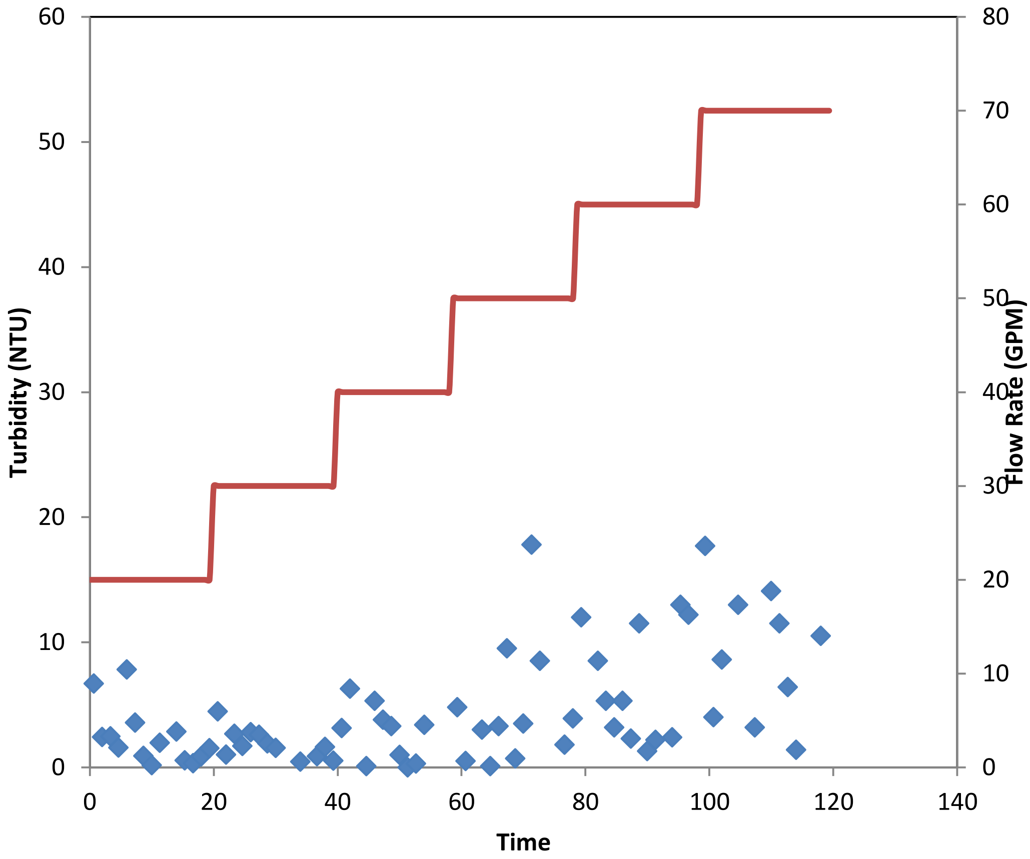

Fig. A-8: 2% Soil-Sement + 0.5% GeoFibers test one

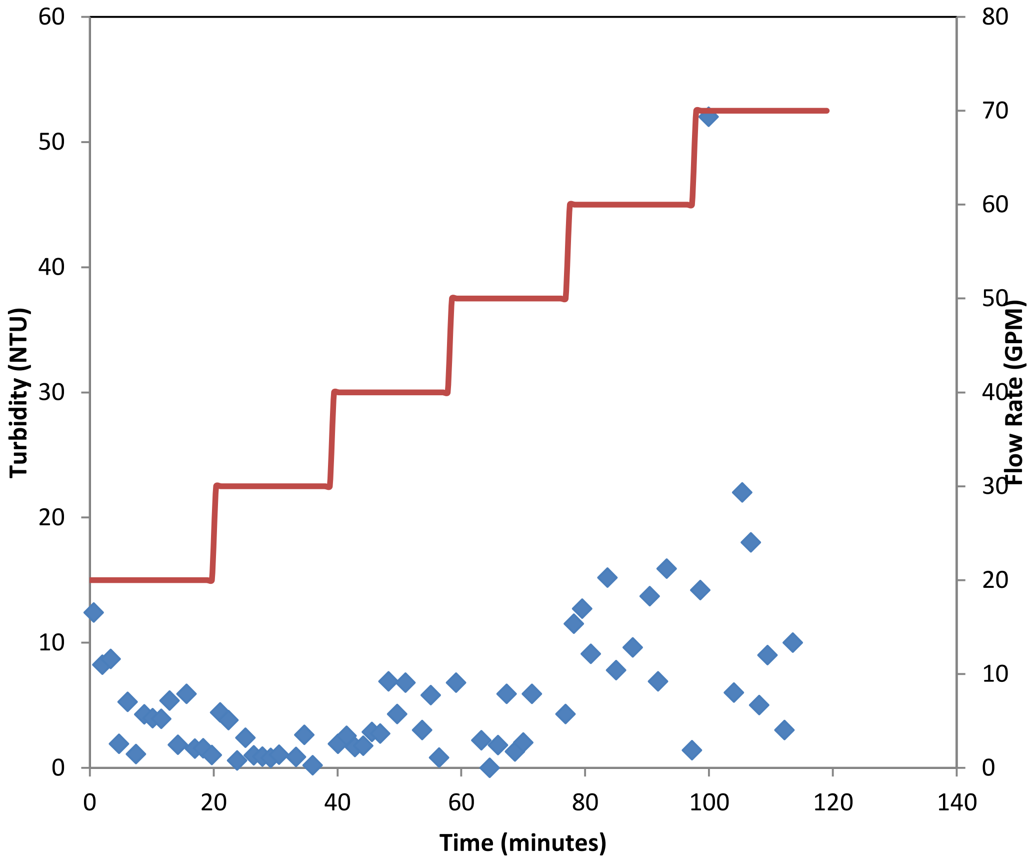

Fig. A-9: 2% Soil-Sement + 0.5% GeoFibers test two

