Roadside Erosion Control and Management Study

Rainfall Simulation Experiment 10

Erosion control and vegetation cover performance of cotton, paper, straw, and wood hydromulch types under simulated rainfall

State of California
Department of Transportation

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Storm Water	Rainfall Simulator	Wood Fiber
Erosion Control	Mulch	Cellulose Fiber
Water Quality	Hydromulch	Paper Fiber
		Cotton Fiber
		Compost

Executive Summary

This report presents the design and results of the tenth primary experiment (RS10) completed by the Roadside Erosion Control and Management Study research program designed to provide data from controlled rainfall simulators. The experiment ran from June 2009 through January 2010. RS10 evaluated a typical SSP-20-040 Erosion Control Hydroseed application that conforms to Caltrans Standard Specifications Section 20: Erosion Control and Highway Planting, specifically sections 20-3.04B Hydro-Seeding, 20-2.07 Fiber, 20-2.10 Seed. The purpose of RS10 was to provide baseline water quality data and analyses about four fiber types (wood, paper, cotton, straw) used with a typical SSP-20-040 specification to statistically test whether a specific fiber type provides significantly better erosion control or significantly better vegetation cover, or both.

Experimental Design

RS10 employed a balanced, one-way Analysis of Variance (ANOVA) with fiber type as the single fixed factor. Levels of the fiber type factor are Wood, cellulose Paper, Cotton, or Straw. Four treatments replicated 4 times each, two bare soil controls, two bare soil plus added seed controls, plus two compost controls, for a total of 22 plastic experimental boxes. The test soil was a sandy clay loam from SR46 east of Paso Robles in District 5, complete with a large seedbank of alien and native annual plant species typical of coastal California roadsides. Natural rainfall between June 1, 2009 and January 31, 2010 when RS10 ended was 10.06 inches. From June through November 2009, supplemental rainfall (~0.5 inch per box per week) was applied to initiate germination and to plant promote growth through the summer. Simulated rainfall was delivered by two Norton Ladder-type variable sweep, pressurized nozzle rainfall simulators developed at the USDA Erosion Research Center at Purdue University. To test treatment effectiveness, a 2-inch simulated storm (0.5 inches for 30 minutes, 1 inch for 1 hour, and 0.5 inches for 30 minutes) was applied after vegetation had grown for six months to where 80% (15 of 18) of the test boxes exhibited at least 70% within-box average plant cover at the soil surface. Measured variables were total runoff, total sediment, turbidity, electrical conductivity, pH, total cadmium, total copper, total nickel, total lead, total zinc, and percent vegetation cover at the soil surface.

Results

Consistent with past experiments involving fiber and compost treatments, the hydroapplied Compost control outperformed all fiber treatments in all measures except for higher levels of soluble salts that could present osmotic problems for some plants when hydroapplied Compost is used in large quantities as a germination medium. Among the fiber treatments, Wood performed better than Cotton, Straw, or Paper in an overall ranked matrix of variables based on statistical significance and mean values. The matrix combines both water quality measures and greatest production of vegetation cover at the soil surface. All metals were in quantities at or below MDL limits. In the ANOVA of metals by fiber treatment, lead was the only metal to exhibit significant lower quantity in the Compost control. No other significant differences were announced for all other metals data for any fiber treatment or control.

