



# Research

## The Efficacy of Erosion Control Blankets and Soil Stabilizers



Minnesota Local Road Research Board

#### FUNDING ACKNOWLEDGEMENT

This project was conducted with funding provided by the Minnesota Local Road Research Board (LRRB). The LRRB's purpose is to develop and manage a program of research for county and municipal state aid road improvements. Funding for LRRB research projects comes from a designated fund equivalent to  $\frac{1}{2}$  of one percent of the annual state aid for county and city roads.

## Technical Report Documentation Page

1. Report No. MN/RC - 2000-15	2.	3. Recipient's Accession No.	
4. Title and Subtitle  THE EFFICACY OF EROSION CONTROL BLANKETS AND SOIL STABILIZERS		5. Report Date May 2000	
		6.	
7. Author(s)  Scott R. Benik                      David D. Biesboer Bruce N. Wilson                    Brad J. Hansen		8. Performing Organization Report No.	
9. Performing Organization Name and Address  University of Minnesota Department of Biosystems & Agricultural Engineering 1390 Eckles Avenue St. Paul, MN 55108		10. Project/Task/Work Unit No.	
		11. Contract (C) or Grant (G) No. c) 74708      wo) 22	
12. Sponsoring Organization Name and Address  Minnesota Department of Transportation 395 John Ireland Boulevard St. Paul Minnesota, 55155		13. Type of Report and Period Covered Final Report 1997 - 1999	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
16. Abstract (Limit: 200 words)  This report presents the results of a two-year field study on the performance of erosion control products under natural and artificial rainfall conditions.  Vegetation, run-off, and erosion data were collected at a newly constructed roadway. Run-off and erosion data were gathered using natural rainfall events and using a rainulator to spray water onto the surface. Treatments included a wood fiber blanket, a straw/coconut blanket, a straw blanket, a bonded fiber matrix, and disk-anchored straw mulch for natural rainfall events. For the rainulator events, a bar soil treatment also was used. Biomass, percent cover, and species composition also were measured at the research site.  Five run-off events from natural rainfall were measured and revealed very little difference in sediment production between the straw, straw/coconut, and the wood fiber blankets. These blankets had approximately one-tenth the erosion that was observed for the straw-mulch plots.  The impact of the erosion control treatment was substantial for early season artificial events. The sediment loading rates from the blankets and bonded fiber matrix plots were roughly one hundred times smaller than the bare soil plots and 10 times smaller than the straw mulch plots. For late season events, the erosion from these products were approximately one-half of that from straw mulch treatments.			
17. Document Analysis/Descriptors  Erosion Control Products Soil Erosion		18. Availability Statement  No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report)  Unclassified	20. Security Class (this page)  Unclassified	21. No. of Pages  119	22. Price

# **THE EFFICACY OF EROSION CONTROL BLANKETS AND SOIL STABILIZERS**

## **Final Report**

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**May 2000**

*Published by:*

Minnesota Department of Transportation  
Office of Research Services  
Mail Stop 330  
395 John Ireland Boulevard  
St. Paul, MN 55155

Any opinions, findings, conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the Minnesota Department of Transportation, the Local Road Research Board or the Minnesota Agricultural Experiment Station. Mention of product names is for informational purposes only and does not imply endorsement. This report does not contain a standard or specified technique.



## ***FUNDING ACKNOWLEDGMENT***

This project was conducted with funding provided by the Minnesota Department of Transportation (Mn/DOT) and by the Minnesota Local Road Research Board (LRRB). The purpose of the LRRB is to develop and manage a program of research for county and municipal state-aid road improvements. Funding for LRRB research projects comes from a designated fund equivalent to one-half of one percent of the annual state aid for county and city roads.

This project was also conducted with funding provided by the Minnesota Agricultural Experiment Station, Regional Project S-273.



## *ACKNOWLEDGMENTS*

The authors express appreciation to the Office of Environmental Services of the Minnesota Department of Transportation for support of this research, and are indebted to Mr. Leo Holm, Mr. Bob Jacobson, and Mr. Dwayne Stenlund for their valuable assistance and support.

The authors would also like to express gratitude to Jackson Landscaping of Lakeville, Minnesota for the donation of product, time and effort, and are indebted to Mr. Bill Jackson and Ms. Jennifer Hildebrandt for their contributions.

The authors would also like to acknowledge several people whose work was instrumental to the completion of this study.

- Jay Michels, MPCA and Tony Johnson, American Excelsior Co. for their assistance on the Technical Advisory Panel.
- Katie Hetchler, Ethan Jahnke, Anita Thompson, Ronnie Daanen, Princesa Van Buren, Udai Singh, Mike Venem, University of Minnesota for their aid in collecting field samples.
- Dr. Jonathan Chaplin and Brian Hetchler, University of Minnesota for the use and maintenance of equipment.
- Judy Weicherding, University of Minnesota for the editing of the manuscript.





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## *Executive Summary*

Protection of steep embankments is needed to prevent excessive soil loss. An effective vegetative cover is required for long-term control of erosion. Erosion control blankets and soil stabilizers are, however, needed temporarily until vegetation is established. These products may adversely impact the re-establishment of vegetation. This is particularly important for native seed mixes that Mn/DOT has been using in response to state and federal mandates. Even under the best of circumstances, native grasses are difficult to establish because of erosion, soil compaction, low soil fertility, salt pollution, and competition from weeds. The focus of the project is therefore to investigate the effectiveness of short-term erosion control measures and their impact on the revegetation of native plant communities.

Vegetation, runoff and erosion data were collected at a newly constructed roadway at the intersection of U. S. Highway 169 and Hennepin County Road 1 (Pioneer Trail) in Eden Prairie, MN. The roadway was constructed in the summer and fall of 1996 and final grading completed in late spring 1997. Runoff and erosion data were gathered using natural rainfall events in the summer of 1997 and using a rainulator to spray water onto the surface in the summer of 1998. Five erosion control products (ECPs) were evaluated using plots of 9.75 m length and varying widths of 1.2 m to 2.4 m. The five treatments were a wood fiber blanket, a straw/coconut blanket, a straw blanket, a bonded fiber matrix and disk-anchored straw mulch for the natural rainfall events. For the rainulator events, the straw blanket treatment was replaced with a bare soil treatment (*i.e.*, no treatment). Biomass, percent cover, and species composition were also measured at the research site.

Our studies of vegetation establishment in the field for erosion control parallels previous studies by others that show that native vegetation is difficult to establish on roadside soils. The placement of erosion control products on the soil surface may place further constraints on plant establishment. Based on our greenhouse studies and field observations by Mn/DOT personnel [1] these types of soil coverings may hinder the development of broad-leaved forbs. Additionally, and perhaps more significantly, weedy grasses such as barnyard grass and foxtail dominate the flora of plots and compete directly with native vegetation. These robust weedy species perhaps have a selective advantage when compared to native species because they can

penetrate erosion control products more easily than the less robust and more slowly growing native species.

Five runoff events from natural rainfall were measured for the summer of 1997. There were no major runoff events for the summer of 1998, partly resulting from the impact of good vegetal cover in the second year of the study. Shortly after the installation of the plot instrumentation equipment, a large rainfall event occurred before the use of protective dikes at the top of the plots. Runoff from this event overtopped the plots causing failure for the bonded fiber matrix treatments. For subsequent events, erosion from these failed plots was approximately five times than that observed with the straw-mulch treatment. Little difference in sediment production occurred between the straw, straw/coconut, and the wood fiber blankets. These blankets had approximately one-tenth the erosion that was observed for the straw-mulch plots.

Runoff and erosion data were collected during the summer of 1998 using rainfall events produced by a rainulator. The first two runs were conducted in the early season without vegetation, with a dry soil and with a wet soil. The second two runs were conducted late in the year with good vegetative cover, and once again, with a dry and wet soil. The impact of the erosion control treatment was substantial for the early season events. The sediment loading rates from the blankets and bonded fiber matrix plots were roughly one hundred times smaller than the bare soil plots and ten times smaller than the straw mulch plots. For the late season events, the erosion from these products were approximately one-half of that from straw mulch treatments.

In summary, our research have identified the following main points on the performance of ECPs and soil stabilizers to control soil erosion and to establish vegetation:

- Establishment of native vegetation along roadsides is difficult. We have seen indications that some types of ECPs hinder the establishment of vegetation, especially broad-leaved forbs. This could lead to costly reseeding and increased maintenance of areas where these products are used.
- The presence of weedy species may significantly impact the composition of plant communities by outcompeting the desired vegetation for water and nutrients.

However, the weedy species are advantageous in controlling soil erosion by their vigorous growth and abundance.

- At the beginning of the growing season, when there was little or no vegetation, bare soil plots had roughly 10 times the sediment yield than plots with straw mulch. The bare soil plots produced 100 times more sediment than plots containing ECPs.
- At the end of the growing season, when there was good vegetative cover, bare soil plots had five times more sediment than plots with straw mulch. The bare soil plots produced 10 times more sediment than plots containing ECPs.





## *Chapter One*

### *Introduction*

#### **Background**

Soil erosion is a serious problem that has negative impact on the quality of soil for plant growth and on the quality of water resources. Soil erosion accelerates whenever the vegetative layer of the soil is either removed or compromised. This frequently occurs in fields of agriculture, surface mining, forestry as well as home, commercial, and road construction. The soil erosion associated with road construction can vary greatly because it occurs in urban, suburban and rural settings. Each setting has its own unique set of parameters that will ultimately impact the erosion process.

Highway construction is an activity that drastically alters a landscape. Cut and fill operations disrupt the site by bringing subsurface soil horizons that are low in fertility to the surface. These activities may leave the soil in its most erodible condition. Annual erosion rates from construction activities have been reported to be as large as 125,000 to 600,000 kg/ha [2, 3]. This compares with annual erosion rates of 500 to 3500 kg/ha for agricultural landscapes and 100 to 300 kg/ha for natural prairie and forested landscapes [2].

Controlling erosion for construction sites is a two-step process. The first step is to achieve short-term erosion control using erosion control products (ECPs) or using natural mulches. Most of these ECPs have mulch components (often a natural product such as straw, coconut or wood fibers) that minimize the impact of raindrops. Photodegradable polymeric netting or organic adhesives work in conjunction with the mulch component to protect the soil from the erosion caused by surface runoff. The second step of erosion control is the establishment of vegetation for long-term soil stabilization. If the ECPs prevent the establishment of desired vegetation, the site will have problems with long-term soil erosion and establishment of noxious weeds. The ideal ECP would promote rapid germination, growth and establishment of seeded plants as well as provide excellent short-term control of erosion.

## Overview of Related Work

Native species have many desirable qualities that make them suitable for planting along rights-of-ways [4]. Of the native grasses, warm season species such as little bluestem and the grama grasses, which germinate and grow when soil temperatures reach ca. 15 to 19 °C, might be particularly useful. They tend to be limited in height, thus requiring lower maintenance in the form of mowing, and they might be salt tolerant [5]. They can also compete well with noxious weedy species [6]. Many of the warm season grasses and combinations of grasses are currently being tested on a large scale for the Mn/DOT at various sites in and near the metropolitan area.

However, native species can be difficult to establish. This is especially true of the desirable warm season grasses. Since they germinate in late spring, after spring or early summer rains, they have the potential to wash away with eroding soils. In situations where it will be desirable to install warm season grasses (such as near the top of the inslope at the right-of-way shoulder) where their tolerance to sodic soils and short-stature is desired, it will be necessary to install them in combination with erosion control blankets, soil stabilizers, or mulches. Erosion control blankets or stabilizers will certainly impact their germination and early growth. This is of special concern since it is currently being determined that even under the best of circumstances, the establishment of warm season grasses ranges from 30 to 60% at best [5]. A compromise will have to be found between providing acceptable erosion control and acceptable levels of plant establishment.

Erosion from construction sites is a complex process that is a function of climate, soil, topography, and vegetation and other surface covers. Of these four factors, vegetation and surface cover are the easiest to manipulate at construction sites and hence are of critical importance to this study. The impact of surface cover factors is typically represented as the ratio of erosion for a particular land use to that obtained from a bare plot [7]. Recent research efforts have attempted to gain insight into the cover factor by studying factors that influence it. Examples of these parameters are prior land-use, canopy cover, surface cover, surface roughness, and soil moisture [8].

The selection of ECPs is currently based on empirical studies conducted at test facilities located in other states. For example, the Texas DOT (Tx/DOT) has evaluated numerous ECPs on standard clay and sand soils for the performance of these products in terms of sediment loss and establishment of vegetation [9]. The research site in Texas has erosion research plots using both 2:1 and 3:1 (H:V) slopes for each soil type. The plot layout for the 2:1 slopes is 6 meters (20 ft.) wide and 15 meters (50 ft.) long. For the 3:1 slopes, the plot layout is 6 meters (20 ft.) wide and 21 meters (70 ft.) long. Refer to Table 1.1 for a summary of results for various ECPs from the Tx/DOT study. They have also collected data on their impact on vegetation. Although these studies are very useful, erosion is dependent on site-specific conditions. Additional analyses are needed for conditions of Minnesota.

Table 1.1: Sediment Loss (kg/10 sq. meters) for Erosion Control Products from a Tx/DOT Study [9].

		SOIL TYPE		Clay	
		Slope (H:V)		2:1	3:1
Manufacturer	Product	2:1	3:1	2:1	3:1
North American Green	Straw Blanket (S150)	23.92	<i>N. T.</i>	0.23	<i>N. T.</i>
	Straw Blanket (S75)	27.01	8.10	0.31	0.27
BonTerra	Straw/Coconut Blanket (CS2)	19.98	<i>N. T.</i>	0.30	<i>N. T.</i>
American Excelsior	Wood Fiber Blanket (Curlex™ I)	9.12	2.94	0.19	0.12
Canadian Forest Products	Bonded Fiber Matrix (EcoAegis™)	29.98	12.26	0.36	0.31
Mat, Inc.	Bonded Fiber Matrix (SoilGuard™)	8.04	<i>N. T.</i>	0.27	<i>N. T.</i>
Control	Bare Soil Condition	50.34	27.21	2.06	1.24

*N. T.* = Not Tested

## Objectives of Project

Little is currently known about the effectiveness of erosion control products and their impact on vegetation establishment for Minnesota conditions. Obtaining this information is the overall goal of the project. The specific research objectives are:

- (1) To determine the impact of ECPs on the germination and growth of vegetation at a completed Mn/DOT construction site,

- (2) To determine the effectiveness of ECPs in controlling erosion using natural rainfall events at the construction site of Objective 1, and
- (3) To determine the effectiveness of ECPs in controlling erosion using artificial rainfall events obtained with a rainulator at the construction site of Objective 1.

The report is divided into five chapters. Chapter Two is used to summarize the results obtained from the vegetation component of the project. It discusses the germination and establishment of vegetation under field conditions. Biomass density and percent cover values are given. Chapter Three is used to present the results obtained from natural rainfall events. It includes sediment yield and runoff depth from five events that occurred during the summer of 1997. The results obtained with a rainulator are presented in Chapter Four. It contains sediment yield and runoff data from runs with different vegetal cover and soil water contents. A summary of the study is given in Chapter Five. It links together the results from the other chapters. The measured hydrographs and sedimentgraphs obtained from the rainulator runs are given in Appendix A. Appendix B contains the vegetative survey notes of the research site. Appendix C offers information from a greenhouse study that was conducted to determine the impacts of several types of erosion control blankets on the germination and early growth of native vegetation.

## *Chapter Two*

### *Experiments on the Establishment of Vegetation*

#### **Introduction**

Long-term erosion control for most construction sites is dependent on the protection provided by vegetation. In addition to controlling erosion, there has also been increased interest in using native species. In this chapter, the data collection and analysis of the vegetation component of the study are presented. A description of the research site is given first. Seedbed preparation and data collection procedures are presented. The results obtained for percent cover, biomass density, and biomass diversity are then given and discussed.

#### **Experimental Procedures**

##### *Site Description*

The research site was located on the east-facing slope of a sedimentation basin that is a part of newly constructed roadway in the southwest metropolitan area of St. Paul-Minneapolis, MN. The sedimentation basin is located in the southwest corner of the intersection of U. S. Highway 169 and Hennepin County Road 1 (Pioneer Trail) in the City of Eden Prairie, MN. The basin was constructed in the summer and fall of 1996, and final grading was completed in late spring 1997. The basin was excavated out of an existing hillside, and the hillside soil was stockpiled on site. Clay soil was hauled to the site to achieve construction specifications for the grade. The stockpiled hillside soil was uniformly spread over the entire basin to a depth of 15 cm (6 in) and served as topsoil. The soils were nutrient poor because of the mixing of subsurface soil and other clay soils.

The first set of plots, used to study the erosion associated with natural rainfall events, were installed in May 1997 (see Chapter Three). None of the plots were vegetated. The plots were hand-raked and smoothed to remove clods of clay and debris. The plots were fertilized with a 22-5-10 slow-release fertilizer (Turfgo™, United Horticultural Supply, Kasota, MN) at a rate of 77 kg-N/ha, 18 kg-P/ha, and 35 kg-K/ha. The plots were seeded with Mn/DOT Seed Mix 15A a native tall-grass prairie seed mix, at a broadcast seeding rate of 50 kg/ha. The

seed was obtained from two local vendors (Mohn Seed Company, Cottonwood, MN and Peterson Seed Company, Savage, MN). The species composition of the seeding mix is given in Tables 2.1 and 2.2. The seeding rate of each grass species was precisely determined by weight for each plot. After seeding and fertilizing, the plots were raked to ensure good seed-to-soil contact.

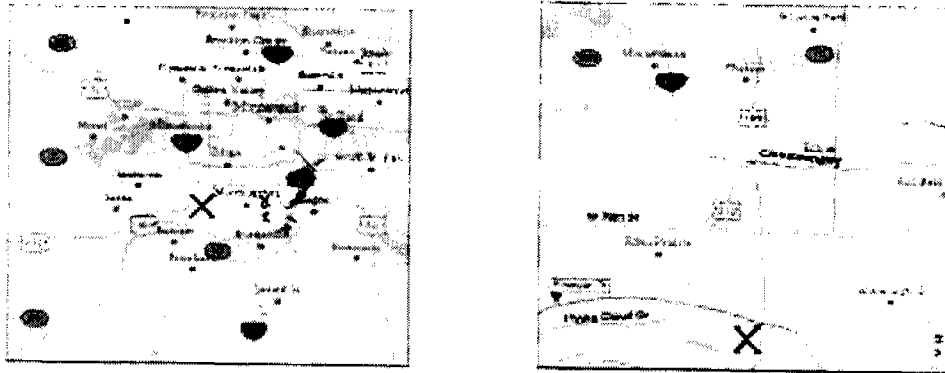


Figure 2.1: Location of the research site in Minneapolis/St. Paul, MN.

### Preparation of the seedbed

Table 2.1: Grass species used in Mn/DOT Mix 15A. Names according to [10].

Species Name	Common Name	Percentage of Seed Mixture
<i>Andropogon gerardi</i> Vitman	Big Bluestem	5.0
<i>Bouteloua curtipendula</i> Michx.	Sideoats Grama	10.0
<i>Elymus canadensis</i> L.	Canadian Wild Rye	5.0
<i>Agropyron caninum</i> (L.) Beauv.	Slender Wheat Grass	5.0
<i>Lolium perenne</i> L. var. <i>aristatum</i> Willd.	Annual Rye Grass	10.0
<i>Panicum virgatum</i> L.	Switch Grass	2.0
<i>Andropogon scoparius</i> Michx.	Little Bluestem	12.0
<i>Sorghastrum nutans</i> L.	Indian Grass	12.0
NA	ReGreen™†	34.0

† A sterile wheat/wheatgrass hybrid. HybriTech™, Seed International, Inc., Wichita, KS.

The second set of plots, used to study the erosion associated with artificial rainfall events, was installed in May 1998 (see Chapter Four). Existing weedy vegetation from the previous growing season was removed by rototilling prior to plot installation. Two weeks after rototilling, the plots were sprayed with glyphosate herbicide. Remaining dead vegetation and erosion control products used to cover the plots during the previous year were removed. The

plots were tilled to a uniform depth of 15 cm (6 in) with a rototiller. The seedbed of the second set of plots was then prepared in a manner identical to the previous set.

Table 2.2: Forb species used in Mn/DOT Mix 15A. Names according to [10].

Species Name	Common Name	Species Name	Common Name
<i>Asclepias tuberosa</i> L.	Butterfly Milkweed	<i>Liatris aspera</i> Michx.	Rough Blazingstar
<i>Aster laevis</i> L.	Smooth-blue Aster	<i>Liatris pycnostachya</i> Michx.	Tall Blazingstar
<i>Astragalus canadensis</i> L.	Canada Milkvetch	<i>Monarda fistulosa</i> L.	Wild Bergamot
<i>Cassia fasciculata</i> L.	Partridge Pea	<i>Penstemon grandiflorus</i> Nutt.	Showy Penstemon
<i>Dalea candida</i> Michx.	White Prairie Clover	<i>Ratibida columnifera</i> (Nutt.) Woot. & Standl.	Columnar Coneflower
<i>Dalea purpureum</i> Vent.	Purple Prairie Clover	<i>Ratibida pinnata</i> (Vent.) Barnh.	Grey-headed Coneflower
<i>Desmodium canadense</i> L.	Showy Tick-trefoil	<i>Rudbeckia hirta</i> L.	Black-eyed Susan
<i>Echinacea angustifolia</i> DC	Narrow-leaved Coneflower	<i>Solidago rigida</i> L.	Stiff Goldenrod
<i>Heliopsis helianthoides</i> L.	Common Ox-eye	<i>Verbena hastata</i> L.	Blue Vervain
<i>Verbena stricta</i> Vent.	Hoary Vervain	<i>Zizia aurea</i> (L.) Koch.	Golden Alexanders

### Percent Cover

The vegetation of each plot was surveyed for percent cover. A transect was laid through the center of the entire length of each plot. The plot was broken into five equal segments along the transect. At each marked segment, a 1-m<sup>2</sup> metal hoop was thrown over the top of the vegetation to estimate of percent cover. The reported values of percent cover were made in late August near the end of the growing season.

### Biomass Density

The above-ground vegetation of the entire plot was harvested with the aid of a gas-powered trimmer to cut the biomass at the end of each growing season. The harvested vegetation was brought back to the laboratory and dried at 75 °C for 24 hours. The vegetation was weighed after drying in order to determine the amount of dry biomass per unit area. The 1997-growing season biomass for the natural event plots was harvested in late-September, 1997. The 1998-growing season biomass for the natural event plots was harvested in early-October, 1998. The 1998-growing season biomass for the artificial event plots was harvested on early-October, 1998.



## *Vegetative Diversity*

In parallel with determination of percent cover and before harvesting the vegetation, biodiversities within plots were noted. The abundance of vegetation was noted in terms of dominance and absence. Ecological competition was noted, such as the relative amounts of grasses and forbs.

## **Results**

Percent cover for a plot was estimated as the mean of five measurements within a plot. The mean of the experimental standard, the straw mulch treatment, was determined as the mean of all measurements percent cover within the standard treatment (N = 1 measurement per station, 5 stations per replicate, 3 replicates per treatment = 15 measurements per treatment). This mean value was used as the standardizing value for all of the other percent cover measurements. Each percent cover measurement was divided by the mean percent cover of the straw mulch to obtain a relative cover value for a given treatment. A mean relative cover value was calculated by using the individual relative cover values for a given treatment. A standard deviation of relative cover was also determined for each treatment.

The amount of biomass for each plot was measured gravimetrically by first harvesting the biomass and then drying the biomass at 75 °C for 24 hours. The biomass density was calculated as the amount of dry biomass per plot area and is presented as kg-biomass/ha. The relative biomass density for each treatment was determined by taking the actual biomass density of each treatment for a given year and making it relative to the straw mulch treatment of that year.

Estimates for vegetative diversity were made from the vegetative survey notes taken for each plot. Commonalties and differences between plots were looked for in terms of grass and forb diversity, dominance of weedy vegetation, presence of native vegetation and overall vegetative composition. The nature of the data is such that statistical trends cannot be made; the data is purely subjective.

### Percent Cover

Figure 2.2 shows that during the first growing seasons of the natural event plots and the artificial event plots, the straw mulch had a higher mean relative cover than any of the erosion control products. The error bars indicate the standard deviation of relative cover and the spread of these bars suggests no statistical difference between the treatments. This figure also shows that differences between all treatments in mean relative cover during the second growing season for the natural event plots are less than in the first growing season. Table 2.3 gives the actual mean values of percent cover with the coefficient of variation for each of the treatments. The coefficient of variation ( $C_v$ ) is defined as the standard deviation divided by the mean.

Table 2.3: Percent Vegetative Cover for 1997 and 1998 seasons.

Treatment	1997 - Natural Event Plots		1998 - Natural Event Plots		1998 - Artificial Event Plots	
	Mean Percent Cover	$C_v$	Mean Percent Cover	$C_v$	Mean Percent Cover	$C_v$
Straw Mulch Treatment	89%	0.16	78%	0.19	70%	0.14
Straw Blanket	68%	0.34	83%	0.19	NA	NA
Straw/Coconut Blanket	79%	0.30	83%	0.11	55%	0.23
Wood Fiber Blanket	66%	0.24	72%	0.18	60%	0.28
Bonded Fiber Matrix	44%†	0.39	78%†	0.16	67%	0.21
Bare Soil Treatment	NA	NA	NA	NA	63%	0.23

† The plots of this treatment resulted from a failure of the bonded fiber matrix treatments. Refer to Chapter Three for further details.

### Biomass Density

The mean biomass density of the treatments relative to the mean biomass density of the straw mulch for the 1997-growing season of the natural event plots is presented in Figure 2.3. The mean relative biomass density of the straw mulch treatment was 1.0, which had the greatest biomass density of all treatments during this season. The mean biomass density of the straw mulch treatment was also the greatest during the second growing season of these plots. The mean relative biomass density of the bonded fiber matrix treatment was 0.3 in the first growing season and 0.8 during the second season. The erosion control blankets performed equally well during the first and second years. The biomass associated with the wood fiber treatment was roughly one-half of the straw mulch biomass density during the second year.

The mean biomass density of the treatments relative to the mean biomass density of the straw mulch for the 1998-growing season of the artificial event plots is presented in Figure 2.3. The mean relative biomass density of the bare soil treatment was 1.1, which had the greatest biomass density of all treatments. The mean relative biomass density of the bonded fiber matrix treatment was 0.5, which had the least amount of biomass of all treatments. The mean relative biomass densities of the wood fiber and the straw/coconut blanket treatments were 0.67 and 0.75, respectively. It should be noted that all of the erosion control treatments (including straw mulch) had less mean biomass density than the bare soil treatment.

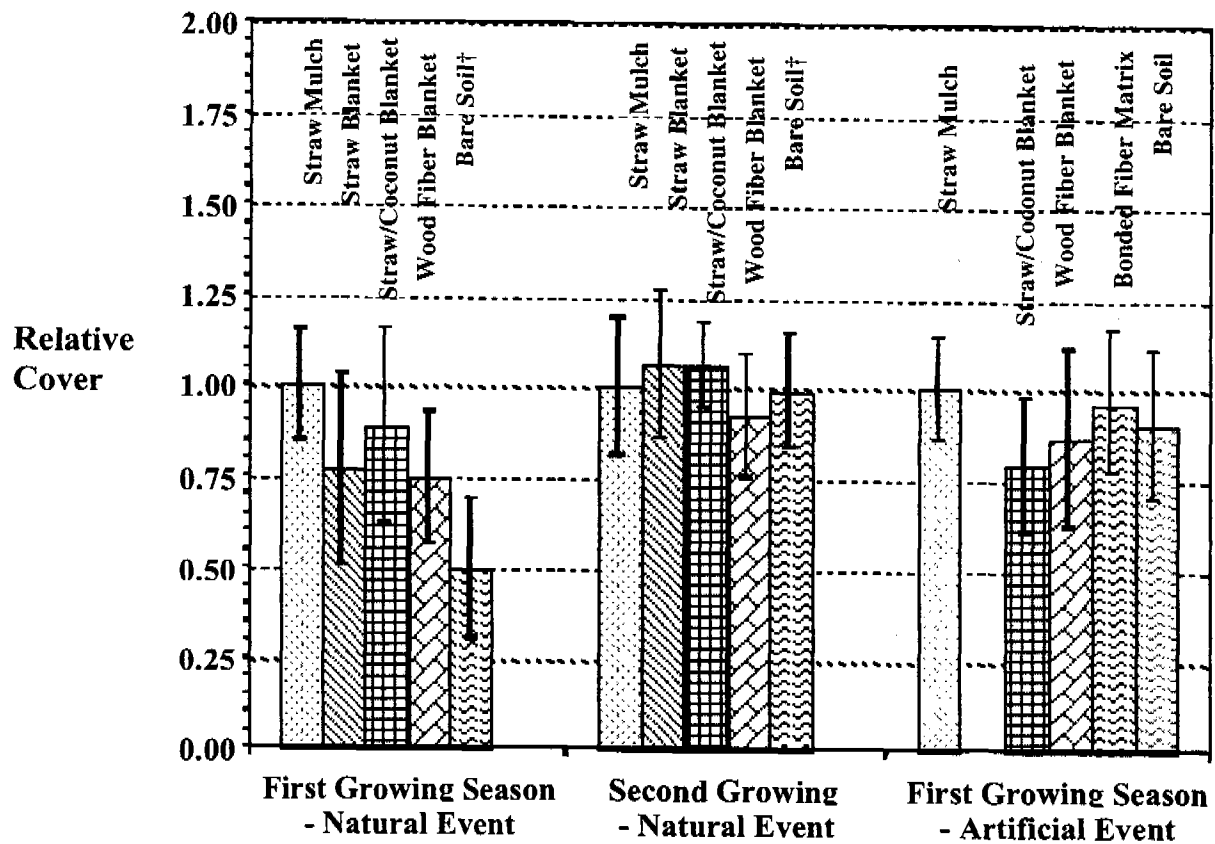


Figure 2.2: Relative Cover for the 1997 and 1998 field seasons. The error bars are the maximum and minimum of the observed values. †The plots of this treatment resulted from a failure of the bonded fiber matrix treatments. Refer to Chapter Three for further details.

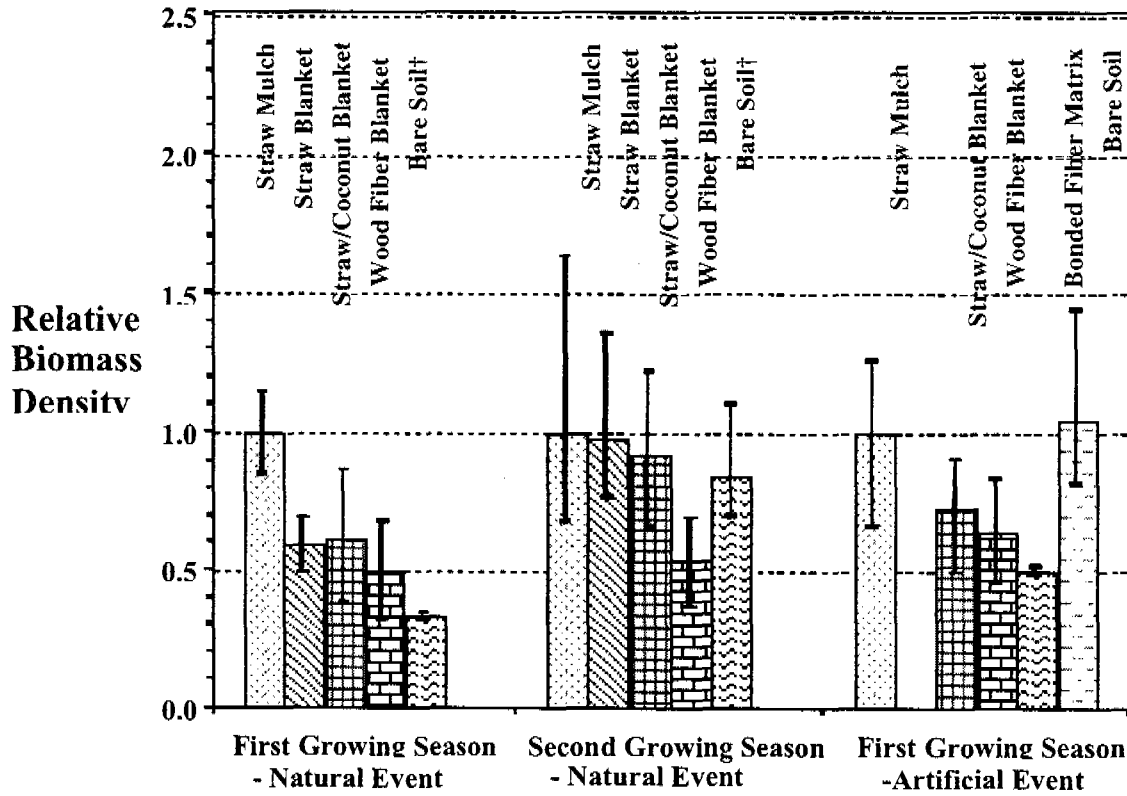


Figure 2.3: Relative Biomass Density for the 1997 and 1998 field seasons compared to straw mulch. The error bars are the maximum and minimum observed values. †The plots of this treatment resulted from a failure of the bonded fiber matrix treatments. Refer to Chapter Three for further details.

*Biomass Diversity*

Appendix B contains condensed versions of the vegetative survey notes taken from the field. The most striking observation was the prevalence of weedy species. Barnyard grass [*Echinochloa crusgalli* (L.) Beauv.] and foxtail [*Setaria vividis* (L.) Beauv.] were the dominant grass species on both the natural and artificial event plots. It was noticed that the presence of these weedy grasses were more abundant than the cover crop within the artificial event plots during the 1998 growing season. Although these weedy grasses also occurred commonly on the natural event plots during the first growing season, they were not as abundant as in the artificial event plots. During the first growing season of the natural event plots, the dominant grass species was the cover crop ReGreen, which never became the dominant grass species on the artificial event plots.

Table 2.4: Vegetative Biomass Density for 1997 and 1998 Seasons.

	1997 - Natural Event Plots	1998 - Natural Event Plots	1998 - Artificial Event Plots
<b>Mean Biomass Density, kg/ha</b>			
Straw Mulch Treatment	3027.3	2009.5	2289.0
Straw Blanket	1804.3	1974.9	NA
Straw/Coconut Blanket	1872.5	1859.2	1666.1
Wood Fiber Blanket	1519.3	1084.8	1475.5
Bonded Fiber Matrix	†	†	1131.0
Bare Soil Treatment	1017.5 †	1694.2 †	2401.3
<b>Maximum Biomass Density, kg /ha</b>			
Straw Mulch Treatment	3481.5	3272.9	2875.9
Straw Blanket	2091.4	2721.4	NA
Straw/Coconut Blanket	2623.7	2448.8	2069.1
Wood Fiber Blanket	2051.9	1395.1	1913.8
Bonded Fiber Matrix	†	†	1175.5
Bare Soil Treatment	1042.8 †	2213.7 †	3297.5
<b>Minimum Biomass Density, kg /ha</b>			
Straw Mulch Treatment	2590.1	1361.5	1516.9
Straw Blanket	1466.0	1530.1	NA
Straw/Coconut Blanket	1160.5	1329.1	1119.0
Wood Fiber Blanket	941.8	729.9	1047.7
Bonded Fiber Matrix	†	†	1106.9
Bare Soil Treatment	975.5 †	1405.2 †	1861.3

† The plots of this treatment resulted from a failure of the bonded fiber matrix treatments. Refer to Chapter Three for further details.

Numerous weedy forb species, in some instances, dominated the vegetation. Ragweed (*Ambrosia artemisiifolia* L.), wild alfalfa (*Medicago sativa* L.), and whiteclover (*Trifolium repens* L.) were the dominant weedy forbs. There were also instances of noxious weed infestation; leafy spurge (*Euphorbia esula* L.) and spotted knapweed (*Centaurea maculosa* Lam.) occurred frequently within the vegetation. It was noticed that the weedy forbs contributed the greatest portion of the harvested biomass during both the first and second growing seasons of the natural event plots, as well as during first growing season of the artificial event plots.

The native grasses never became fully established during the first year of either the natural or the artificial event plots. Only one species, a single side-oats grama grass, of the native grasses reached a level of maturity to produce seed within the first growing season on both sets of plots. The presence of native grasses was noted, but the diminutive stature of the grasses did not allow for identification or differentiation. It should be noted that native

grasses exhibit reduced growth rates in nutrient-poor, created soils, therefore it is not expected to see establishment of native grasses for the first 3 - 5 years after initial seeding. During the second growing season of the natural event plots, some of the native grasses did produce seed. It was noticed that of the native species included in the seed mix, only three species regularly produced seed; big bluestem (*Andropogon gerardii* Vitman.), indiagrass (*Sorghastrum nutans* L.), and side-oats grama grass (*Bouteloua curtipendula* Michx.). A few other native grasses produced seed (e. g., switchgrass, *Panicum virgatum* L.), but these species were not common in all plots.

The native forbs never became fully established during neither the first-growing season of the natural event plots nor the artificial event plots. Two forb species that seemed to be prevalent to a certain degree within the first growing seasons were black-eyed susans (*Rudbeckia hirta* L.) and purple-prairie clover (*Dalea purpureum* Vent.). However, the black-eyed susans seemed to be less abundant during the second growing season.

## **Discussion**

During the first growing season of the natural event plots, the poor vegetative establishment of the bonded fiber matrix treatment was probably caused by seeds being washed away during the intense July 1, 1997 storm event. After this storm event, the sections of the bonded fiber matrix plots that were least impacted were the areas that had an established cover crop. The sections of greatest rill formation were the sections corresponding to areas of poor establishment of the cover crop. This observation indicates the importance of reseeded after a slope failure. While the total biomass of these plots seemed to recover during the second growing season (due to the prevalence of weedy vegetation), the reduced diversity may indicate that most of the native seed was washed away.

During the first-growing seasons of the natural and artificial event plots, the straw mulch treatments attained both the highest mean relative cover as well as the highest mean relative biomass density. There were minor differences in relative cover and relative biomass density between all of the treatments during the second season of growth. The increased relative cover and relative biomass density may indicate that the erosion control products may be negatively impacting the establishment of the vegetation.

One manner in which the inhibition was noticed was the occurrence of "tenting" caused when plants grow upwardly against the erosion control blankets. Tenting is the process where the plastic netting of erosion control blankets provides a physical barrier preventing the dicotyledons of broad-leafed forb species from passing through the blanket. As the forb grows, the blanket loses contact with the soil surface and is "tented" above the soil. The spikelet nature of the grass seedlings allows for grass species to efficiently pass through the blanket and netting. The prevention of forb species from passing through the blanket may cause the diversity of a stand to be dominated by grasses and have a reduced amount of forb species. Tenting is also of concern for erosion control protection because of the loss of contact between the blanket and the soil surface.

### **Key Findings**

- In the first growing season of growth of the natural event plots and the artificial event plots, the straw mulch had a higher mean relative cover than any of the erosion control products.
- Differences between all treatments in mean relative cover during the second growing season for the natural event plots are less than in the first growing season, which may be an indication of the reduction of overall weedy species individuals.
- The native grasses never became fully established during the first year of either the natural or the artificial event plots. During the second growing season of the natural event plots, some of the native grasses did produce seed.
- It was noticed that the weedy forbs contributed the greatest portion of the harvested biomass during both the first and second growing seasons of the natural event plots, as well as during first growing season of the artificial event plots.

## *Chapter Three*

### *Experiments Using Natural Rainfall Events*

#### **Introduction**

The most straightforward approach to evaluate different erosion control products (ECPs) is to measure their performance under natural conditions. This approach was taken in the study for the rainfall events during the summers of 1997 and 1998. The first summer corresponds to a newly constructed site, and erosion control is strongly influenced by the effectiveness of the ECP. In the second year, the vegetation cover plays a greater role in controlling erosion.

The results obtained from the natural rainfall events are presented in this chapter. The experimental procedures are given first. This includes a description of the erosion plots, the instrumentation systems to collect soil loss and runoff, and data analysis procedures. The results are then presented, and conclusions are drawn on the effectiveness of the different ECPs.

#### **Experimental Procedures**

##### *Description and Preparation of Erosion Plots*

Runoff and erosion data were gathered at the research site previously described in Chapter Two. Four ECPs and a straw mulch cover condition were evaluated on the east-facing slope. The ECPs were: (1) straw blanket, (2) straw/coconut blanket, (3) wood fiber blanket, and (4) bonded fiber matrix (BFM). Three replicates were used for each cover condition. The experimental layout of the east-facing slope is shown schematically in Figure 3.1.

The erosion plots were installed at the site in May 1997. Each of the research plots had a uniform side slope of 2.8:1. The length of the plots was 9.75 m (32 ft) for all plots. The width of the plots was determined by product width. The wood fiber blanket width was 1.2 m (4 ft), the straw blanket was 2 m (6.6 ft) wide, and the straw/coconut blanket and the



bonded fiber matrix were 2.4 m (8 ft) wide. The disk-anchored straw mulch had a width of 1.2 m (4 ft). Varying the plot width was necessary to minimize the effects of installation techniques (*i.e.*, seams) on the performance of the products. A series of sheet metal borders were placed around the perimeter of each erosion plot to prevent the lateral flow of one plot from entering another plot. The 15 cm (6 in) borders were driven 7.5 cm (3 in) into the soil surface. The seedbed was prepared as described in Chapter Two.

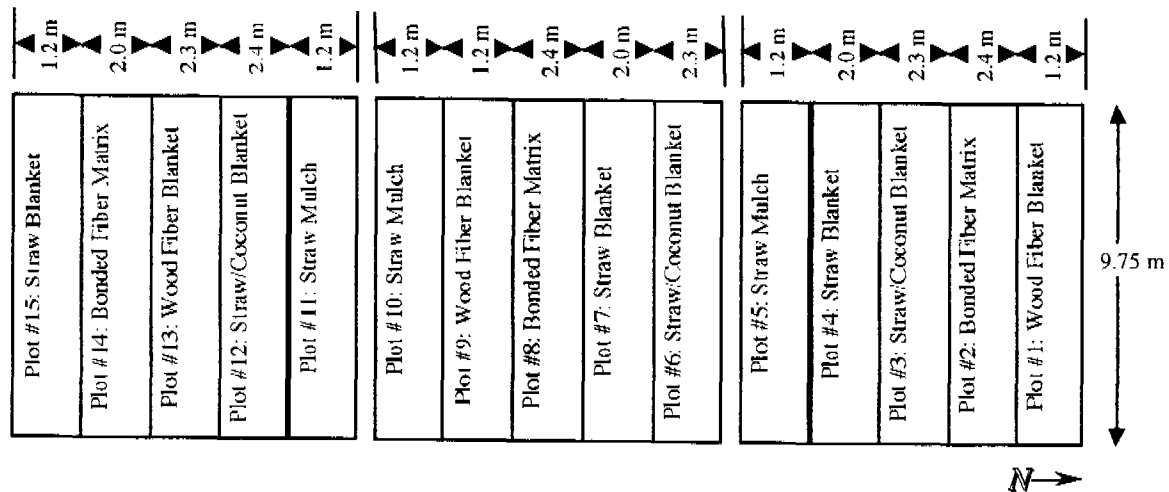


Figure 3.1: Layout of the Natural Rainfall Event Plots. The plots were orientated with the flow occurring from the top of the graphic towards the bottom.

After the plot borders installation and seedbed preparation, all of the ECPs were installed according to instructions provided by the manufacturer. A local company that sells the product applied the bonded fiber matrix treatment. The straw mulch was applied by hand-scattering and was anchored into the soil with a garden spade. Clear polyethylene sheeting was placed over the plots and was removed after the runoff collection system was installed and was on the plots for five days.

### Data Collection

A 1.2 m (4 ft) wide runoff collector was installed at the base of each plot. The purpose of the collector was to intercept and direct runoff to a 102 mm (4 in) diameter PVC pipe of 1.2 m (4 ft) length. Borders were installed to direct runoff for plots wider than 1.2 m (4 ft) to the collector. A metal shield was installed over the plot to prevent rain from entering the

collector. The collector was designed so that 100% of the runoff from each plot would be routed to a tipping bucket located at the outlet of the collector. The tipping bucket was designed to discharge 15% of the runoff into a collection tank and to discharge the remaining 85% into the pond of the sediment basin. Storage tanks for runoff and sediment collection were 246 liters (65 gallons) in size. Based upon the total number of tips for a storm event, the total volume of runoff for the storm event was calculated. A tipping bucket rain gauge located at the bottom of the plots was connected to a data logger and was used to record both rainfall depth and intensity of the storm event.

After a rainfall event, 250 ml of a 0.2 M aluminum ammonium sulfate solution was added for every 10 L of runoff in the storage tanks. The aluminum ammonium sulfate acted as a flocculent to settle out clay and other fine particles. The total runoff volume in the tank was recorded. After a three hour waiting period, the clean runoff water was removed. The settled sediment was then collected using an electric vacuum pump and deposited into one and two liter storage bottles. After most of the sediment was removed with the vacuum pump, the tanks were flushed with a known volume of water and collected with the vacuum pump to capture the remaining sediment in the storage tank. Sediment samples were dried at 105 °C for 48 hours to remove free water.

## **Results and Discussion**

### *Rainfall Events*

The research plots were installed and the plastic was taken off of the plots on June 11, 1997. The month of June was very dry, and no measurable runoff events occurred during this month. However, the month of July 1997 in the St. Paul-Minneapolis metropolitan area was the second wettest month on record. A large storm occurred on July 1, 1997, which included depth of rain in a 30-minute burst of 7.6 cm (3 in). Since the diversion dikes were not yet installed, runoff from the area upslope of the plots overtopped some, and possibly all, of the research plots.

All of the bonded fiber matrix plots failed during the storm of July 1, 1997. The upslope plot border may have partially contributed to the failure by creating an artificial overfall condition

at the top of each plot. After the storm event, there was significant rill formation through the entire length of the erosion test plot even though some product remained on portions of the plot. The bonded fiber matrix product provided very little protection for subsequent events. Rill formation occurred in the straw mulch plots but not to the extent of the bonded fiber matrix plots. For subsequent events, we will refer to these plots as being a bare soil condition.

Other frequent storm events with rainfall depths greater than 2.5 cm (1 in.) occurred in the month of July 1997. One storm event caused the water level in the basin to rise 1 m (3 ft.) above its normal elevation. The combination of intense storm events and poorly established vegetation resulted in significant erosion in and out of the plots, causing a malfunction of the data collection for some of the events (such as an event on July 19, 1997). During the last portion of July 1997, the data system was further protected to prevent any data loss resulting from future intense storms. Because of these problems, only the results of five storms beginning on July 25, 1997 are considered reliable and are used in this report. Summary statistics for these storms are given in Table 3.1.