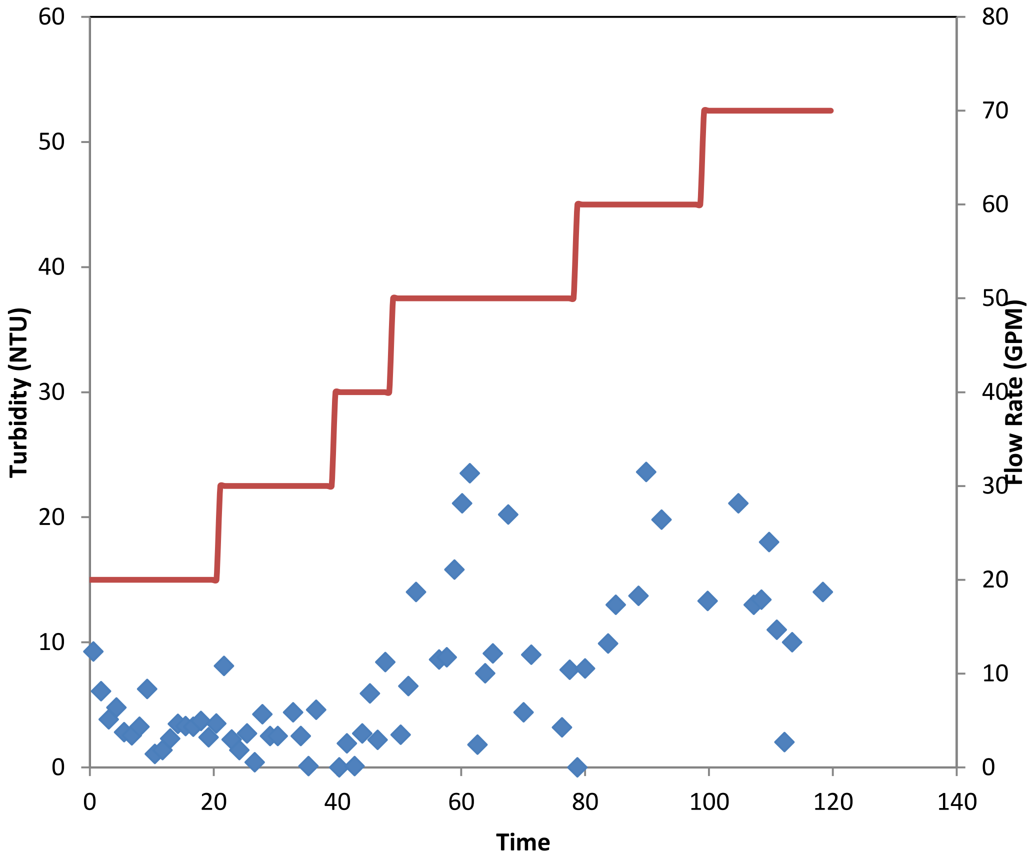

Fig. A-10: 0.5% Geofibers + 4% EnviroKleen test one

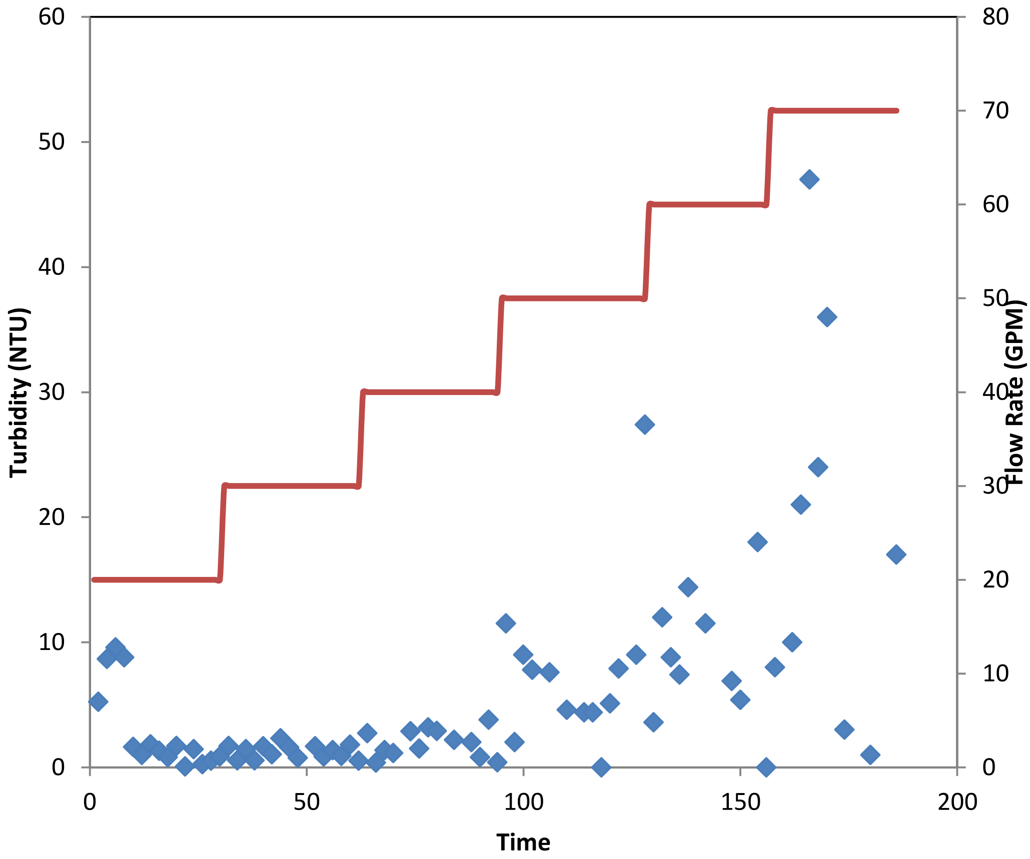

Fig. A-11: 0.5% Geofibers + 4% EnviroKleen test two