Although the seeded native species were a complete failure in RS10, greater than 70% plant cover at the soil surface was evident in all fiber treatments, except Paper, and the Bare+seedbank control produced over 95% plant cover at the soil surface from the soil seedbank alone. Outcomes from both the Paper treatment and the Bare+seedbank control hold wider implications for erosion control and roadside vegetation management. The Paper treatment performed well as a sediment control, second to Wood of the fiber treatments and 114 times better than Bare soil, but the consistently poor production of vegetation in this experiment, and empirical evidence from past roadside hydroseedings, negate any positive benefits as an erosion control treatment when vegetation establishment is also a goal. However, for project applications where temporary erosion control is required and vegetation production is *not* desired, such as a temporary rainseason cover, or as a weed control between planted live container stock, paper hydromulch could be useful. The Bare+seedbank control production of over 95% plant cover at the soil surface from the soil seedbank alone, coupled with good to excellent ratings in water quality [*Runoff*: not significantly different from any fiber treatments; *Sediment*: significantly better than Cotton, Paper, Straw; *Turbidity*: not significantly different from any fiber treatment: *pH*: significantly better than Cotton, Paper, Straw, and Wood; *metals (Cd, Cu, Ni, Pb, Zn)*: not significantly different from any fiber treatment], suggests that the typical mix of alien and native winter-annuals common over much of cismontane California roadsides has the potential to perform as well as or better than the fiber products tested as an erosion control treatment, if given sufficient water and time to establish over 95% plant cover at the soil surface. This caveat is an extremely important one as large local variation in sufficient fall to spring precipitation produces large local variation in annual plant cover and density. However, as a parallel to RS8 where simulated rainfall trials of groundcover cultivars (Iceplants, Ivy, Lantana, Myoporum, Rosemary) showed that these common roadside plantings may be performing storm water treatment as intended, the common roadside annuals also may be performing storm water treatment sufficient to not exceed regulatory limits.

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Experiment Description

1.1 Experiment Context

During 2000, Caltrans Storm Water, in cooperation with the Sacramento State University Office of Water Programs and the Earth and Soil Sciences Department of Cal Poly State University, San Luis Obispo, initiated a research program to statistically test for significant differences in water quality and vegetation establishment among existing soil stabilization specifications used by Caltrans to better reduce runoff and sediment transport in compliance with regulatory requirements. To date, results have been reported elsewhere for nine primary experiments (Caltrans 2001, 2002, 2004, 2005a, 2005b, 2007).

This report presents the design and results of the tenth primary experiment (RS10) completed by this research program designed to provide data from controlled rainfall simulations.

1.2 Experiment Topic

In collaboration with Caltrans Division of Design Landscape Architecture Program, RS10 was designed to evaluate a typical SSP-20-040 Erosion Control Hydroseed application that conforms to Caltrans Standard Specifications Section 20: Erosion Control and Highway Planting, specifically sections 20-3.04B Hydro-Seeding, 20-2.07 Fiber, 20-2.10 Seed.

The purpose of RS10 was to provide baseline water quality data and analyses about four fiber types (wood, paper, cotton, straw) used with a typical SSP-20-040 specification to statistically test:

– whether a specific fiber type provides significantly better erosion control;

– whether a specific fiber type provides significantly better vegetation cover.

1.2.1 Wood Fiber

Wood fiber is manufactured from wood or wood waste from lumber mills, paper mills, or urban sources.

Typically, wood fiber is applied at rates of 600 to 2,000 pounds/acre, either in a single or two-step application.

Benefits:

- Wood fiber biodegrades more slowly than paper.
- Wood fibers are longer than paper fibers and wood fibers mesh together to form a stronger fiber matrix.
- Wood requires less water to apply than paper.
- Wood holds more moisture and releases moisture more slowly than paper.
- Wood permits more air to pass through to seed. At rates up to 3000 lbs/acre, wood permits air to pass to the seed to prevent die off.

Limitations:

- Wood fiber costs more per pound than paper fiber.

1.2.2 Paper (Cellulose) Fiber

Paper fiber is made from recycled newsprint, magazine, or other waste paper sources. Paper has shorter fiber lengths than wood fiber mulches because paper mulch derives from fiber initially manufactured to create smooth surfaces for paper products and other non-mulch uses. When applied, the shorter fibers of cellulose products may clump rather than interlock.

Typically, paper fiber is applied at the rate of 2,000 to 4,000 pounds/acre.

Benefits:

- Cellulose fiber costs less than wood fiber.

Limitations:

- Applied at higher rates, cellulose fiber may create a "papier-mâché" type layer, leading to poor seed germination.

1.2.3 Cellulose and Wood Fiber Blend

Blended mulches of 50% wood fiber and 50% cellulose fiber combine the performance characteristics of wood fiber, which interlocks for erosion protection, and the economy of clean, recycled paper fiber for bulk.