Table 3.1: Natural Rainfall Event Summary.

<b>Date</b>	<b>Total Rainfall Depth (mm)</b>	<b>Rainfall Duration (hr)</b>	<b>Comments</b>
7/25/97	19.0	3.25	Early season, little vegetation
8/05/97	16.0	3.73	These two storms have combined sediment and runoff data
8/14/97	6.4	1.50	
8/19/97	81.5	7.92	
9/08/97	24.6	1.01	
9/16/97	55.9	4.22	Late season, established vegetation

The data collection system was also used during storms for the summer of 1998. However, no significant runoff events occurred during the second summer of the study. This was partially caused by the good growth of vegetation on the plots as previously discussed in Chapter Two. In addition, the storms were not as intense as those occurring in 1997 were.

## Analysis of Runoff Data

Runoff depths are summarized in Table 3.2 for the five storms of the summer of 1997. The results are shown as a dimensionless depth in Figure 3.2. The dimensionless depths are defined as the runoff depth for the treatment relative to the straw mulch plots, where the straw mulch plots are taken as the standard. This dimensionless representation is discussed in greater detail in Chapter Four. The values in Figure 3.2 are the averages from 3 replicates. The error bars are the maximum and minimum values.

Table 3.2: Natural Rainfall Event Runoff Depths.

	7/25/97	8/14/97	8/19/97	9/8/97	9/16/97
<b>Mean Runoff Depth, mm</b>					
Bare Soil†	10.3	15.5	15.5	38.5	46.9
Straw Mulch	2.1	2.7	2.7	21.8	21.2
Straw Blanket	4.1	12.3	12.3	25.6	30.9
Straw/Coconut Blanket	2.8	3.7	3.7	23.1	31.7
Wood Fiber Blanket	6.4	8.4	8.4	29.3	33.3
<b>Max Runoff Depth, mm</b>					
Bare Soil†	11.7	20.1	20.1	49.2	54.5
Straw Mulch	3.9	3.6	3.6	30.7	22.9
Straw Blanket	6.2	29.7	29.7	40.2	53.3
Straw/Coconut Blanket	3.6	4.7	4.7	41.9	45.6
Wood Fiber Blanket	9.8	18.4	18.4	35.8	40.8
<b>Min Runoff Depth, mm</b>					
Bare Soil†	9.2	12.3	12.3	21.8	39.5
Straw Mulch	1.1	1.1	1.1	11.2	17.9
Straw Blanket	2.1	2.6	2.6	16.9	14.8
Straw/Coconut Blanket	1.8	2.2	2.2	7.1	16.8
Wood Fiber Blanket	2.5	2.7	2.7	22.9	24.6

† The plots of this treatment resulted from the failure of the bonded fiber matrix treatments.

As shown by Figure 3.2, runoff depth varied by storm. The greatest runoff depth was for the failed plots of bonded fiber matrix. The straw mulch treatment consistently had the least amount of runoff. The three erosion blankets had very similar amounts of surface runoff. Runoff trends are most likely related to the amount of vegetative growth. For example, the bonded fiber matrix plots had the smallest biomass, and the straw mulch the largest. Vegetation can increase infiltration by providing more flow along plant roots and by decreasing the moisture content of the soil with a larger evapotranspiration rate.

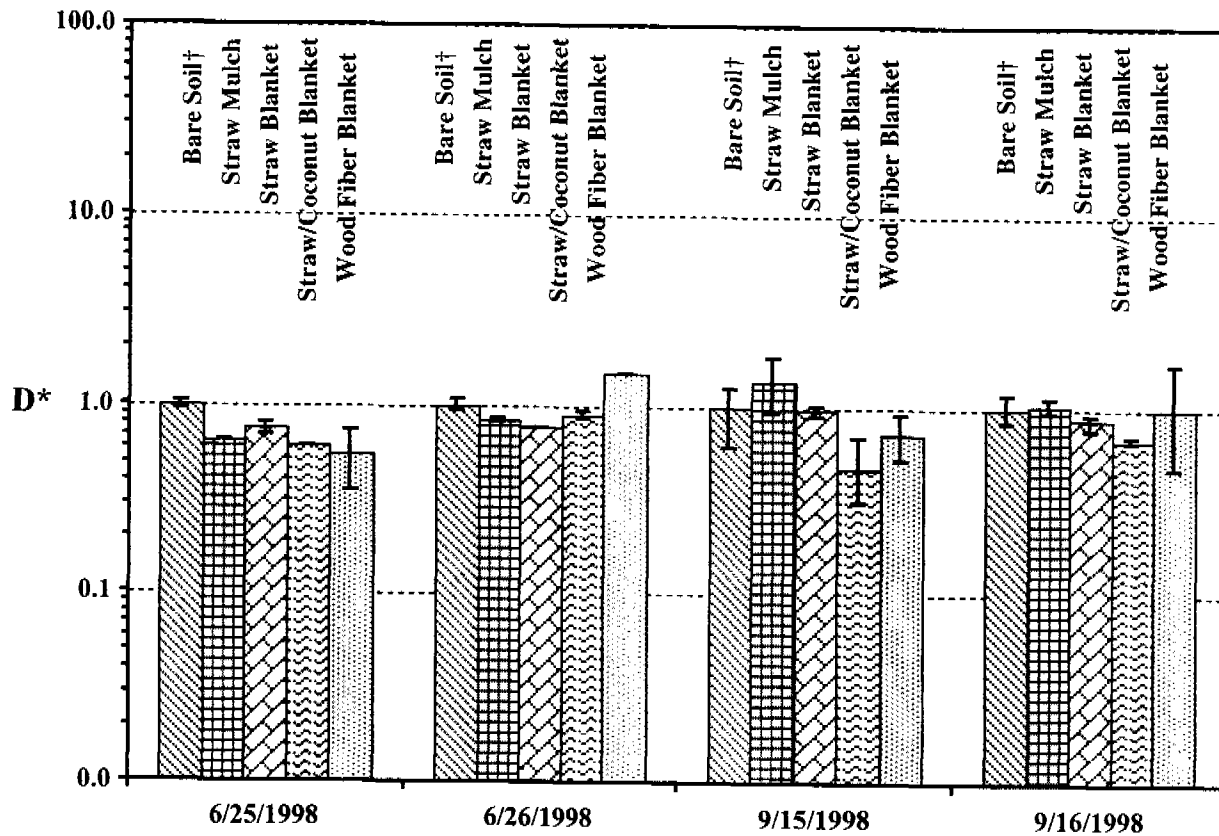


Figure 3.2: Dimensionless Runoff Depth for the Natural Rainfall Events. † The plots of this treatment resulted from the failure of the bonded fiber matrix treatments.

### *Analysis of Sediment Yield*

Sediment yield data for the five storms are shown summarized in Table 3.3. Dimensionless representation is shown in Figure 3.3. The dimensionless sediment yield is the yield for the treatment relative to that observed for the straw mulch plots. Once again, this dimensionless representation is discussed in greater detail in Chapter Four. The average values from three replicates are plotted with error bars indicating the range among replicates.

As expected, the greatest soil erosion occurred for the failed bonded fiber matrix plots, which were considered to be a bare soil condition. Because of the minimum protection after failure, erosion from these plots likely corresponds to that expected from a bare soil condition. The soil erosion here was approximately 10 times greater than the straw mulch plots and 100 times greater than the erosion blanket plots. The second largest erosion occurred for the straw mulch plots. There were little differences among erosion for the different blankets.

All of the blankets had approximately 10 times less erosion than the straw mulch. Since the runoff from these plots are greater than that of the straw mulch, the blankets are effective in protecting the soil from raindrop impact and the shear forces of surface runoff.

Table 3.3: Natural Rainfall Event Sediment Yield.

	7/25/97	8/14/97	8/19/97	9/8/97	9/16/97
<b>Mean Sediment Yield, kg/ha</b>					
Bare Soil†	762.9	787.5	188.6	5437.9	4295.5
Straw Mulch	108.1	99.0	53.6	2124.5	732.2
Straw Blanket	15.9	9.8	8.8	102.8	79.2
Straw/Coconut Blanket	17.7	16.6	7.5	227.6	179.3
Wood Fiber Blanket	28.8	15.1	19.4	257.7	157.2
<b>Max Sediment Yield, kg/ha</b>					
Bare Soil†	1006.8	1182.9	356.6	7787.2	5206.6
Straw Mulch	152.0	182.0	111.7	3700.8	1792.3
Straw Blanket	26.5	13.4	13.3	177.5	144.3
Straw/Coconut Blanket	30.8	31.9	8.5	435.8	417.5
Wood Fiber Blanket	37.7	23.8	27.6	261.8	221.8
<b>Min Sediment Yield, kg/ha</b>					
Bare Soil†	476.6	544.8	83.5	3013.2	3081.7
Straw Mulch	24.8	26.6	13.7	242.1	167.3
Straw Blanket	6.9	4.2	6.3	46.4	27.2
Straw/Coconut Blanket	7.0	8.0	6.2	43.6	29.0
Wood Fiber Blanket	20.3	7.1	12.3	253.6	50.1

† The plots of this treatment resulted from the failure of the bonded fiber matrix treatments.

Inspection of the blankets at the end of the season showed the blankets had apparently lost little of the original integrity and protection ability. The vegetation had established itself and was effective in reducing erosion from the plots.

## Summary and Conclusions

Five erosion control practices were evaluated for natural rainfall for the summers of 1997 and 1998. Three replicates of each practice were used. Shortly after installation of the plots, an intense thunderstorm produced runoff that overtopped the top of the plots. The bonded fiber matrix product failed during this event. Results from these plots for subsequent storms represent the likely response from plots with a bare soil condition (no treatment). Runoff and erosion were measured for five storms in 1997. There were no storms in the summer of 1998 that resulted in measurable runoff.

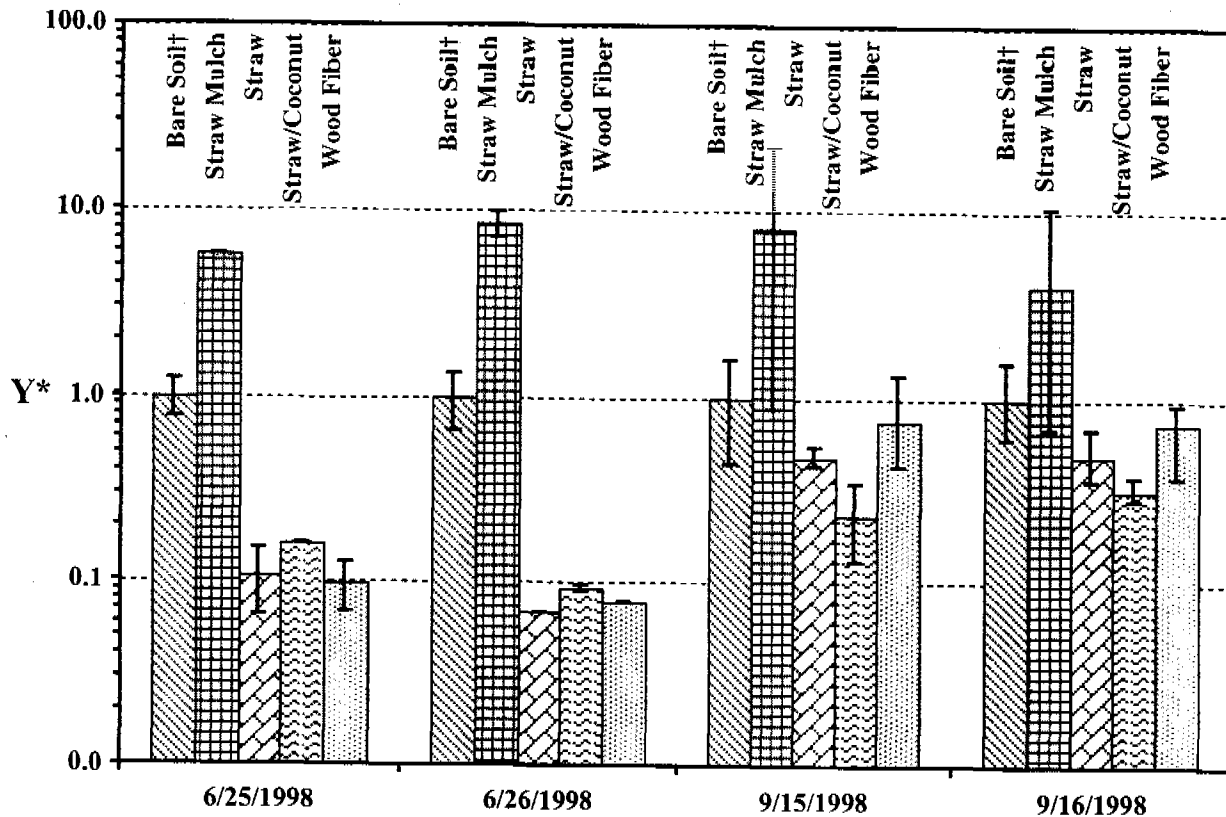


Figure 3.3: Dimensionless Sediment Yield for the Natural Rainfall Events. † The plots of this treatment resulted from the failure of the bonded fiber matrix treatments.

Runoff and erosion rates were varied substantially by storm. The greatest runoff was for the failed plots of bonded fiber matrix, and the least runoff was for the straw mulch treatment. Runoff trends appeared to be related to the amount of biomass. The greatest soil erosion occurred for the failed bonded fiber matrix plots. The soil erosion here was approximately 10 times greater than the straw mulch plots and 100 times greater than the erosion blanket plots. Before final conclusions are drawn, the results of the natural rainfall events will be combined with those obtained from artificial events described and discussed in the next chapter.

### Key Findings

- The greatest runoff depth was for the bare soil condition (failed plots of bonded fiber matrix). The straw mulch treatment consistently had the least amount of runoff. The three erosion blankets had similar amounts of surface runoff.

- Runoff trends are most likely related to the amount of vegetative growth.
- The soil erosion for the bare soil condition was approximately 10 times greater than the straw mulch plots and 100 times greater than the erosion blanket plots.
- There were little differences among erosion for the different blankets. All of the blankets had approximately 10 times less erosion than the straw mulch.





## *Chapter Four*

### *Experiments Using Artificial Rainfall Events*

#### **Introduction**

In Chapter Three, the runoff and erosion results obtained from natural rainfall events were presented and discussed. Although natural events are an intuitively appealing method for studying erosion, there are several problems with this approach. Storms frequently occur at times when the researcher is not at the site. Equipment failure or unusual activities are either unnoticed or prevent the recording of valuable data. For example, excessive erosion around the instrumentation systems prevented the collection of data from storms at our site. It would have been useful to observe the overtopping event on July 1, 1997 in the interpretation of the results given in Chapter Three. Natural rainfall events also make it more difficult to separate the impact of storm characteristics from that of vegetation or other factors.

An alternative to natural rainfall events is to use artificial rainfall obtained from rainulators. A rainulator is designed so that impact energy of its droplets corresponds to that of natural rainfall [11]. The rainulator can generate runoff events when the researchers are at the site. Visual observations of the erosion process often provide valuable insight. In addition, the same rainfall event can be used at different times in the year. It is then possible to assess the impact of vegetal growth and blanket degradation on runoff and erosion data without adjusting for differences in storm characteristics.

The results obtained by the rainulator are described and discussed in this chapter. The format is similar to Chapter Three. The experimental procedures, including plot description and data collection descriptions, are presented first. The results are then presented and discussed. Conclusions are drawn on the effectiveness of different ECPs from artificial rainfall events.

## **Experimental Procedures**

### *Description and Preparation of Erosion Plots*

The runoff and erosion data from this component of the study were gathered at the site previously described in Chapter Two. The plots here were installed on the west-facing slope. The length and width of the plots and the sheet metal between plots were identical to those described for the natural rainfall events in Chapter Three. Five treatments were also used for the artificial simulator runs. However, based on the results from the natural rainfall events, it was decided to include a bare soil as one of the treatments. Since the blanket responses were similar for the natural events, only the wood fiber and the straw/coconut treatments were used. The remaining treatments were the straw mulch and the bond fiber matrix product.

The layout of the erosion control products and treatments are shown in Figure 4.1. The orientation of the groups was from Group #1 at the northern edge of the hillslope to Group #4 at the southern edge of the hillslope.

The plot borders installation and seedbed preparation were similar to those used to the natural rainfall events described in Chapter Three. Once again, all of the blankets were installed according to manufacturer instructions. The straw mulch was applied by handscattering and anchored into the soil with a garden spade to simulate disc-anchoring. The bare soil treatment was left as is with no further alteration. Black polyethylene plastic sheets covered the plots after the treatments were installed for one week prior to the first rainfall simulation to maintain dry soil conditions for the simulations. The tarps were removed during daylight hours except on days when it rained.

The runoff collection system was installed after plot installation. A schematic depicting the runoff collection system is shown in Figure 4.2. A runoff collector, made out of 10 cm (4 in) PVC pipe and 1.2 m (4 ft) long, was placed at the base of each plot. The purpose of the collector was to intercept runoff and sediment from each of the plots. The ends of 2.4 m and 2.3 m plots were angled to the runoff collector. A metal shield was installed over the collector to prevent rain from entering the collector. The collector was designed so that 100% of the runoff from each plot would be routed through a 10 cm (4 in) PVC pipe to a

sampling location. Rainfall gages were placed around the edges of the plot. These gages were used to determine the total rainfall depth and to estimate possible spatial variability.

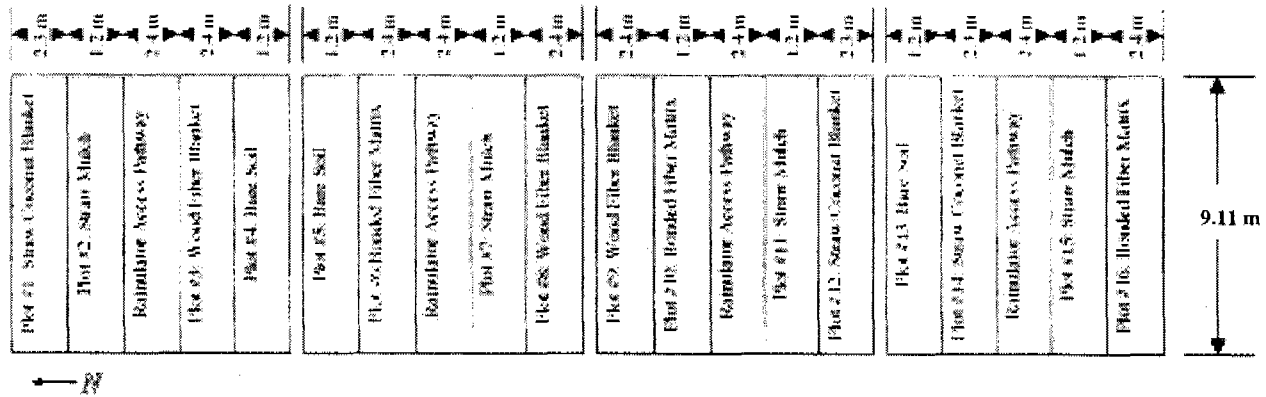


Figure 4.1: Layout of the Artificial Event Plots

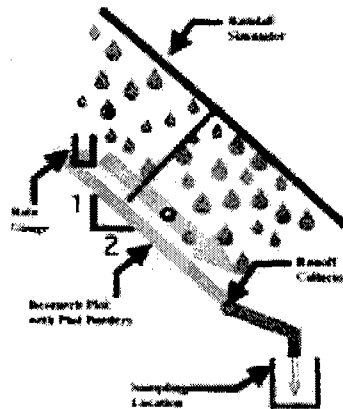


Figure 4.2: Runoff Collection System for the Artificial Rainfall Events.

The rainfall events took place under two seasonal conditions, early season (prior to germination) and late season (optimal vegetative growth). There was also a dry soil condition and a wet soil condition within each of the seasonal runs. The terms “early season dry soil” refer to data collected on June 26, 1998; “late season dry soil” refers to data collected on September 15, 1998; “late season wet soil” refer to data collected on September 16, 1998.

### *Description of and Modifications to the Rainulator*

The rainfall events were obtained using a rotating boom rainulator [11], which is depicted in Figure 4.3. Nozzles were interspersed along the booms to provide a uniform rainfall distribution. Four plots are rained on simultaneously. To evaluate the difference in initial soil water content, two runs are typically used with the rainulator. The first run is for the initial soil water content and is called a dry run, referring to a dry soil condition. The second run occurs roughly one-day later and is called a wet run, referring to a wet soil condition. The event duration was long enough to ensure equilibrium conditions. Since the time to equilibrium is longer for the dry runs, the initial experimental design selected an event duration of 90 minutes for dry runs and 60 minutes for wet runs.

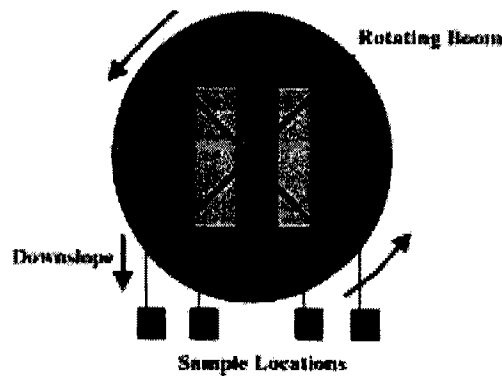


Figure 4.3: Rotating Boom Rainulator. Rainulator showing the ability to simultaneously rain on four plots with an access pathway through the middle of the section.

Minor modifications of the rainulator were necessary because of the steep slope for this research. The first modification was the addition of pressure regulators at each nozzle along the booms of the rainulator. These pressure regulators corrected for possible non-uniform pressure distributions along the booms. The regulators were designed so that a constant 55 kPa (8 psi) water pressure was maintained at the nozzles of the rainulator. The second modification was the addition of turnbuckles to the support wires between the rainulator and the mounting post and also to the support wires between the booms. This latter modification was done after a problem occurred in the field with slack between booms.

During the early season simulations before the addition of the turnbuckles, the coupling that connected a single boom to the mounting post of the simulator was sheared from two

different booms. The events were stopped and the broken booms were removed. The events were restarted with two booms missing from the simulator. The booms were repaired and the shearing problem eliminated by the addition of the turnbuckles. The data from the June 24 and 25, 1998 events are not presented because of difficulties in analysis caused by the broken booms.

The water source for the rainulator was a fire hydrant located on site, which operated at a pressure well in excess of 100 kPa (14.5 psi). The fire hydrant was connected to the municipal drinking water supply of the City of Eden Prairie, MN. There was an adjustable pressure relief system put in line between the water source and the rainulator to maintain a pressure near 70 kPa (10 psi) at the nozzles.

### *Methods for Data Analysis*

Much of the analyses of the runoff and erosion data are made relative to the results of the straw mulch plots for the same date using dimensionless variables. Differences among treatments for a given event are more easily identified using these variables. The computation of the average response of the straw mulch plots is frequently used in this analysis, and it is defined in general terms as

$$\left( \frac{\bar{X}}{t_{STORM}} \right)_{STANDARD} = \frac{1}{N} \sum_{i=1}^N \left( \frac{X_i}{t_{STORM,i}} \right)_{STANDARD} \quad (1)$$

where the right-hand side is the average response for the straw mulch plots, symbol  $X$  represents characteristics of interest, such as runoff rate or sediment loading rate, and  $t_{STORM}$  is the storm duration. As previously discussed, there are  $N=4$  straw mulch plots.

Dimensionless time ( $t^*$ ) is a useful parameter defined by Equation 2. It varies from zero (beginning of rainfall event) to a value greater than unity (end of runoff for the treatment). A value of unity indicates the end of the rainfall event.

$$t^* = \left( \frac{t}{\bar{t}_{STORM}} \right)_{TREATMENT} \quad (2)$$

where  $t$  is the actual time and  $\bar{t}_{STORM}$  is the average duration of the rainfall events for the treatment replicates.

An important parameter that varies with the time is the dimensionless runoff rate ( $Q^*$ ), defined as the ratio of the runoff rate for the treatment to the mean runoff rate per unit area of the straw mulch. It is defined mathematically as

$$Q^* = \frac{(Q/A_{PLOT})_{TREATMENT}}{(\overline{Runoff}/\bar{t}_{STORM})_{STANDARD}} \quad (3)$$

where  $\overline{Runoff}$  is the average runoff depth for the straw mulch replicates as defined by Equation 1,  $\bar{t}_{STORM}$  is defined as the average duration of the rainfall events for the standard replicates,  $A_{PLOT}$  is the area of the research plot, and  $Q$  is the observed runoff rate at time  $t$ .

The time-varying dimensionless sediment loading rate ( $Q_s^*$ ) is defined as the sediment loading rate per unit area of each treatment to the mean sediment loading rate per unit area of the straw mulch as shown by Equation 4.

$$Q_s^* = \frac{(Q_s/A_{PLOT})_{TREATMENT}}{(\overline{Yield}/\bar{t}_{STORM})_{STANDARD}} \quad (4)$$

where  $Q_s$  is the time-varying sediment load rate, computed from the observed data as the product of the runoff rate and the sediment concentration, and where  $\overline{Yield}$  is the average sediment yield (defined by Equation 1) per unit area for the straw mulch replicates.

A dimensionless sediment concentration ( $C_s^*$ ) can simply be defined as the ratio of the dimensionless sediment loading rate and the dimensionless runoff rate, or

$$C_s^* = \frac{Q_s^*}{Q^*} = \frac{C}{\overline{Runoff}} \quad (5)$$

where the numerator is the observed concentration and the denominator is a measure of the average concentration for the straw mulch plots. In Appendix A, the dimensionless

hydrographs, sedimentgraphs, and pollutographs are shown for all the runs by plotting the values of  $Q^*$ ,  $Q_s^*$  and  $C_s^*$  with respect to  $t^*$ .

Thusfar, the dimensionless variables are defined that vary with time during a run. A representative dimensionless variable for the entire run can be obtained by integrating the dimensionless graphs with respect to  $t^*$ . The integration of the dimensionless hydrograph results in a dimensionless runoff depth ( $D^*$ ) as shown below.

$$D^* = \int Q^* dt^* = \frac{\left( \text{Runoff} / t_{STORM} \right)_{TREATMENT}}{\left( \text{Runoff} / t_{STORM} \right)_{STANDARD}} \quad (6)$$

where  $Runoff$  and  $t_{STORM}$  are the measured runoff depth and event duration for the plot. Physically,  $D^*$  is the ratio of the average runoff rate per unit area of the plot to that of the standard straw mulch plots. If the storm durations are equal, then  $D^*$  is the ratio of the runoff depth relative to the standard.

The integration of the dimensionless sedimentgraph results in a dimensionless sediment yield ( $Y^*$ ). This yield is the ratio of the average sediment loading rate per unit area of the plot to that of the straw mulch treatment (Equation 7). Mathematically, it is defined as

$$Y^* = \int Q_s^* dt^* = \frac{\left( \text{Yield} / t_{STORM} \right)_{TREATMENT}}{\left( \text{Yield} / t_{STORM} \right)_{STANDARD}} \quad (7)$$

If the storm durations are equal,  $Y^*$  is the sediment yield per unit area of the treatment relative to the standard straw mulch plots

## Results and Discussion

### *Analysis of Rainfall Data*

Rainfall intensities for the different dates and different treatments are shown in Figure 4.4, and the rainfall depths are summarized in Table 4.1. The average intensities were 70, 80, 81, and 82 mm/hr for the 6/25, 6/26, 9/15, 9/16 simulations, respectively. The average across all simulations was 80 mm/hr. The error bars are the maximum and minimum observed values. As shown by Figure 4.4, the rainfall intensities were relatively constant between dates and



among the different treatments. All of the average intensities for a given treatment and date lies within 5% of the overall average intensity.

Table 4.1: Artificial Rainfall Event Summary.

Plot	6/25/98		6/26/98		9/15/98		9/16/98	
	Mean Rainfall Depth, mm	Cv	Mean Rainfall Depth, mm	Cv	Mean Rainfall Depth, mm	Cv	Mean Rainfall Depth, mm	Cv
1, 2	-	-	-	0.27	136.10	0.06	71.85	0.07
3, 4	-	-	143.93	0.22	145.51	0.09	72.57	0.08
5, 6	-	-	158.57	0.18	128.45	0.12	66.77	0.10
7, 8	-	-	153.85	0.09	132.50	0.15	71.48	0.05
9, 10	57.57	0.25	-	-	128.63	0.12	64.59	0.13
11, 12	60.45	0.26	-	-	141.15	0.16	72.93	0.07
13, 14	58.84	0.25	-	-	135.39	0.13	64.23	0.07
15, 16	58.84	0.25	-	-	135.39	0.07	72.21	0.08

As previously discussed the duration of the rainfall events varied according to the estimated time for the plot to reach equilibrium conditions. The rainfall duration for the early and late season dry runs were 1.87 hours and 1.67 hours, respectively. The duration of the early and late season wet runs were 0.83 and 0.87 hours, respectively.

The coefficient of variation ( $C_v$ ) in Table 4.1 is a measure of the spatial uniformity of rainfall depth over the plot. It is computed from the rainfall gages around the plot (need to include this as well in description of plots). In addition to potential limitation inherent with the rainulator, wind speed and direction can also influence the uniformity of the rainfall depth. Since the coefficient of variation is standard deviation divided by the mean, a small value indicates little spatial variability. Although the maximum  $C_v$  value was 0.27, there was generally a uniform rainfall depth over the plots.

Soil samples were taken prior to the rainfall simulation to determine the initial soil water content (SWC). The gravimetric values are shown in Figure 4.5. The mean soil water content of all treatments was 23%, 19%, 11% and 20% for the early season wet, early season dry, late season dry, and late season wet events, respectively. The error bars are the maximum and minimum observed values.

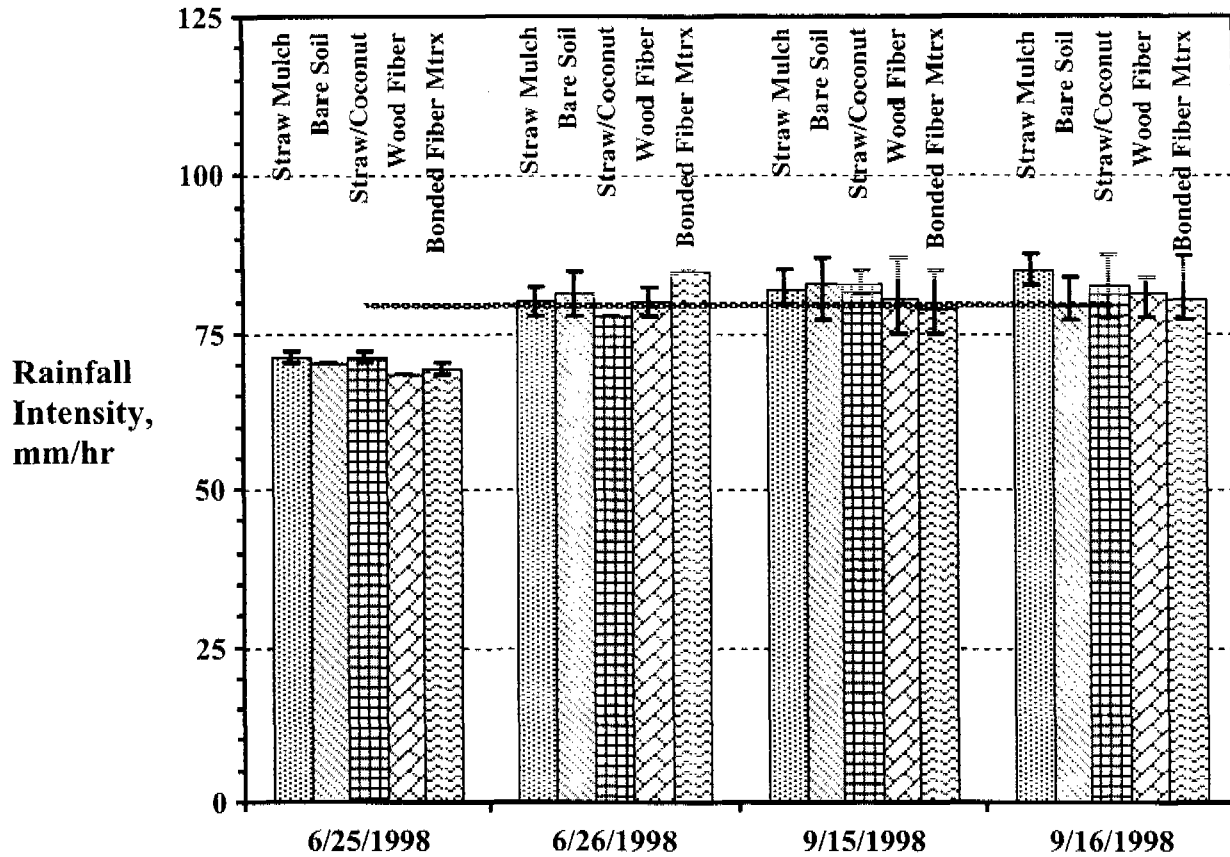


Figure 4.4: Rainfall Intensity during the Artificial Rainfall Events. The error bars are the maximum and minimum of the observed values. The horizontal line in the average intensity across all event days.

The research plots were initially covered with tarps to create a dry soil condition for the first set of runs. However, there was a natural rainfall event the night prior to the start of the runs. During this natural, several of the tarps were blown off of the plots and these plots were subsequently exposed to rain. This explains the discrepancies in the soil water content for the early season dry runs. The soil water content of the straw/coconut blanket treatment was drier (SWC = 13.5%) than the other treatments because it remained covered by the tarp during the natural rainfall event. The bonded fiber matrix plot was wetter (SWC = 23%) than the other treatments because it was completely exposed to the rain. Several of the other plots were only partially exposed to the natural rainfall event.

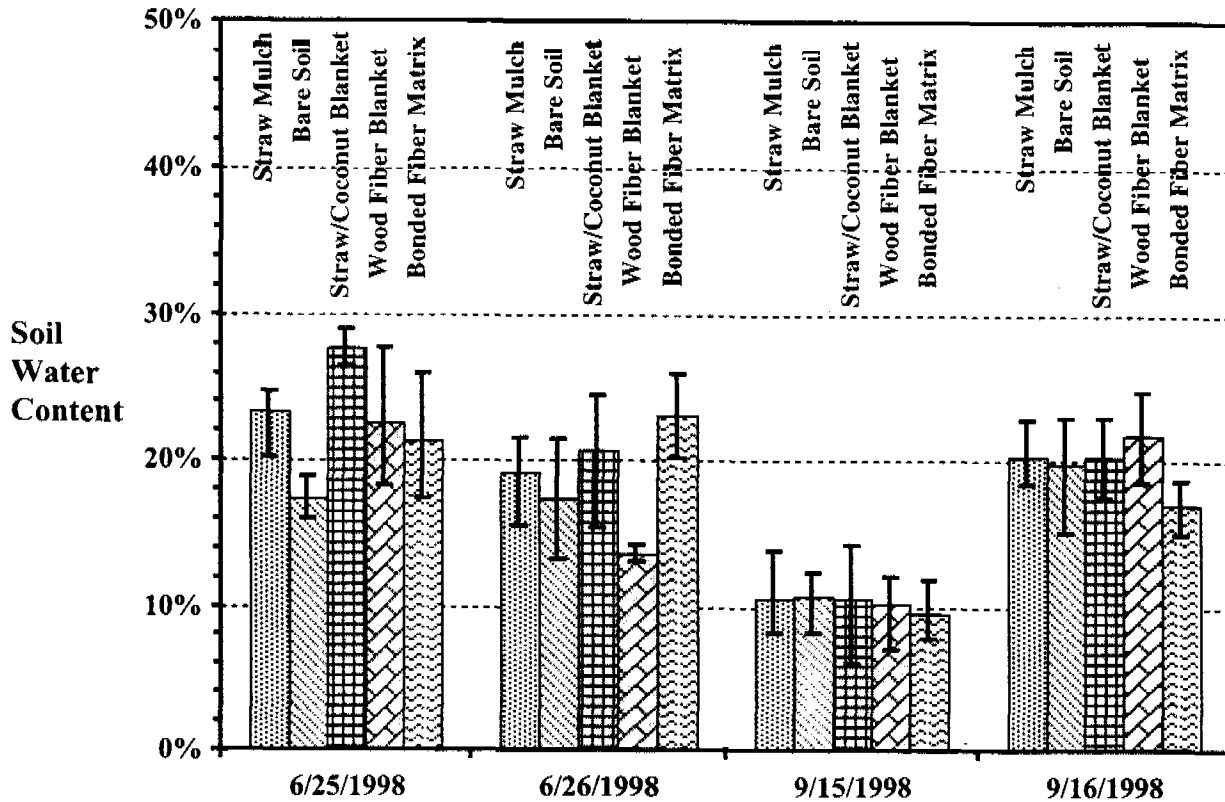


Figure 4.5: Soil Water Content (SWC) prior to the Artificial Rainfall Event.

Little natural rainfall occurred prior to the start of late season dry runs. Consequently, the average soil water content (across all plots) was 10.5% and was approximately uniform. The late season wet runs were conducted the day after the dry runs and the average water content was approximately 20%. The base soil (18%) and bonded fiber matrix plots (17%) had soil water contents smaller than the mean value.

#### *Analysis of Runoff Depth*

The runoff depths for the different treatments and dates are summarized in Table 4.2. The dimensionless runoff depths are shown in Figure 4.6. The error bars are the maximum and minimum observed values. The dimensionless depth is defined by Equation 6. Because only one of the June events contained data without equipment problems, only the events that occurred on plots 1 through 8 are shown.

Table 4.2: Mean Runoff Depths (mm) for the Artificial Rainfall Events.

	<b>Straw Mulch Treatment</b>	<b>Bare Soil Treatment</b>	<b>Straw/ Coconut Blanket</b>	<b>Wood Fiber Blanket</b>	<b>Bonded Fiber Matrix</b>
6/25/98 (Early Season-Wet Soil)	67.3	43.9	50.5	41.4	36.7
6/26/98(Early Season-Dry Soil)	121.0	101.5	92.8	108.2	177.6
9/15/98(Late Season-Dry Soil)	51.4	69.2	49.8	24.7	36.8
9/16/98(Late Season-Wet Soil)	56.5	58.6	48.6	38.9	55.8

The mean dimensionless runoff depth of the bare soil treatment is higher than the straw mulch treatment in both of the late season simulations, but was lower than the straw mulch treatment during the early season-dry soil simulation. The erosion control product treatments had mean dimensionless depths lower than the straw mulch treatment. The ranking of the treatments in terms of dimensionless runoff volume is the same in both of the late season simulations.

For the early season wet run, differences in soil water content between the treatments had little influence in the runoff depth. For example, the straw/coconut treatment had the lowest soil water content and the bonded fiber matrix treatment had the highest soil water content; nonetheless, the two products had similar runoff depths. Overall, there appears to be no apparent trends of runoff depth with different treatments.

#### *Analysis of Sediment Yield*

The sediment yield data are summarized in Table 4.3. The dimensionless sediment yields are summarized in Figure 4.7. Once again, the error bars represent the maximum and minimum values observed for the three replicates. The dimensionless sediment yield is defined by Equation 7.

The mean dimensionless sediment yield of the bare soil treatments is considerably larger than the straw mulch treatment for all events. For example, during the dry runs, the bare soil plots have sediment yields that are approximately eight times greater than the sediment yields of the straw mulch. The mean dimensionless sediment yields of the ECPs are considerably smaller than the sediment yield of the straw mulch. The soil lost to erosion from these products is approximately one-tenth the straw mulch values for the early season runs and approximately one-half of the erosion for the late season runs. Vegetal growth may have

played a role in the late season simulations. The straw mulch treatments had twice the mean biomass density than the ECPs plots.

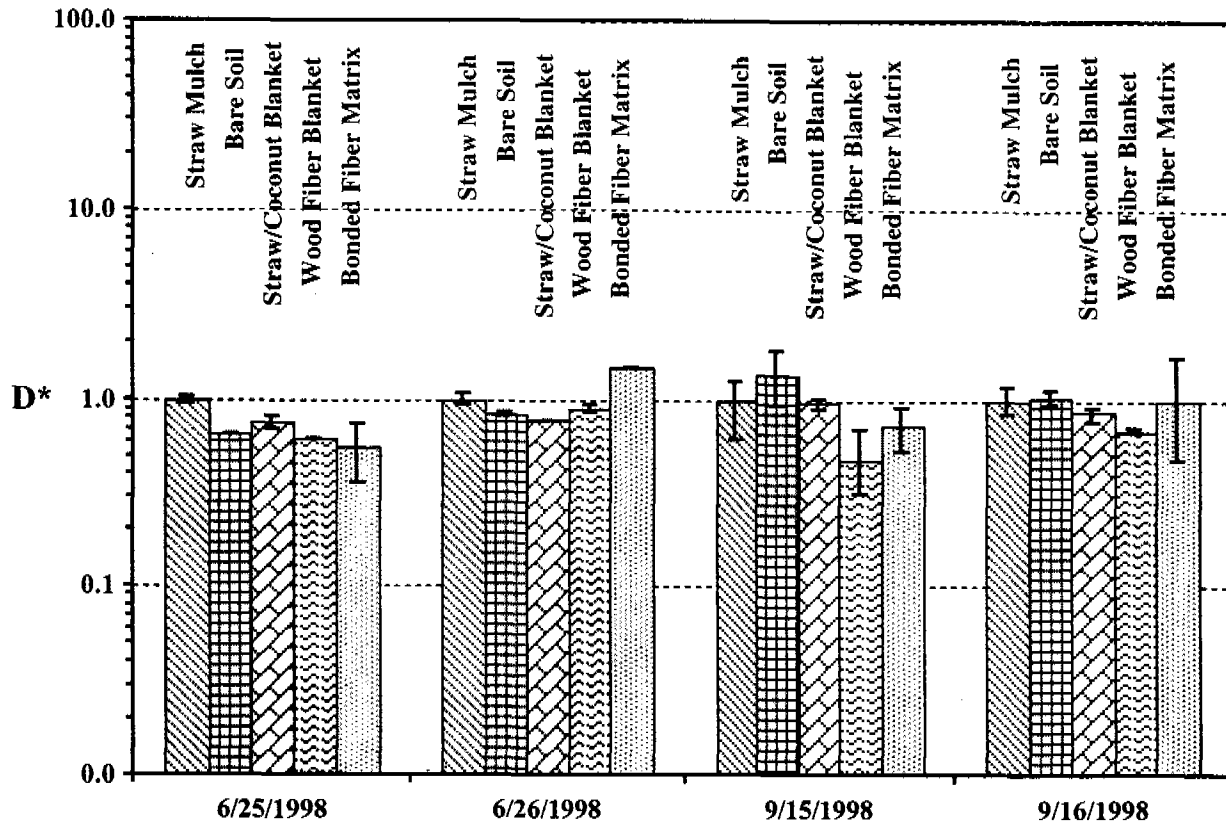


Figure 4.6: Dimensionless Runoff Depth for the Artificial Rainfall Events.

Table 4.3: Sediment Yield Summary for the Artificial Rainfall Events.

<i>Mean Sediment Yield, kg/ha</i>	<b>Straw Mulch Treatment</b>	<b>Bare Soil Treatment</b>	<b>Straw/ Coconut Blanket</b>	<b>Wood Fiber Blanket</b>	<b>Bonded Fiber Matrix</b>
6/25/98 (Early Season-Wet Soil)	1680	9560	180	270	160
6/26/98 (Early Season-Dry Soil)	10,830	91,960	730	990	840
9/15/98 (Late Season-Dry Soil)	260	2080	130	60	200
9/16/98 (Late Season-Wet Soil)	280	1120	140	90	210

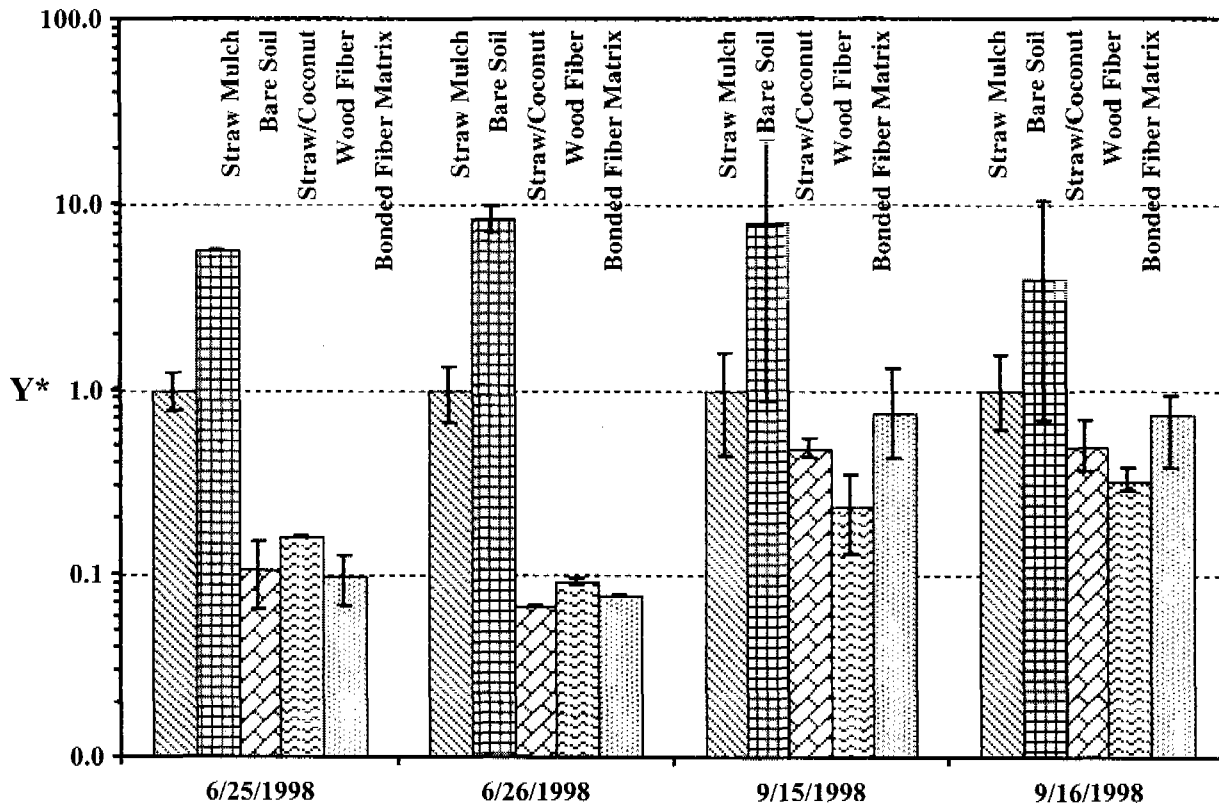


Figure 4.7: Dimensionless Sediment Yield for the Artificial Rainfall Events.