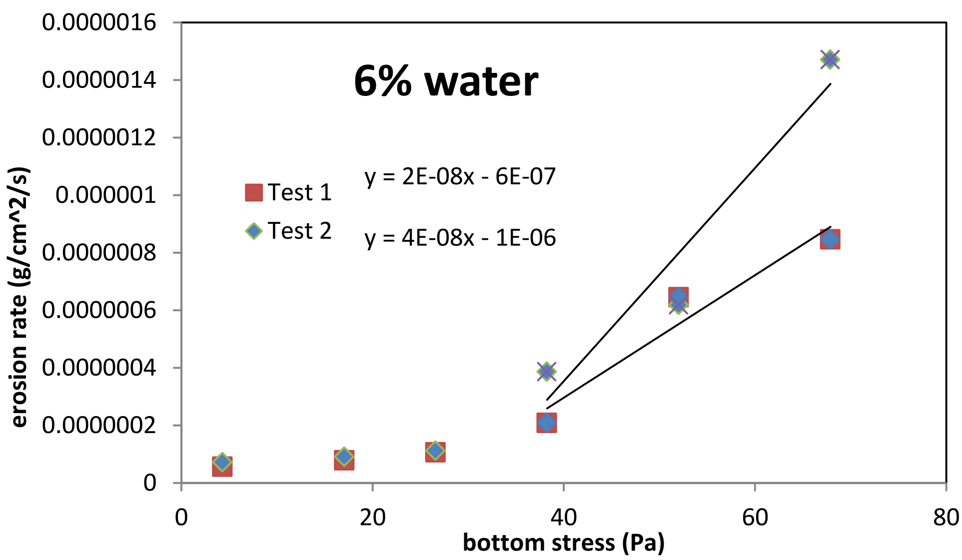

Fig. A-12: Erosion rate versus bottom stress for 6% water tests

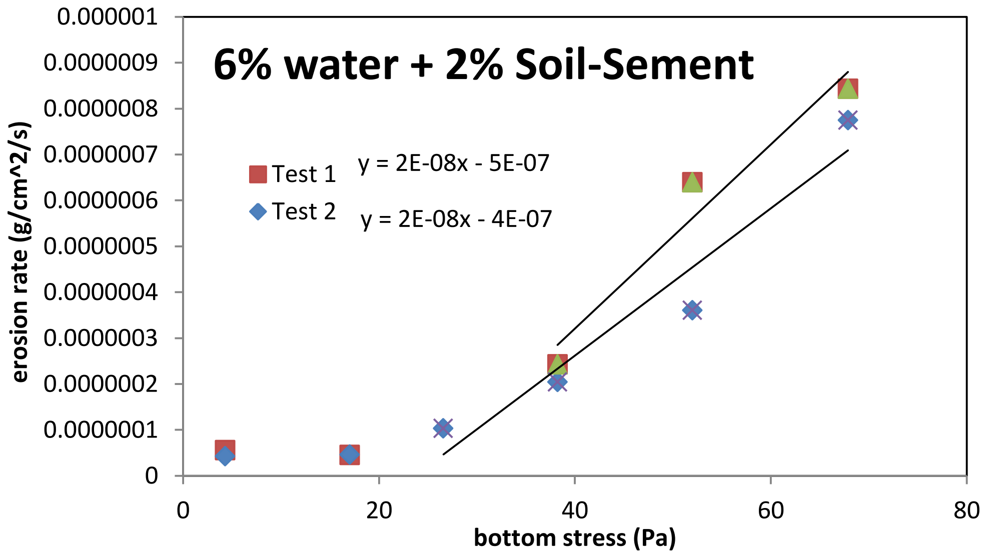

Fig. A-13: Erosion rate versus bottom stress for 6% water + 2% Soil-Sement