Cellulose/Wood blended fiber is applied at a total rate of 2000 to 3,000 pounds/acre, either in a single or two-step application.

Benefits:

- Less expensive than wood mulch alone.
- Combines the erosion protection benefits of wood with the cost efficiency of paper.

Limitations:

- More expensive than cellulose mulch used alone.

1.2.4 Cotton Fiber

Hydroapplied "cotton" fiber is typically a blend of mechanically processed straw, cotton fibers, and tackifier in a ratio of 65:25:10:10 straw : cotton : tackifier : water.

Cotton fiber is applied at a total rate of 2000 to 3,000 pounds/acre, either in a single or two-step application.

Benefits:

- Manufacturers claim that more fiber can be applied per tankfull using less water than wood fiber requires to apply.
- Manufacturers claim that straw-cotton-tackifier blends can replace need for rolled erosion control blankets or netting.

Limitations:

- More expensive than other fiber types.
- More nozzle clogging at lower application pressure

1.2.5 Straw Fiber

Hydroapplied mechanically processed straw is typically blended with cellulose and other fibers in a ratio of 80:5:5:10 straw : cellulose : other fiber : water.

Straw fiber is applied at a total rate of 2,000 to 4,000 pounds/acre, either in a single or two-step application.

Benefits:

- Manufacturers claim that more fiber can be applied per tankfull using less water than wood fiber requires to apply.

Limitations:

- More expensive than other fiber types.
- More nozzle clogging at lower application pressure

Section 2
Materials and Methods

2.1 Experimental design

Model

A balanced, one-way Analysis of Variance (ANOVA) with fiber type as the single fixed factor. Levels of the fiber type factor are Wood, cellulose Paper, Cotton, or Straw.

Number of treatments

Four treatments replicated 4 times each, two bare soil controls (worst-case comparison), two bare soil plus added seed controls, plus two compost controls (best-case comparison), for a total of 22 experimental boxes.

Measured variables

total runoff
total sediment
turbidity
EC
pH

total cadmium
total copper
total nickel
total lead
total zinc

vegetation cover at soil surface

Constants

box slope (2:1 H:V, 50%, 27º)
box aspect (south)
soil type
fiber application rate (2500 lb/ac per layer)

Psyllium tackifier (100 lb/ac)
seed application rate (36 lb/ac)
seed mix
rainfall regime

Seed Mix

A simple mix of one perennial grass, one annual grass, one perennial rhizomatous forb, and one annual legume forb. These species are widespread California natives and typically perform well when hydroseeded.

Duration	Lifeform	Vernacular Name	Scientific Name	lbsPLS/ac	PLS/ft^2
Perennial	Grass	California Brome	*Bromus carinatus*	25	52
Annual	Grass	Small Fescue	*Festuca (Vulpia) microstachys*	6	60
Perennial	Forb	Western Yarrow	*Achillea millefolium ssp lanulosa*	1	60
Annual	Legume Forb	Spanish Lotus	*Lotus purshianus*	4	8
				36	**180**