## Summary and Conclusions

A rainulator was used to study runoff and erosion for five different covers: bare soil, straw mulch, wood fiber blanket, straw/coconut blanket and bonded fiber matrix. The rainulator allows the same storm characteristics to be repeated during the year. It also has the advantages of allowing the researcher to observe the runoff event. Dimensionless variables were used in the analysis using the straw mulch treatment as the standard.

The conclusions from this component of the project are straightforward. There were no apparent trends in runoff depth. The erosion control products did a superb job of controlling soil erosion. There was approximately a magnitude reduction in erosion between the bare plot and the straw mulch. With little vegetation, there was roughly a magnitude reduction in erosion between straw mulch plots and the erosion control products. Therefore, the total reduction between bare plots and the erosion control plots were approximately one hundred.

Differences in erosion between the straw mulch and the other treatments decreased for the late season runs. This is likely the result of the vegetational growth over the summer months.

### **Key Findings**

- For the early season wet run, differences in soil water content between the treatments had little influence in the runoff depth. Overall, there appears to be no apparent trends of runoff depth with different treatments.
- The mean dimensionless sediment yield of the bare soil treatments is considerably larger than the straw mulch treatment for all events.
- The mean dimensionless sediment yields of the ECPs are considerably smaller than the sediment yield of the straw mulch. The soil lost to erosion from these products is approximately one-tenth the straw mulch values for the early seasons runs and approximately one-half of the erosion for the late seasons runs.
- Vegetal growth may have played a role in the late season simulations. The straw mulch treatments had twice the mean biomass density than the ECPs plots.

## *Chapter Five*

### *Summary and Conclusions*

Erosion control products (ECPs) were tested on the slopes of a sedimentation basin for their effectiveness in controlling erosion and their impacts on establishing vegetation. Both natural and artificial (obtained with a rainulator) rainfall events were used in this study. The natural rainfall events allowed for "real world" data to be collected. The artificial rainfall events allowed for greater control of storm characteristics. The ECPs tested were a wood fiber blanket, a straw/coconut blanket, a straw blanket, and a bonded fiber matrix. The performance of these products was compared to the widely used disk-anchored straw mulch. A bare soil condition was incorporated directly into the rainulator runs and indirectly in the natural events as the result of the failure of the bonded fiber matrix product.

The site was seeded with native, tall-grass prairie seeds and the establishment of vegetation was monitored over time. During the first growing season, the plots were dominated by weedy vegetation, and the presence of native species was minor. The weedy vegetation was dominant across all treatments and was not confined to specific treatments. The amount of weedy biomass was similar across the treatments as well. The only observed impact that the ECPs had on the vegetation was the occurrence of tenting in some of the ECP plots. The dominance of weedy vegetation and the low occurrence of native vegetation suggest that weeds are impacting the native species more than the ECPs. Although the first straw mulch treatment had a higher biomass density, the range of values suggests no substantial trends among treatments. The short duration of the study limits the evaluation of the possible recovery of native species. Long-term monitoring is needed to determine the ultimate recovery of these species.

Essentially three different treatments were used for both the natural and artificial rainfall conditions. The first set is the ECPs, which are the erosion control blankets and the bonded fiber matrix product. The second set is the straw mulch, representing natural mulch treatments. The third set is no treatment. This set consists of the failed bonded fiber matrix product for the natural events and the bare soil condition for the artificial events. Trends between these three



sets of treatments were consistent with both the natural and artificial rainfall events, especially in the early season runs when the erosion control performance is not affected by vegetation.

No noticeable trends in the runoff depth among the different treatments were observed. Their impact on controlling erosion is therefore related to their protection of the soil from raindrop impact and surface runoff.

The combined results of dimensionless sediment yields for the natural and artificial rainfall events are shown in Figure 5.1. As given in Chapter Four, the dimensionless sediment yield is defined as the load from the treatment plots relative to that observed for the straw mulch plots. For the early season events with little vegetation, the erosion from the straw mulch plots was approximately ten times greater than that obtained from the ECP plots. The erosion from the no treatment plots was approximately ten times greater than that from the straw mulch plots. The ECPs therefore reduced erosion from the no treatment plots by a factor of approximately one hundred when there was little vegetation. For the late season runs with considerable vegetation, different trends were observed. Here the erosion from the straw mulch plots was five times greater than the ECP plots, and the erosion from the straw mulch plots was two times greater than the no treatment plots. The erosion from the ECPs plots were therefore one-tenth the erosion of the no treatment plots when there was considerable vegetation. Although this reduction is still substantial, the impact of vegetation also had a major influence on the observed erosion.

For the events with little vegetation, the erosion from the straw mulch plots was approximately ten times greater than that obtained from the ECP plots. The erosion from the no treatment plots was approximately ten times greater than that from the straw mulch plots. The ECPs therefore reduced erosion from the no treatment plots by a factor of approximately one hundred when there was little vegetation. For the runs with considerable vegetation, different trends were observed. Erosion from the straw mulch plots was five times greater than the ECP plots, and the erosion from the straw mulch plots was two times greater than the no treatment plots. The erosion from the ECPs plots were therefore one-tenth the erosion of the no treatment plots when there was considerable vegetation. Although this reduction is still substantial, the impact of vegetation also had a major influence on the observed erosion.



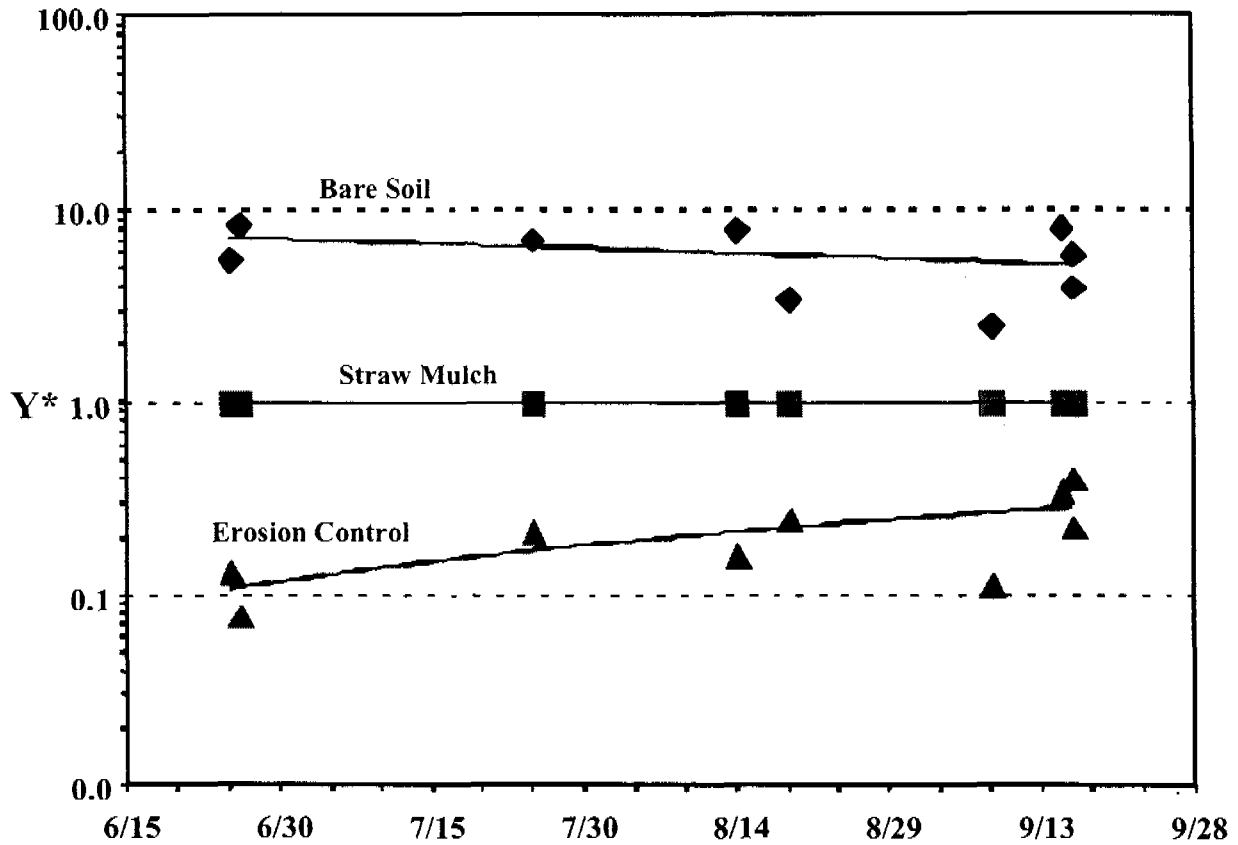


Figure 5.1: Trend in Dimensionless Sediment Yield through a single growing season.

A potential concern for the study was the relatively short plot lengths. Additional field testing is recommended using longer plot lengths and using a different soil type. Long-term progress in selecting erosion control measures can best be made by obtaining a better understanding of the interactions of the control measures with the detachment and transport of sediment. The effectiveness of blankets and turf mats can then be evaluated using simulation tools instead of expensive field experiments. This approach is widely used to assess erosion for different agricultural practices. Similar techniques are needed for construction and roadside sites.

**Future Work**

The future of modeling erosion along highway rights-of-way needs to become more fundamentally developed rather than empirically based. In hydrological modeling, there are four main components: (1) a climate model, (2) an infiltration/runoff model related to soil type and

amount of biomass, (3) a sediment transport model, and (4) a vegetation/surface cover model. Many climate models have been thoroughly developed in other disciplines (i. e. agriculture, weather services, etc.), therefore; minimal adaptation would be required for the use of these models on rights-of-way. The last three models need to be further developed for the roadside condition. The underpinnings of the models can be borrowed from more developed models, but would have to be adapted. The main adaptation would be calibration of the models to the roadside environment.

Current research at the University is looking at the sediment transport model for roadsides. The main emphasis of the research is determining the partitioning of shear forces acting on the soil surface, the erosion control protection and the vegetation. Future research will look at vegetal growth models for roadside conditions. Both the quantity and type of vegetation play important roles in controlling soil erosion. Developing ecological models that predict species competition (especially between desirable and weedy vegetation) will help designers determine when an adequate stand of vegetation would exist and what level of erosion control is required to protect the soil until this stand of vegetation is achieved. Vegetation models are an important component in erosion modeling along the roadside.

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*Appendix A*  
*Sedimentgraphs & Hydrographs*  
*Obtained from Artificial Rainfall Events*

The following sediment and hydrographs were taken from the artificial rainfall event series of plots during the summer growing season of 1998. The format of the graphs is as follows. The plot number, the treatment (*i. e.* bare soil, straw mulch or one of the erosion control products) and the date of simulation are listed in the heading of the graph. The first set of graphs is the sediment and hydrographs with dimensions. The second set of graphs is the dimensionless sediment and hydrographs. The runoff rate is plotted on the right-hand ordinate and sediment concentration is plotted on the left-hand ordinate. The variables are plotted as functions of time, located on the abscissa.

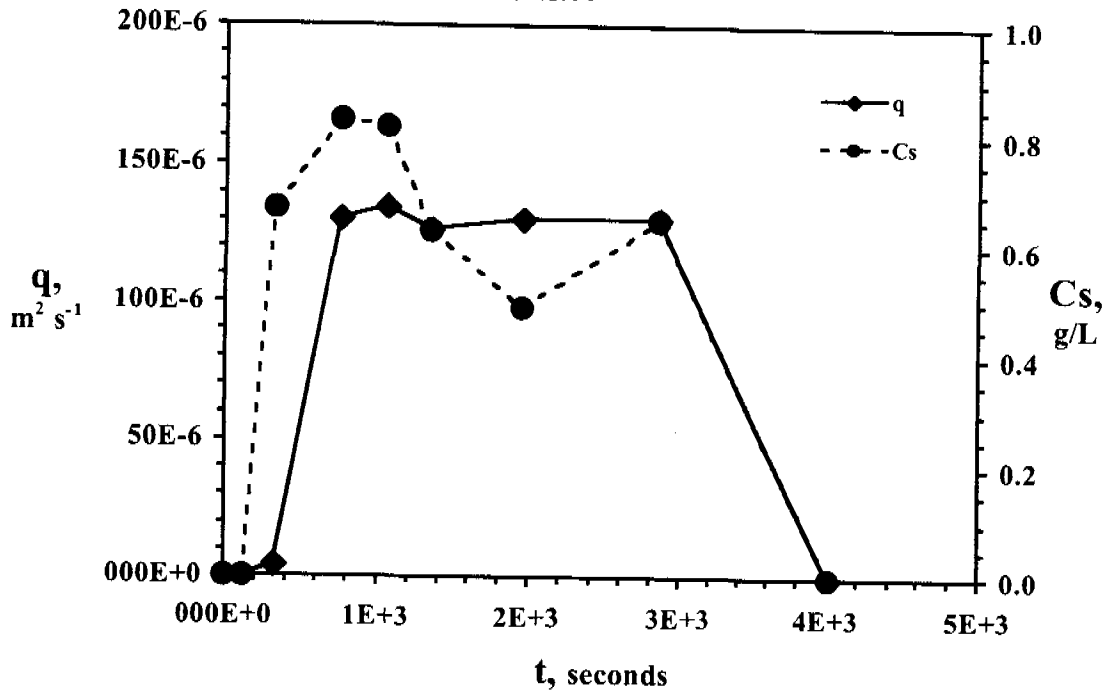


**APPENDIX A**

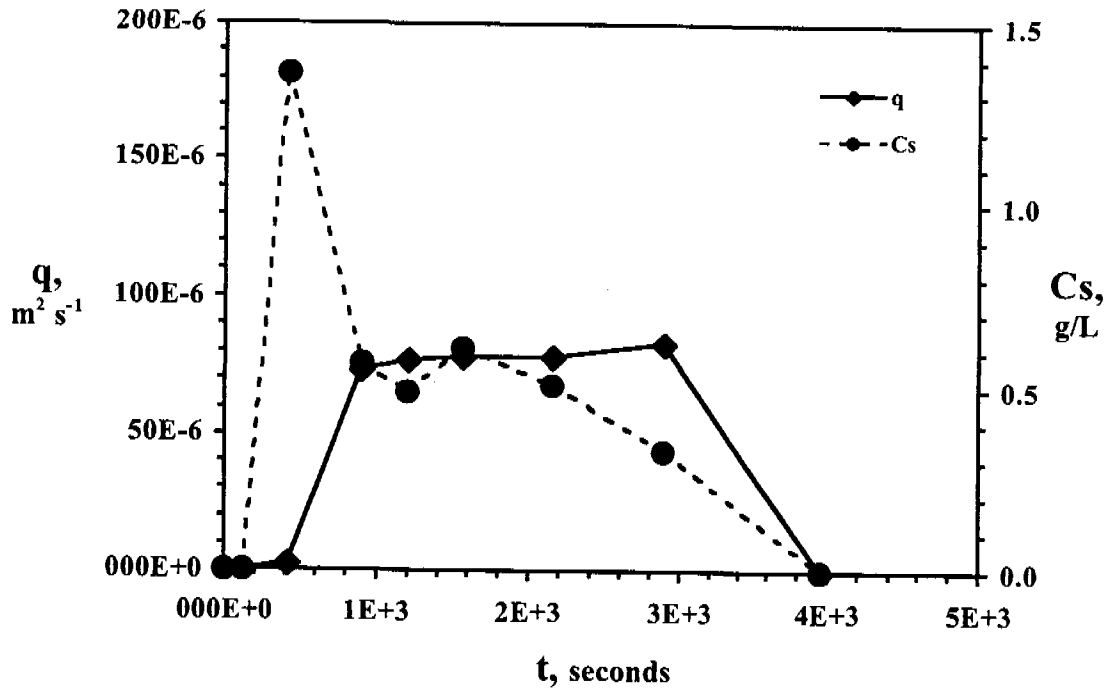
**SEDIMENTGRAPHS & HYDROGRAPHS  
OBTAINED FROM ARTIFICIAL RAINFALL  
EVENTS**



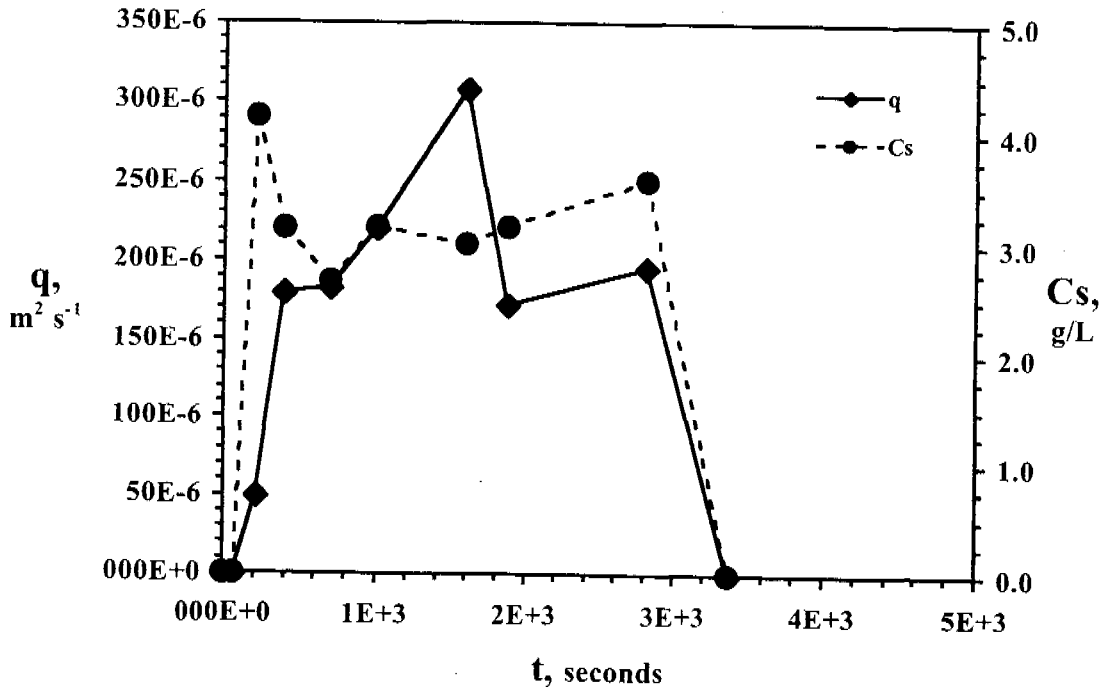
Plot 9, Wood Fiber Blanket Treatment  
6/25/99



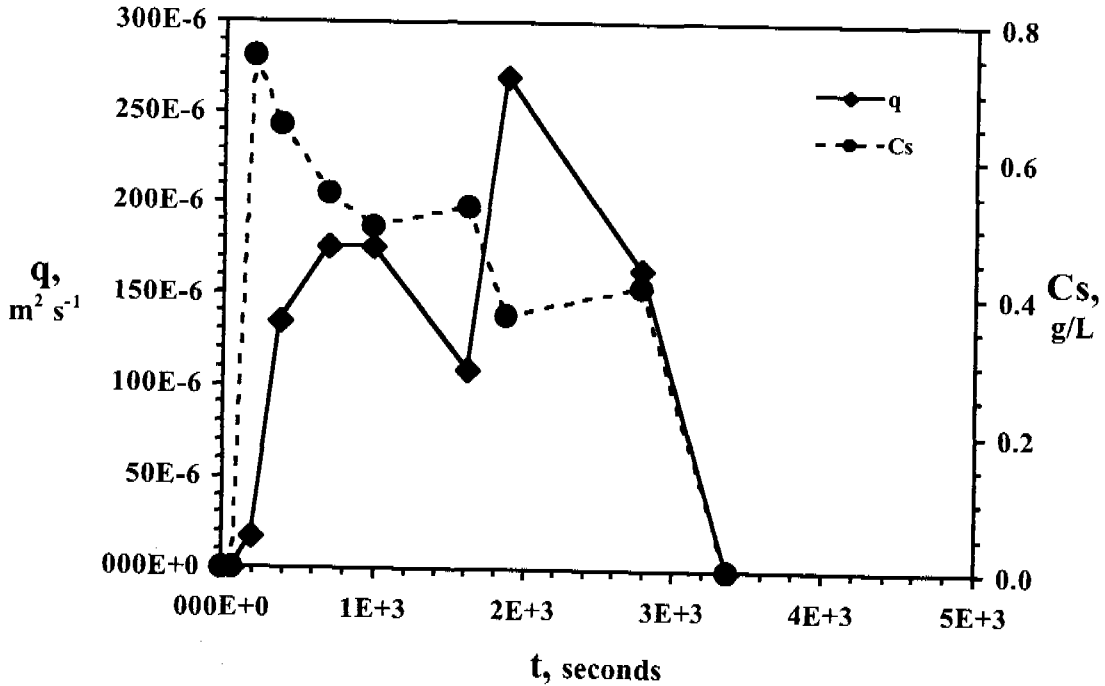
Plot 10, BFM Treatment  
6/25/99



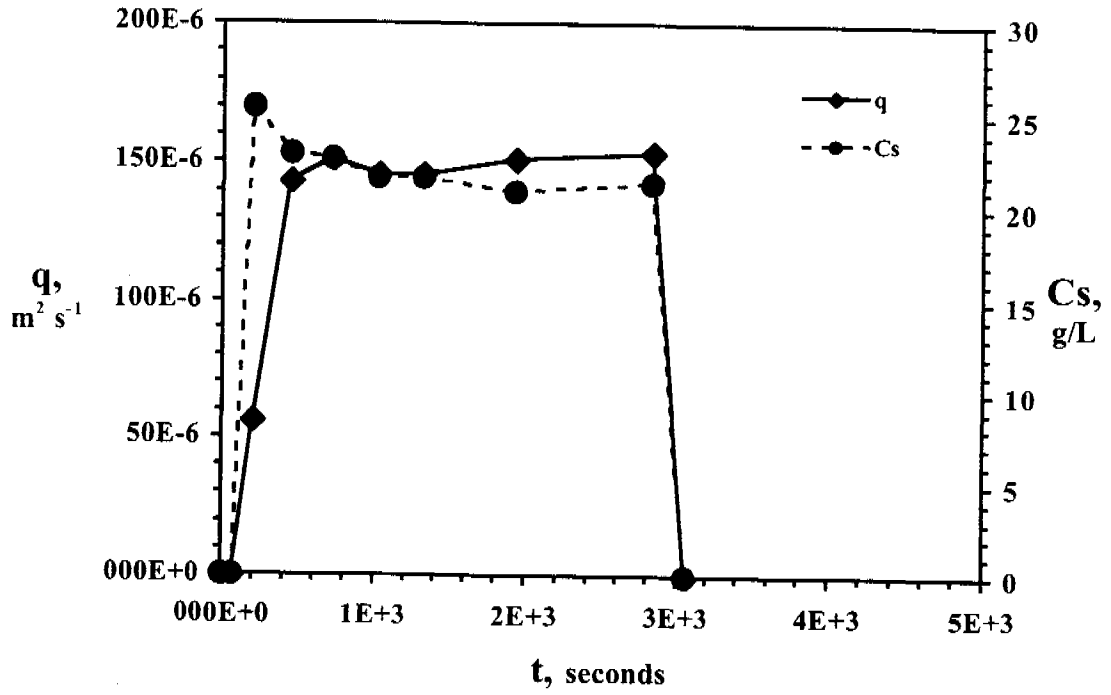
Plot 11, Straw Mulch Treatment  
6/25/99



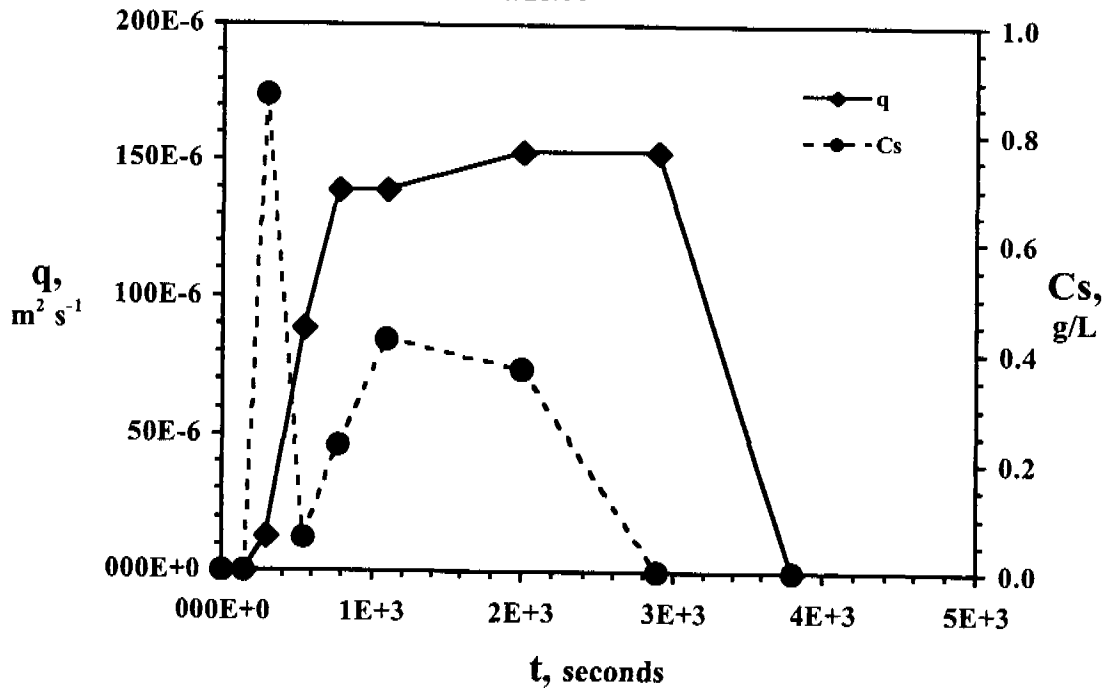
Plot 12, Straw/Coconut Blanket Treatment  
6/25/99



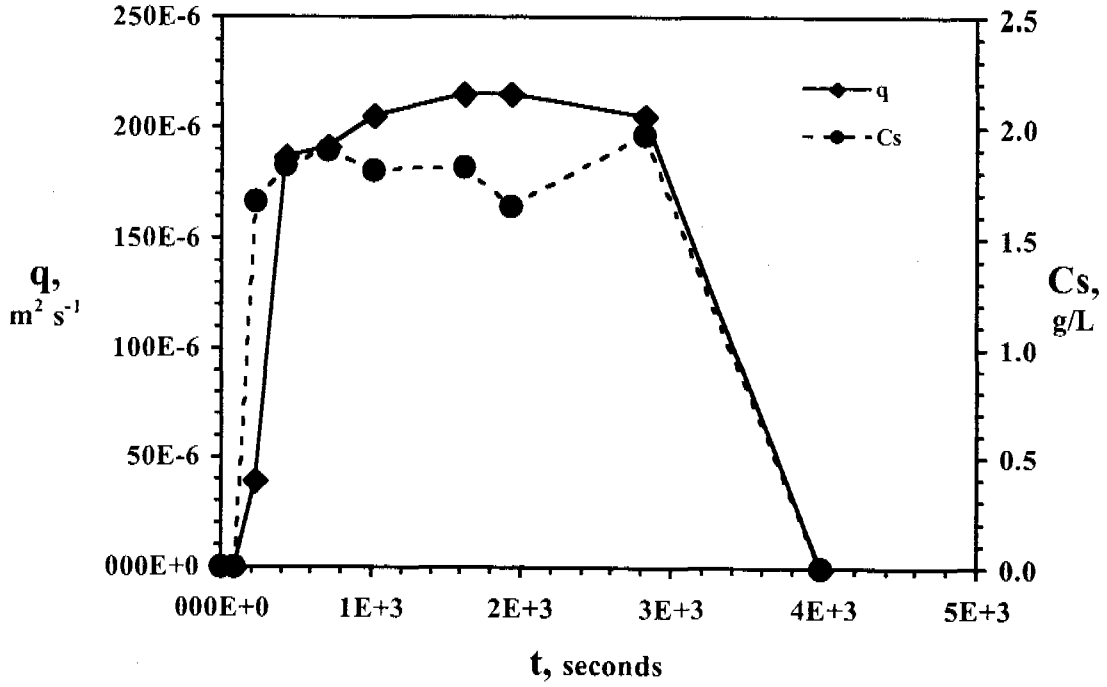
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6/25/99



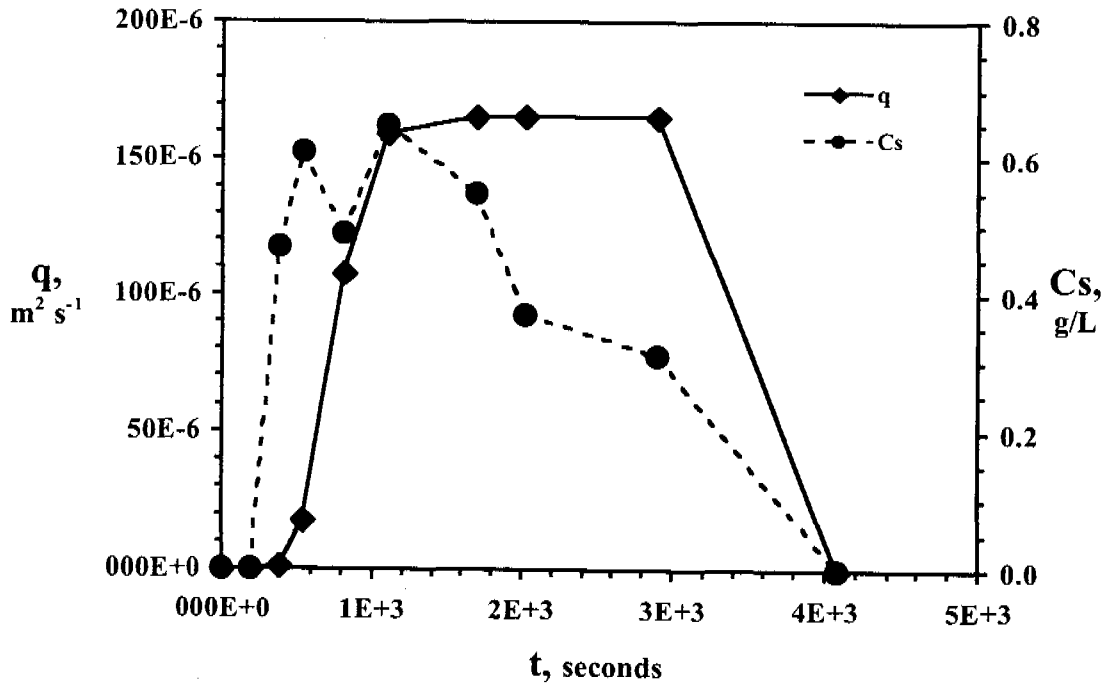
Plot 14, Straw/Coconut Blanket Treatment  
6/25/99



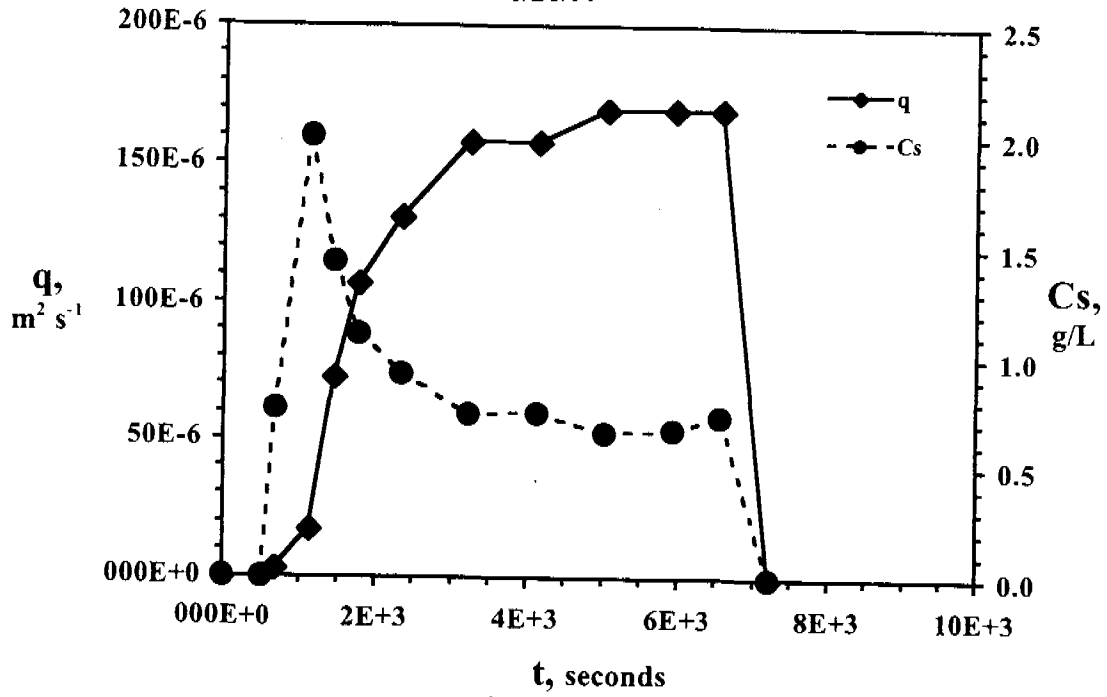
Plot 15, Straw Mulch Treatment  
6/25/99



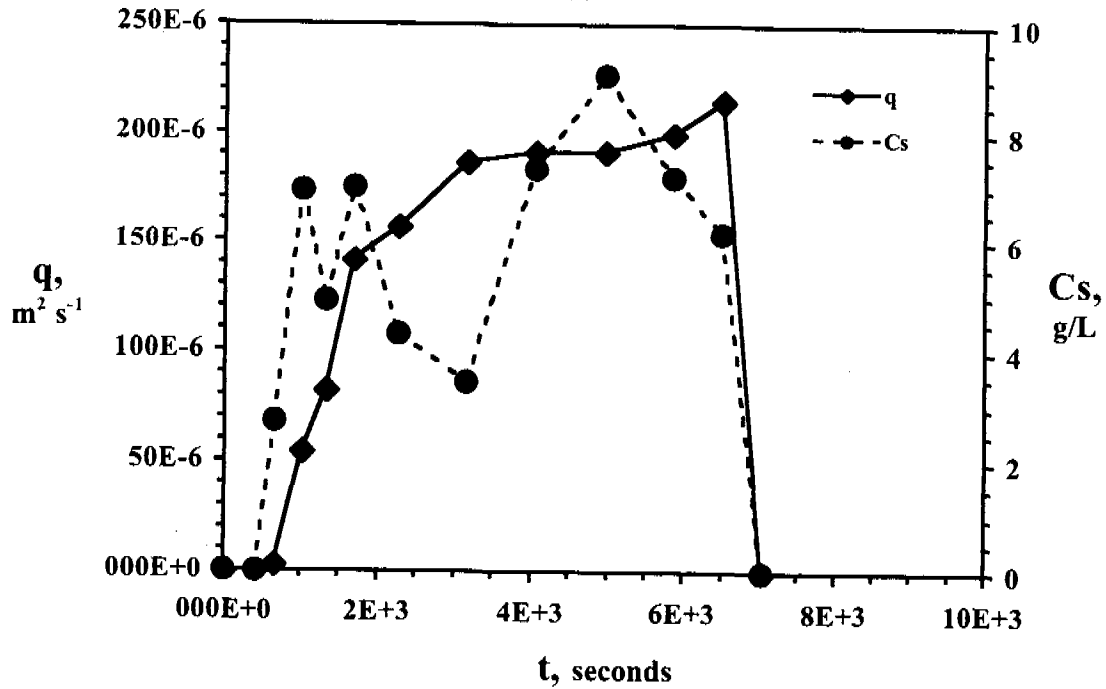
Plot 16, BFM Treatment  
6/25/99



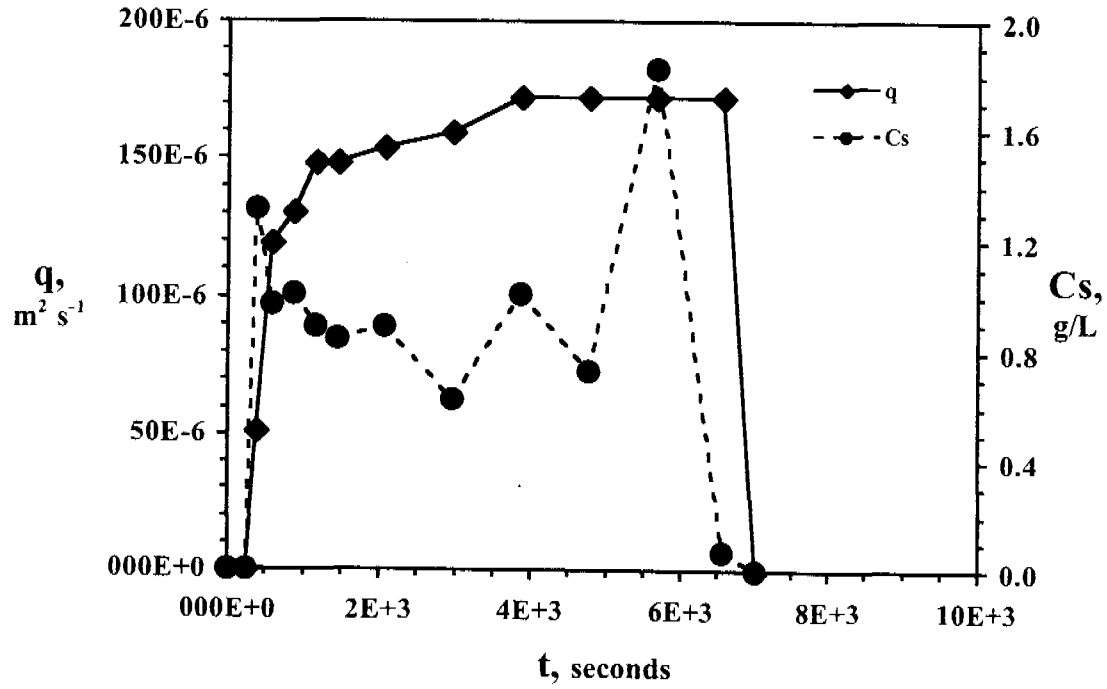
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6/26/99



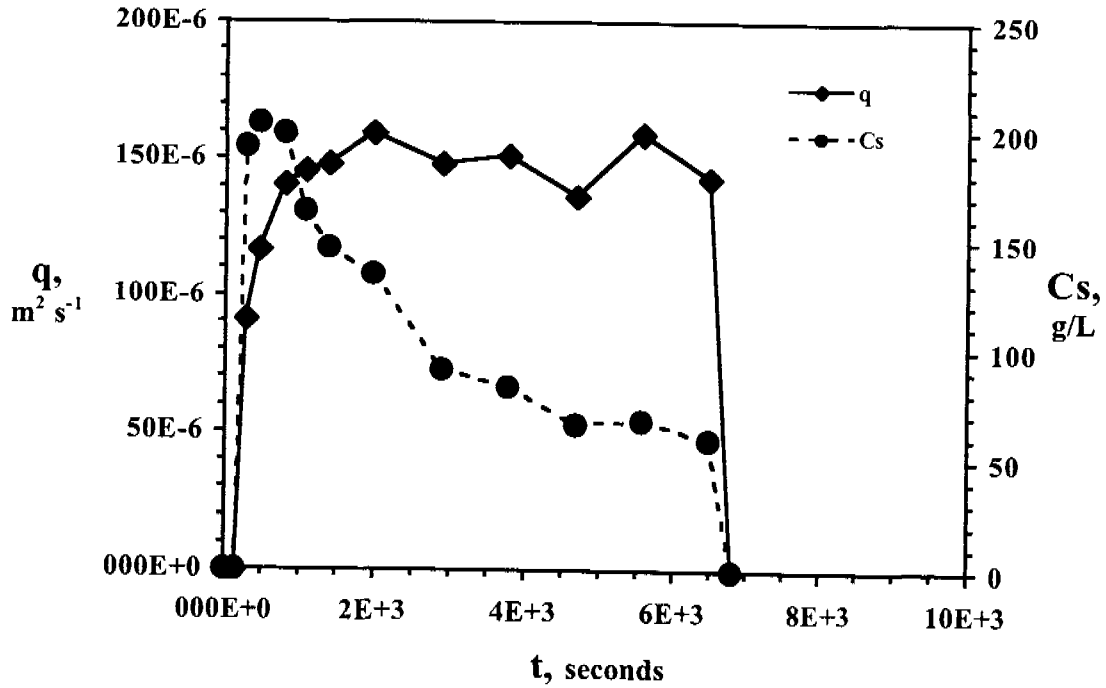
Plot 2, Straw Mulch Treatment  
6/26/99



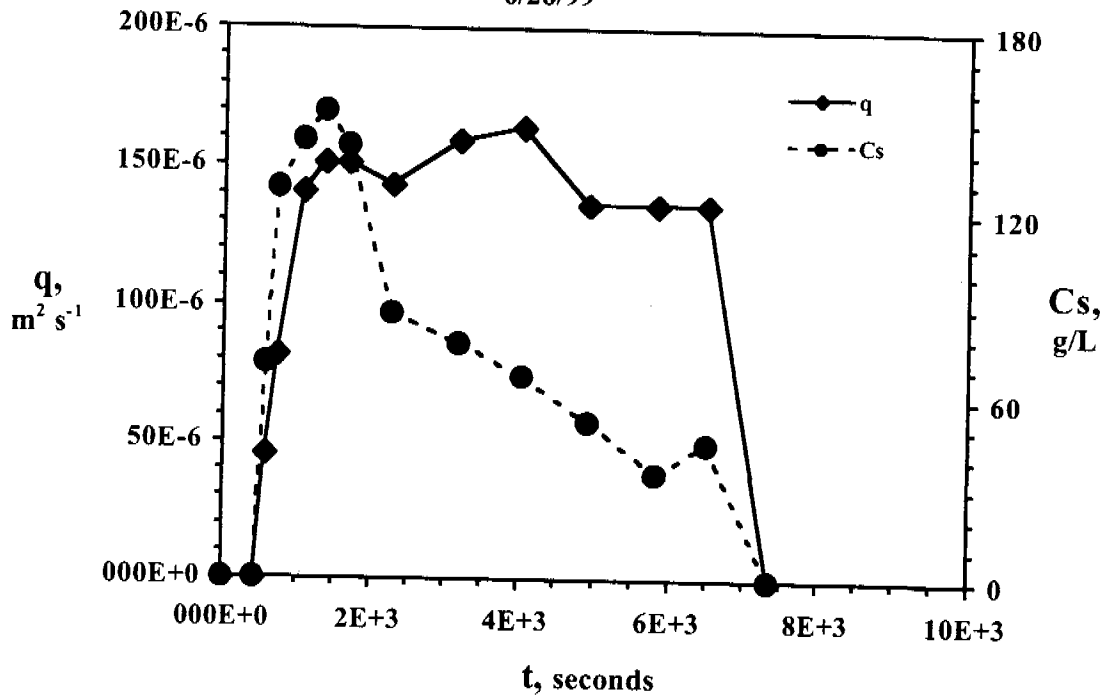
Plot 3, Wood Fiber Blanket Treatment  
6/26/99