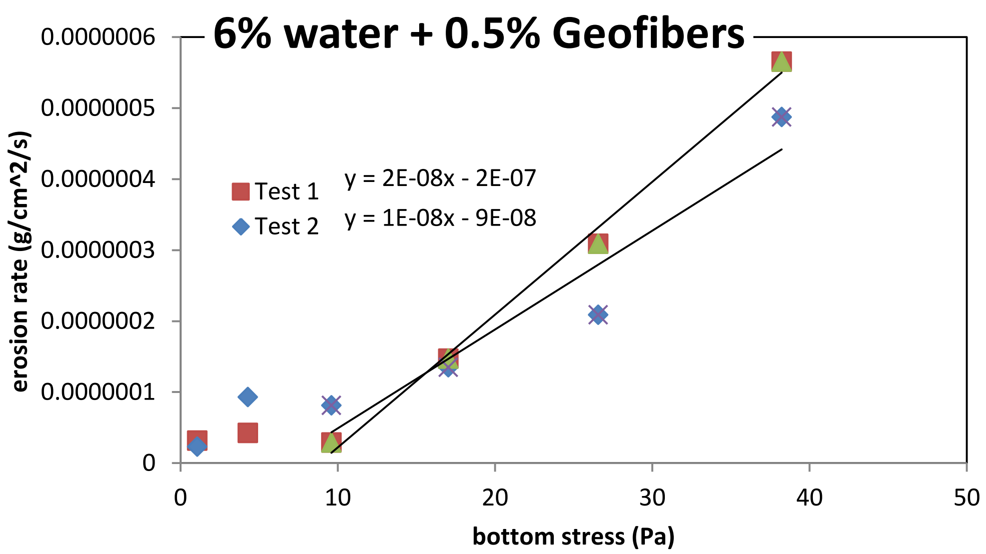

Fig. A-14: Erosion rate versus bottom stress for 6% water + 0.5% Geofibers

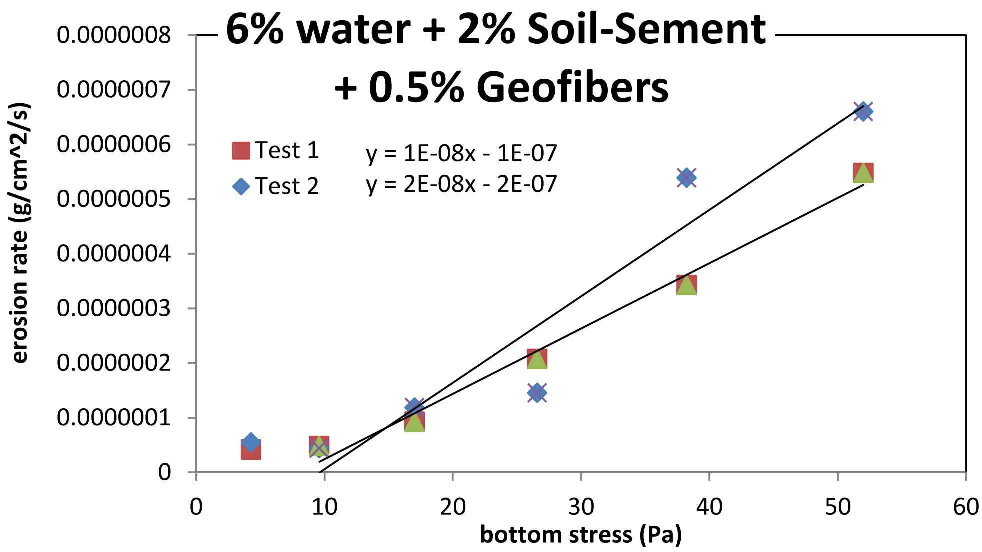

Fig. A-15: Erosion rate versus