2.2 Materials

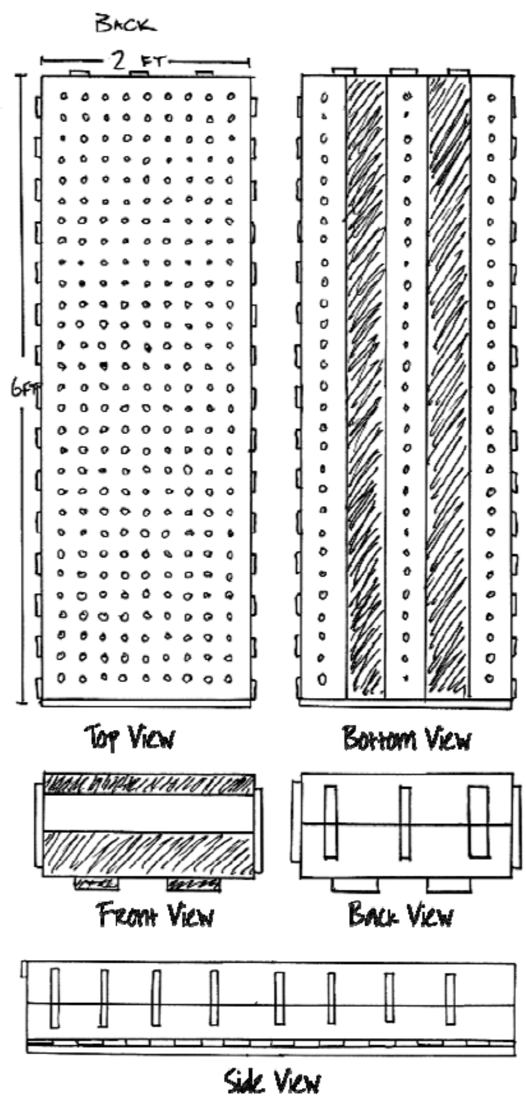
2.2.1 Site set-up

Each box was positioned flat in rows on a concrete slab 70 ft long by 35 ft wide, and oriented such that soil surfaces faced approximately 165˚ south for adequate sun exposure. A one-ton chain hoist was used to move boxes to under the rainfall simulators.

2.2.2 Test boxes

Test boxes measured 6 ft x 2 ft x 1 ft, conforming to field plot tests conducted by Pearce et al. (1998). Box sides were constructed of polyvinyl chloride lumber. Box bottoms were formed from food-grade high-density polyethylene cutting board plastic perforated for drainage. Silt fabric lined the inside to minimize soil loss. The purpose of using plastic materials was to avoid contamination of metals analyses by leached copper and other metals from chromated copper arsenate pressure-treated wood, as used in all previous experiments in this series.

A length of vinyl gutter was used to collect runoff from the base of each erosion test box and channel it into a 8 qt plastic collection container.
A rectangular piece of synthetic pond liner was cut and riveted to the vinyl gutter to prevent direct rainfall from entering the erosion collection system.



Box Sides:
- PVC Polymer: 70 - 95%
- Inert Fillers: 0 - 30% $CaCO_3$, TiO_2
- Heat Stabilizer: 0 - 2% Organotin Compounds
- Lubricants: 0 - 4% Calcium Stearate; Parafin; Polyethylene, Polyamide compounds, or Esters
- Process Aids: 0 - 2% Acrylic compounds
- Impact Modifiers: 0 - 10% CPE, ABS, MBS, or Acrylic compounds
- Colorants: 0 - 2% Organic and inorganic
- Chemical Blowing Agents: 0 - 1% Azo compounds or Sodium Bicarbonate

Perforated Bottoms:
- High-density Polyethylene (HDPE)
  Polyethyene thermoplastic synthesized from petroleum

Section of PVC Lumber

2.2.3 Test soil

Soil was collected by District 5 personnel from a road cut adjacent to SR 46 east of Paso Robles in San Luis Obispo County. Soil was compacted in the test boxes to at least 90% (calculated from bulk density), as typically required for construction fill (Caltrans 2002). Soil properties are listed in **Table 2.1**.

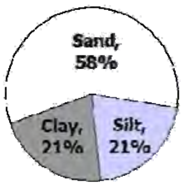


Table 2.1. Test soil properties.

Collection Site	USDA Type	%Sand	%Silt	%Clay	Small Gravels	pH
SR 46 East, PM 37.9	Sandy Clay Loam	58	21	21	< 2% < 1.27 cm	8.1

2.2.4 Soil seed bank

Prior to the run of RS10, the plant species listed in **Table 2.2** were observed following germination and growth in the test soil during the 2009 winter-spring season. Nearly all of these are the common alien forbs and grasses of Central Coastal California. The most-abundant species are those listed in bold type. Species identifications were verified using Hickman et al. (1993).