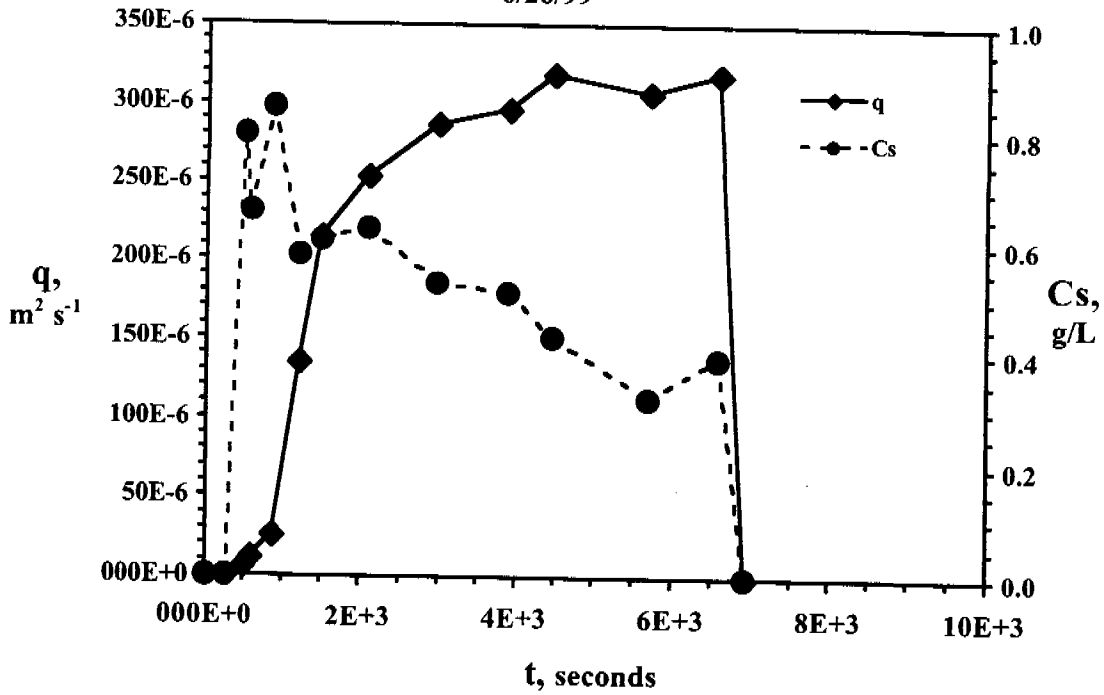
Plot 4, Bare Soil Treatment  
6/26/99



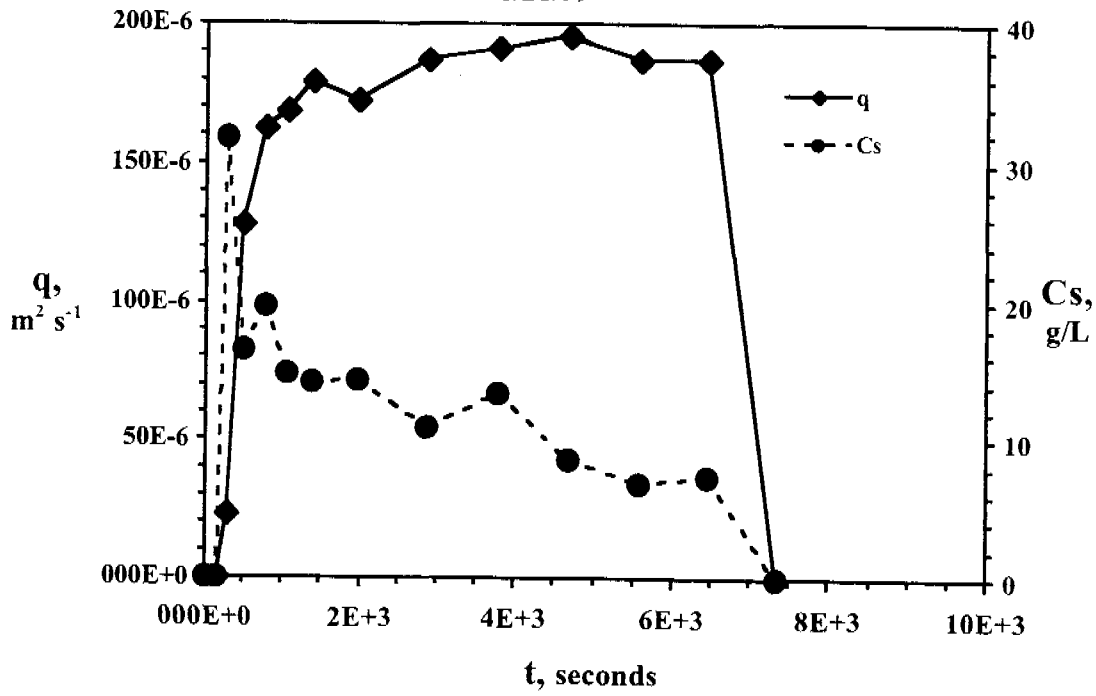
Plot 5, Bare Soil Treatment  
6/26/99



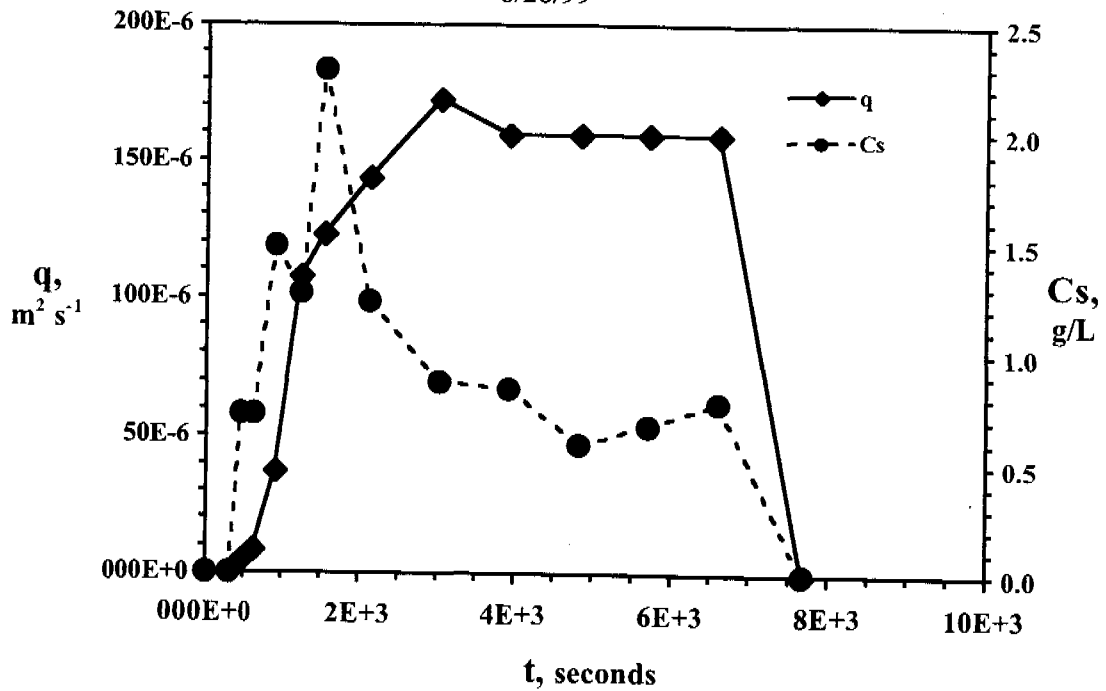
Plot 6, BFM Treatment  
6/26/99



Plot 7, BFM Treatment  
6/26/99

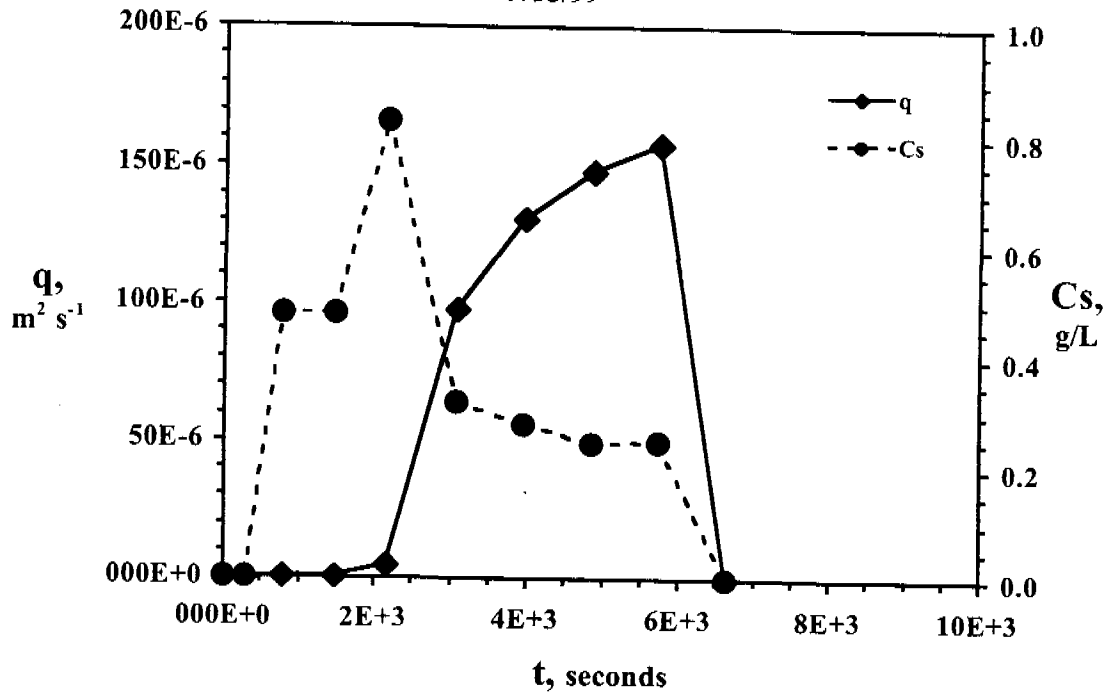


Plot 8, Wood Fiber Blanket Treatment  
6/26/99

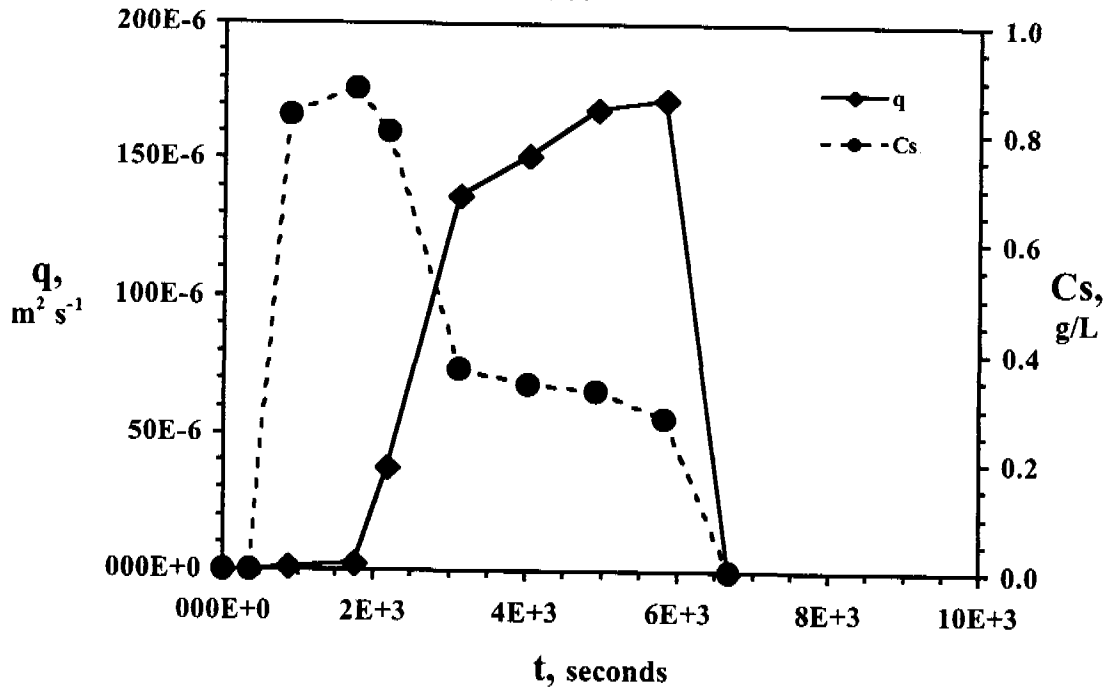




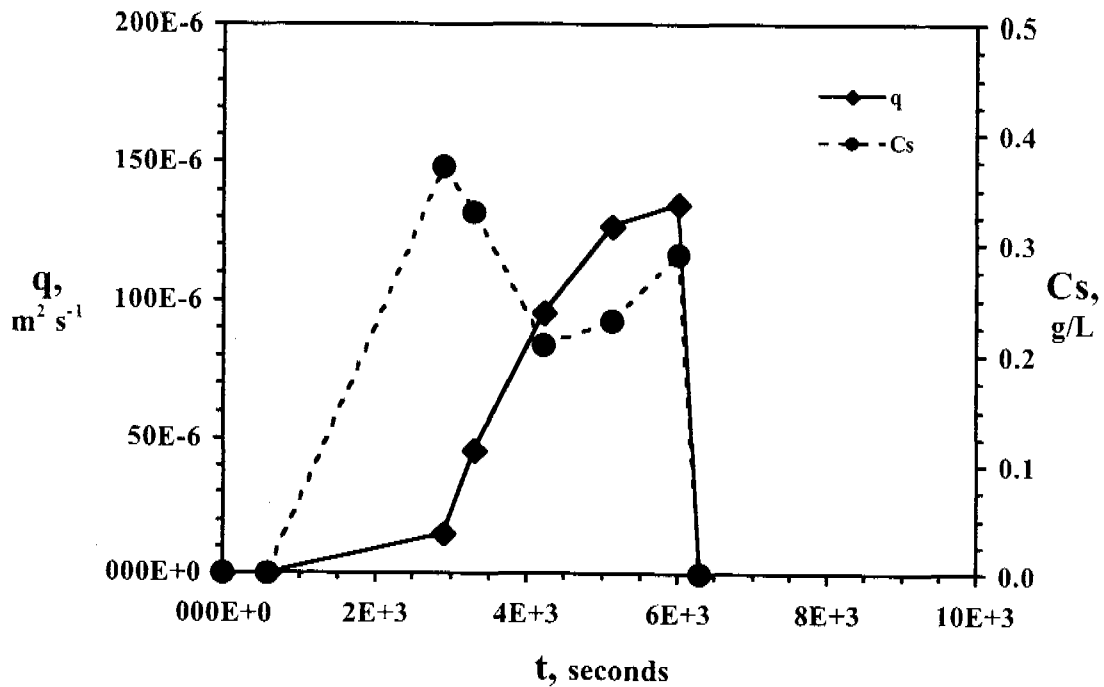
Plot 1, Straw/Coconut Blanket Treatment  
9/15/99



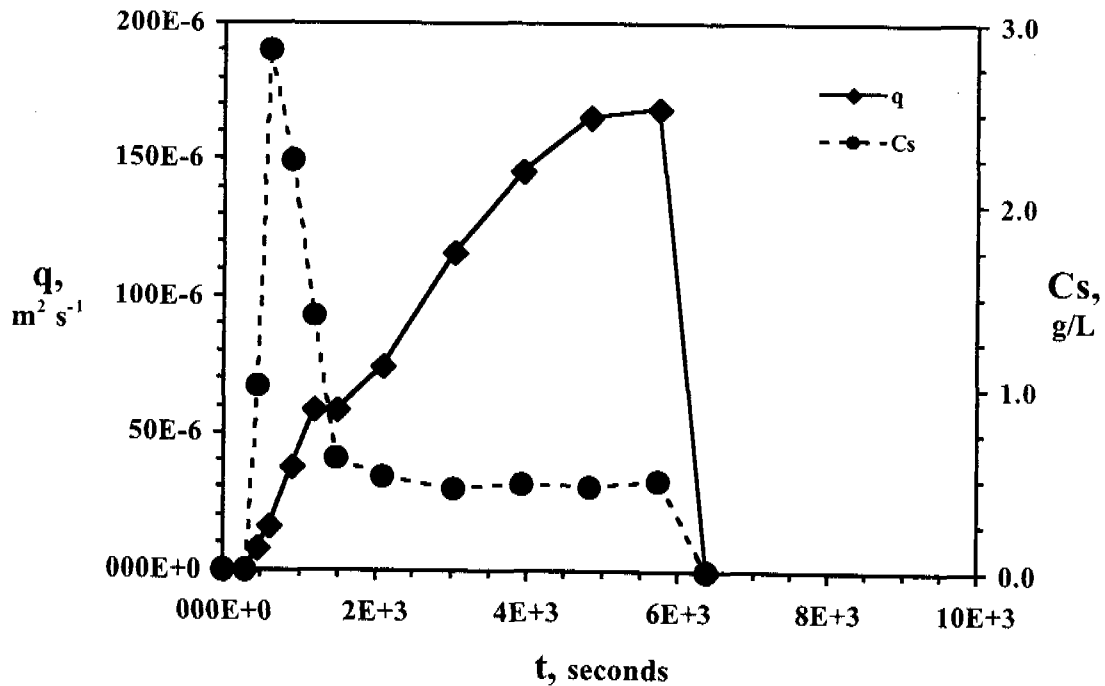
Plot 2, Straw Mulch Treatment  
9/15/99



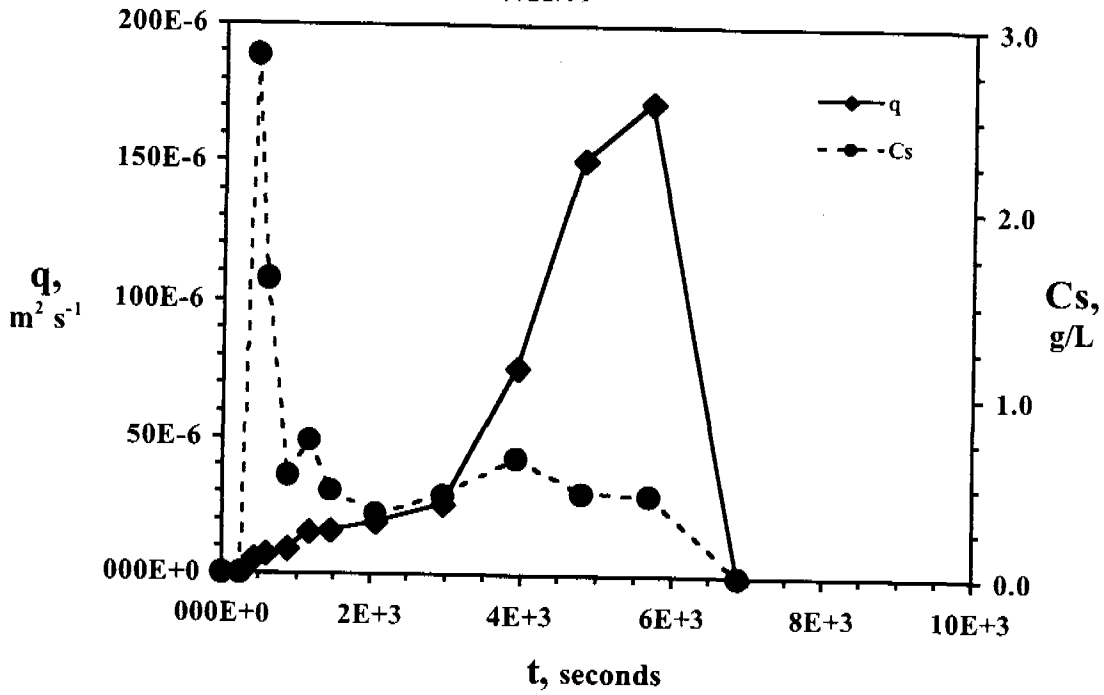
Plot 3, Wood Fiber Blanket Treatment  
9/15/99



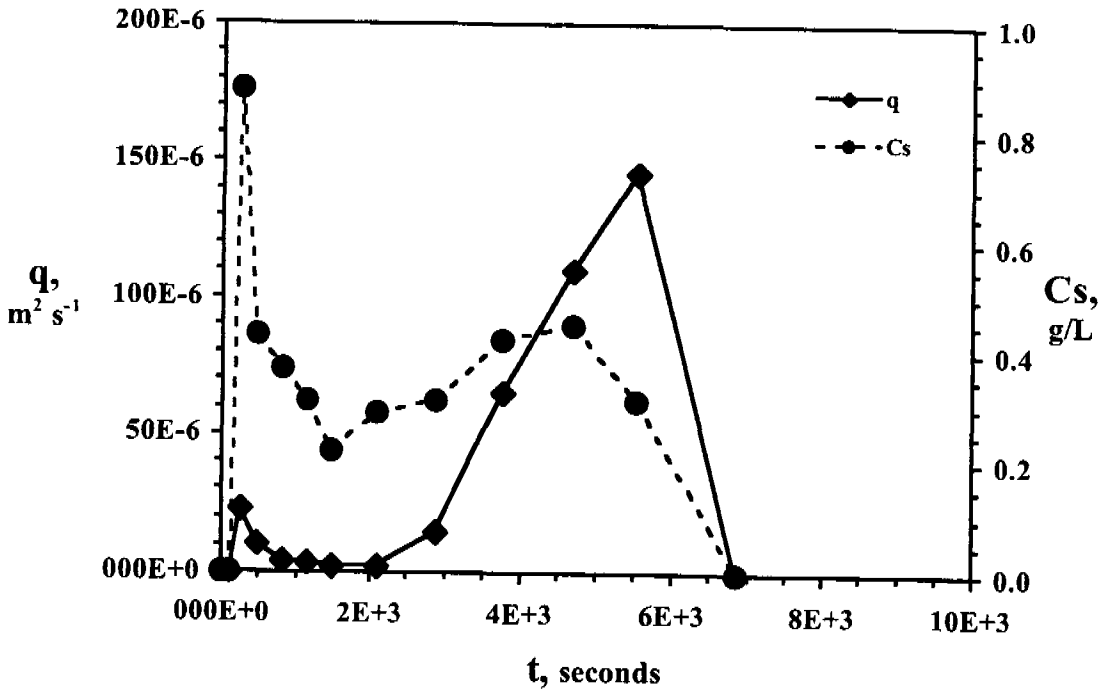
Plot 4, Bare Soil Treatment  
9/15/99



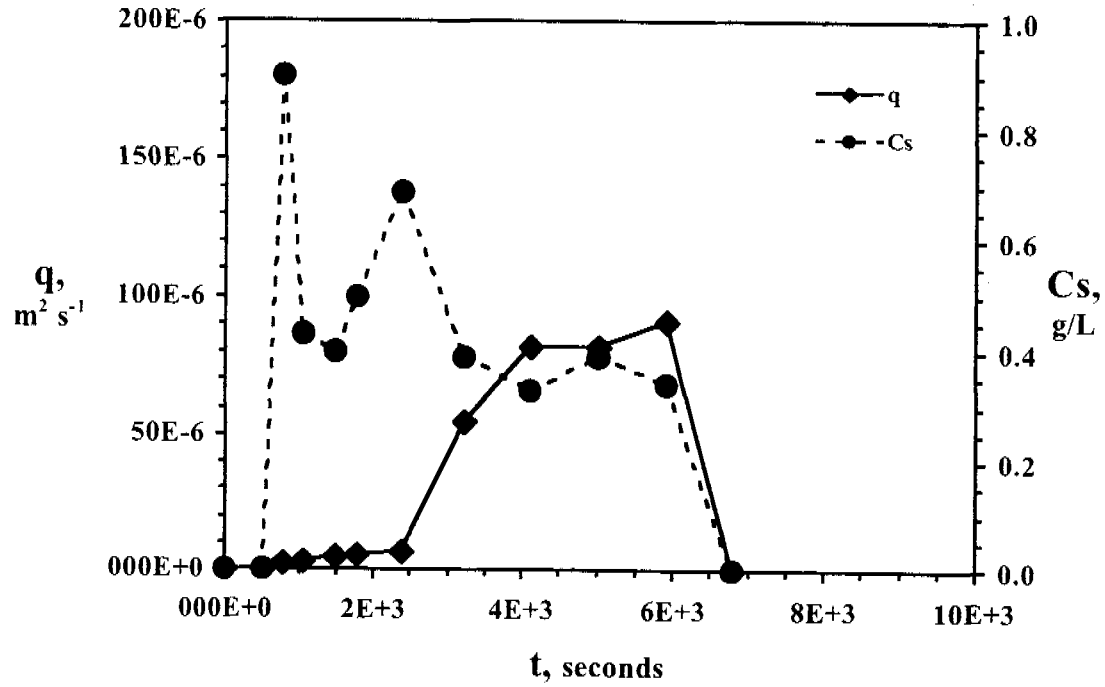
Plot 5, Bare Soil Treatment  
9/15/99



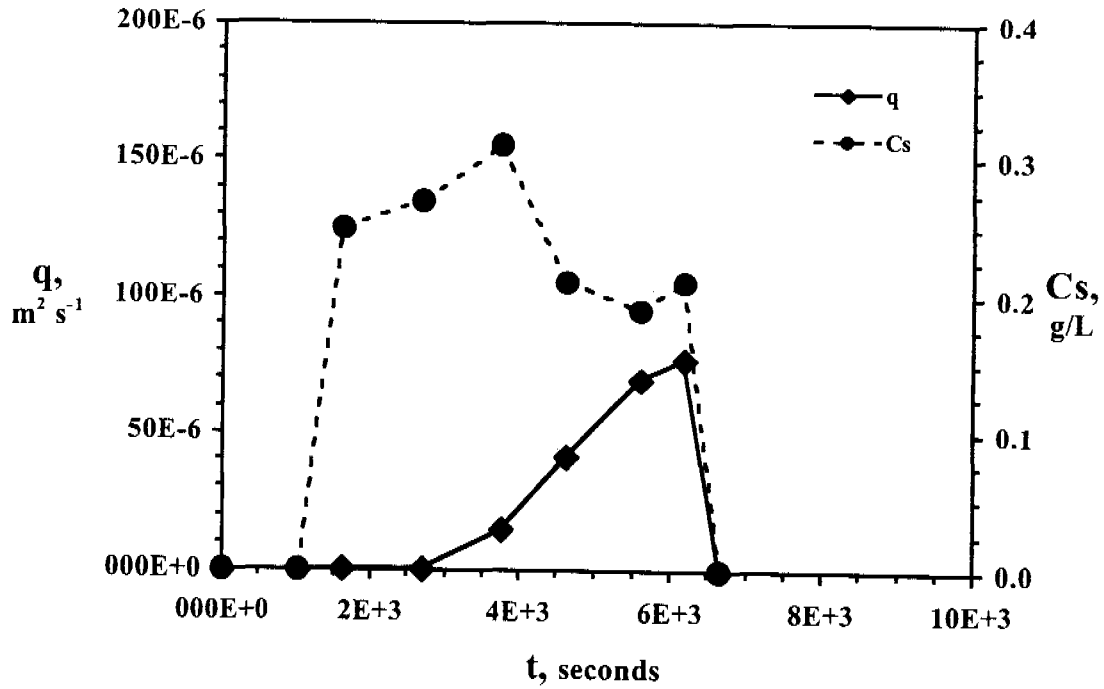
Plot 6, BFM Treatment  
9/15/99



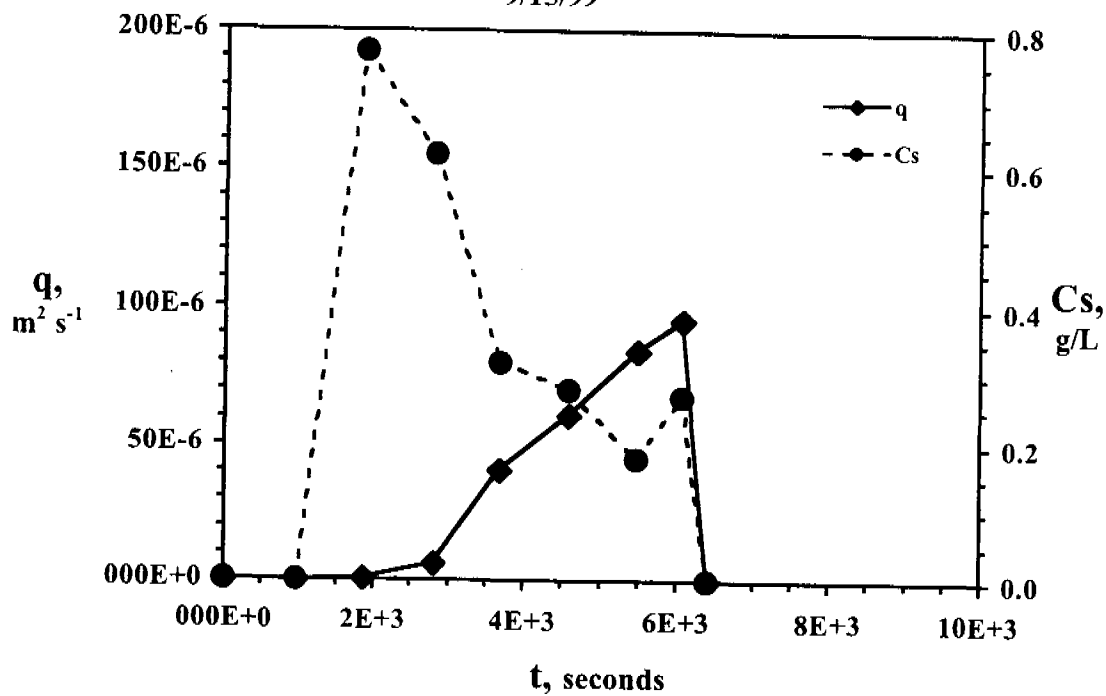
Plot 7, Straw Mulch Treatment  
9/15/99



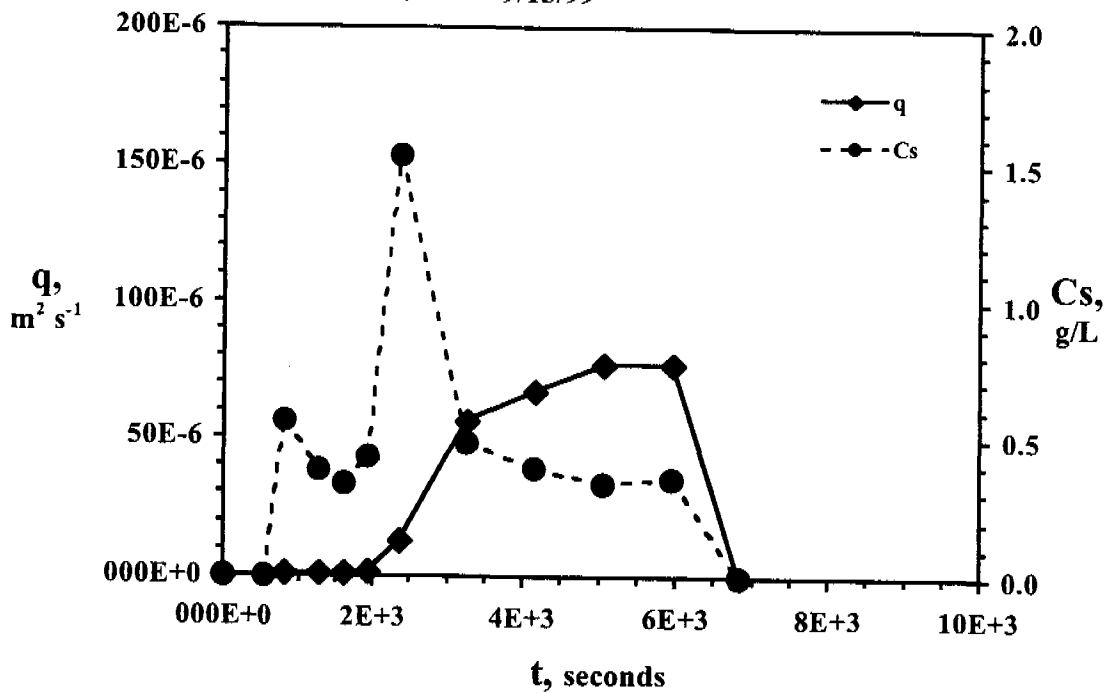
Plot 8, Wood Fiber Blanket Treatment  
9/15/99



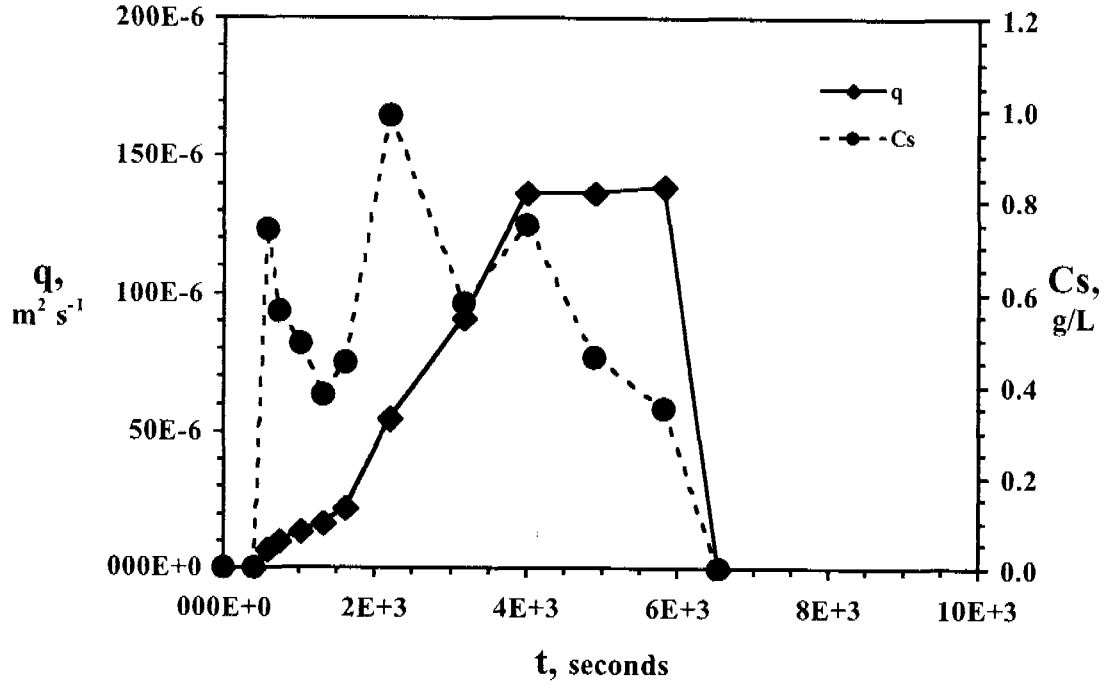
Plot 9, Wood Fiber Blanket Treatment  
9/15/99



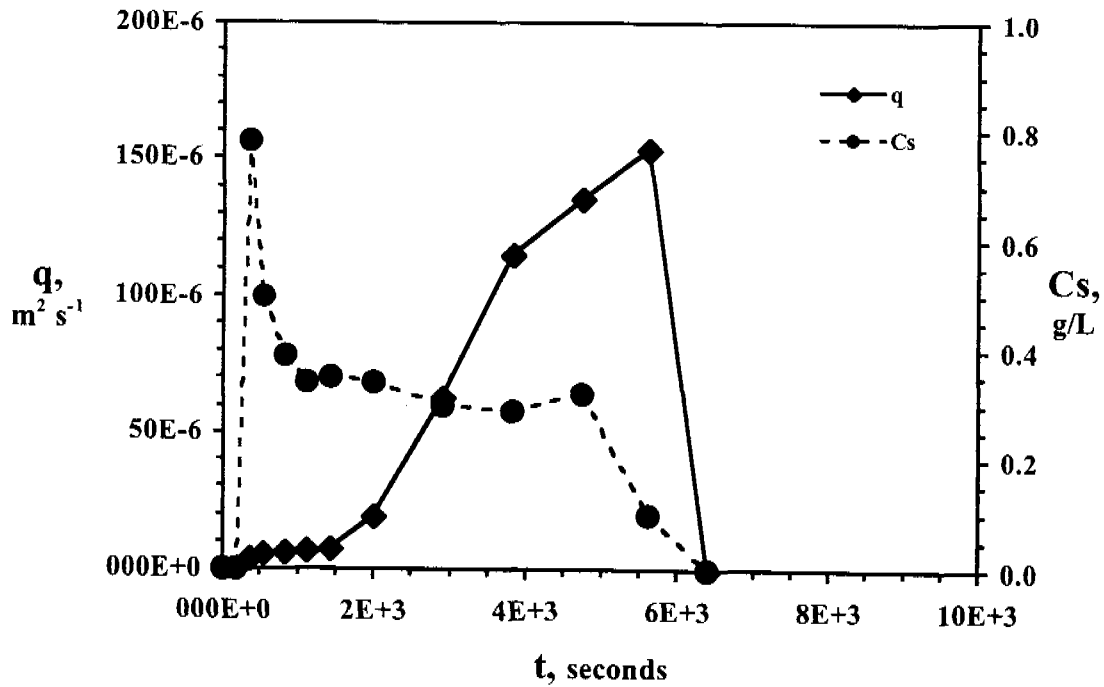
Plot 10, BFM Treatment  
9/15/99



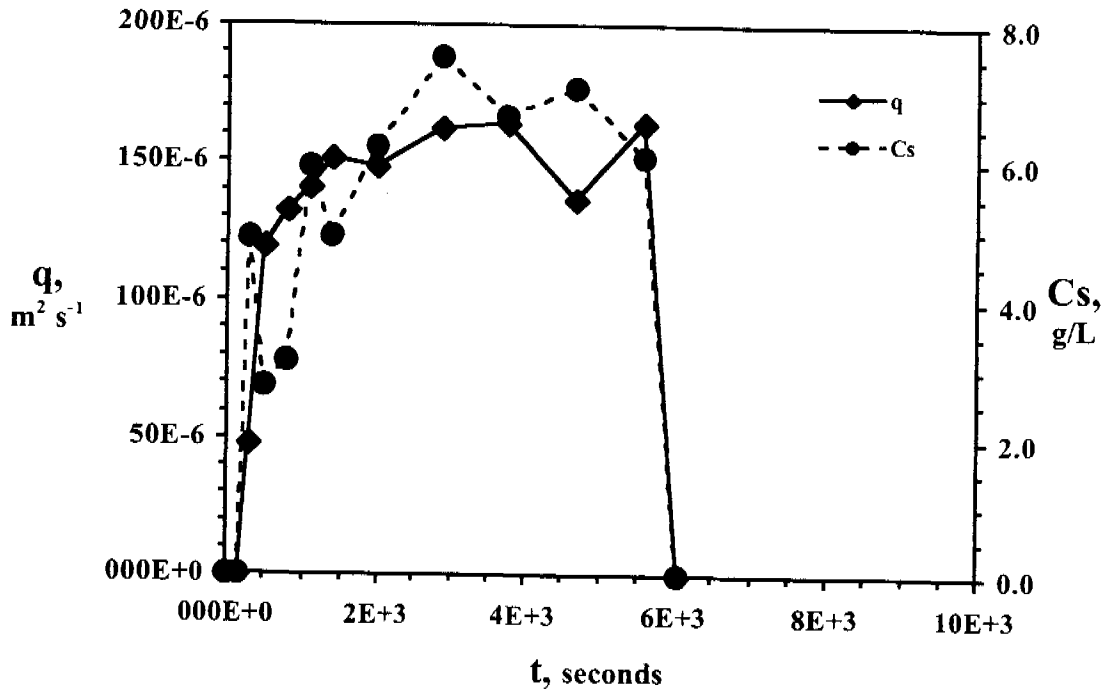
Plot 11 Straw Mulch Treatment  
9/15/99



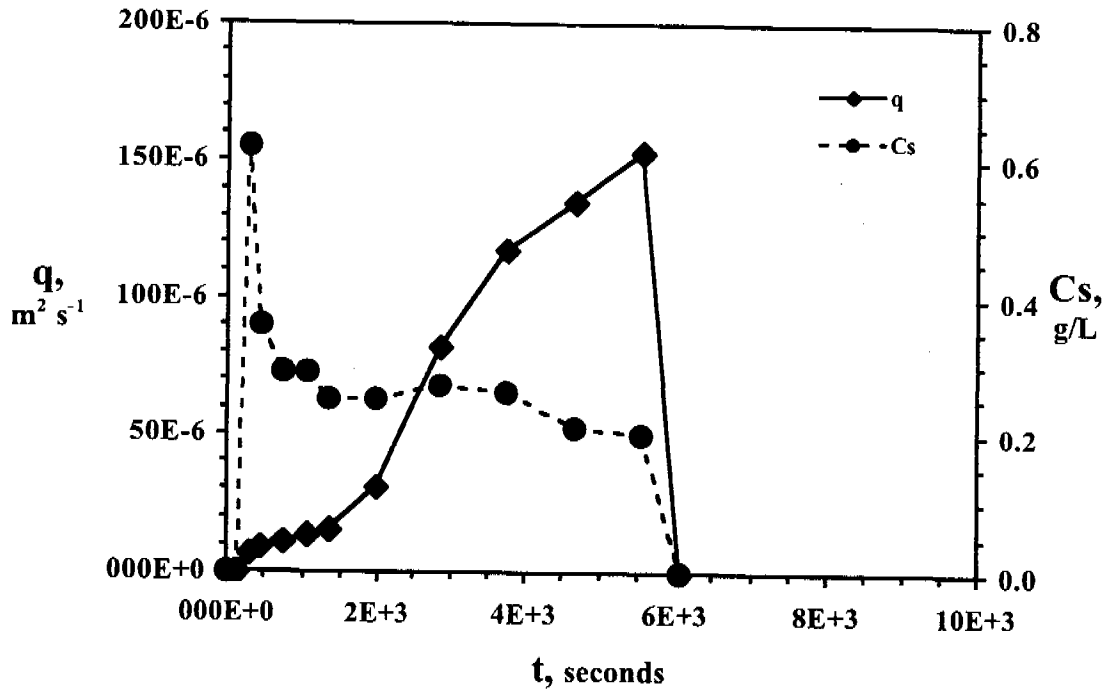
Plot 12 Straw/Coconut Blanket Treatment  
9/15/99



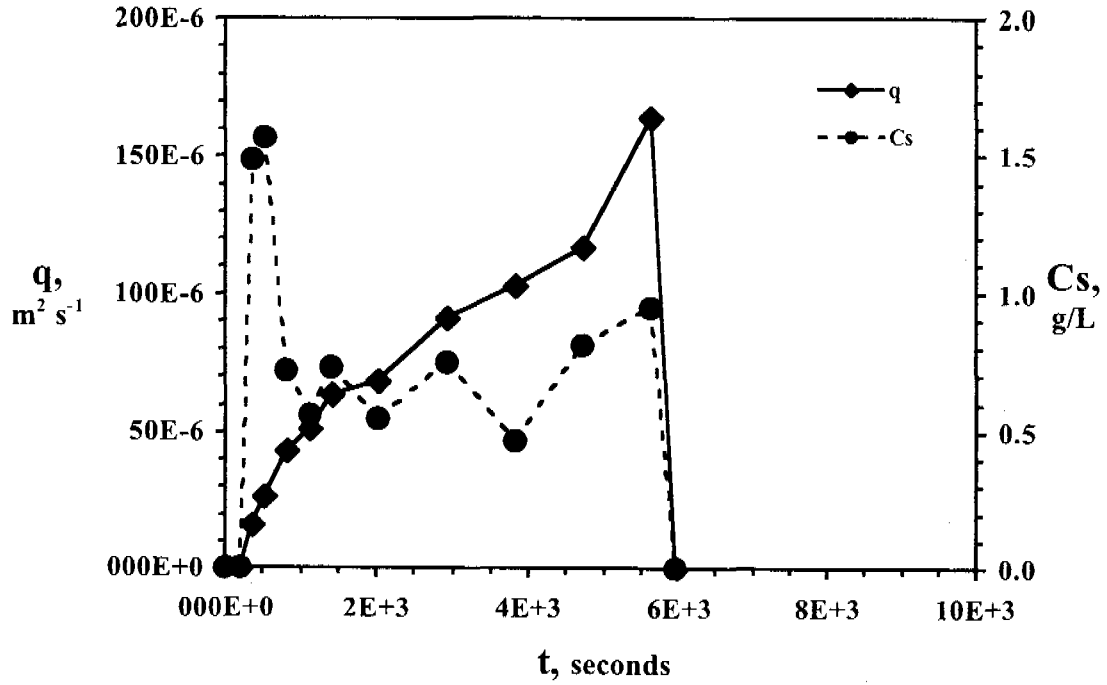
Plot 13 Bare Soil Treatment  
9/15/99



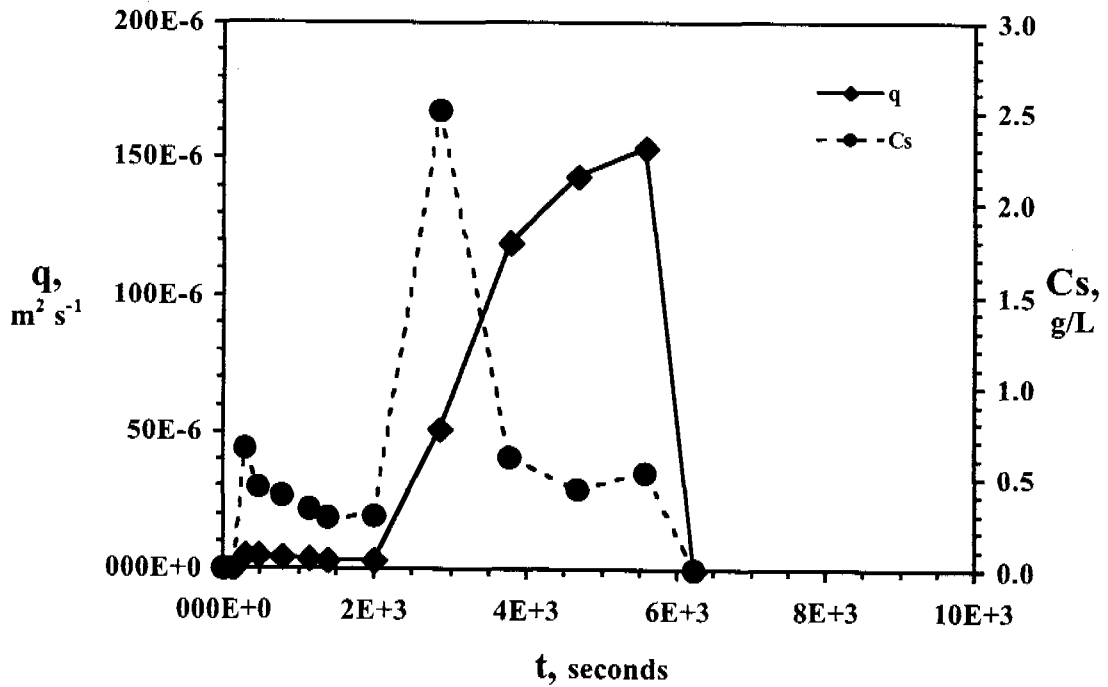
Plot 14 Straw/Coconut Blanket Treatment  
9/15/99