bottom stress for 6% water + 2% Soil-Sement + 0.5% Geofibers

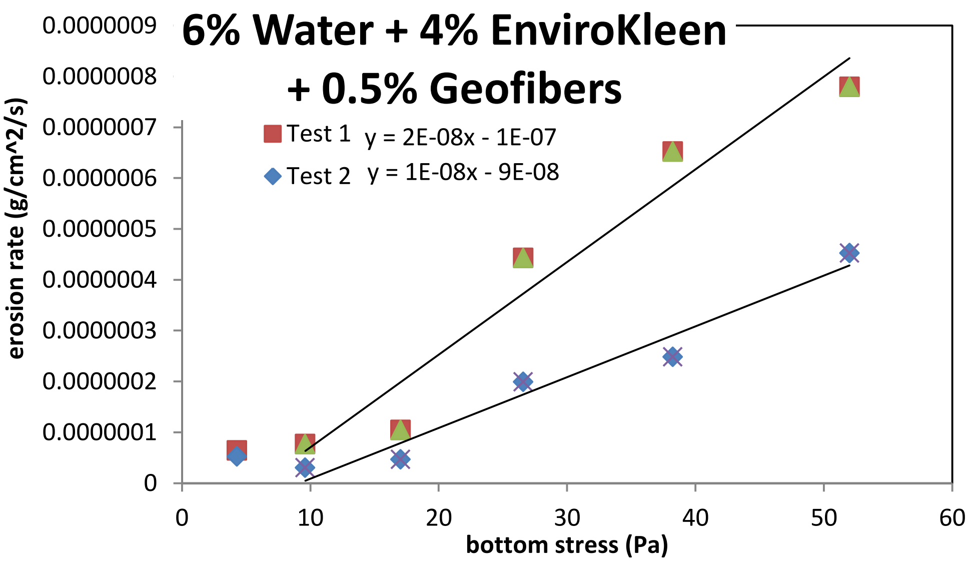

Fig. A-16: Erosion rate versus bottom stress for 6% water + 4% EnviroKleen + 0.5% Geofibers