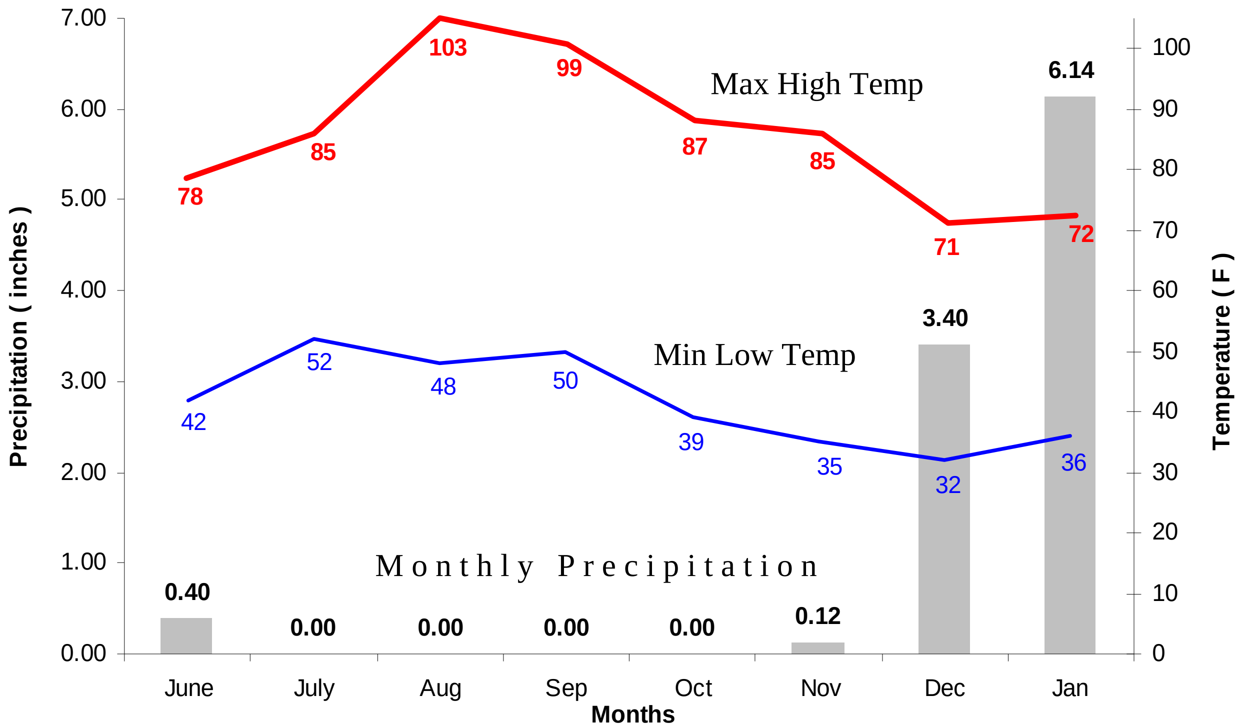
Table 2.2. Plant species germinated in test soil seed bank 2009.

Scientific Name	Common Name
Native Annual Forbs	
Amsinckia menziesii	Fiddleneck
Alien Annual Forbs	
Anagallis arevensis	Scarlet Pimpernel
Brassica nigra	Mustard
Centaurea solstitialis	Yellow Star Thistle
Erodium cicutarium	**Red Stem Filaree**
Erodium botrys	**Broadleaf Filaree**
Lactuca serriola	Prickly Lettuce
Malva parviflora	**Little Mallow**
Marrubium vulgare	White Horehound
Medicago polymorpha	Bur Clover
Melilotus indica	**Yellow Sweetclover**
Picris echioides	Bristly Ox-Tongue
Polygonum arenastrum	Oval-Leaf Knotweed
Sonchus asper	Prickly Sow Thistle
Alien Annual Grasses	
Avena fatua	**Common Wild Oat**
Bromus diandrus	**Ripgut Brome**
Bromus rubens	**Red Brome**
Bromus hordeaceus	**Soft Chess**
Festuca / Vulpia myuros	**Rattail Fescue**

2.2.5 Natural rainfall and irrigation regime

Natural rainfall between June 1, 2009 and January 31, 2010 when RS10 ended was 10.06 inches. **Figure 2.1** shows monthly natural precipitation and temperature extremes during RS10. From June through November 2009, supplemental rainfall (~ 0.5 inch per box per week) was applied to initiate germination and to plant promote growth through the summer.

Figure 2.1. Monthly natural precipitation and temperature extremes during RS10.