Plot 15 Straw Mulch Treatment  
9/15/99

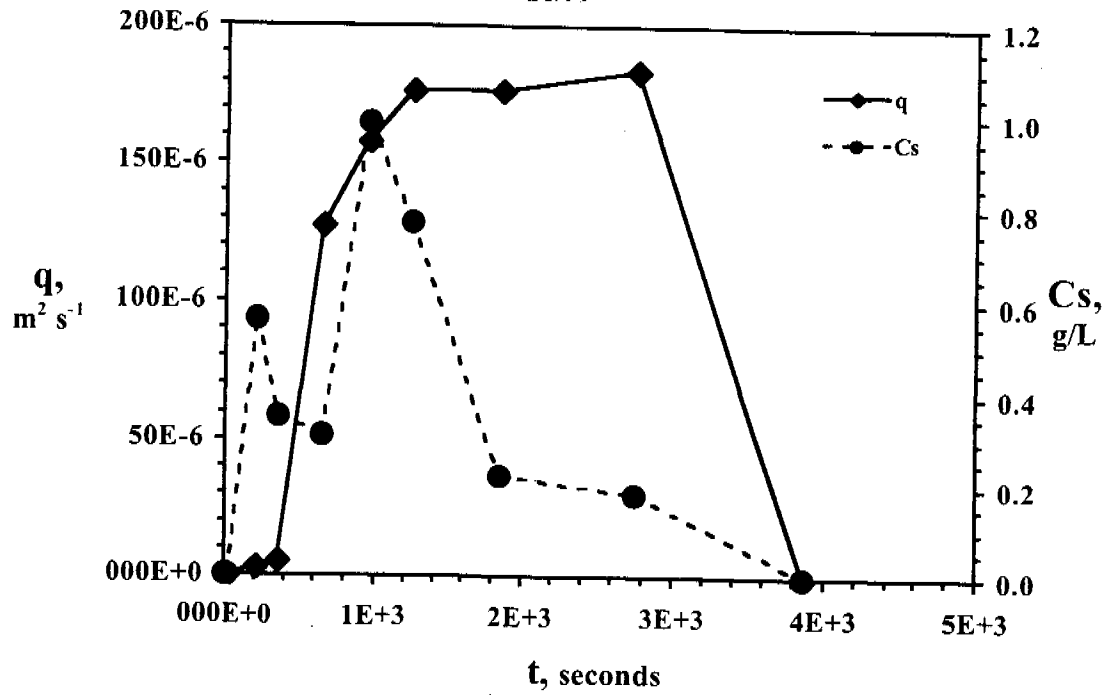


Plot 16 BFM Treatment  
9/15/99

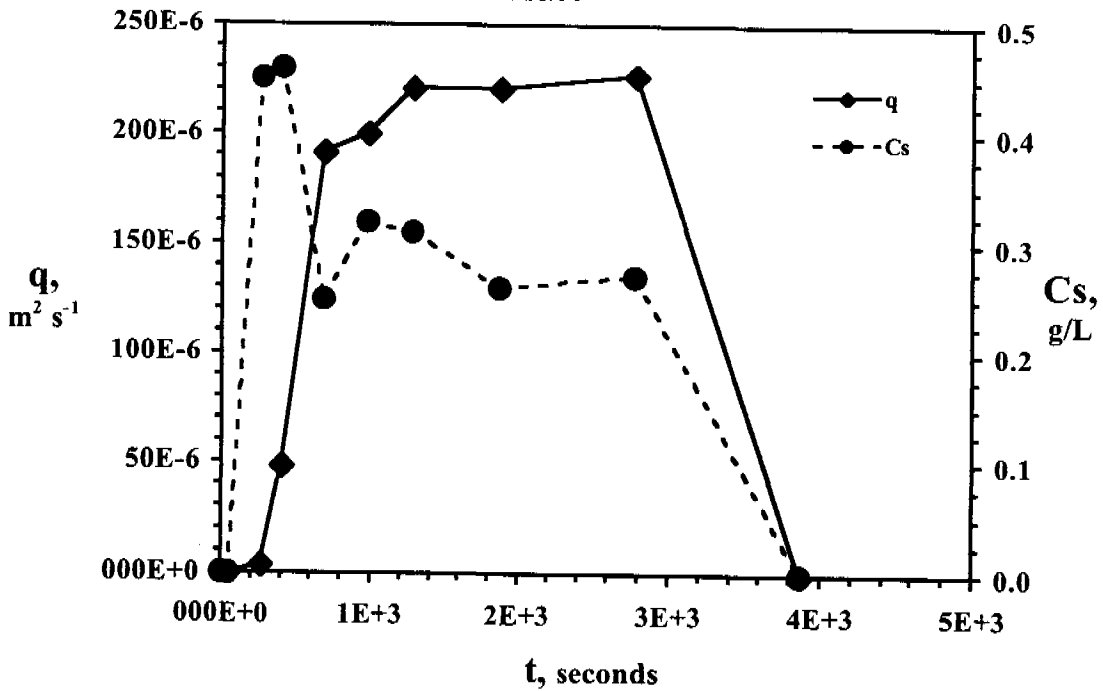




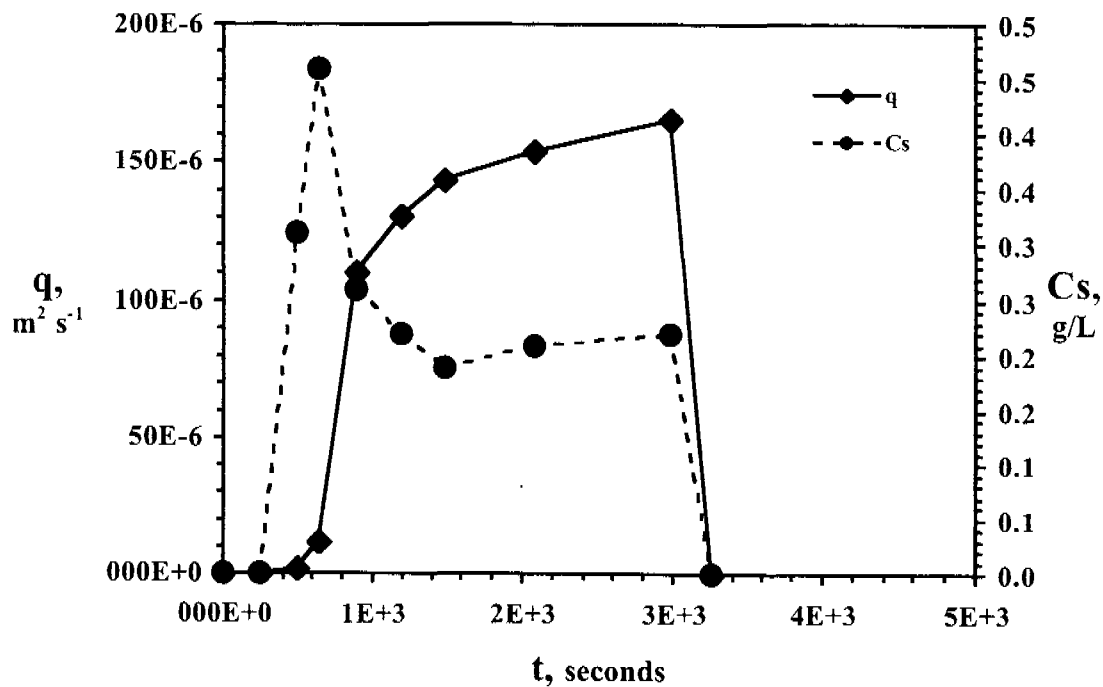
Plot 1, Straw/Coconut Blanket Treatment  
9/16/99



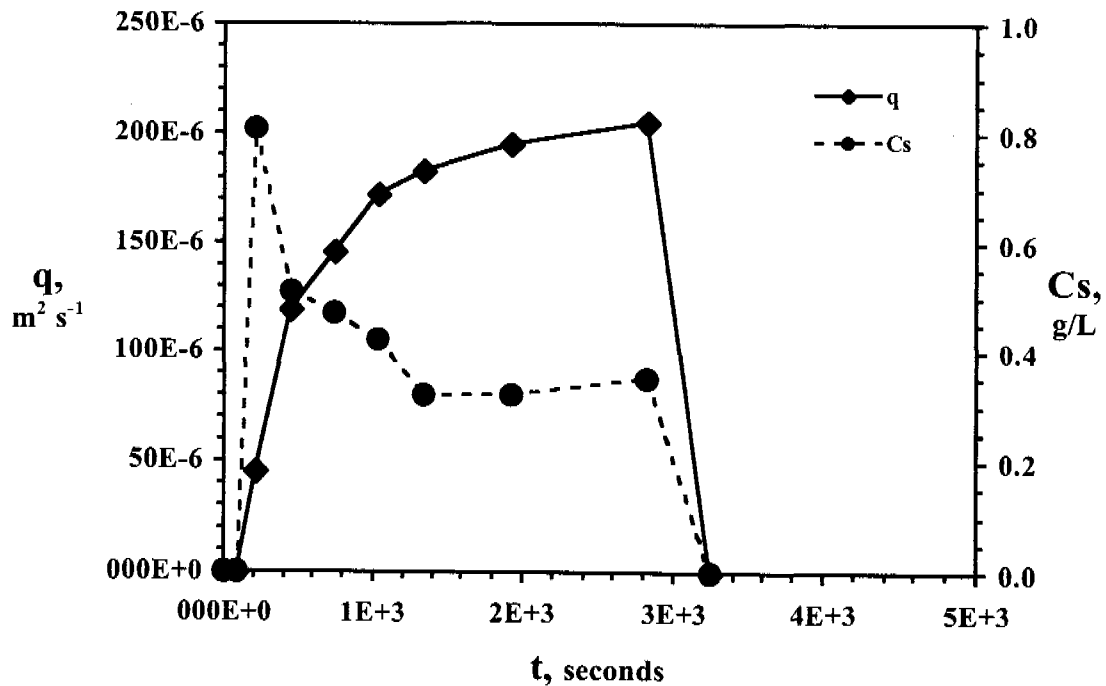
Plot 2, Straw Mulch Treatment  
9/16/99



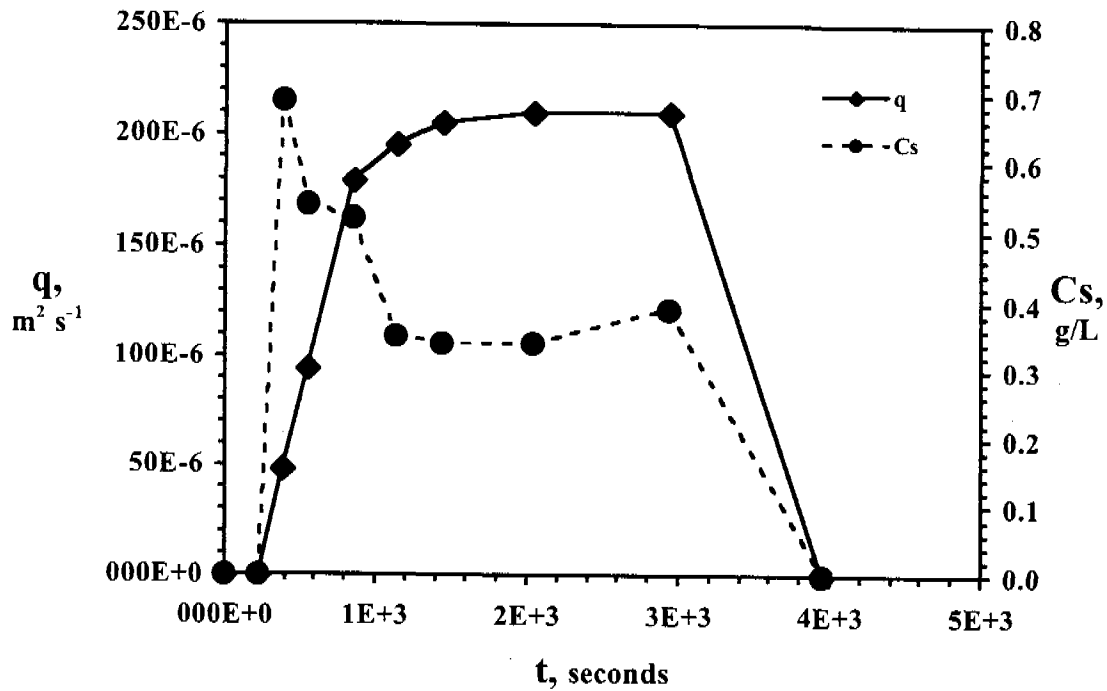
Plot 3, Wood Fiber Blanket Treatment  
9/15/99



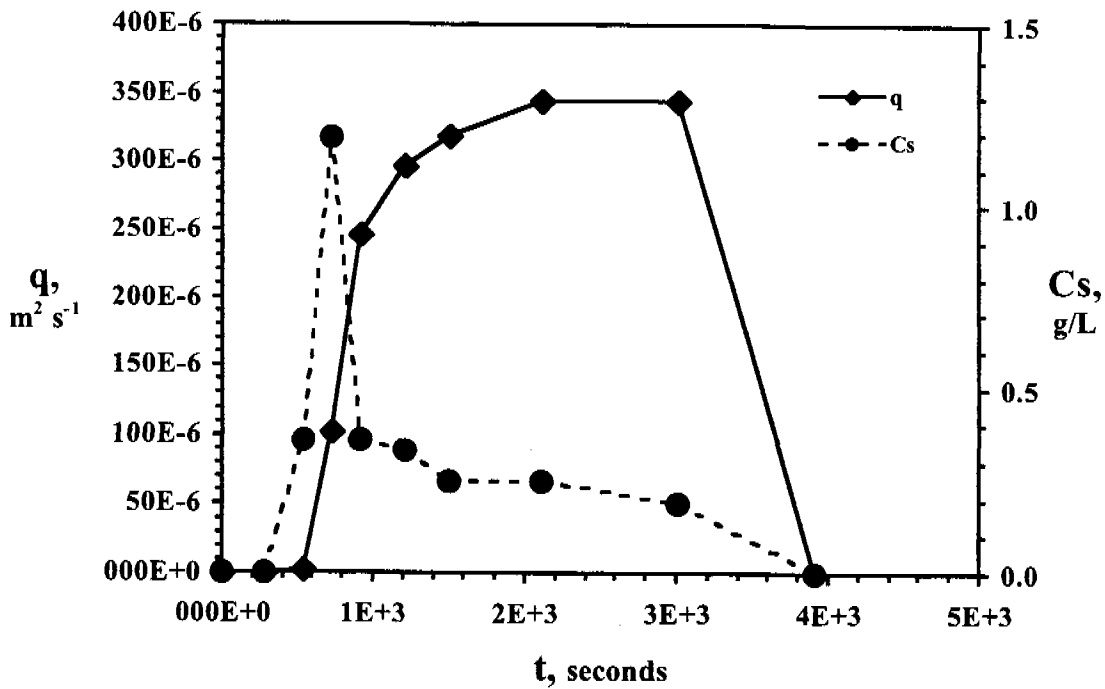
Plot 4, Bare Soil Treatment  
9/15/99



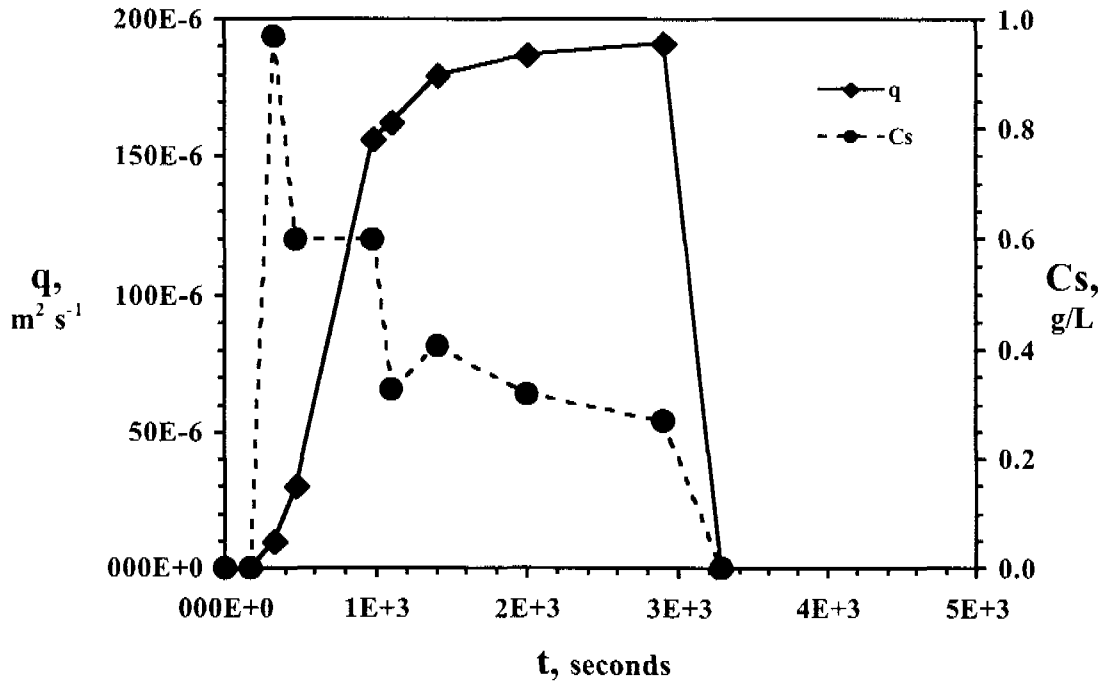
Plot 5, Bare Soil Treatment  
9/16/99



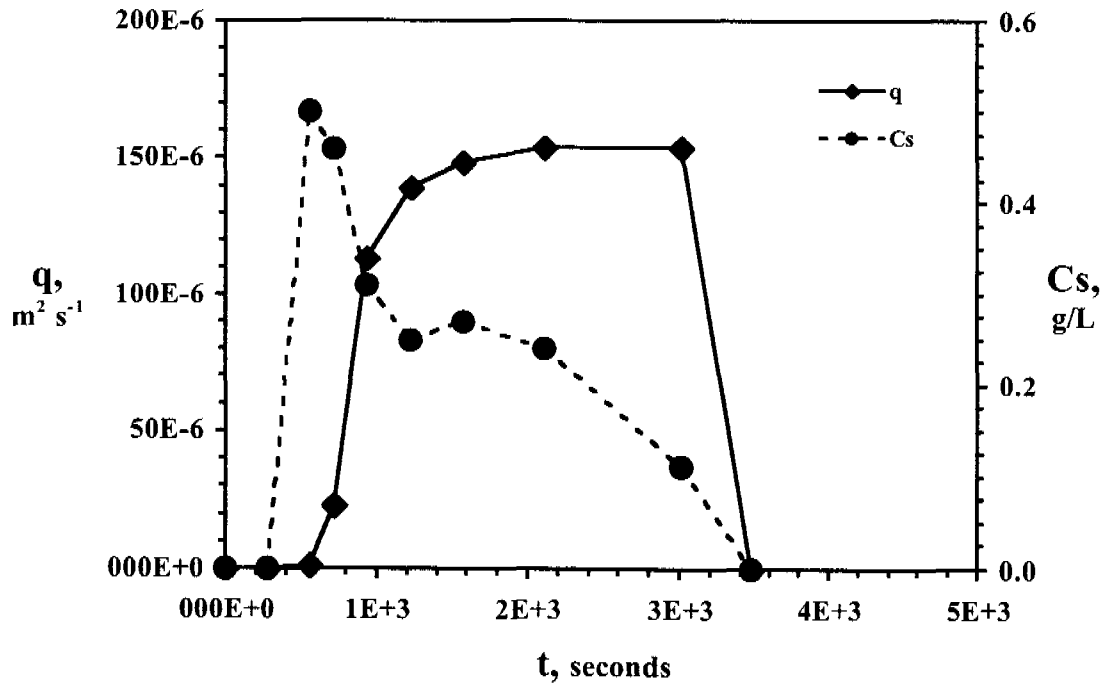
Plot 6, BFM Treatment  
9/16/99



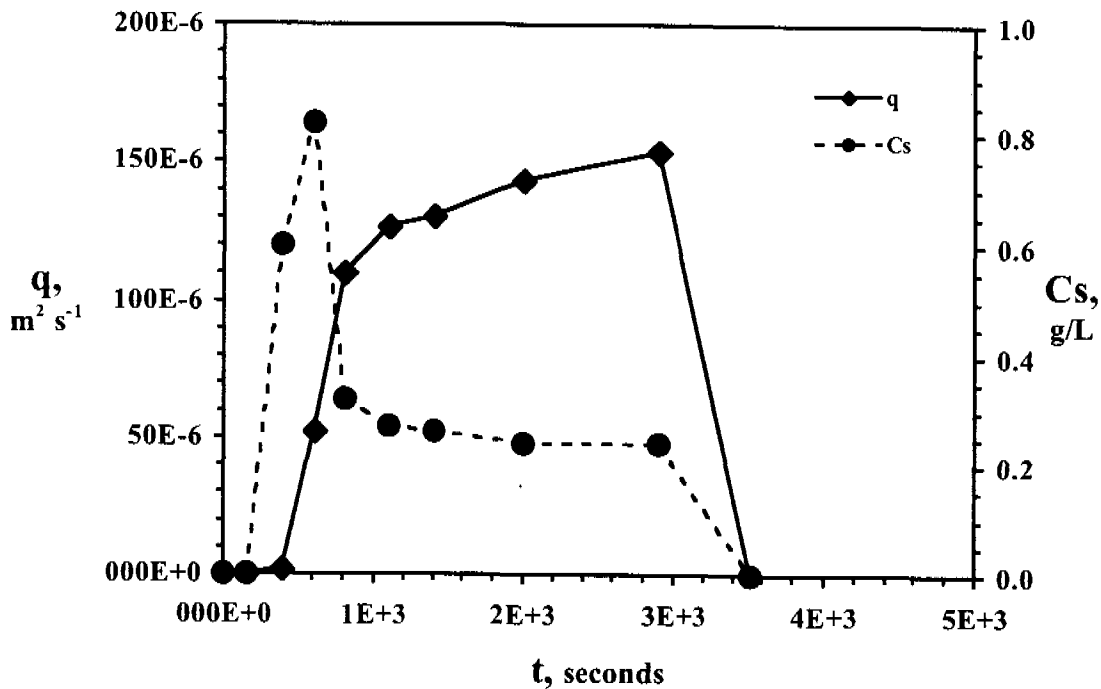
Plot 7, Straw/Coconut Blanket Treatment  
9/16/99



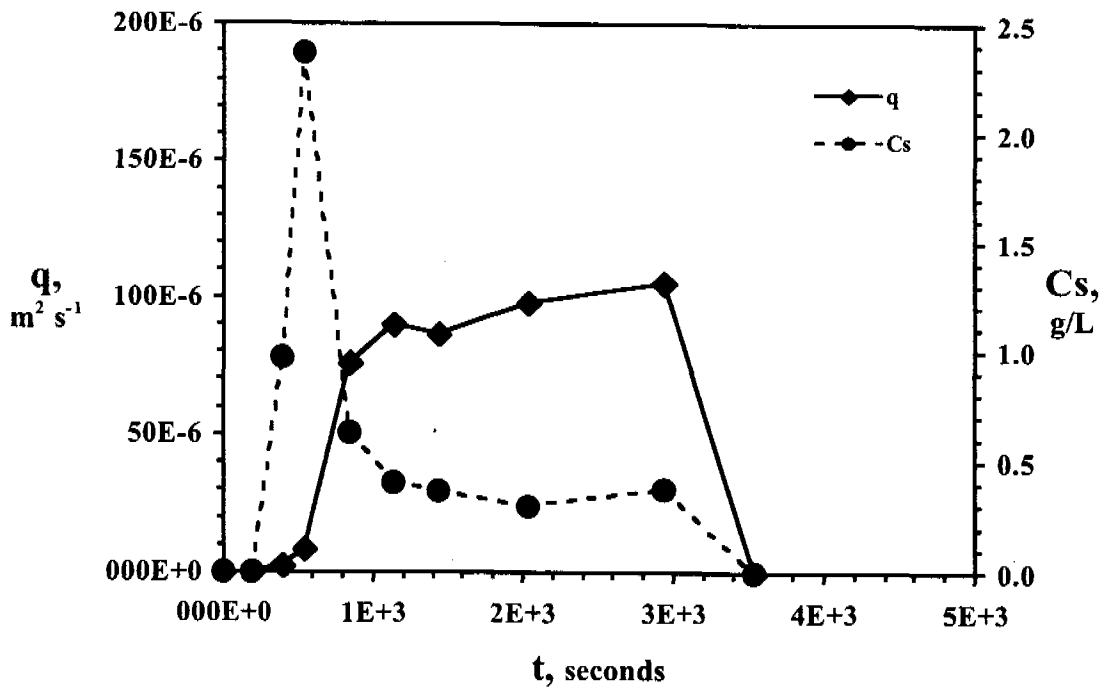
Plot 8, Wood Fiber Blanket Treatment  
9/16/99



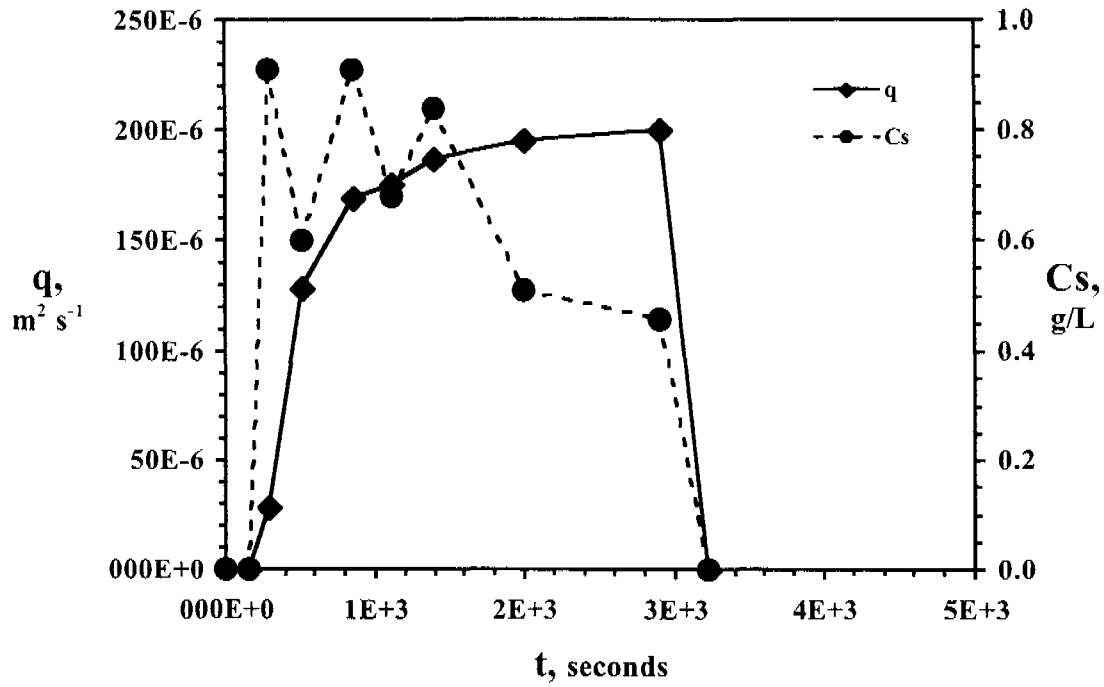
Plot 9, Wood Fiber Blanket Treatment  
9/16/99



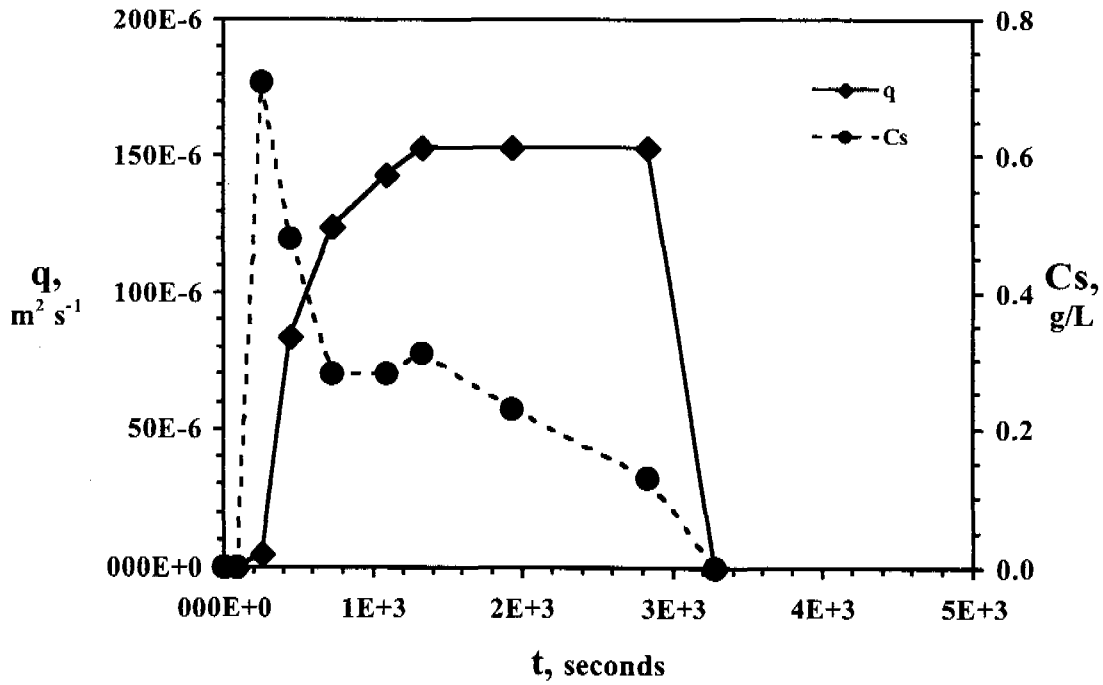
Plot 10, BFM Treatment  
9/16/99



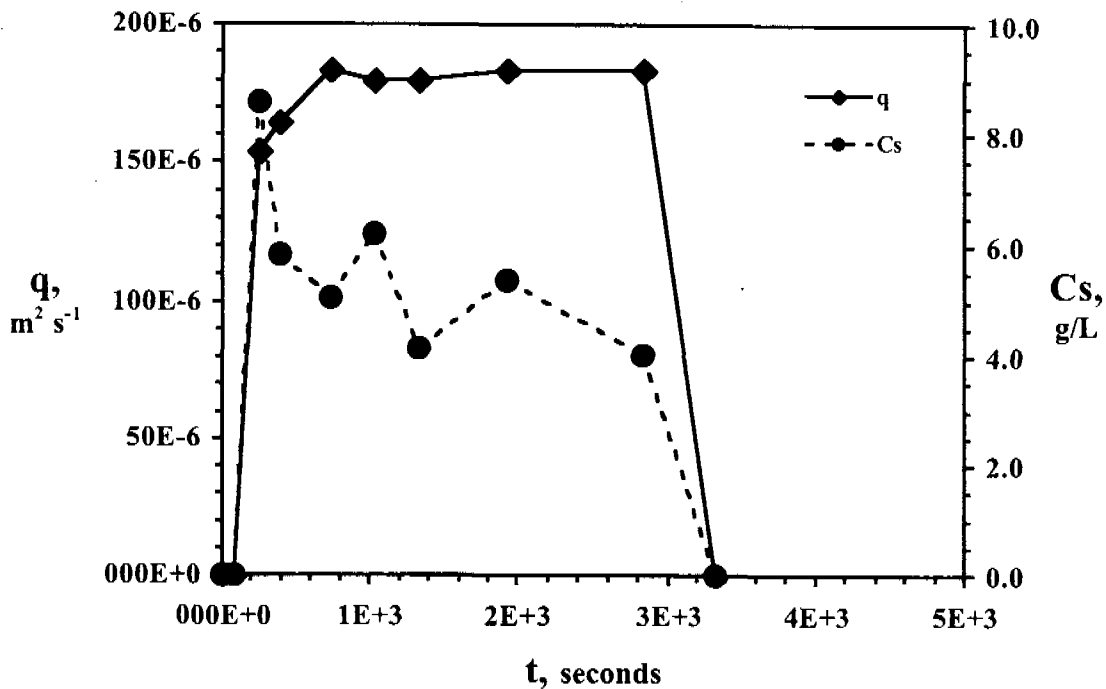
Plot 11, Straw Mulch Treatment  
9/16/99



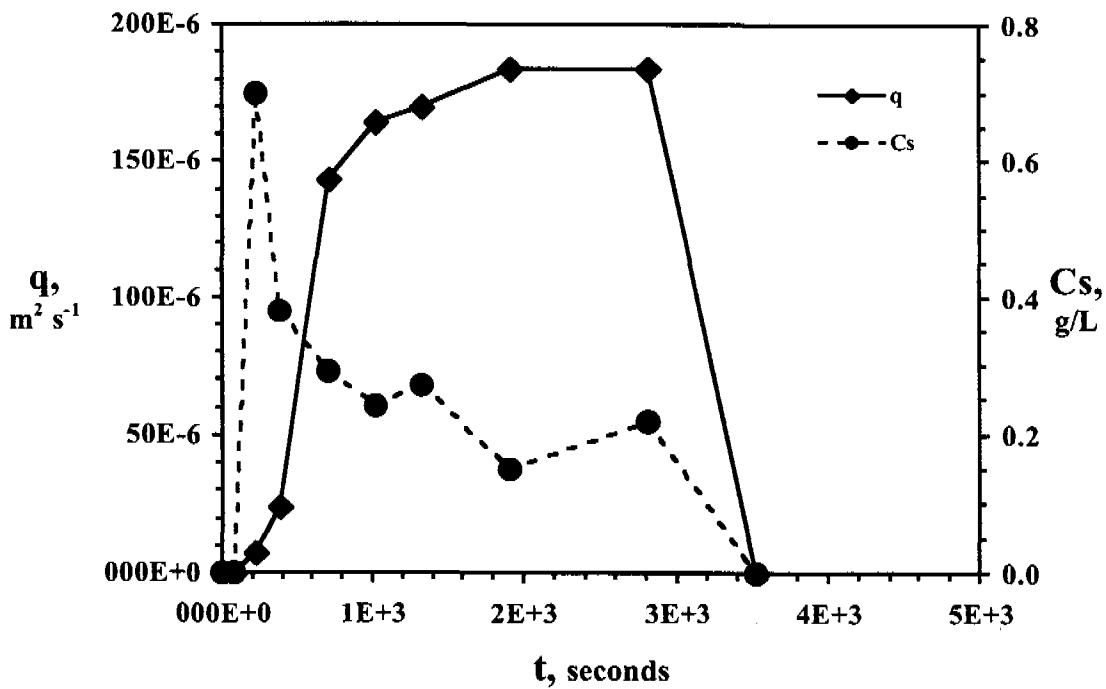
Plot 12, Straw/Coconut Blanket Treatment  
9/16/99



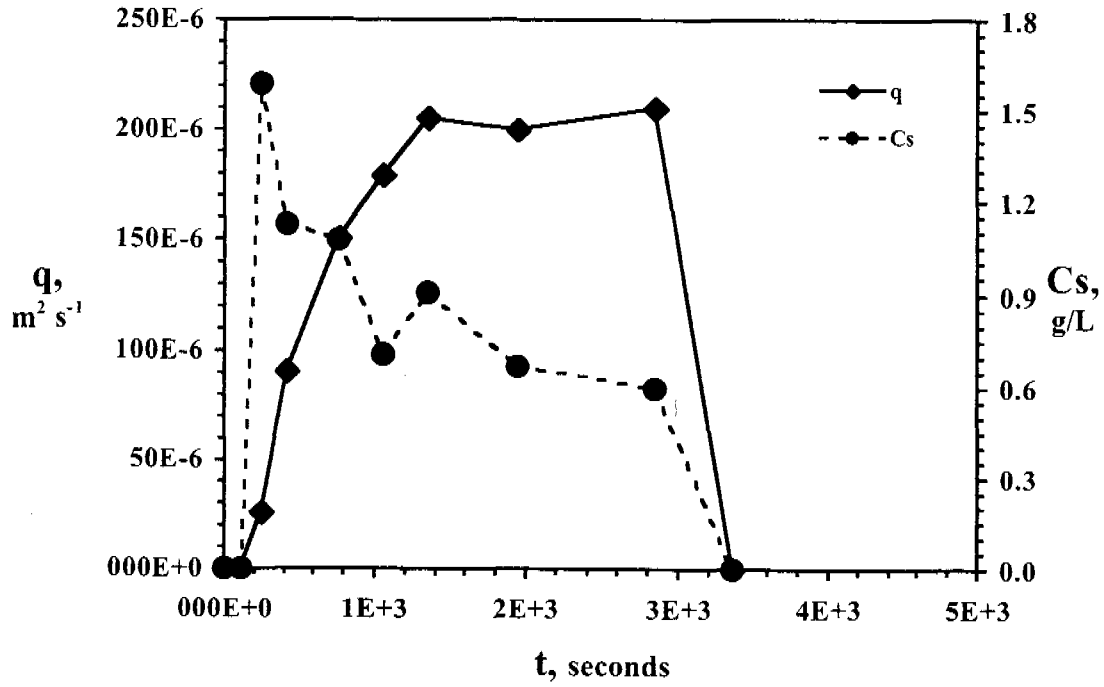
Plot 13, Bare Soil Treatment  
9/16/99



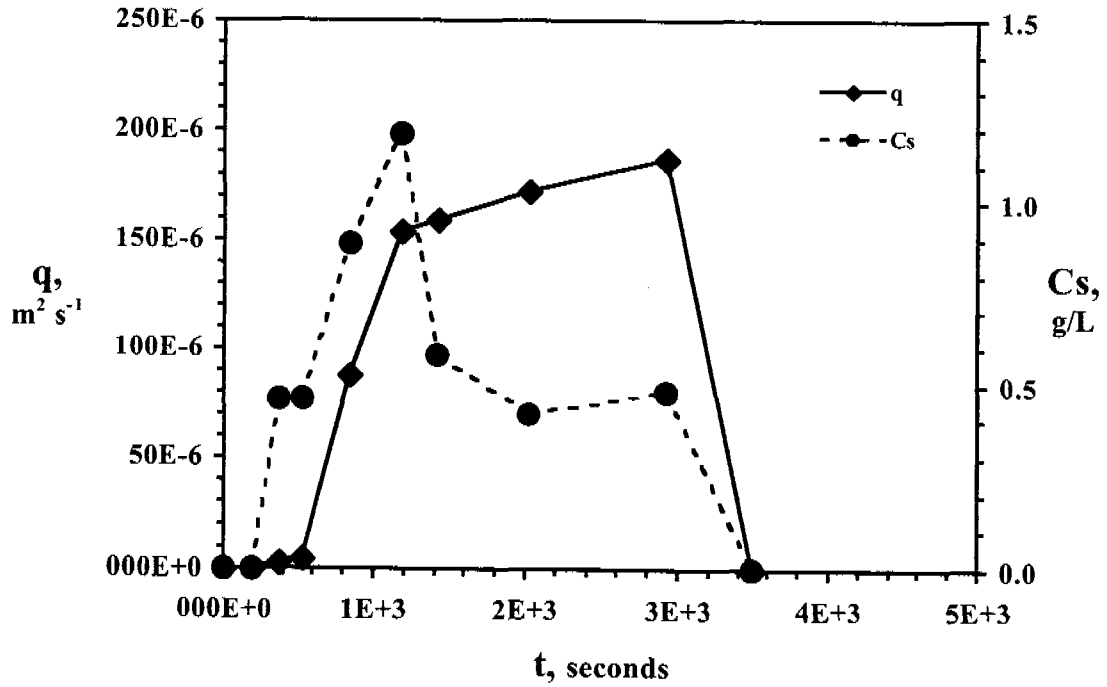
Plot 14, Straw/Coconut Blanket Treatment  
9/16/99



Plot 15, Straw/Coconut Blanket Treatment  
9/16/99

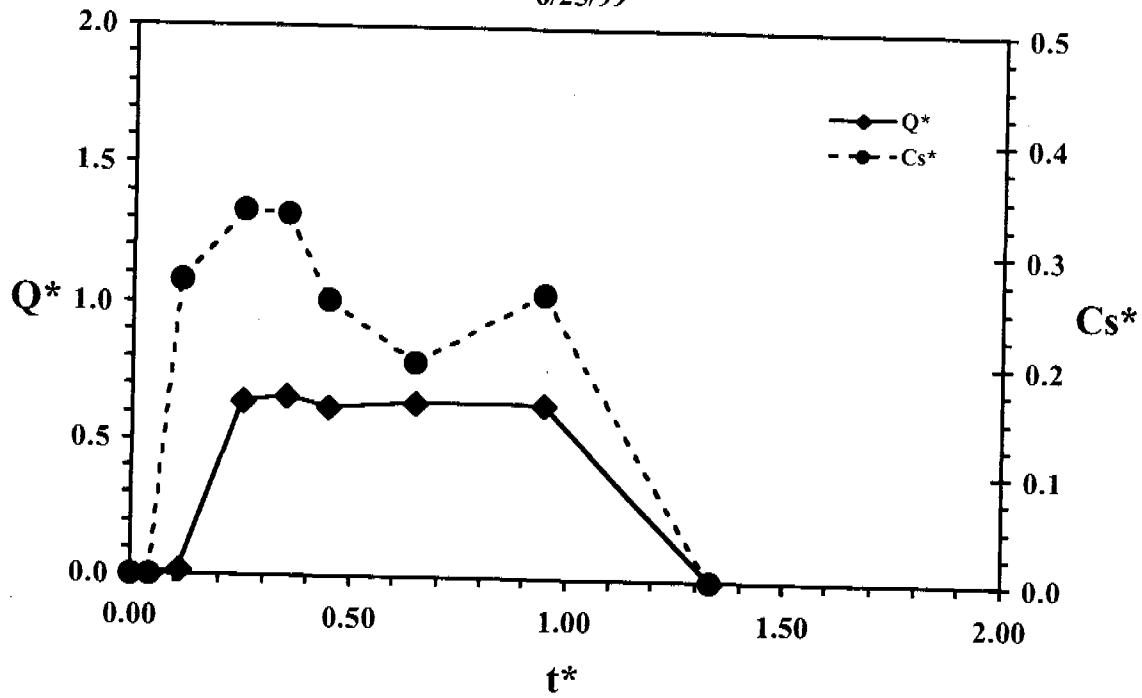


Plot 16, BFM Treatment  
9/16/99

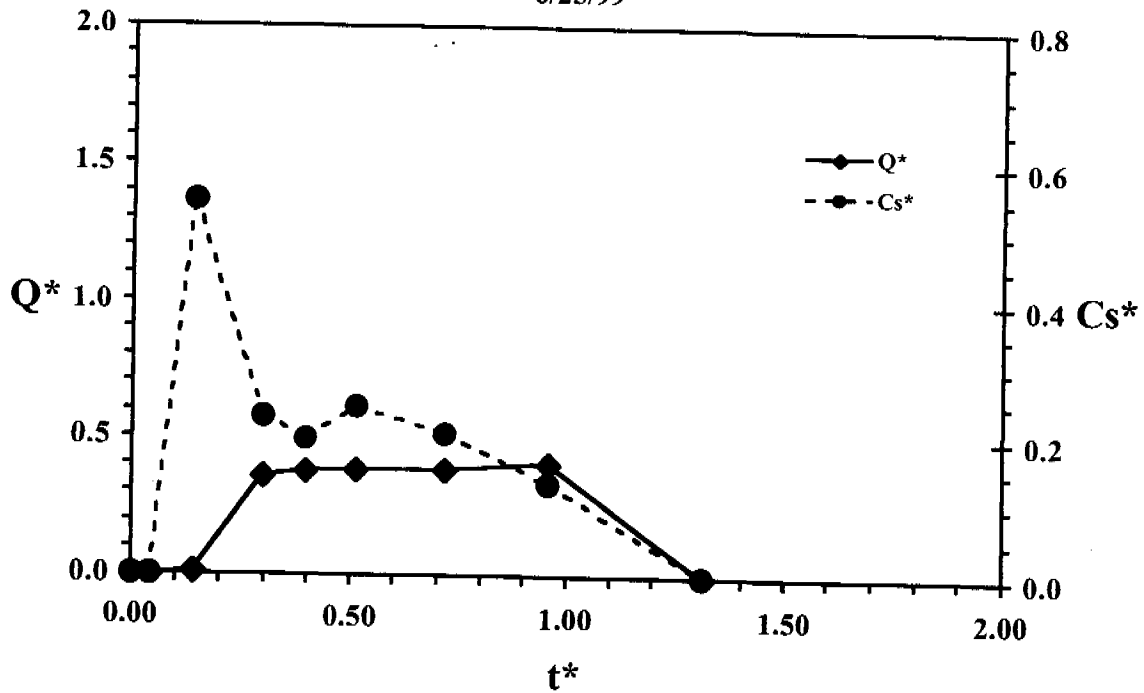




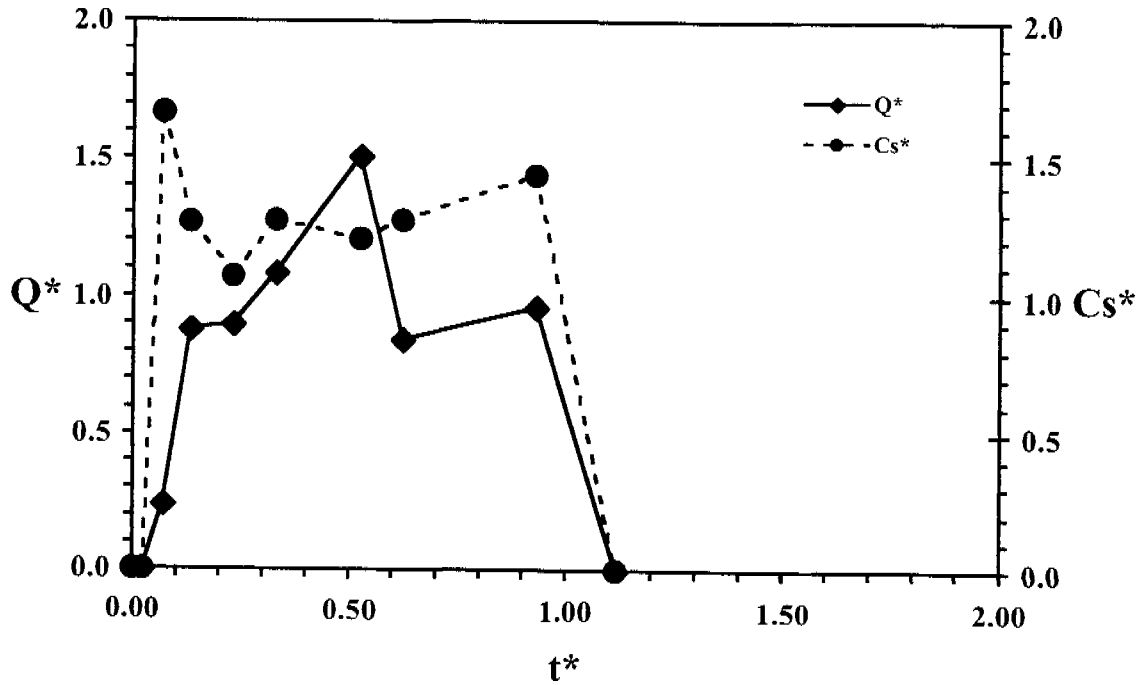
Plot 9, Treatment  
6/25/99



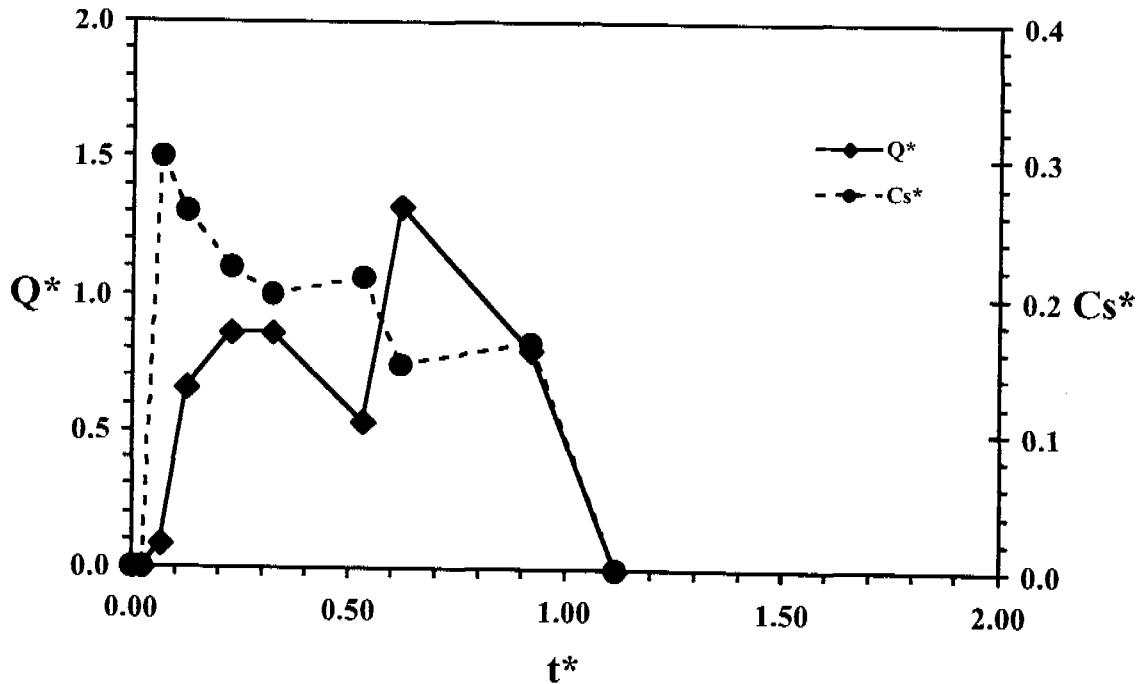
Plot 10, BFM Treatment  
6/25/99



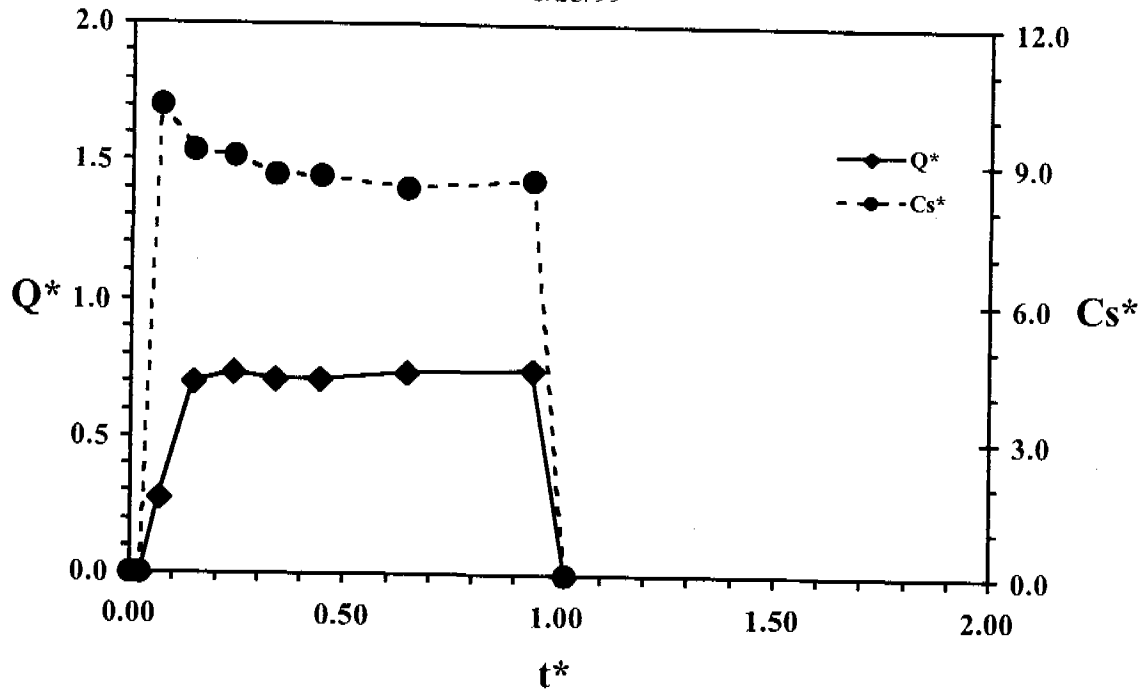
Plot 11, Straw Mulch Treatment  
6/25/99