Fig. A-17: Before and After Pictures of 6% w – Test 1

Fig. A-18: Before and After Pictures of 6% w – Test 2

Fig. A-19: Before and After Pictures of 6% w + 2% SS – Test 1

Fig. A-20: Before and After Pictures of 6% w + 2% SS – Test 2

Fig. A-21: Before and After Pictures of 6% w + 0.5% GF – Test 1

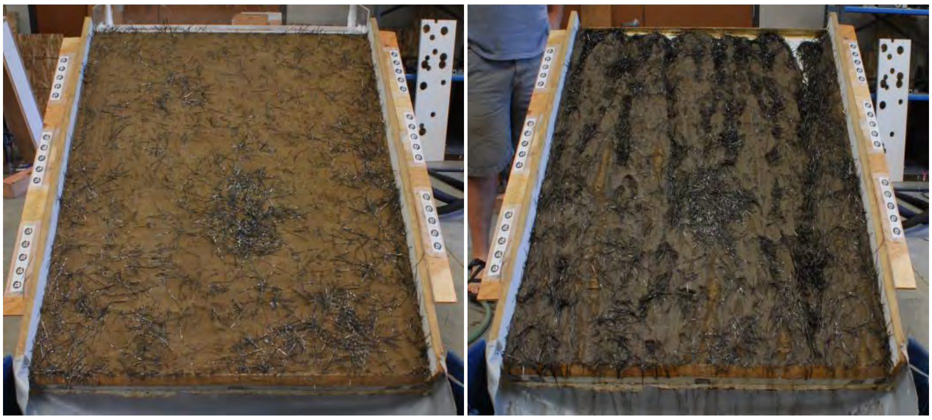

Fig. A-22: Before and After Pictures of 6% w + 0.5% GF – Test 2

Fig. A-23: Before and After Pictures of 6% w + 2% SS + 0.5% GF – Test 1

Fig. A-24: Before and After Pictures of 6% w + 2% SS + 0.5% GF – Test 2

Fig. A-25: Before and After Pictures of 6% w + 4% EVK + 0.5% GF – Test 1

Fig. A-26: Before and After Pictures of 6% w + 4% EVK + 0.5% GF – Test 2

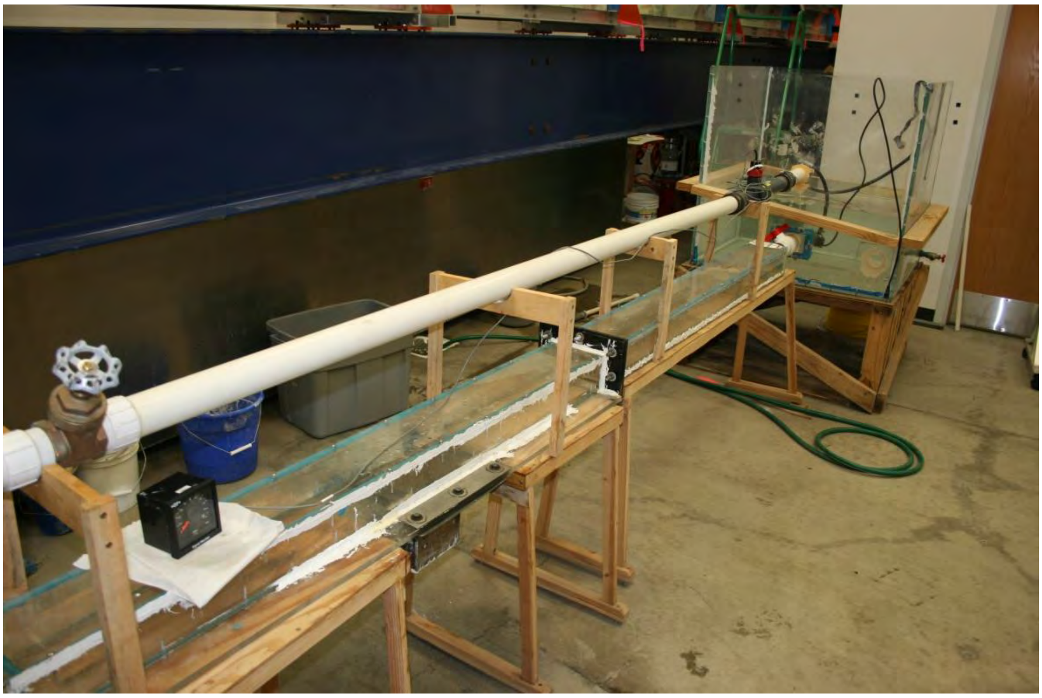

Fig. A-27: The flume used to determine critical shear stress