2.2.6 Simulated rainfall

Simulated rainfall was delivered by two Norton Ladder-type variable sweep, pressurized nozzle rainfall simulators developed at the USDA Erosion Research Center at Purdue University and manufactured by Advanced Design and Machine, Clarks Hill, IN.
Drop size distribution was tested using Eigel and Moore’s (1983) oil method. Lateral uniformity between simulators was tested using two empty erosion test boxes each filled with 48 six-inch cans and subjected to a typical two-hour storm. Average values were calculated and the amount each value deviated from the average was added and used to determine the coefficient of uniformity for each simulator. Coefficient of uniformity measured for both simulators was 94%.

To test treatment effectiveness, a 2-inch simulated storm (0.5 inches for 30 minutes, 1 inch for 1 hour, and 0.5 inches for 30 minutes) was applied after vegetation had grown for six months to where 80% (15 of 18) of the test boxes exhibited at least 70% within-box average plant cover at the soil surface.

2.3 Data collection and analyses

2.3.1 Vegetation data collection and analyses

Percent vegetation cover at the soil surface was estimated from a top down view on each box by a single experienced observer/recorder on the same day (protocol derived from Interagency Technical Team 1996). **Figure 2.2** shows the scoring sheet structure for vegetation cover data collection. Estimated percent cover was recorded for the following ten categories:

1. Bare soil
2. Mulch (the fiber type treatments: wood, paper, cotton, Straw)
3. *Bromus carinatus* (California Brome)
4. *Festuca/Vulpia microstachys* (Small Fescue)
5. *Achillea millefolium* (Western Yarrow)
6. *Lotus purshianus* (Spanish Lotus)
7. Other perennial grass
8. Other annual grass
9. Other perennial forb
10. Other annual forb

Figure 2.2. Structure of scoring sheet for vegetation cover data collection.

Box	Treatment	Div	Bare	Mulch	Bromus carinatus	Vulpia microstachys	Achillea millefolium	Lotus purshianus	Other Per Grass	Other Ann Grass	Other Per Forb	Other Ann Forb
1	Cotton	Top	%	%	%	%	%	%	%	%	%	%
1	Cotton	Toe	%	%	%	%	%	%	%	%	%	%
"	"	"	"	"	"	"	"	"	"	"	"	"
18	Straw	Toe	%	%	%	%	%	%	%	%	%	%

2.3.2 Runoff data collection and analyses

Runoff was analysed for sediment load, pH, and salt concentration. Total solids were analysed using a procedure that combined methods described by ASTM D3977-97 (ASTM 2002) and EPA method 160.2 (USEPA 2001). After collection of each weighed runoff sample, samples received 10-20 ml 1M $AlCl3$, a common water treatment flocculent. Any remaining sediment on the walls or bottom of the storage container was rinsed into an evaporating dish to be oven dried at 115 °C for 24 to 48 hours and then weighed.

Total water runoff was calculated by subtracting the sediment and container weight from the original total collection weight. The total sediment included the evaporated sediment weight.

Sediment concentration (mg/L) was calculated from the total runoff and total sediment values. For each collection, salt concentration (electrical conductivity) and pH were analysed using a pH/EC/TDS/Temperature meter built by Hanna Instruments, Inc.

Water quality variables were analysed (after a normalization transformation, if needed) using Analysis of Variance (ANOVA), after necessary transformations to achieve homogeneity of variances, if possible, for all responses except pH. Post comparisons of treatment means used the Tukey test (Tukey 1984).

2.3.3 Total soil metals (Cadmium, Copper, Lead, Nickel, and Zinc) analyses

This procedure provides a measurement of cadmium, copper, lead, nickel, and zinc in water. This method is based on filtering a water sample and determining the quantity of each metal in the sample via Flame Atomic Absorption Spectrophotometry.

Metal Standards

Prepare 100 mL of 0, 0.10, 0.50, 2.50, 5.00, and 10.00 ppm standards using 1000 ppm multi-element (Cd, Cu, Pb, Ni, Zn) stock solution. Use deionized water as the matrix. Store the standards in polyethylene containers in the refrigerator at 4^{o} C.