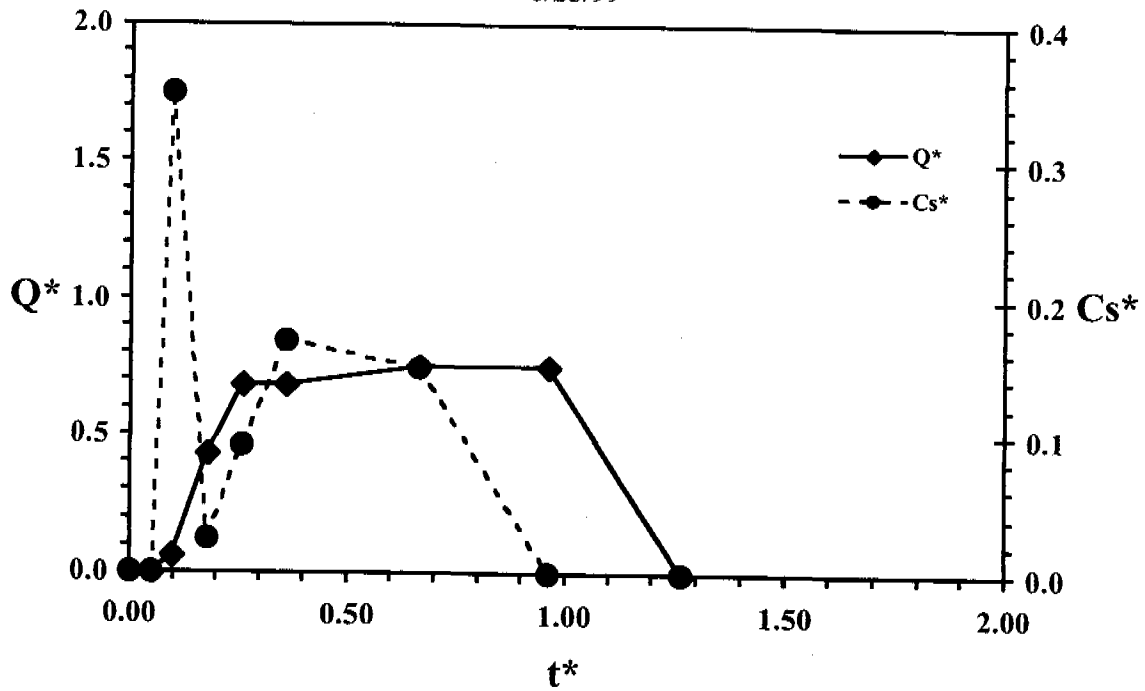
Plot 12, Straw/Coconut Blanket Treatment  
6/25/99



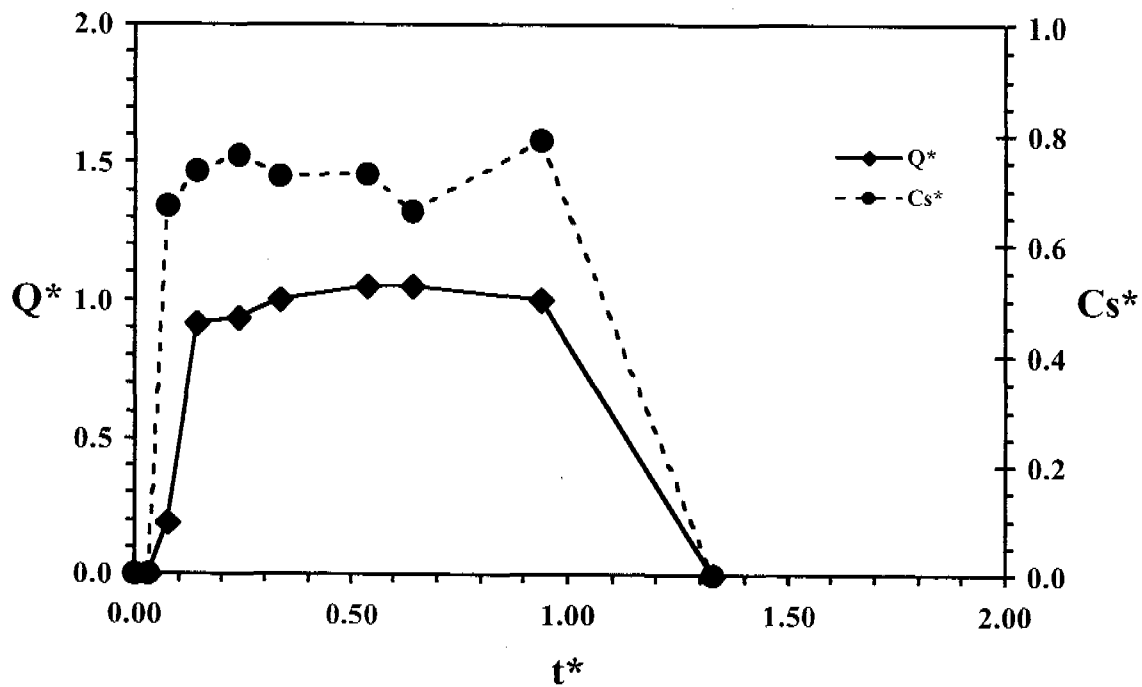
Plot 13, Bare Soil Treatment  
6/25/99



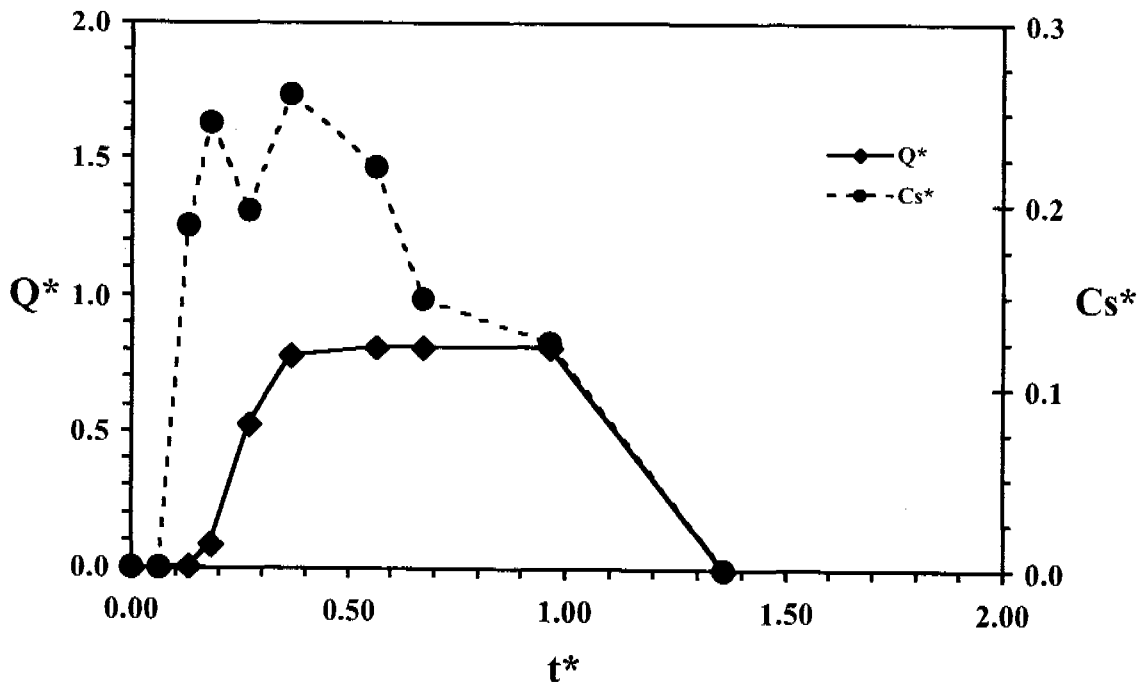
Plot 14, Straw/Coconut Blanket Treatment  
6/25/99



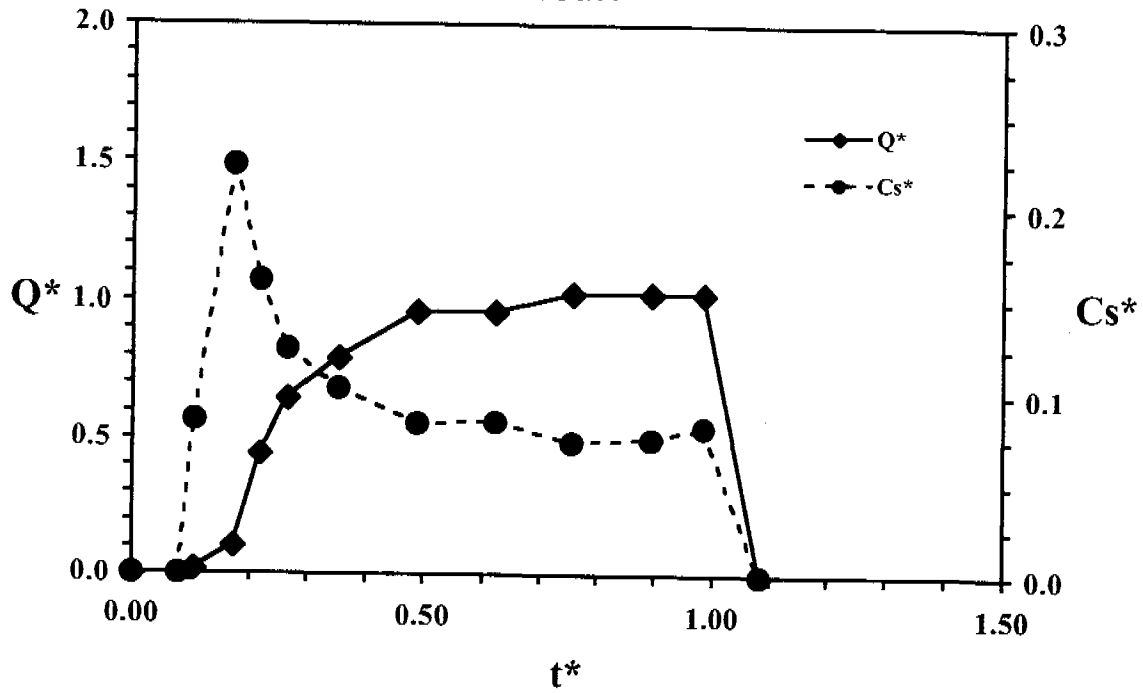
Plot 15, Straw Mulch Treatment  
6/25/99



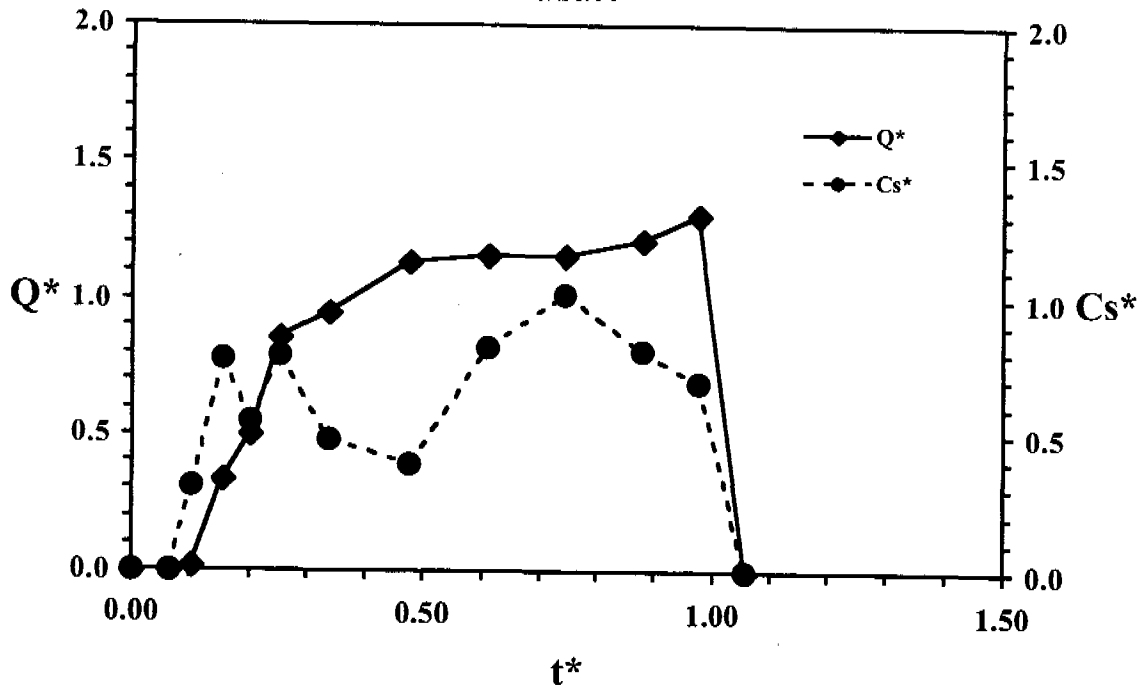
Plot 16, BFM Treatment  
6/25/99



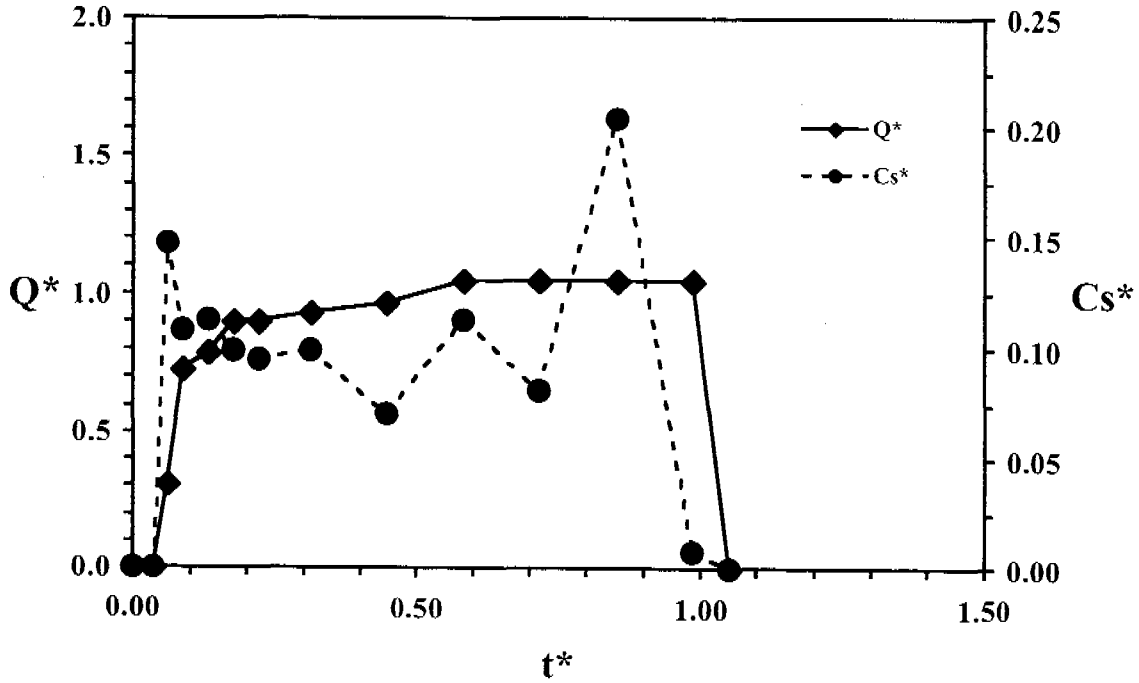
Plot 1, Straw/Coconut Blanket Treatment  
6/26/99



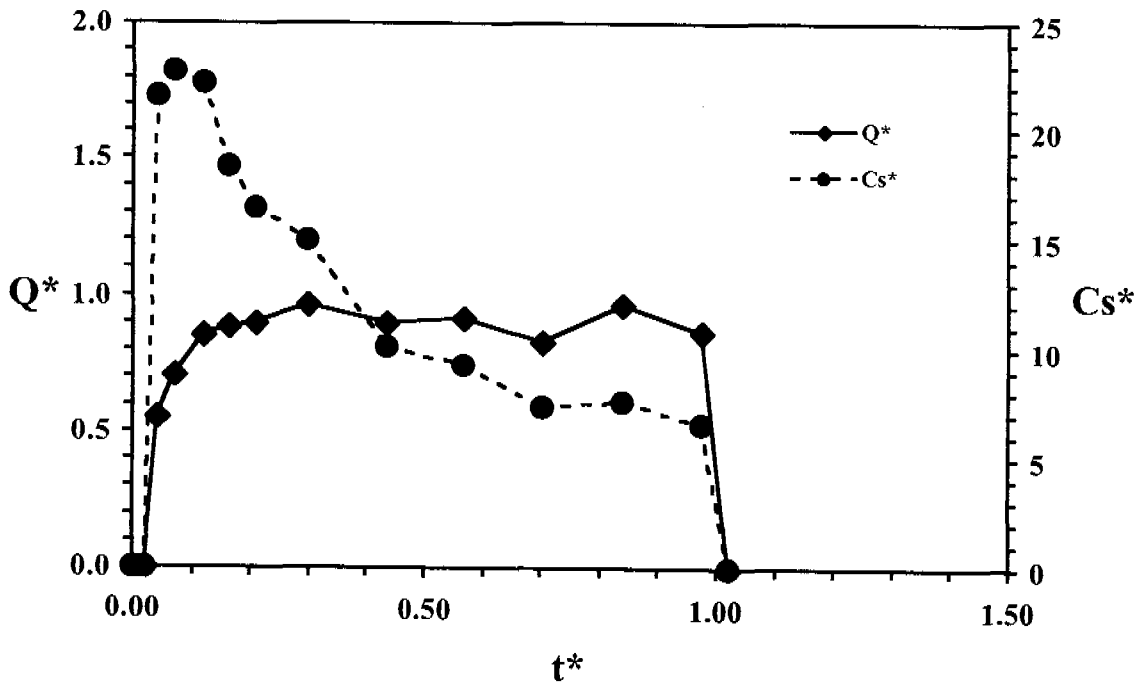
Plot 2, Straw Mulch Treatment  
6/26/99



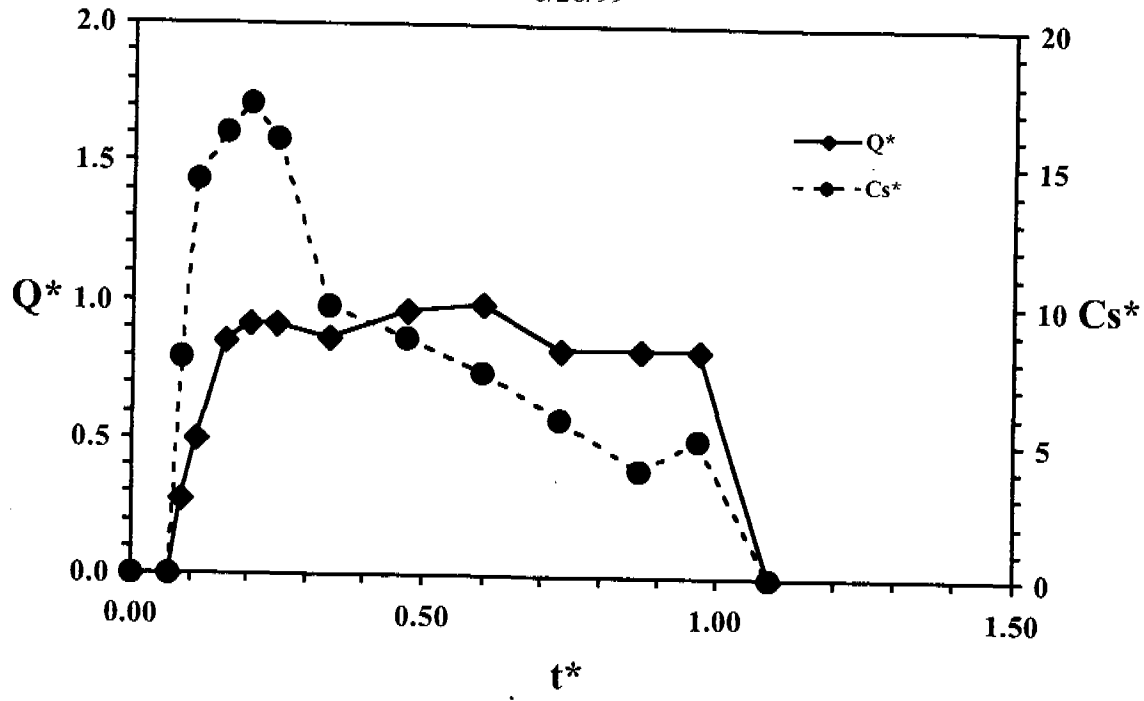
Plot 3, Wood Fiber Blanket Treatment  
6/26/99



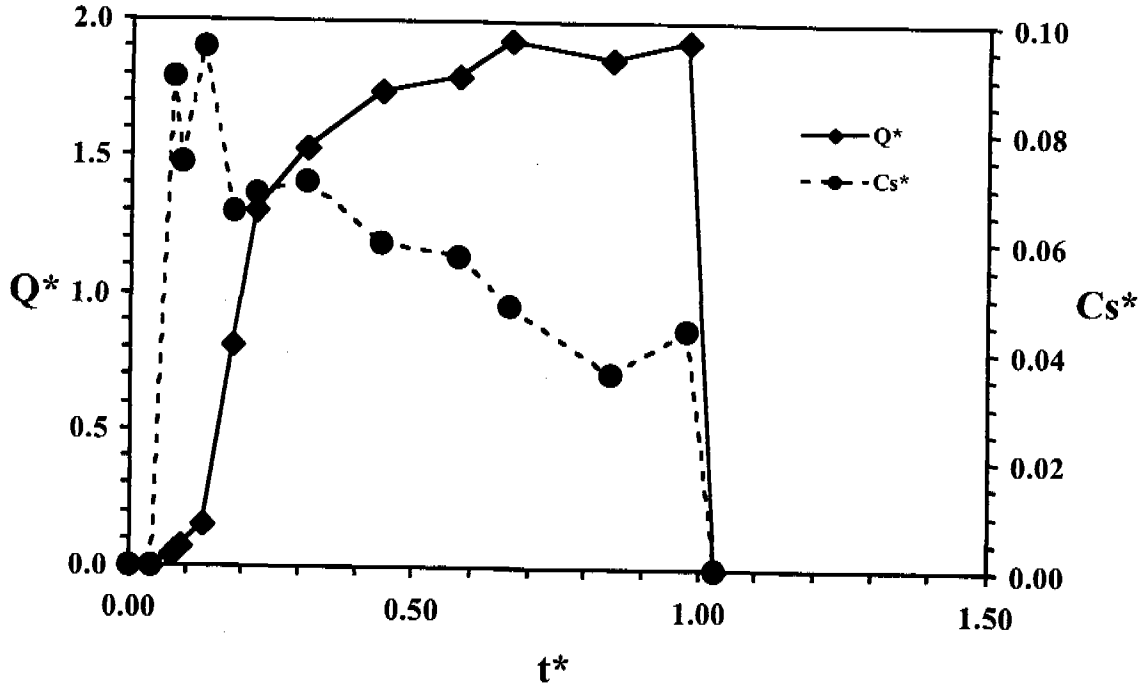
Plot 4, Bare Soil Treatment  
6/26/99



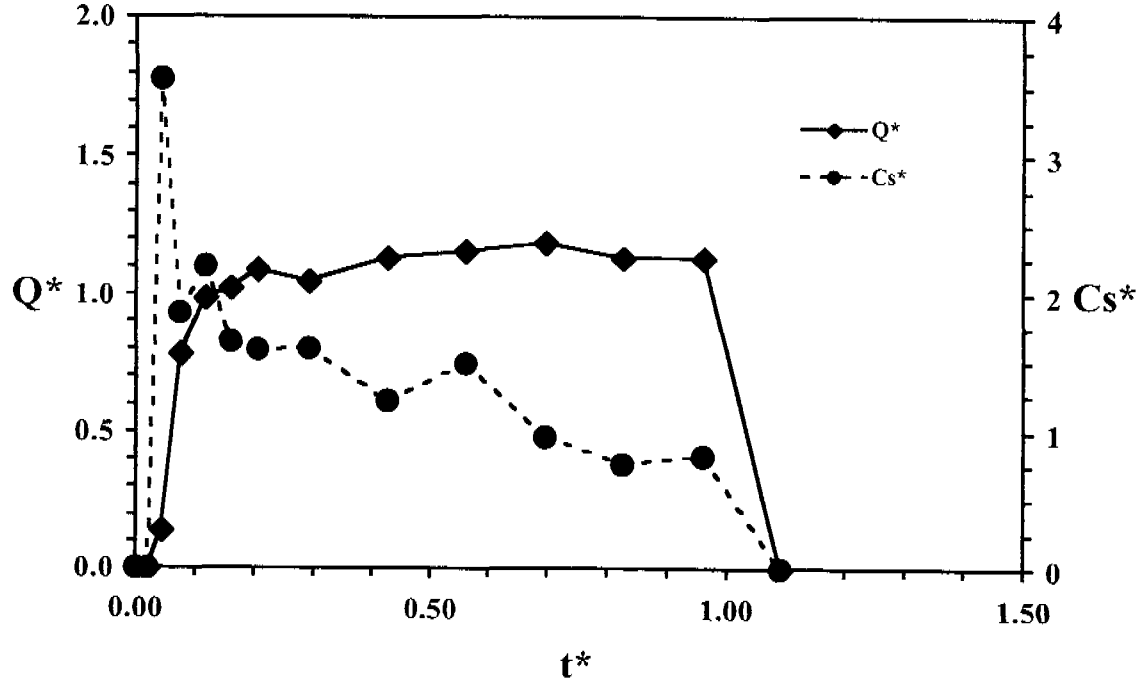
Plot 5, Bare Soil Treatment  
6/26/99



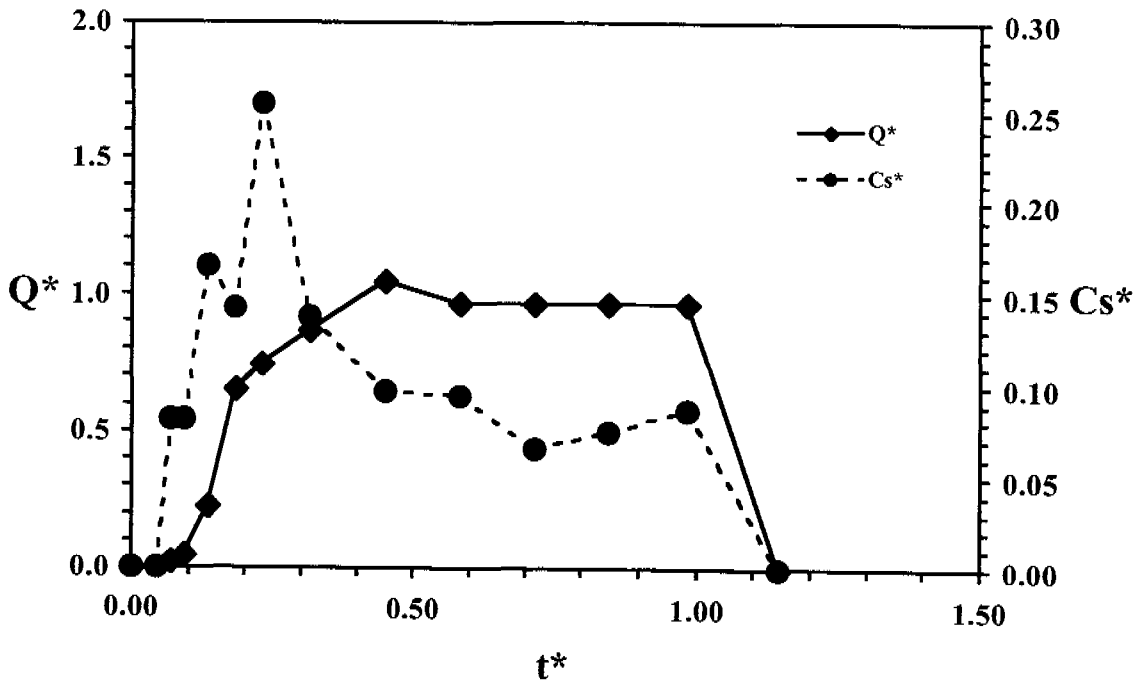
Plot 6, BFM Treatment  
6/26/99



Plot 7, Straw Mulch Treatment  
6/26/99

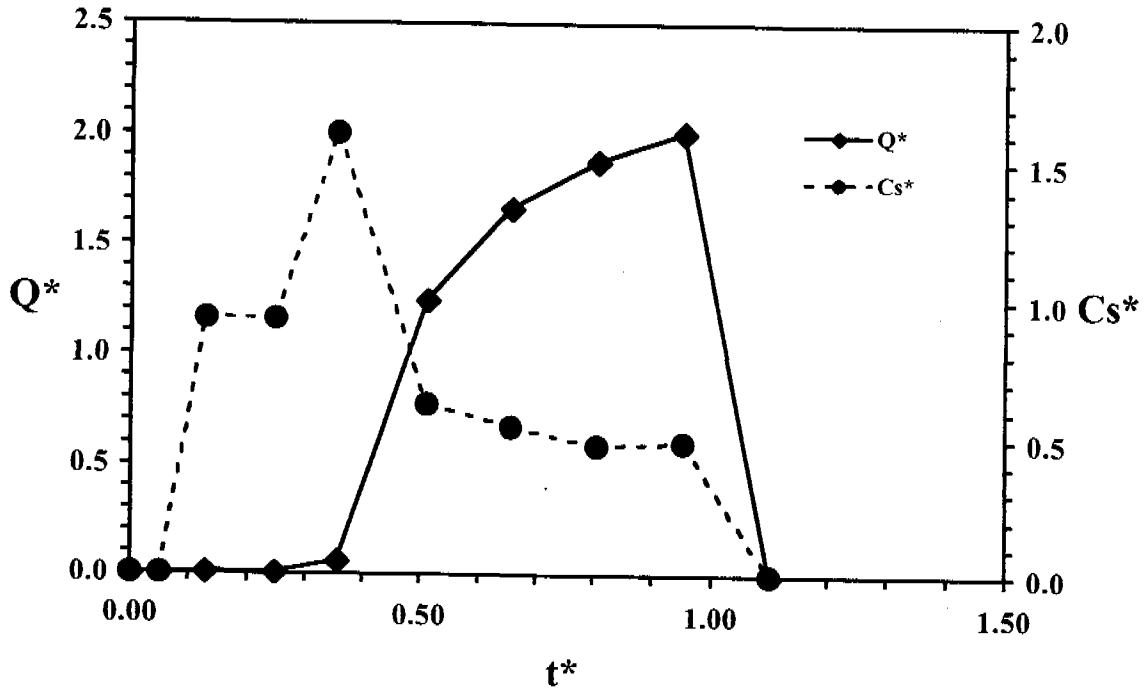


Plot 8, Wood Fiber Blanket Treatment  
6/26/99

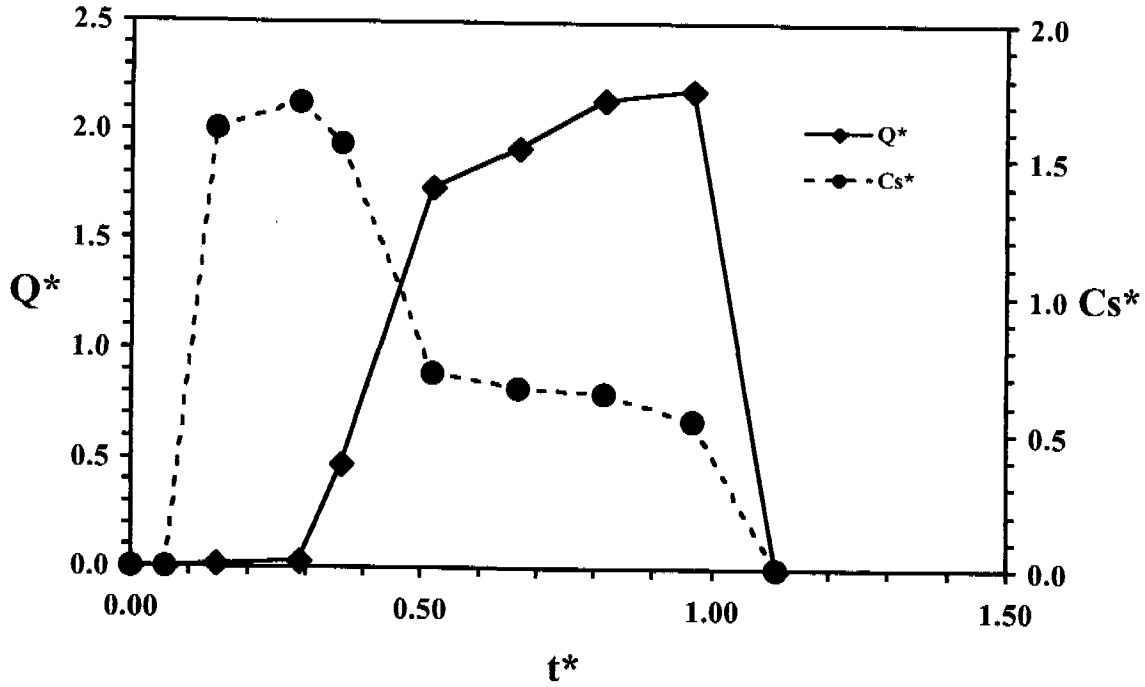




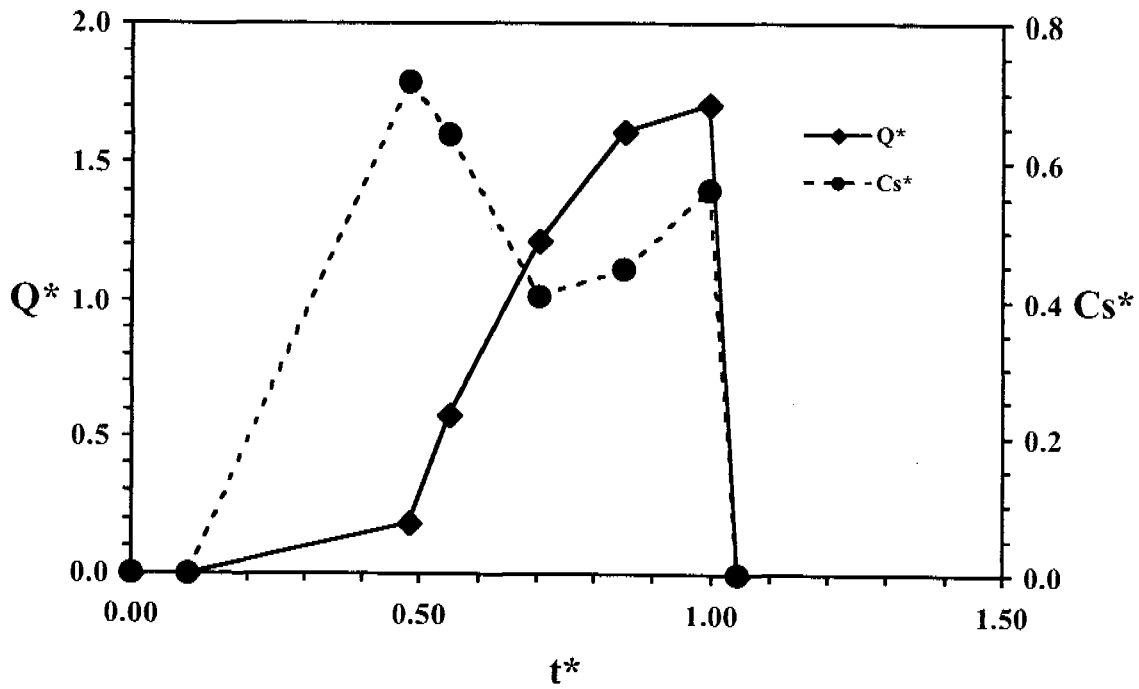
Plot 1, Straw/Coconut Blanket Treatment  
9/15/99



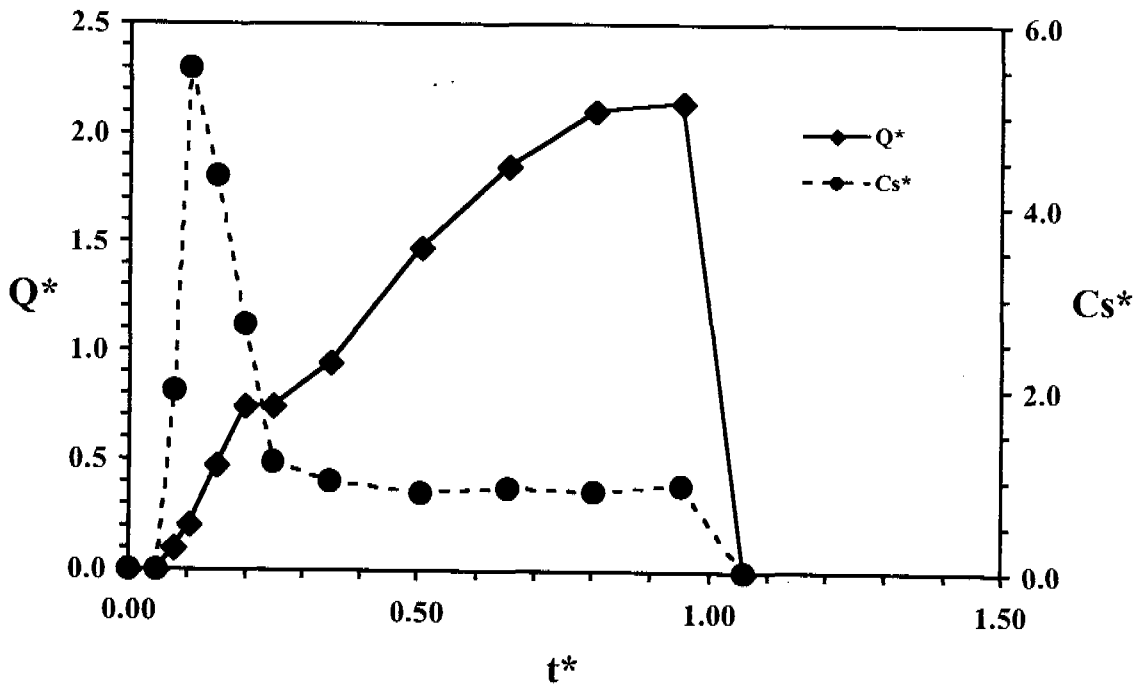
Plot 2, Straw Mulch Treatment  
9/15/99



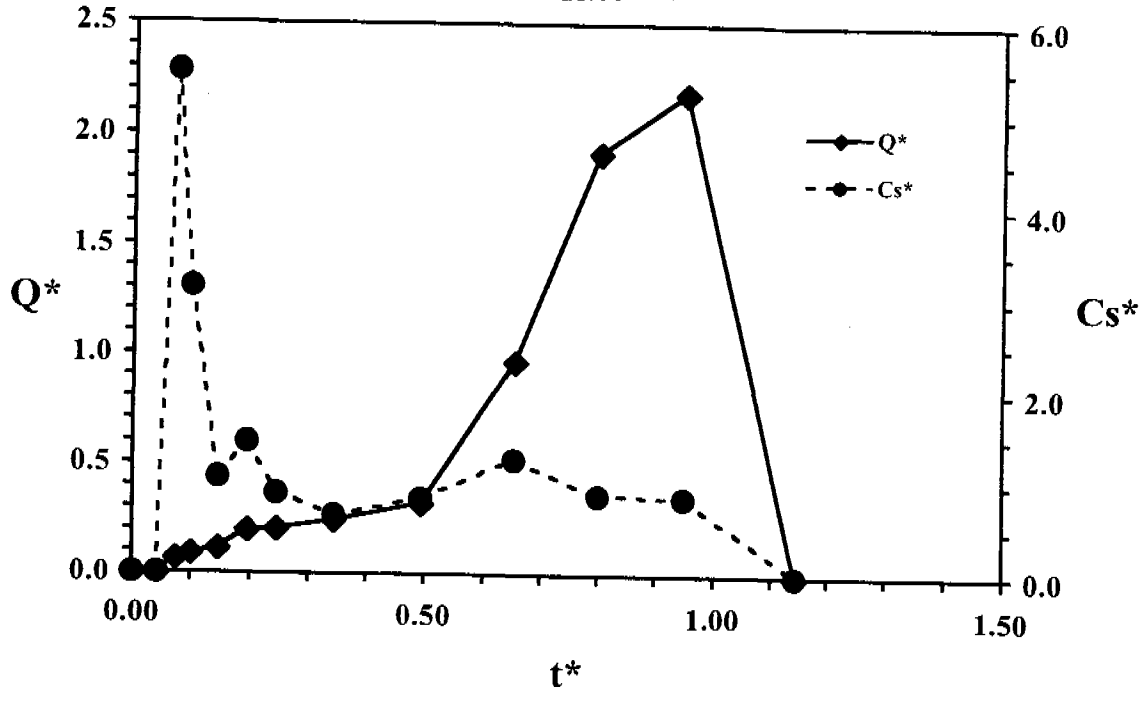
Plot 3, Wood Fiber Blanket Treatment  
9/15/99



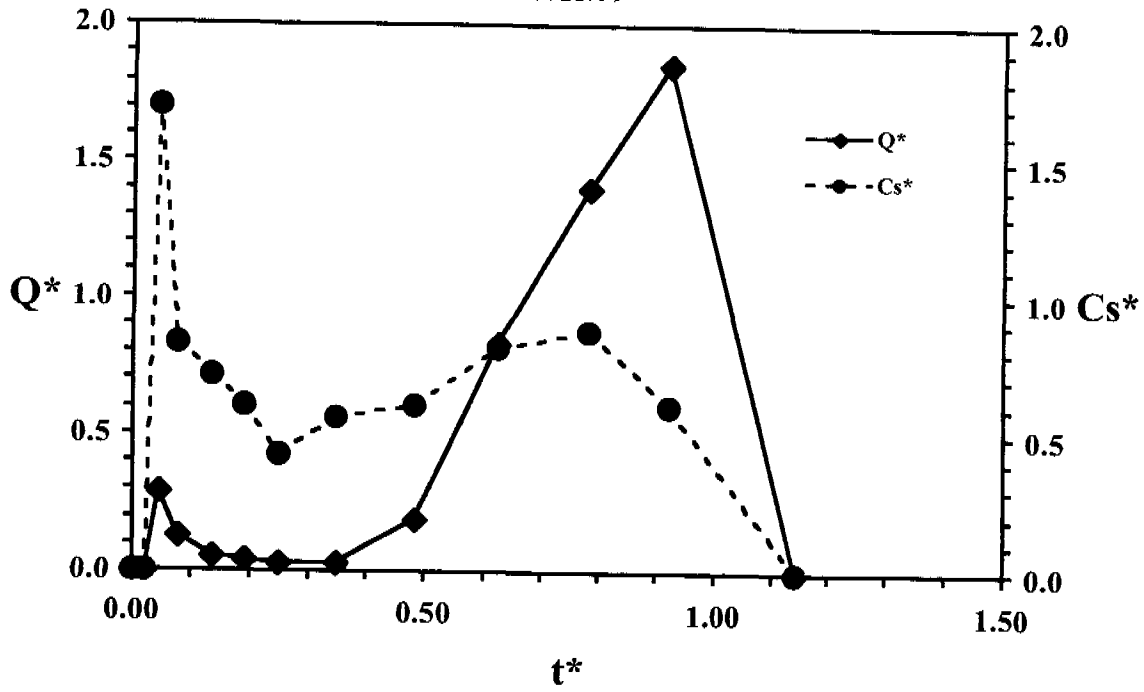
Plot 4, Bare Soil Treatment  
9/15/99



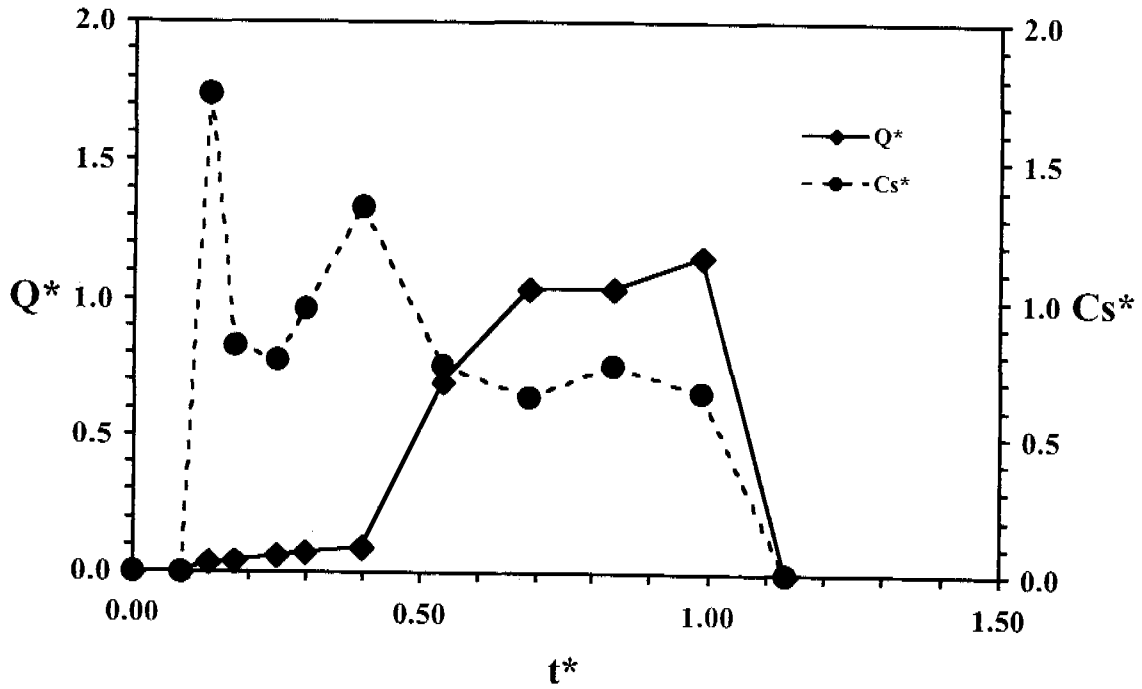
Plot 5, Bare Soil Treatment  
9/15/99



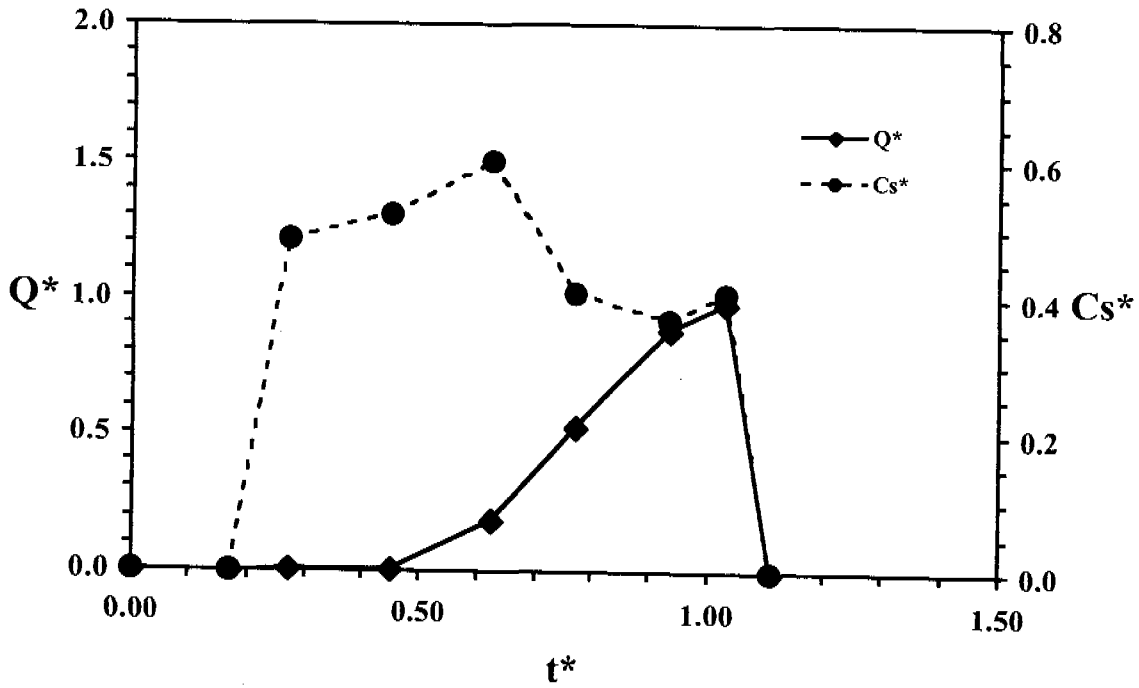
Plot 6, BFM Treatment  
9/15/99



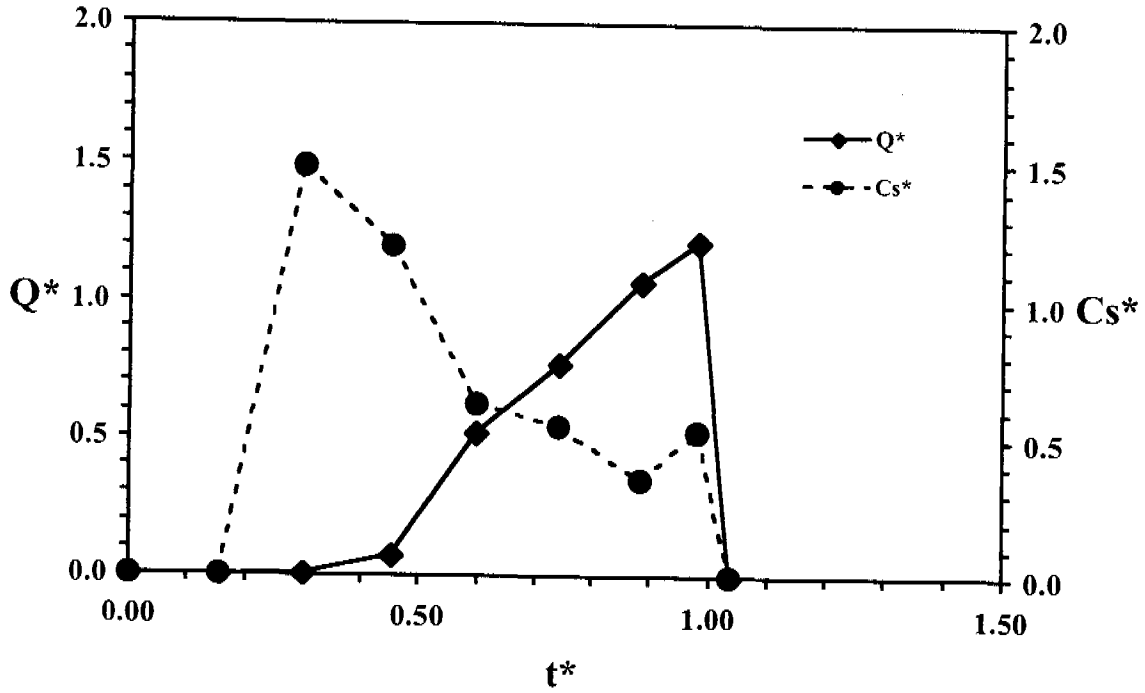
Plot 7, Straw Mulch Treatment  
9/15/99



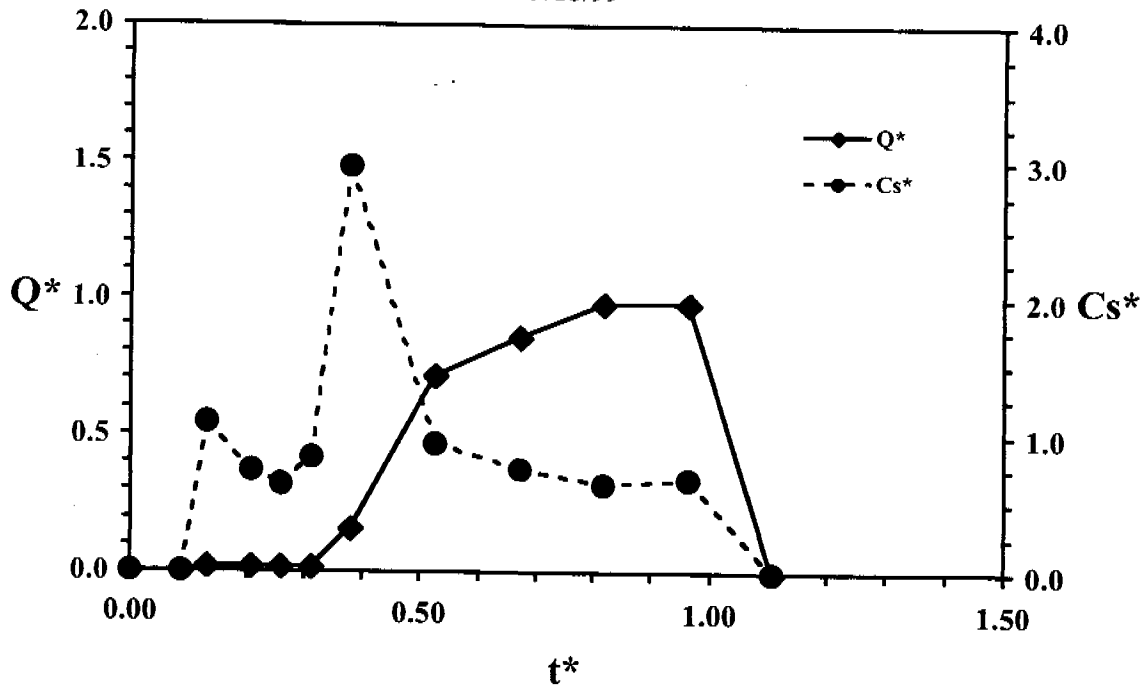
Plot 8, Wood Fiber Blanket Treatment  
9/15/99



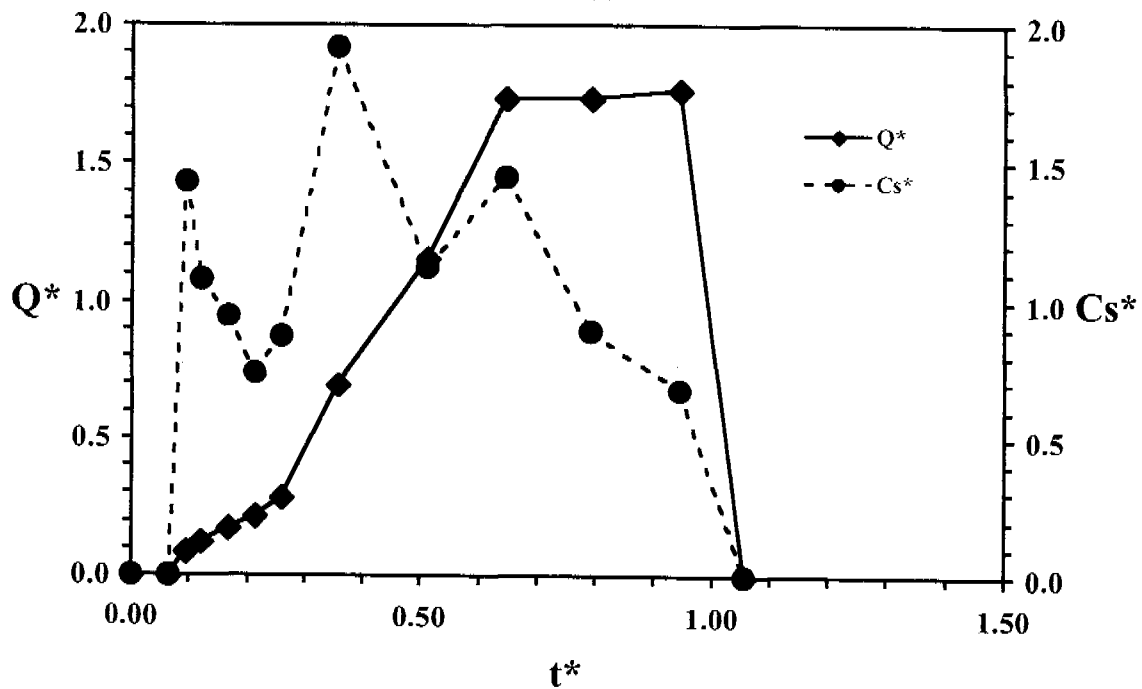
Plot 9, Wood Fiber Blanket Treatment  
9/15/99



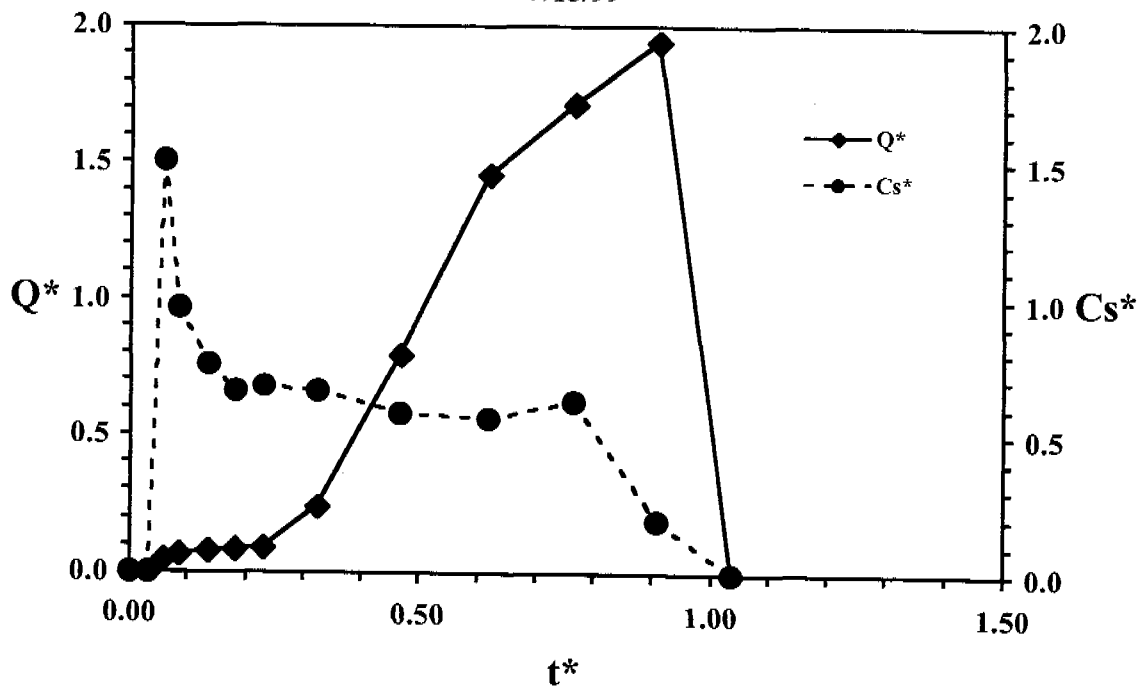
Plot 10, BFM Treatment  
9/15/99



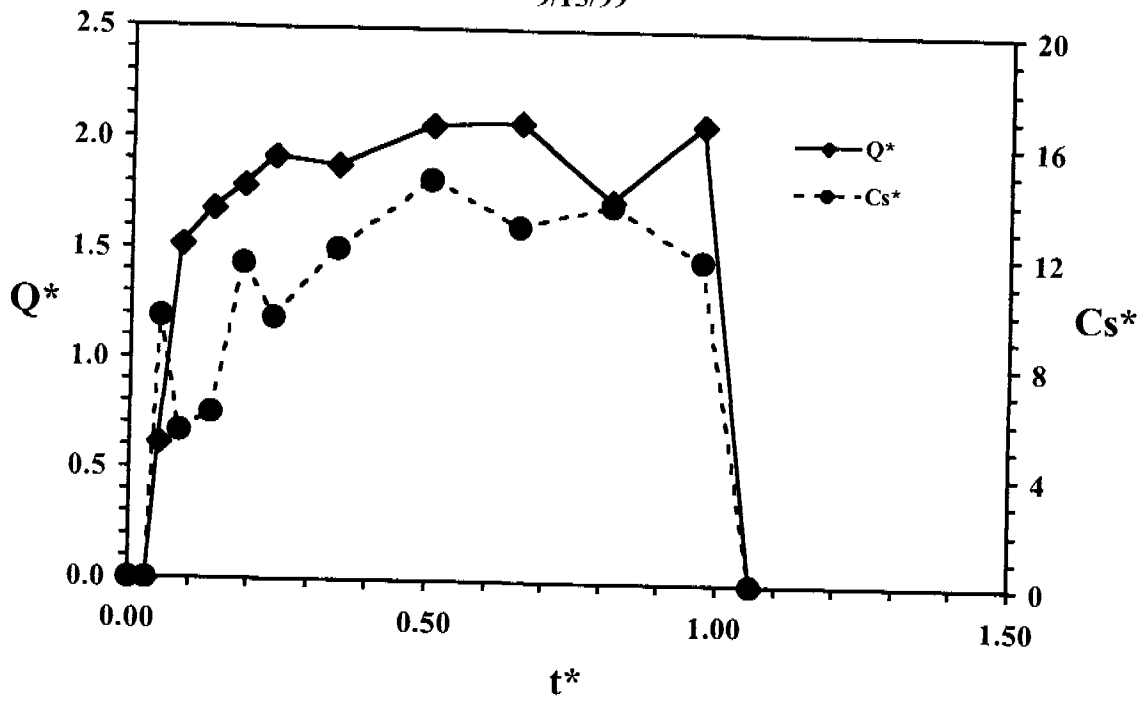
Plot 11 Straw Mulch Treatment  
9/15/99



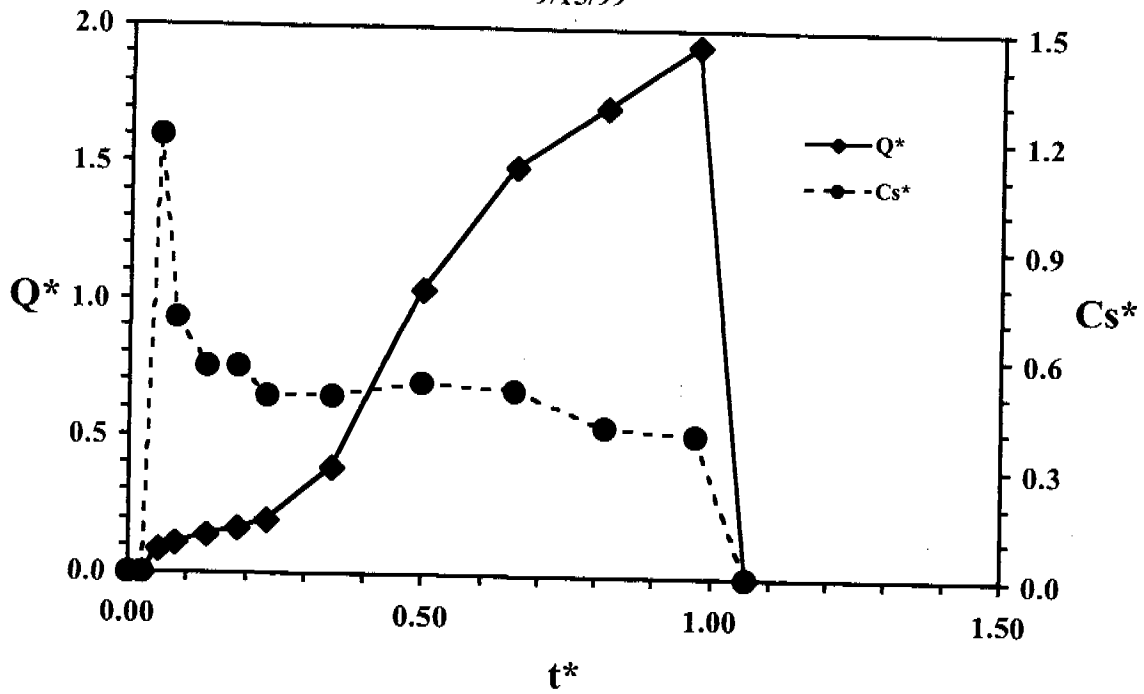
Plot 12 Straw/Coconut Blanket Treatment  
9/15/99



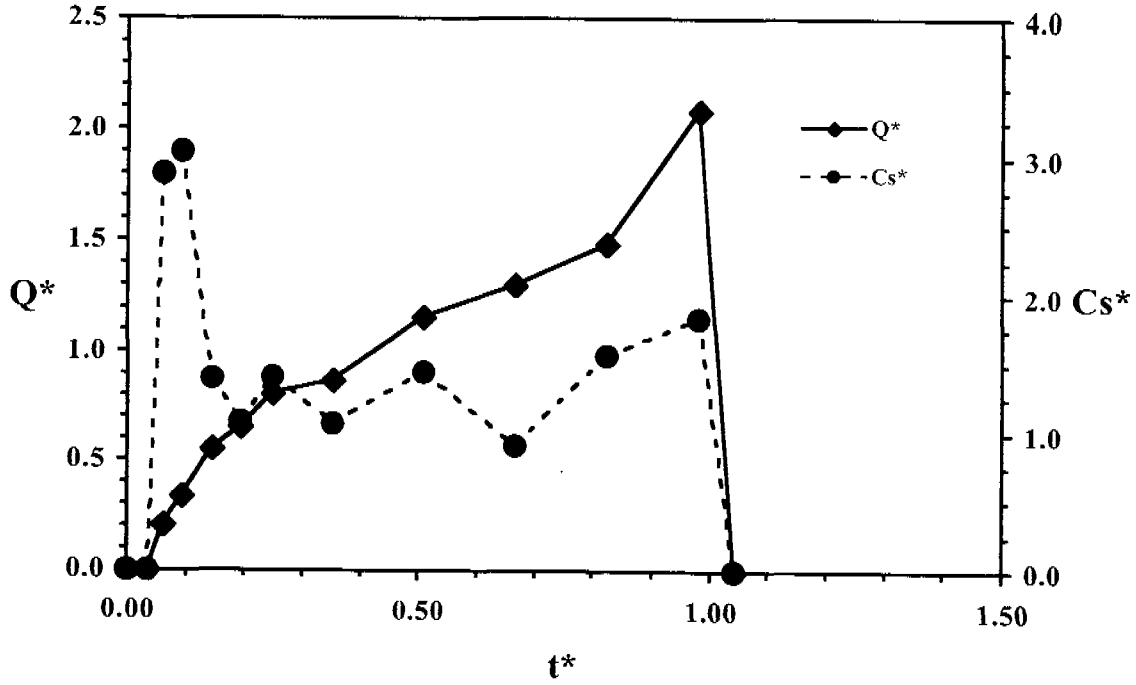
Plot 13 Bare Soil Treatment  
9/15/99



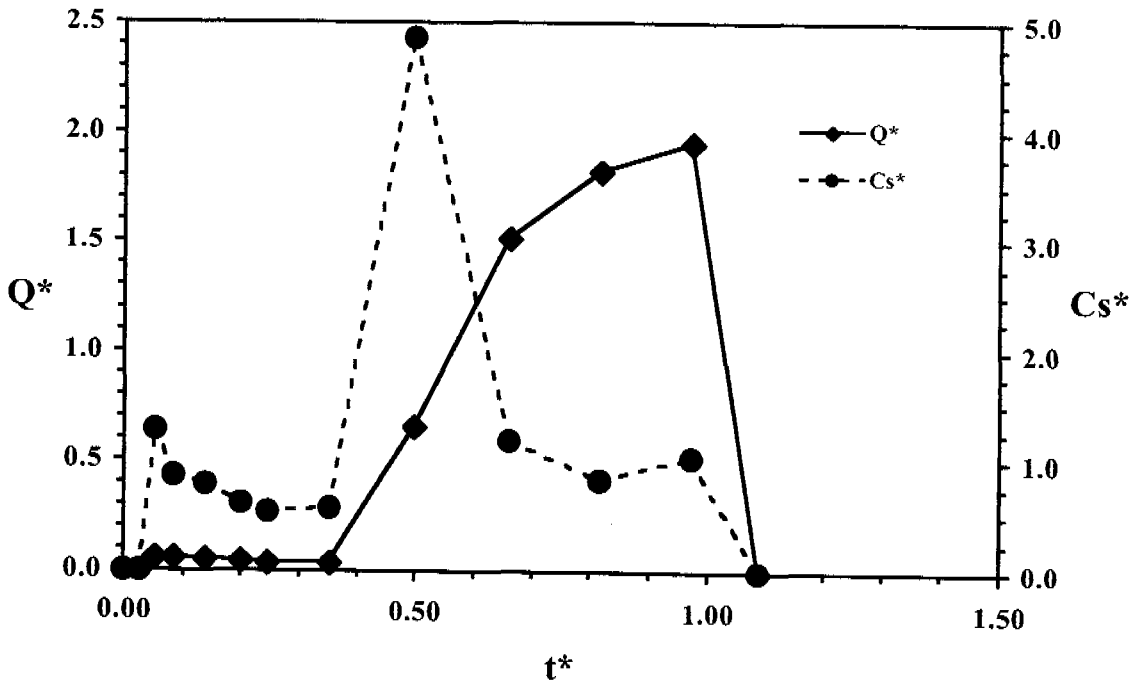
Plot 14 Straw/Coconut Blanket Treatment  
9/15/99



Plot 15 Straw Mulch Treatment  
9/15/99

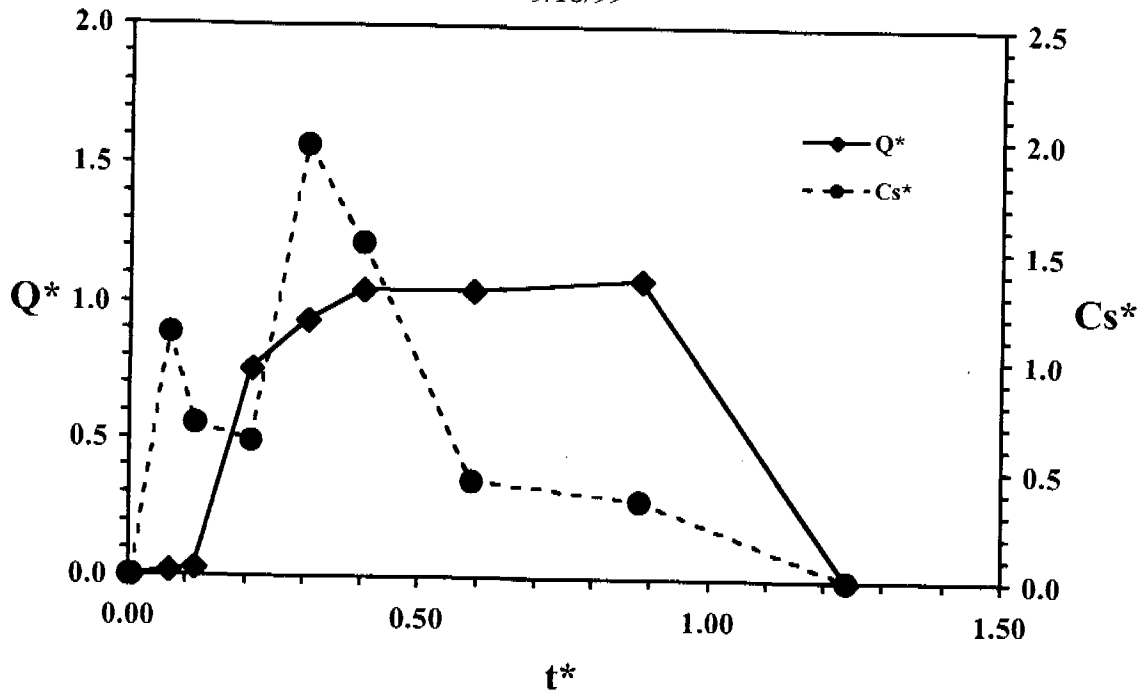


Plot 16 BFM Treatment  
9/15/99

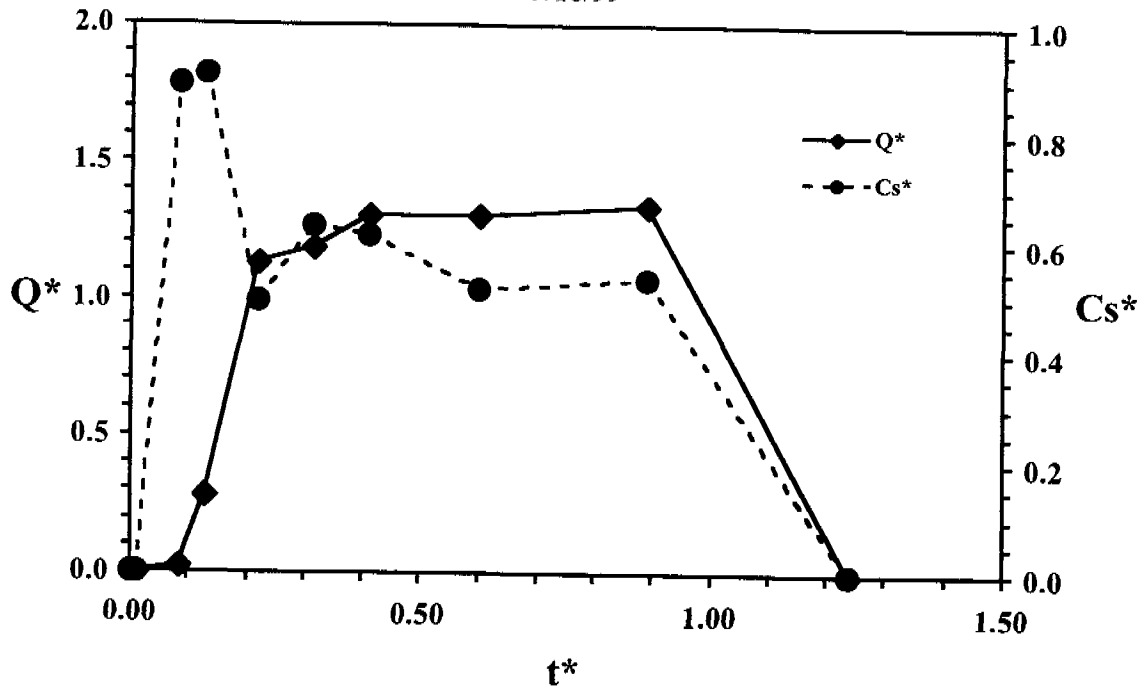




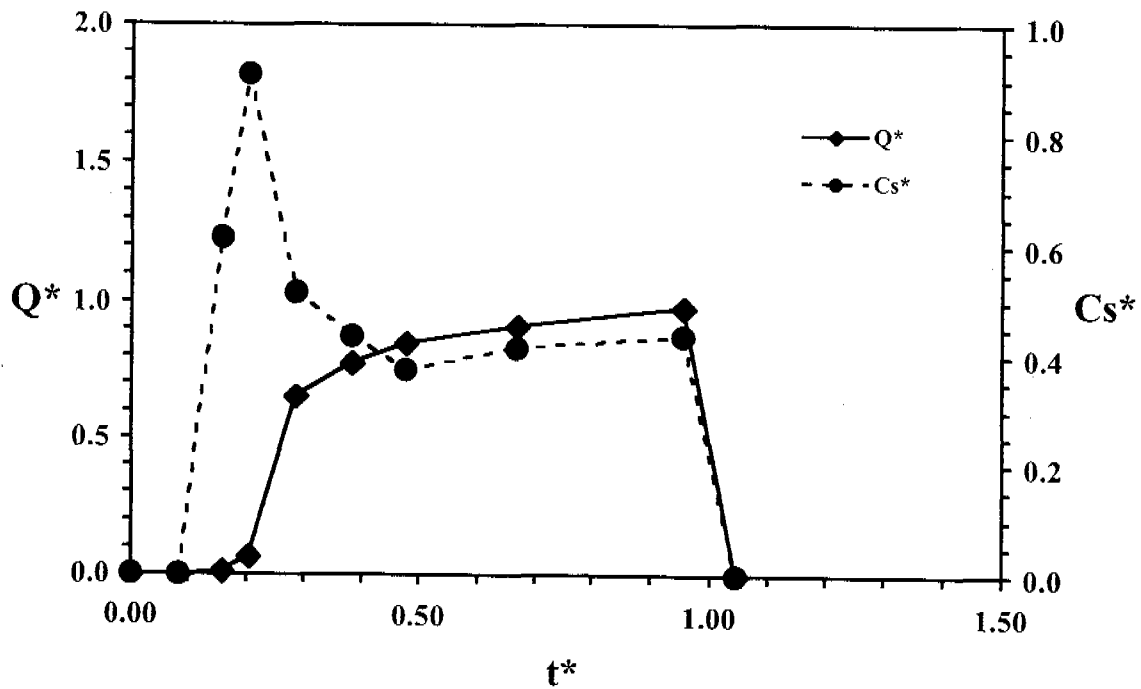
Plot 1, Straw/Coconut Blanket Treatment  
9/16/99



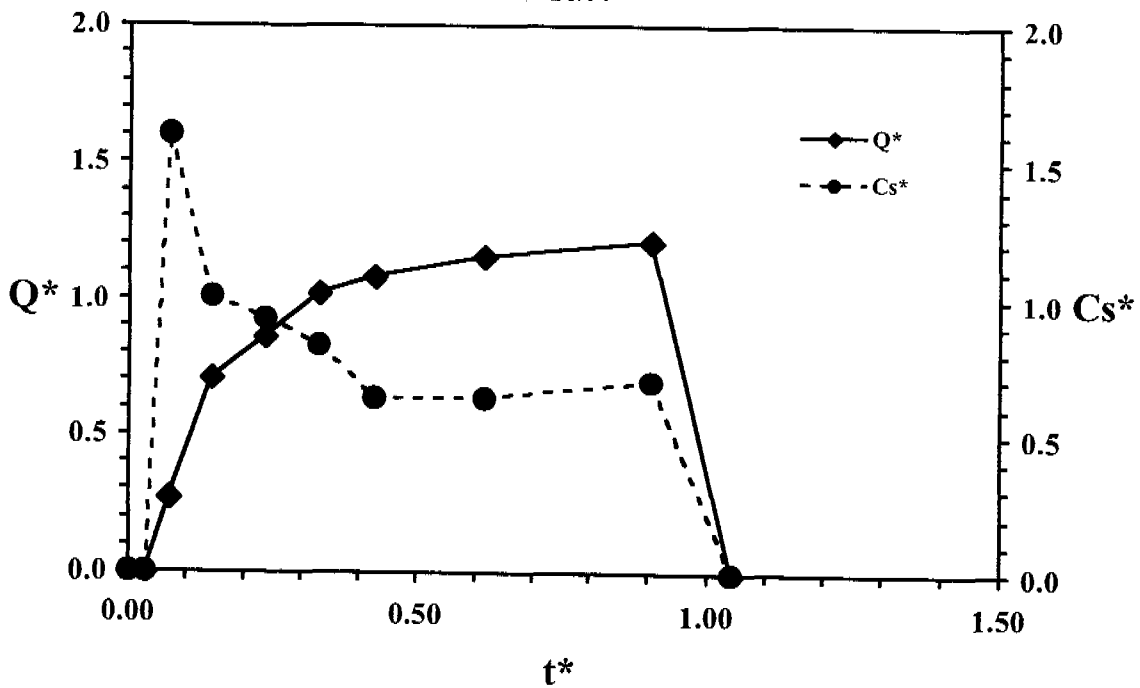
Plot 2, Straw Mulch Treatment  
9/16/99



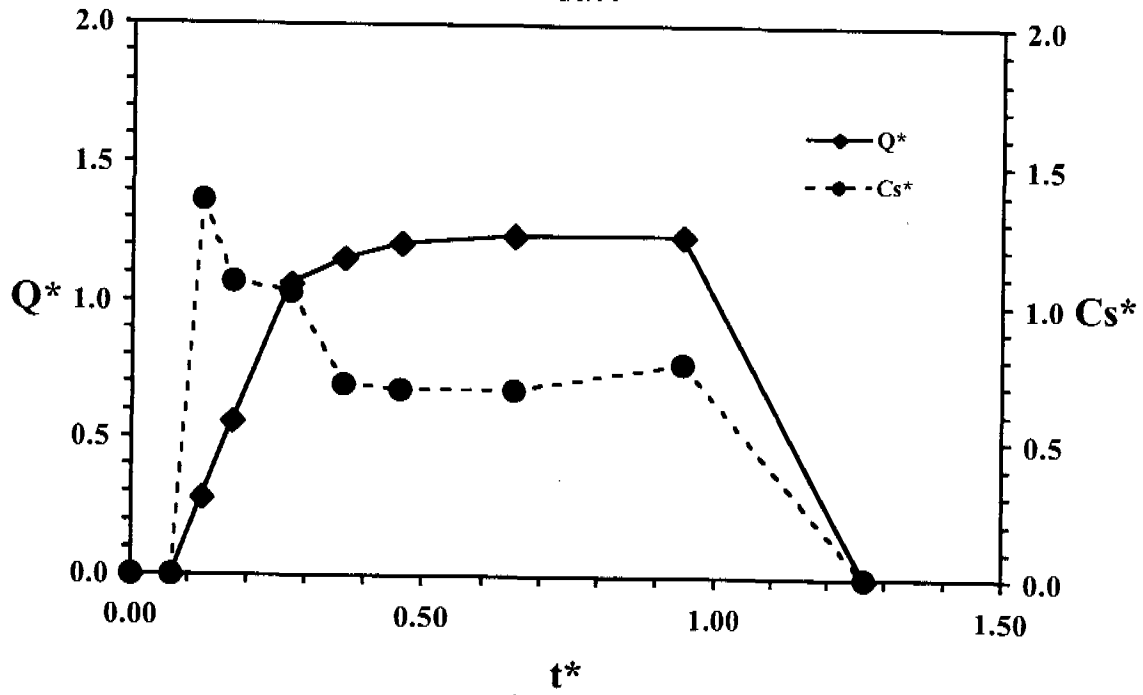
Plot 3, Wood Fiber Blanket Treatment  
9/16/99



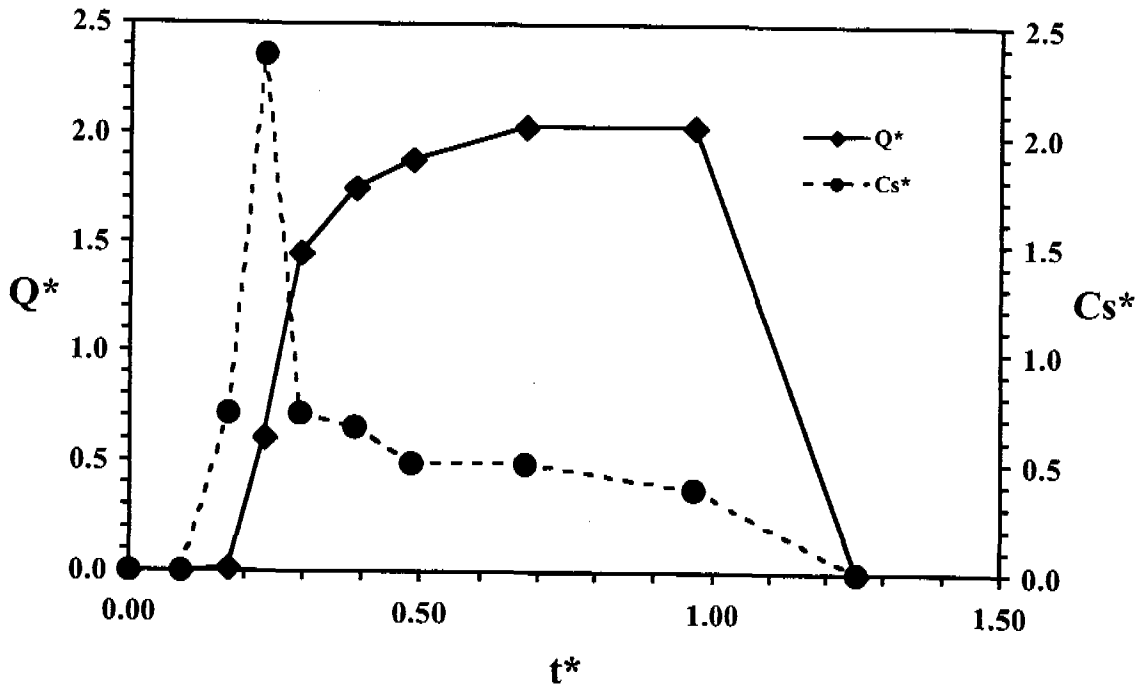
Plot 4, Bare Soil Treatment  
9/16/99



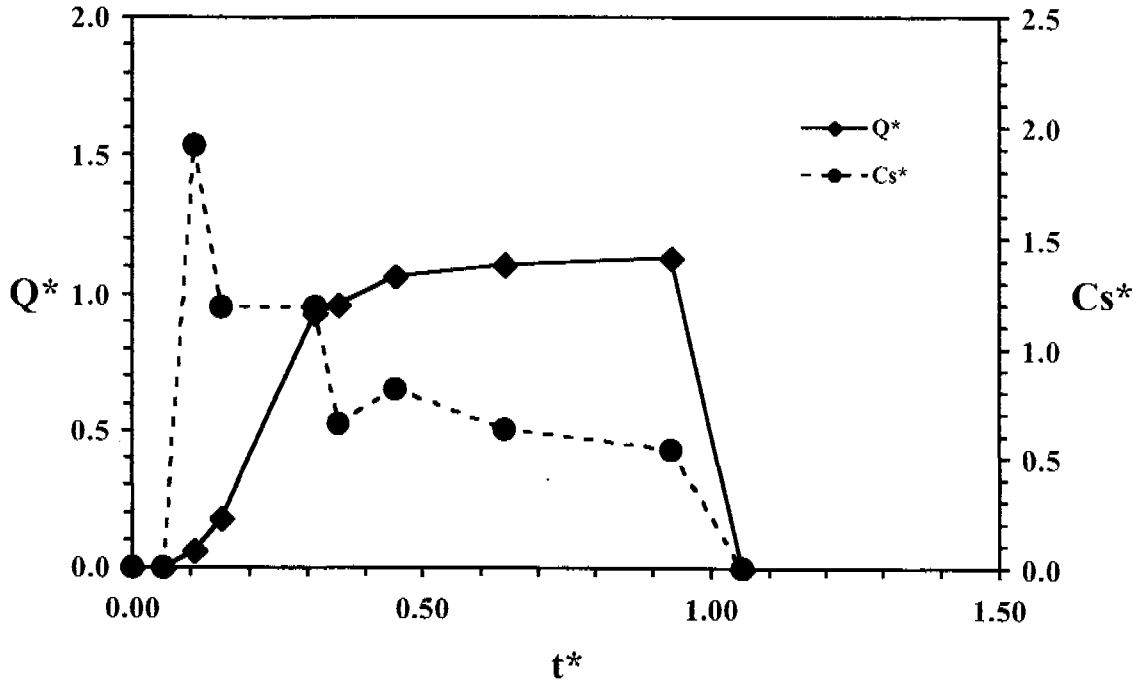
Plot 5, Bare Soil Treatment  
9/16/99



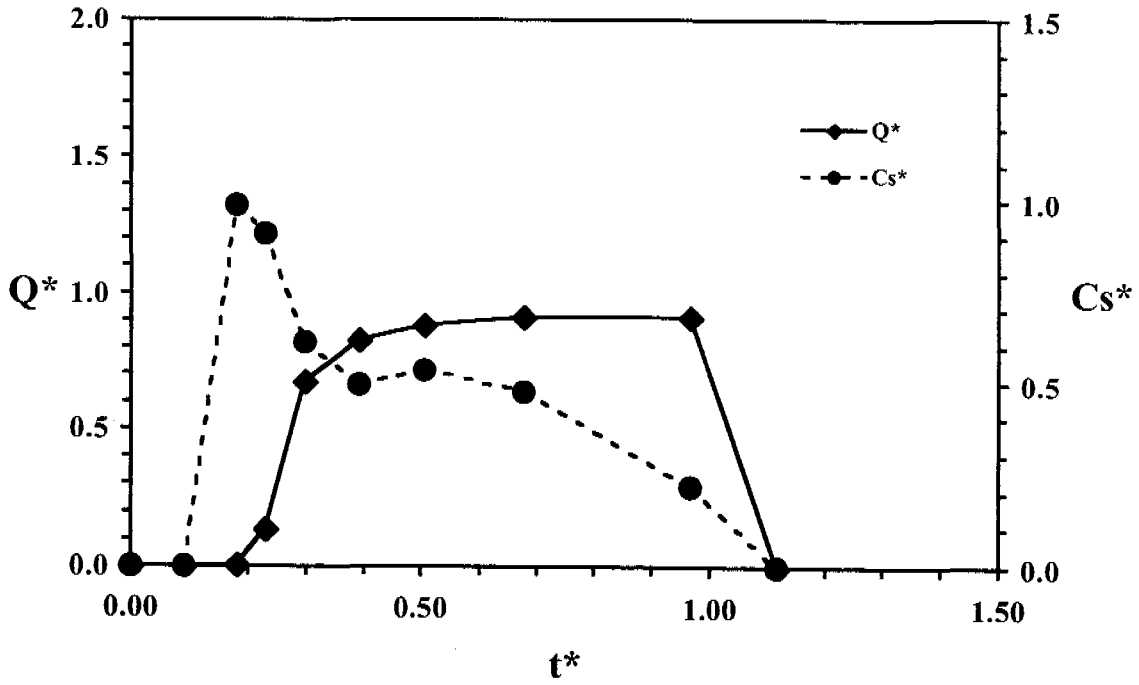
Plot 6, BFM Treatment  
9/16/99



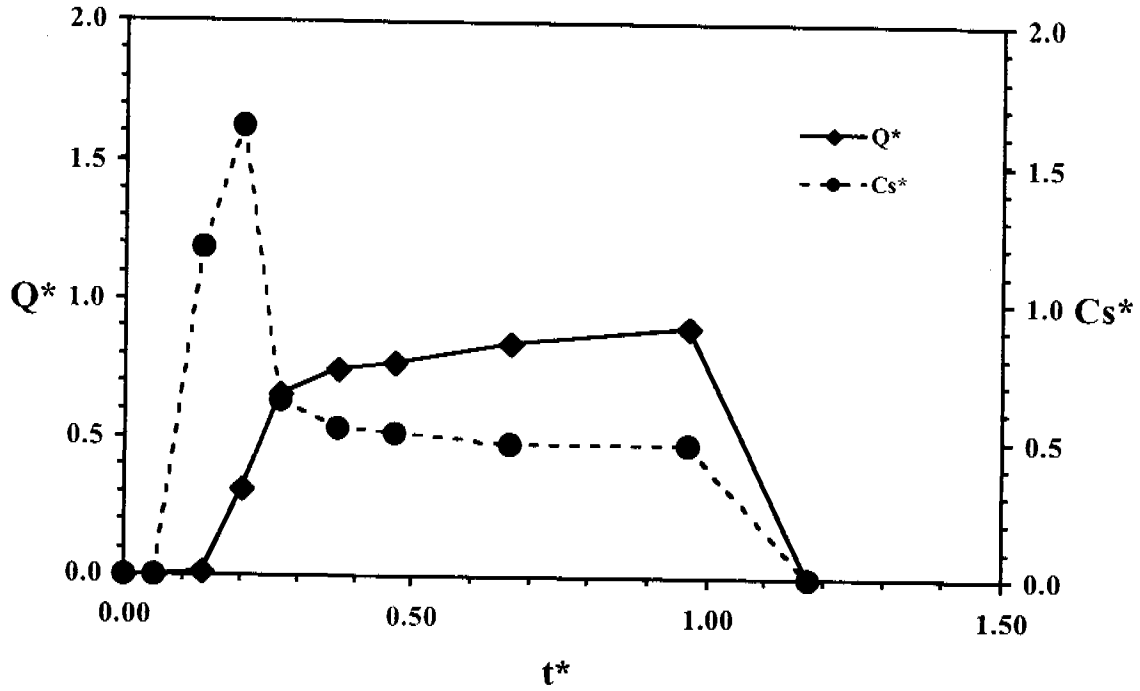
Plot 7, Straw Mulch Treatment  
9/16/99



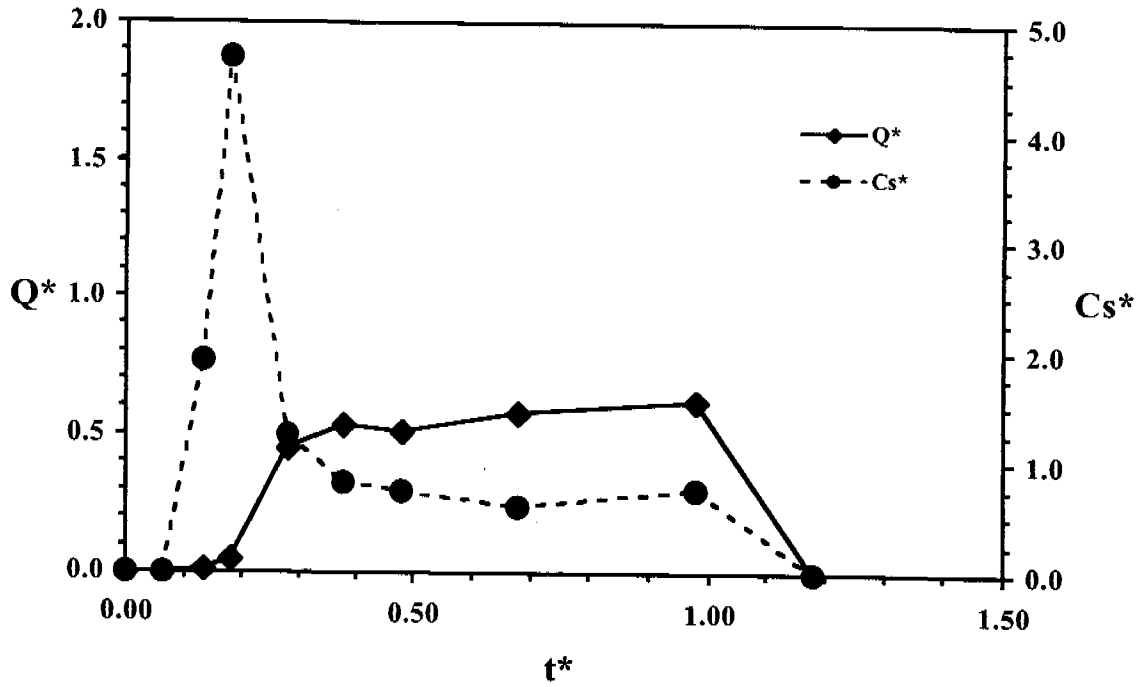
Plot 8, Wood Fiber Blanket Treatment  
9/16/99



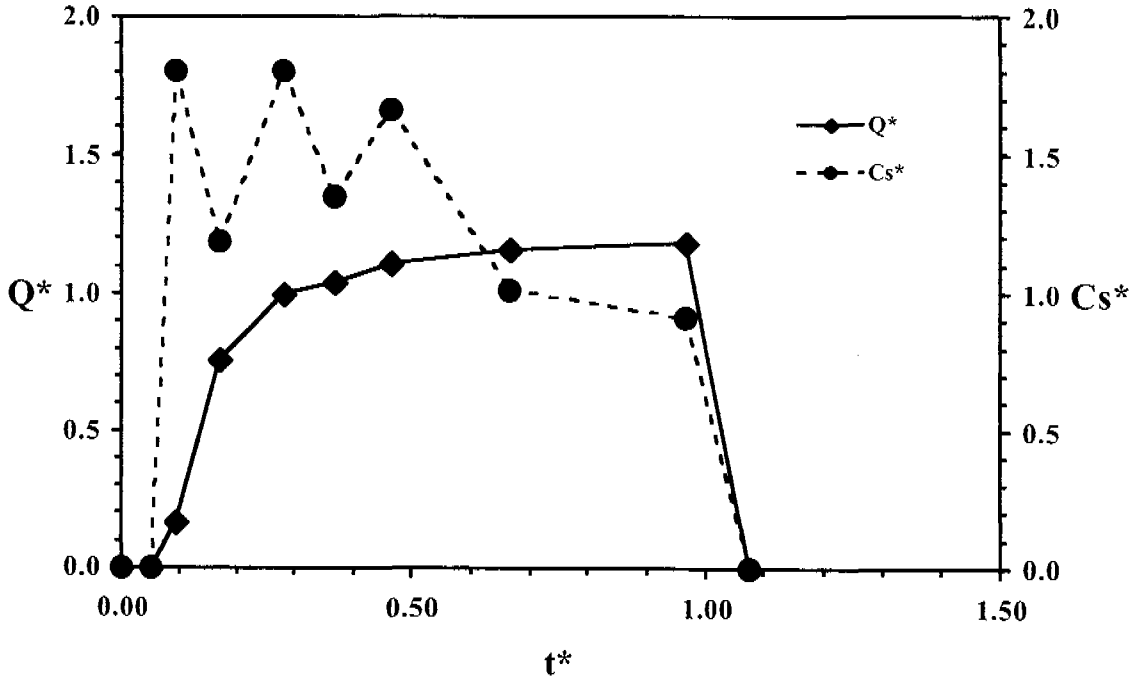
Plot 9 Wood Fiber Blanket Treatment  
9/16/99



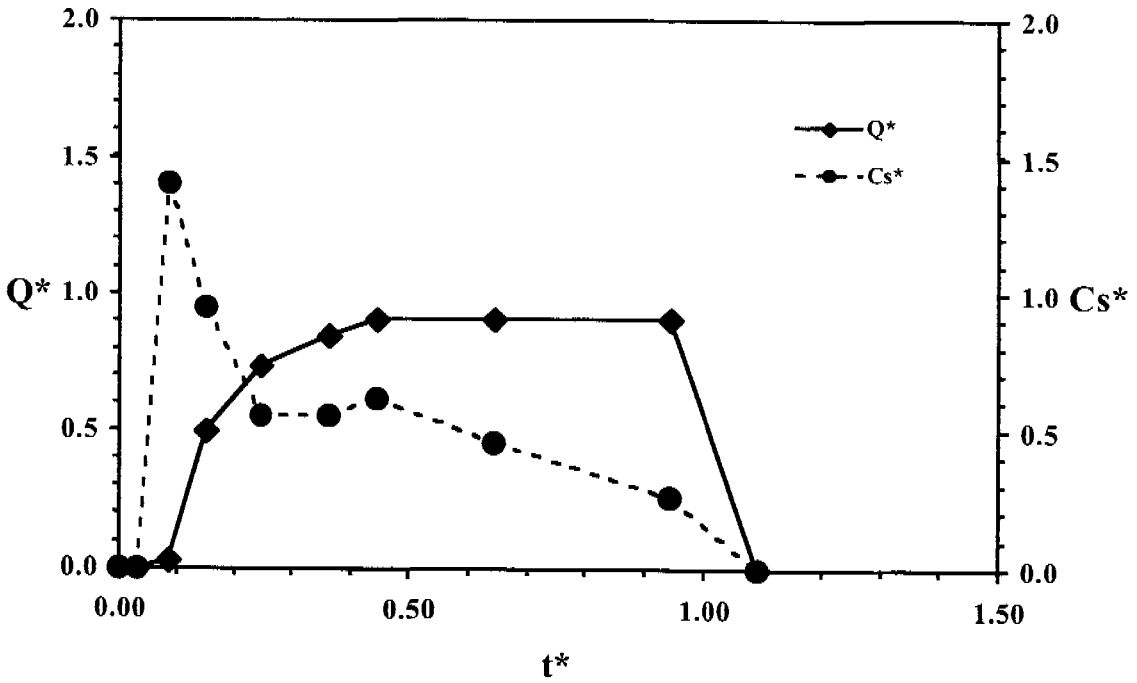
Plot 10 Wood Fiber Blanket Treatment  
9/16/99



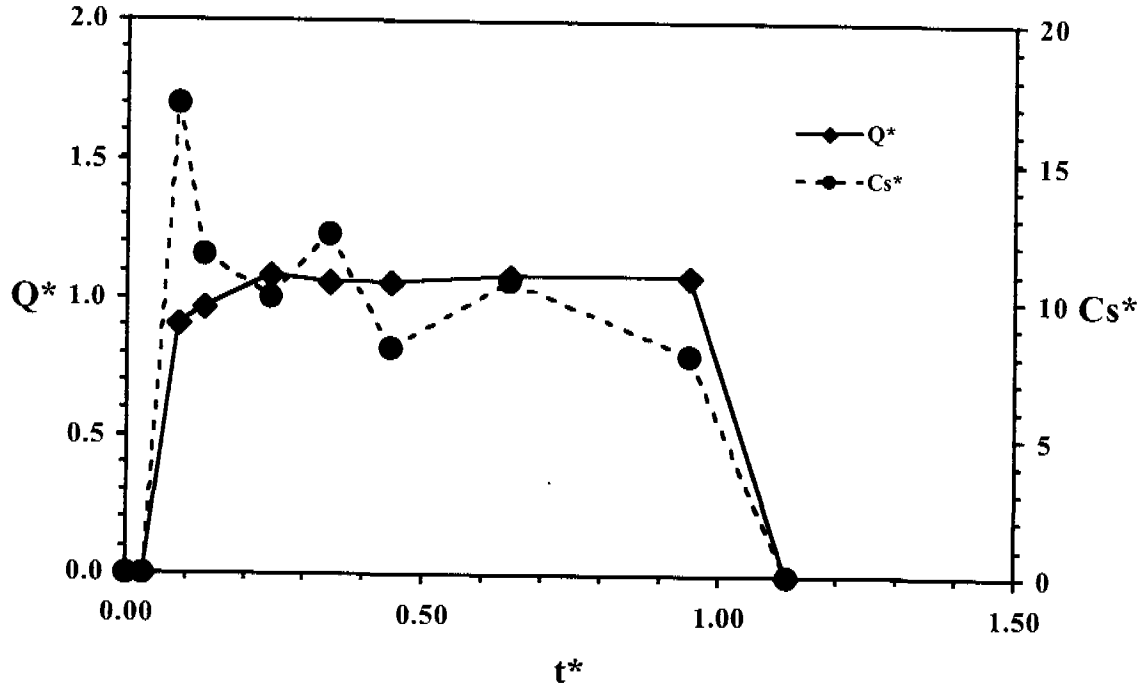
Plot 11 Straw Mulch Treatment  
9/16/99



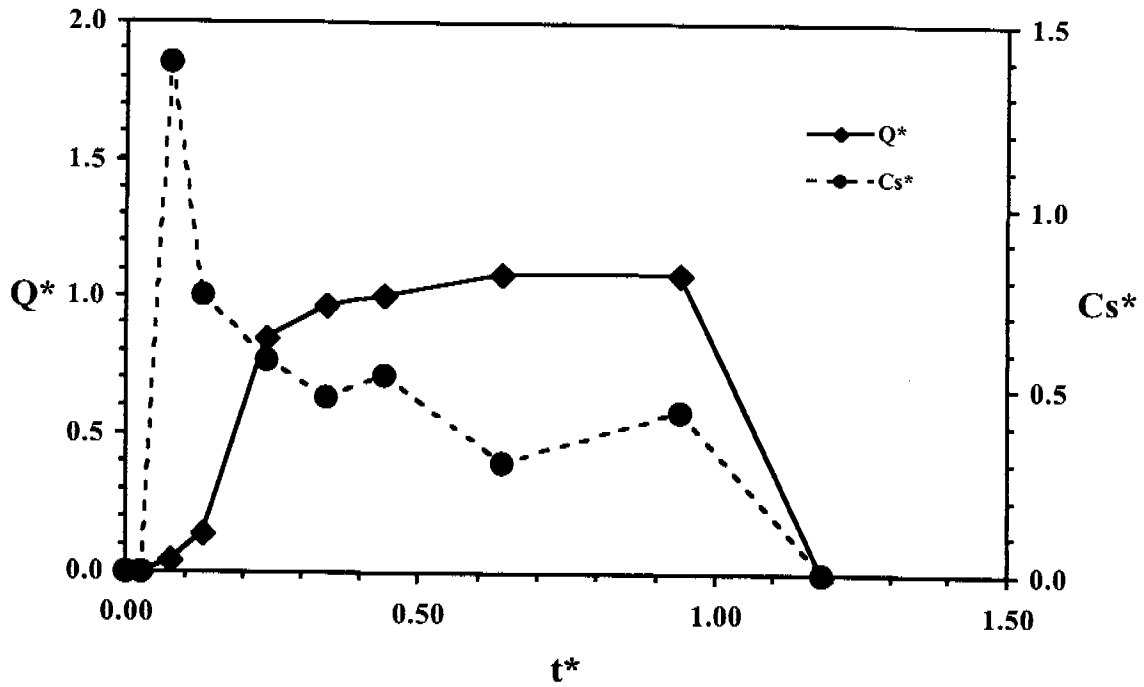
Plot 12 Straw/Coconut Blanket Treatment  
9/16/99



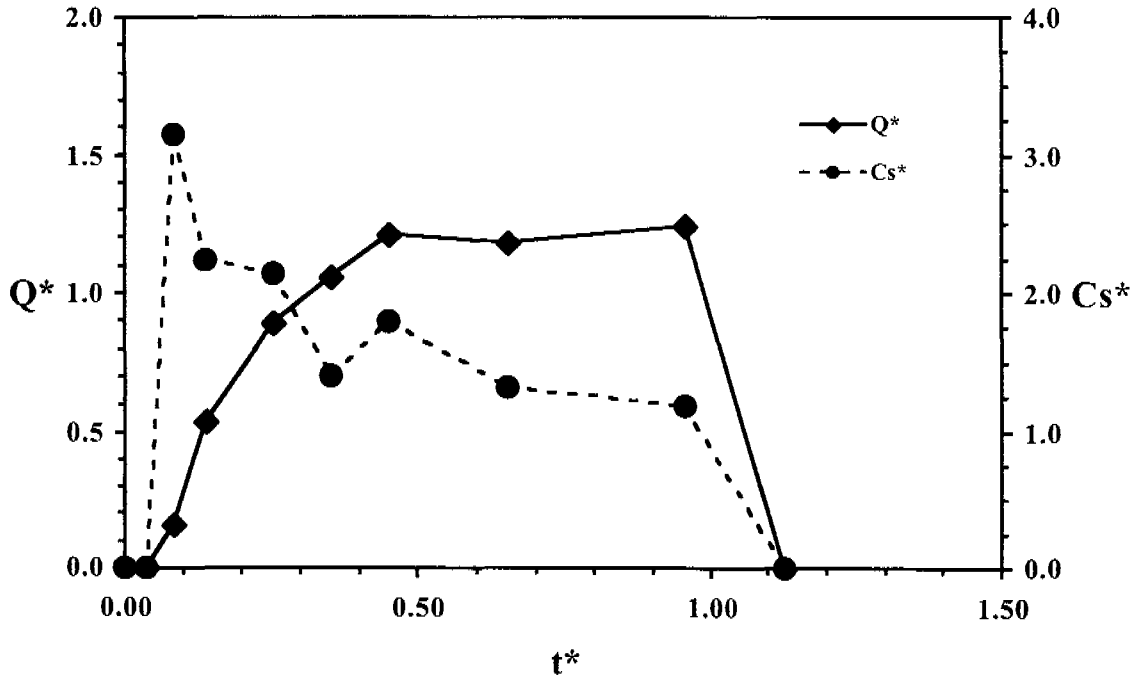
Plot 13 Bare Soil Treatment  
9/16/99



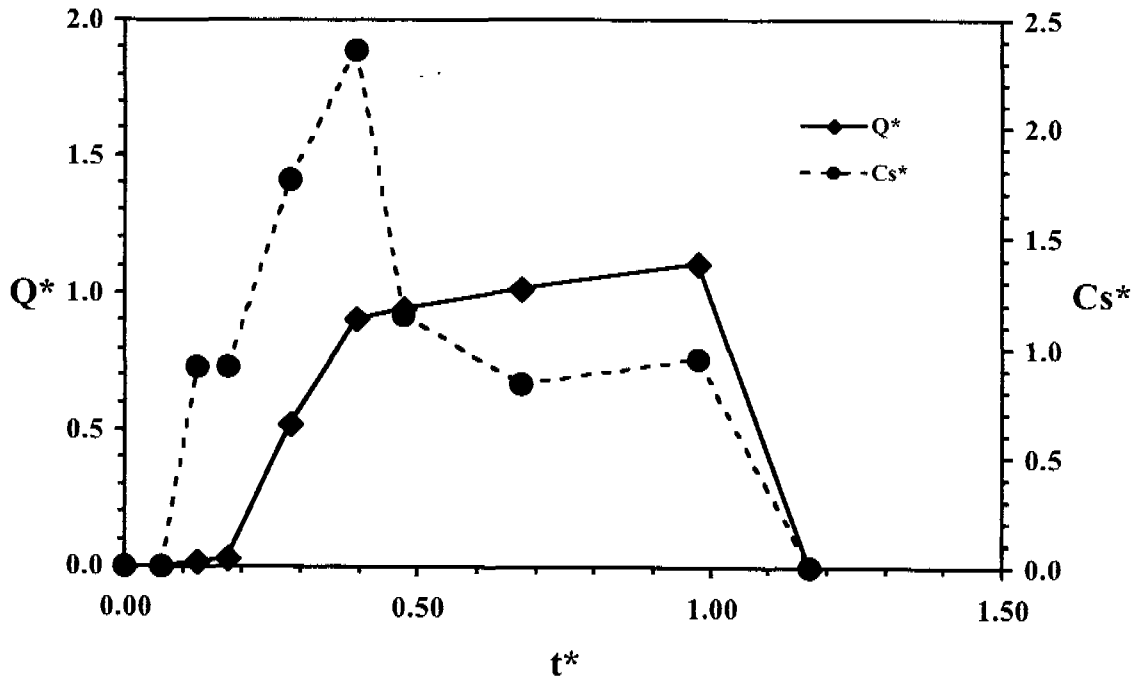
Plot 14 Straw/Coconut Blanket Treatment  
9/16/99



Plot 15 Straw Mulch Treatment  
9/16/99



Plot 16 BFM Treatment  
9/16/99







## **APPENDIX B**

### **VEGETATIVE SURVEY NOTES**



## *Appendix B*

### *Vegetative Survey Notes*

The following notes were taken from the Natural Rainfall Event Series of plots during late-September 1997, the first season of growth. Common names were used rather than scientific names for all species. The format of the notes is Plot Number and Plot Treatment; observations of Vegetative Characteristics; and observations of Treatment Characteristics.

#### Plot 1, Wood Fiber Blanket

- Barnyard grass and White clover appear to be the dominant species.
- The plot is very weedy.
- There is a lot of Regreen present.
- There seems to be uniform vegetation distribution throughout the plot.
- Giant timothy, ragweed, spotted knapweed, and crab grass were noted.
- There are a few black-eyed susans present.
- There is one side-oats grama individual.
- Some possible native grasses are present but are unidentifiable due to small size ( $\approx$ 2-3")
- The netting is still strong
- The wood fibers have somewhat degraded, but there are still fibers remaining.
- The overall canopy is > 1' tall.

#### Plot 2, Bonded Fiber Matrix

- There are significantly more Regreen plants present here than in Plot 1.
- There is very poor vegetative diversity, mostly Regreen and weeds
- Barnyard grass, Mullein, thistle, ragweed are noted.
- The overall canopy is 3' tall.
- The plot is deeply rilled soils; most of soil is exposed.
- There are no remnants of the BFM.
- There are no signs of native grasses.
- The vegetation does not appear to be adequately protecting the site compared to vegetation of surrounding plots.
- The occurrence of rills is low in areas of dense vegetation.

#### Plot 3, Straw/Coconut Blanket

- There is mostly Regreen and weeds.
- Barnyard grass and White clover are dominant species.
- Noted that vegetation is somewhat taller than surrounding plots.
- Blanket condition, especially the netting, is very good.
- Straw fibers have somewhat degraded, but coconut fibers still present.

#### Plot 4, Straw Blanket

- Regreen is the dominant grass.
- There are some foxtail and barnyard grasses present.
- Noticed that the same weedy species are present in the surrounding plots.
- The netting is absent.
- The straw fibers are present but degraded, but still enough to protect the slope
- The canopy is 3-4 ft.

#### Plot 5, Straw mulch

- Good vegetation establishment.
- Dominant grasses are barnyard grass, foxtail & Regreen.
- Some black-eyed susans were noted.
- Ragweed, mullein, alfalfa, and white clover are present.
- The straw mulch is decomposing, overall in a fair to poor condition.
- Scouring and rilling are present, some locations of the soil are exposed.

#### Plot 6, Straw/Coconut Blanket

- Same weedy species as before and in equal abundance.
- Blanket is in very good condition, especially the netting.

#### Plot 7, Straw Blanket

- Same weedy species as before and in equal abundance.
- The straw fibers have decomposed.
- The netting is absent.

#### Plot 8, Bonded Fiber Matrix

- This plot is nearly identical to Plot 2 in terms of weedy vegetation.
- Scouring and rilling of the soil is readily noticed.
- There is frequent occurrence of exposed soil surfaces.
- No remnants of BFM are noticeable

#### Plot 9, Wood Fiber Blanket

- Regreen, barnyard grass and foxtail are dominant grasses.
- There are numerous possible natives that are 0 -1 ft tall (unidentifiable).
- Mullein, ragweed, clover, leafy spurge, and alfalfa are present.
- One black-eyed susan and yellow coneflower is noticed
- The netting is strong.
- The wood fibers are present.
- The canopy is 3-5 ft tall because of weeds.

Plot 10, Straw Mulch Treatment

- Some natives are present. Switchgrass and side-oats grama.
- Several possible natives, but too small for identification
- Regreen, barnyard grass and foxtail are dominant grasses.
- There are numerous possible natives that are 0 -1 ft tall (unidentifiable).
- Mullein, ragweed, & clover are present.
- The straw fibers are not noticeable; well decomposed.
- There is some scouring and rilling noticed.
- The canopy is 3-4 ft tall because of weeds

Plot 11, Straw Mulch Treatment

- Nearly identical to Plot 10 with respect to weedy vegetation.
- Well decomposed straw fibers.
- Some scouring and rilling is noticed.

Plot 12, Straw/Coconut Blanket

- Same weedy vegetation that is in all of the other plots.
- Blanket is in good shape; netting is strong.
- Some side-oats grama grass is present (< 5 individuals).

Plot 13, Wood Fiber Blanket

- Same weeds as before.
- Blanket is in good shape.
- Netting is strong.
- Some side-oats grama grass present (< 5 individuals).

Plot 14, Bonded Fiber Matrix

- Nearly the entire plot is composed of Regreen.
- The amount of weedy vegetation seems to be reduced.
- BFM is not present.
- Scouring and rilling of soil surface is noticed.
- A good portion of soil surface is exposed.

Plot 15, Straw Blanket

- Same weeds and weedy diversity as before.
- Blanket is in good shape, straw fibers have not decomposed as in other straw plots.
- A few native species present, but unidentifiable due to small size.

The following notes were taken from the Natural Rainfall Event Series of plots during early-October 1998, the second season of growth. Common names were used rather than scientific names for all species. The format of the notes are: Plot Number and Plot Treatment; observations of Vegetative Characteristics; and observations of Treatment Characteristics.

#### Plot 1, Wood Fiber Blanket

- White clover is dominant species.
- There are very few grasses; mostly forbs (black-eyed susans).
- There is very little Regreen.
- Some Indiangrass species are present ( $\approx 10$  individuals); some have flowered.
- Alfalfa, ragweed, Canadian thistle are noticed.
- Some yellow coneflower has bloomed.
- Some possible native grasses; unidentifiable due to small size ( $\approx 2-3''$ ).
- The netting is still strong.
- The wood fibers have somewhat degraded, but there are still fibers remaining.
- Canopy is  $< 1'$  tall

#### Plot 2, Bonded Fiber Matrix

- There is significantly more Regreen than in Plot 1.
- Regreen and foxtail appear to be dominant grasses.
- Mullein, thistle, alfalfa, are ragweed are present.
- Canopy is  $> 3'$  tall.
- Black-eyed susans & yellow coneflowers appear to be common native forbs.
- There are no remnants of the BFM.
- There are some native grasses, but most are 2-3" tall.
- There are no natives with seed heads.
- The vegetation appears to be adequately protecting the site.

#### Plot 3, Straw/Coconut Blanket

- There is a good mix of forbs.
- Most of the vegetation are forbs (the three plots so far appear to mostly forbs).
- Black-eyed susans & yellow coneflower are present.
- Mullein, ragweed, alfalfa, and white clover are present.
- There is one side-oats grama with seedhead.
- Regreen and foxtail are dominant grasses.
- There is some type of barley grass present.
- There is an indiangrass with seedhead.
- The netting is still strong.
- The coconut fibers are still present; the straw fibers have decomposed.
- The canopy is 3-4 ft.

#### Plot 4, Straw Blanket

- Regreen is the dominant grass.
- There is some foxtail.
- black-eyed susans & yellow coneflower are frequently occurring.
- Mullein, Ragweed, Alfalfa, and white clover are present.
- There are small daisy-like forbs present.
- There is a purple prairie clover with flowers.
- There are numerous types of unidentifiable yellow flowers.
- Netting is absent.
- Straw fibers are absent.
- The canopy is 3-4 ft.

#### Plot 5, Straw mulch

- There is some leafy spurge noticed.
- The dominant grasses are foxtail & Regreen.
- Black-eyed susans & yellow coneflower are noticed.
- ragweed, mullein, alfalfa, and white clover are present.
- The straw mulch not distinguishable from last year's litter.
- There are side-oats grama with seed head (< 10 plants per plot).
- There are some native grasses, but most are 2-3" tall.

#### Plot 6, Straw/Coconut Blanket

- Natives are present; much more than on previous plots.
- Big bluestem, indiangrass, and side-oats grama all have seedheads.
- All of above natives are have at least 10 individuals and are 1- 2ft tall.
- There is less Regreen and foxtail than surrounding plots.
- Mullein, ragweed, and white clover are present.
- Black-eyed susans and yellow coneflower are present.
- The netting is strong.
- The coconut fibers are present.
- There is a barley grass present.
- Some leafy spurge is noticed.

#### Plot 7, Straw Blanket

- Natives are present.
- Big bluestem, indiangrass, and side-oats grama all have seedheads.
- All of above natives are have at least 5 individuals and are 1- 2 ft tall.
- Regreen and foxtail are dominant grasses.
- Mullein, ragweed, and white clover are present.
- Black-eyed susans and yellow coneflower are present.
- The netting is absent.
- The straw fibers are not noticeable.
- The canopy is 2-3ft tall.



#### Plot 8, Bonded Fiber Matrix

- Natives are present. Big bluestem, indiagrass, side-oats grama all have seedheads.
- All of above natives are have at least 10 individuals and are 1- 5 (!) ft tall.
- There are numerous possible natives that are 0 -1 ft tall (unidentifiable).
- Regreen and foxtail are the dominant grasses.
- Mullein, ragweed, and white clover are present.
- Black-eyed susans, yellow coneflower, and purple prairie clover are noticed.
- BFM is absent.
- The canopy is 4-5 ft tall because of natives.

#### Plot 9, Wood Fiber Blanket

- Natives are present. Big bluestem, indiagrass, side-oats grama all have seedheads.
- All of above natives are have at least 10 individuals and are 2- 3 ft tall.
- Regreen and foxtail are the dominant grasses.
- Mullein, ragweed, and white clover are present.
- Black-eyed susans and yellow coneflower are noticed.
- There are numerous possible natives that are 0 -1 ft tall (unidentifiable).
- The netting is strong.
- The wood fibers are present.
- The canopy is 3-5 ft tall because of weeds.

#### Plot 10, Straw Mulch Treatment

- Some natives are present. Switchgrass, side-oats grama have seedheads.
- The above natives have 5 individuals and are 2- 3 ft tall.
- Several possible natives that are 0 -1 ft tall with no seed.
- Regreen and foxtail are dominant grasses.
- Mullein, ragweed, clover, leafy spurge, and devil's walking stick are present.
- The straw fibers are not noticeable.
- The canopy is 3-4 ft tall because of weeds.

#### Plot 11, Straw Mulch Treatment

- Some natives are present. Switchgrass, side-oats grama have seedheads.
- The above natives have 5 individuals and are 2- 3 ft tall.
- Several possible natives are 0 -1 ft tall with no seed (unidentifiable).
- Regreen and foxtail are dominant grasses.
- Mullein, ragweed, clover, and leafy spurge are present.
- Black-eyed susans and yellow coneflower are noticed.
- The straw fibers are not noticeable.
- The canopy is 3-4 ft tall because of Regreen.

Plot 12, Straw/Coconut Blanket

- Some natives are present. Indiangrass, side-oats grama have seedheads.
- All of above natives have at least 10 individuals and are 1- 2 ft tall.
- Regreen and foxtail are present but NOT as dominant as surrounding plots.
- Mullein, ragweed, clover, and leafy spurge are present.
- Black-eyed susans and yellow coneflower are noticed.
- The netting is absent.
- The straw fibers are not noticeable.
- The canopy is 3-4 ft tall.

Plot 13, Wood Fiber Blanket

- Natives are present. Big bluestem, indiangrass, side-oats grama all have seedheads
- The above natives have at least 10 individuals and are 1 - 2 ft tall.
- Regreen and foxtail are present but NOT as dominant as surrounding plots.
- Mullein, ragweed, clover, alfalfa and leafy spurge are present.
- Black-eyed susans and yellow coneflower are noticed.
- Netting is strong.
- The wood fibers are present.
- The canopy is 3-4 ft tall because of weeds.

Plot 14, Bonded Fiber Matrix

- Natives are present. Big bluestem, indiangrass, switchgrass, side-oats grama all have seedheads.
- Some of above natives are have at least 10 individuals and are 1 -2 ft tall.
- There are numerous possible natives that are 0 -1 ft tall (unidentifiable).
- Regreen and foxtail are the dominant grasses.
- Mullein, ragweed, clover, alfalfa and leafy spurge are present.
- Black-eyed susans and yellow coneflower are noticed.
- BFM is absent.
- The straw fibers are not noticeable.
- The canopy is 3-4 ft tall because of natives.

Plot 15, Straw Blanket

- Natives are present; more than on previous plots.
- Big bluestem, indiangrass, side-oats grama all have seedheads
- The above natives have at least 10 individuals and are 1- 2 ft tall.
- There are a lot of possible natives that are 0 - 1 ft tall with no seed heads.
- Regreen and foxtail are the dominant grasses.
- Mullein, ragweed, clover, alfalfa and leafy spurge are present.
- Black-eyed susans and yellow coneflower are noticed.
- The netting is strong.
- There are some coconut fibers remaining.
- The canopy is 3 ft tall.

The following notes were taken from the Artificial Rainfall Event Series of plots during early-October 1998, the first season of growth. Common names were used rather than scientific names for all species. The format of the notes are: Plot Number and Plot Treatment; observations of Vegetative Characteristics; and observations of Treatment Characteristics.

#### Plot 1, Straw/Coconut Blanket

- Barnyardgrass and foxtail are the dominant species.
- Very little Regreen; none with seed.
- Mullein, ragweed, canadian thistle, and velvet leaf are present.
- There appears to be a low species diversity.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- There is a low forb diversity; no native forbs.
- The netting is still strong.
- The straw and coconut fibers have not degraded.
- The canopy is 3 -4 ft tall.

#### Plot 2, Straw Mulch

- There is very little Regreen, none with seed.
- Barnyardgrass and foxtail are the dominant species.
- Mullein, ragweed, Canadian thistle, and velvet leaf are present.
- The canopy is 3 -4 ft tall.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- There is a low forb diversity; no native forbs.
- Mulch is not degraded.

#### Plot 3, Wood Fiber Blanket

- There is a low forb diversity; no native forbs.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- Barnyardgrass and foxtail are the dominant species.
- There is very little Regreen, none with seed.
- The netting is strong.
- The wood fibers are present.
- The canopy is 3-4 ft.

#### Plot 4, Bare Soil

- There is a low forb diversity; no native forbs.
- Mullein, ragweed, Canadian thistle, and velvet leaf are present.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- Barnyardgrass and foxtail are the dominant species.
- There is very little Regreen, none with seed (4 - 6" tall).
- canopy is 4-5 ft

#### Plot 5, Bare Soil

- There is a low forb diversity; no native forbs.
- Mullein, ragweed, and velvet leaf are present.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- Barnyardgrass and foxtail are the dominant grass species.
- There is very little Regreen, none with seed (4 - 6" tall).
- The soil has showed signs of rilling.
- The canopy is 4-5 ft.

#### Plot 6, Bonded Fiber Matrix.

- Mullein, ragweed, and velvet leaf are present.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- Barnyardgrass and foxtail are the dominant grass species.
- There is very little Regreen, none with seed (4 - 6" tall).
- The BFM is present.
- The canopy is 3-4 ft.

#### Plot 7, Straw Mulch

- There is a low forb diversity; no native forbs.
- Mullein, ragweed, and velvet leaf are present.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- Barnyardgrass and foxtail are the dominant grass species.
- There is one cattail species.
- There is very little Regreen.
- The straw mulch is present, but somewhat degraded.

#### Plot 8, Wood Fiber Blanket

- There is a low forb diversity; no native forbs.
- Mullein, ragweed, and velvet leaf are present.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- Barnyardgrass and foxtail are the dominant grass species.
- There is very little Regreen.
- The wood fibers not degraded; the netting is strong.
- The canopy is 3-4 ft.

#### Plot 9, Wood Fiber Blanket

- There is a low forb diversity; no native forbs.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- Barnyardgrass and foxtail are the dominant grass species.
- There is very little Regreen.
- The wood fibers not degraded; the netting is strong.
- The canopy is 3-4 ft.

Plot 10, Bonded Fiber Matrix

- There is a low forb diversity; no native forbs.
- Mullein, ragweed, and velvet leaf are present.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- Barnyardgrass and foxtail are the dominant grass species.
- There is very little Regreen, none with seed (4 - 6" tall).
- The BFM is present.
- The canopy is 3-4 ft.

Plot 11, Straw Mulch Treatment

- There is a low forb diversity; no native forbs.
- Mullein, ragweed, and velvet leaf are present.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- Barnyardgrass and foxtail are the dominant grass species.
- There is very little Regreen, none with seed (4 - 6" tall).
- The straw mulch is present, but somewhat degraded.
- The canopy is 3-4 ft.

Plot 12, Straw/Coconut Blanket

- There is a low forb diversity; no native forbs.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- Barnyardgrass and foxtail are the dominant grass species.
- There is very little Regreen, none with seed (4 - 6" tall).
- The netting is still strong.
- The straw and coconut fibers have somewhat degraded.
- The canopy is 3 -4 ft tall.

Plot 13, Bare Soil

- Mullein, ragweed, and velvet leaf are present.
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- Barnyardgrass and foxtail are the dominant grass species.
- There is very little Regreen, none with seed (4 - 6" tall).
- The canopy is 4-5 ft.

Plot 14, Straw/Coconut Blanket

- Barnyardgrass and foxtail are the dominant grass species.
- There is very little Regreen, none with seed (4 - 6" tall).
- There are no identifiable native grasses due to small size ( $\approx 2-3''$ ).
- There is a low forb diversity; no native forbs.
- The netting is still strong.
- The straw and coconut fibers have somewhat degraded.
- The canopy is 3 -4 ft tall.

#### Plot 15, Straw Mulch Treatment

- There appears to be a higher forb diversity than any other plot.
- There are a lot of sedges with flowers.
- There are a few black-eyed susans with flowers.
- There is still mullein, ragweed, canadian thistle, and velvet leaf.
- There are no identifiable native grasses; due to small size ( $\approx 2-3$ ").
- Barnyardgrass and foxtail are the dominant grass species.
- There is very little Regreen, none with seed (4 - 6" tall).
- The straw mulch is present, but somewhat degraded.

#### Plot 16, Bonded Fiber Matrix

- It is possible that this plots has a higher total diversity than other plots.
- There is less total amount of grasses than other plots.
- There are some sedges with flowers.
- There are a few yellow coneflowers with flowers.
- Mullein, ragweed, and velvet leaf are present.
- There are no identifiable native grasses; due to small size ( $\approx 2-3$ ").
- There are even some ( $\approx 10$  individuals) side-oats grama grass with seed.
- There is some barnyardgrass and foxtail, but not as much as in other plots.
- There is very little Regreen, none with seed (4 - 6" tall).
- The BFM is present, but somewhat degraded.
- The canopy is 2-3 ft tall.



## **APPENDIX C**

### **RESULTS OF GREENHOUSE STUDY**





## *Appendix C*

### *Results of Greenhouse Study*

#### **Background**

The scope of this task was to determine the impact of erosion control blankets on the germination of native grasses under greenhouse conditions.

#### **Summary of Methods**

In the first greenhouse experiment, Mn/DOT seed mixture 15A was planted at the recommended broadcast rate of 50 kg/ha, under erosion control blankets in mid-December, 1996. Although approximately nine erosion control products were originally intended to be tested, the experiment was expanded to test 15 products because of the large number of blankets currently being marketed. For each product, three standard 2 ft<sup>2</sup> flats were filled with well composted, steam sterilized greenhouse soil, sowed, then covered with a particular erosion control product (15 products x 3 flats + 3 uncovered controls = 48 flats). Flats were watered regularly until the termination of the experiment on January 1997. A trial of a soil stabilizer was not pursued because it could not be sprayed during the winter months, when the experiment was initiated.

In the second greenhouse experiment, two forbs were chosen as the native vegetation. This experiment was tested on a similar range of erosion control products as in the first, with the exception that a bonded fiber matrix treatment was now included. The experimental design and setup was similar to that of the preceding experiment.

#### **Results and Discussion**

The results of the first experiment are shown in Figure C-1. Figure C-1 illustrates the total aboveground biomass present in the flats at the end of the experiment. Several observations can be made on the basis of this first experiment.

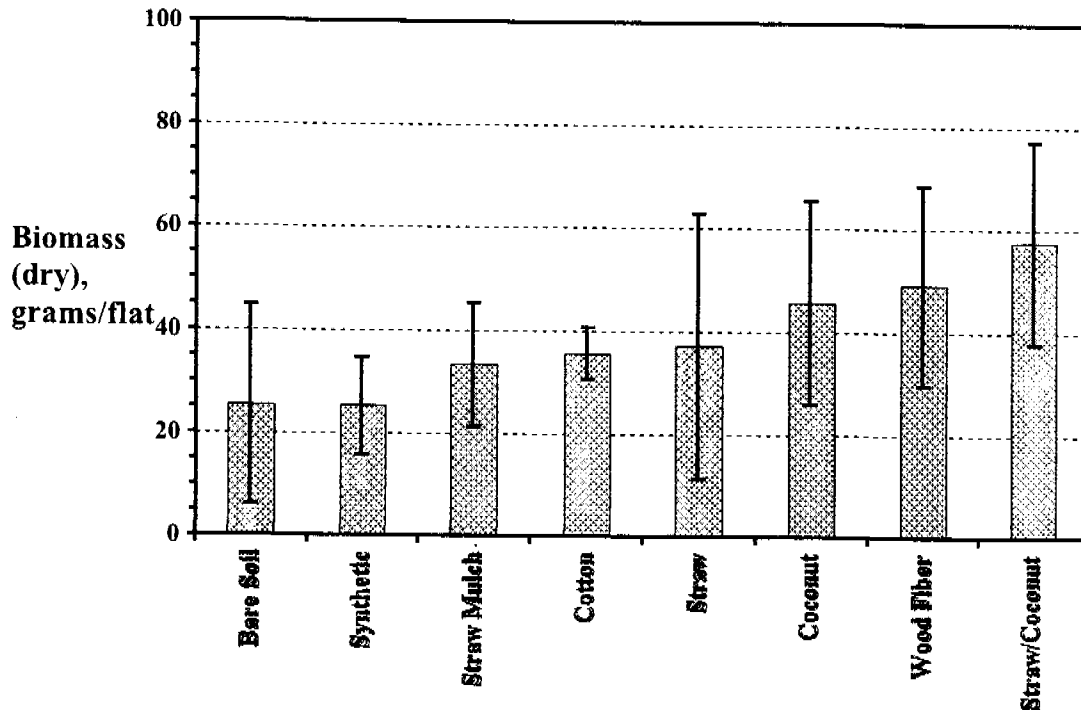


Figure C-1: Biomass production of Mn/DOT Mix 15A under greenhouse conditions for several types of erosion control blankets. The error bars are the standard deviation of each treatment.

The bare soil treatment supported the least amount of biomass. We suspect that ECPs act as moisture barrier, *i.e.* the ECPs retain more moisture in the soil for germination than do uncovered soils. The bare soils and soils treated with the synthetic blankets dried out quite rapidly under greenhouse conditions.

There was a notable trend for the blankets to perform similarly within classes under these conditions, with a pronounced trend toward an increase in biomass for the thicker, heavier mats. This trend is probably related to moisture retention under the blankets allowing for more rapid growth and development of seedlings. High velocity mats performed well during the course of this experiment.

Variation was extremely high in the amount of aerial biomass collected from the distinct classes of plants. Although it was our intention to measure the aboveground and

belowground biomass and record seedling counts for the plants present in the flats, it was not practical. In particular, we had the following problems.

First, our aboveground biomass consisted of approximately 98% cover grasses. Oats and rye-grass responded vigorously to these growing conditions and completely out-competed native species in the flats. While they germinated and grew well, they had detrimental effects on both the mats and on simultaneous germination of native species. The large, robust oats in particular would “tent” the mats causing poor surface to mat contact; and would occasionally lift the mat surfaces and damage them.

Secondly, we suspect the profuse growth of oats and rye grass both depleted nutrients from the flat soil and completely shaded out native grasses as evidenced by their chlorotic appearance at the time of harvest. Native species are notoriously slow to grow under both greenhouse and field conditions, often taking years to establish stable populations in the field.

Thirdly, representative dicotyledonous species in the mix with their large cotyledons, could not penetrate the mats very well. Their mortality was quite high indicating poor compatibility of dicots with most of the products tested. Finally, we had a very difficult time harvesting belowground biomass. The root biomass of the cover crops dwarfed the biomass of the native species, thus not giving us data about the performance of the native species in our mixes.

A second experiment was started immediately after the preceding experiment to test the ability of forbs to penetrate erosion control blankets. Four replicate flats of each product were planted to a single mixture of two native forbs, black-eyed susans (*Rudbeckia hirta*) and purple prairie clover (*Dalea purpureum*). These forbs are representative of native dicots that have large, rounded cotyledons and narrow strap-shaped cotyledons. Observations of this experiment suggest that most erosion control products will not be very compatible with native dicotyledons in the field. For the treatments where there was less of a growth barrier (*i. e.*, bare soil, straw mulch, and the bonded fiber matrix), the forbs had higher mean biomass production than for treatments that offered a higher resistance to growth (*i. e.*, the

erosion control blankets). Figure C-2 shows the biomass production of the forbs for the various erosion control products that were tested.

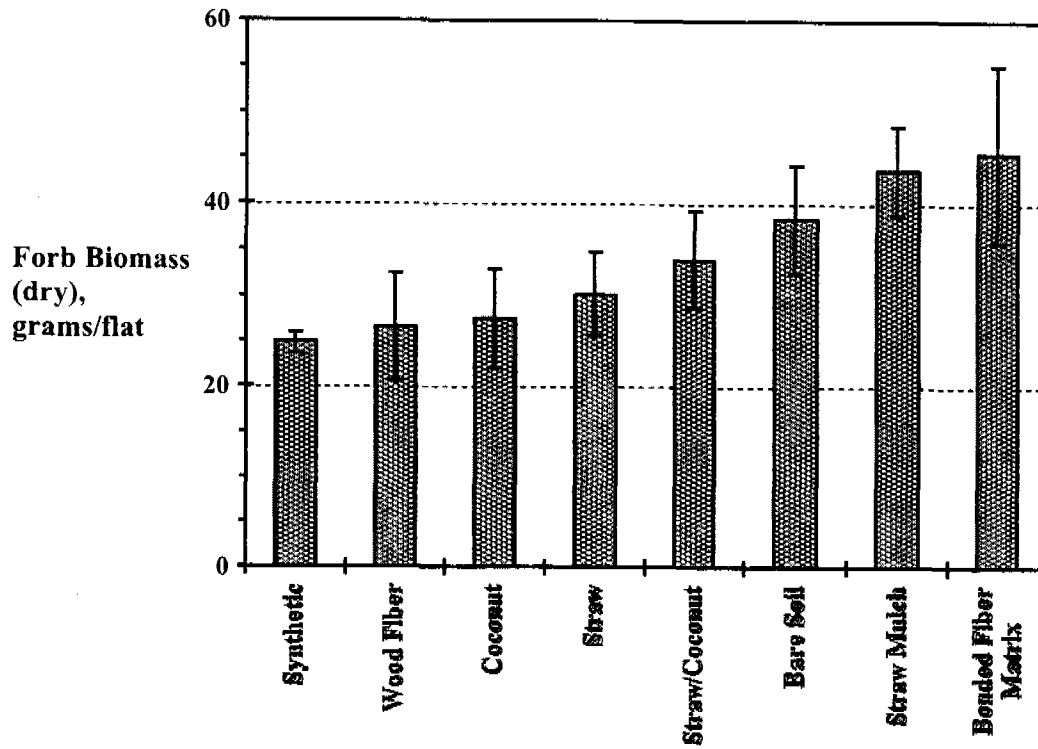


Figure C-2: Biomass production of native forbs under greenhouse conditions for several types of erosion control products. The error bars are the standard deviation of each treatment.





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