Metal Procedure

1. Filter approximately 40 mL of water through Whatman No. 1 filter paper into a clean 45 mL flip-top vial.
2. Prepare 4 method blanks the same way. Method blanks contain the water used to rain on the soil and must be collected the same day as the run-off water samples.

Metal Analysis

Analyze metals using FAAS following appropriate QA/QC.

Quality Control

1. Perform calibration with at least 4 standards and maintain an $R^2 \geq 0.99$.
2. Run an ICV after each calibration and maintain % R = 90 % - 110 % of the known value.
3. Run a CCV every 10 samples or at the end of a batch, whichever comes first, and maintain % R = 90 % - 110 % of the known value.
4. Analyze a replicate every 10 samples or at the end of a batch, whichever comes first, and maintain % R = 90 % - 110 %.
5. Analyze a spiked sample every 10 samples or at the end of a batch, whichever comes first, and maintain % R = 90 % - 110 % of the known value.
6. Calculate an MDL using the 4 method blanks.

Quality Control Formulas

$$\% \text{ R (ICV, CCV)} = \frac{\text{Mid - range external standard concentration}}{\text{Mid - range known external standard concentration}} x100\%$$

$$\% \text{ R} = \frac{\text{Replicate concentration}}{\text{Original concentration}} x100\%$$

$$\% \text{ R (spike)} = \frac{\text{(Sample + spike concentration) - (sample concentration)}}{\text{Spike concentration}} x100\%$$

$$\text{MDL} = \text{Average}_{\text{Blank}} + (s_{Blank} \; x t_{\alpha = 0.01})$$

Section 3

Results and Analyses

3.1 Vegetation Cover

Although raw cover percentage values were arcsine-transformed before running Homogeneity of Variance tests necessary to pass this fundamental assumption of any Analysis of Variance, heterogeneity of variances was announced by both Bartlett's Test and Levene's Test, as is frequently the case with percentages.

Because the sample sizes were equal and the observational data were recorded by the same observer on the same day, a parametric ANOVA was run as it is known to perform well despite nonnormality and heterogeneity of variances (Zar 1984).

General Linear Model: VEG COVER TOTAL versus Treatment, Div

Factor	Type	Levels	Values
Treatment	fixed	5	Bare, Cotton, Paper, Straw, Wood
Div	fixed	3	Whole box, Toe half, Top half

Analysis of Variance for VEG COVER TOTAL, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	4	3.45842	3.45842	0.86460	37.71	0.000
Div	2	0.04881	0.04881	0.02441	1.06	0.352
Error	53	1.21516	1.21516	0.02293		
Total	59	4.72240				

S = 0.151419   R-Sq = 74.27%   R-Sq(adj) = 71.36%

```
                    Individual 95% CIs For Mean Based on
                    Pooled StDev
Treatment     Mean  --------+---------+---------+---------+-
Bare       1.35887                              (--*---)
Cotton     0.87874            (--*---)
Paper      0.63344  (--*---)
Straw      0.84078          (---*--)
Wood       1.01275                 (---*--)
                    --------+---------+---------+---------+-
                         0.75      1.00      1.25      1.50
```

```
               Individual 95% CIs For Mean Based on Pooled StDev
Div      Mean  ---------+---------+---------+---------+
Box  0.941498       (----------*----------)
Toe  0.981435             (-----------*----------)
Top  0.911818  (----------*----------)
               ---------+---------+---------+---------+
                    0.900     0.960     1.020     1.080
```

The Treatment effect was significant ($p = 0.000$), but the Box Division effect was not significant; thus, no differences in plant cover comparing Top half, Toe half, or Whole boxes, although in every case the Toe half exhibited slightly more plant cover, presumably from longer water retention over the growing season.

The **Bare+seed** control boxes produced a significantly greater (**97.5** %) average total plant cover at the soil surface, while the **Paper** treatment produced a significantly lesser (**57.4** %) average total plant cover at the soil surface. The Wood (84%), Cotton (77%), and Straw (74%) treatments were not significantly different from one another in average total plant cover at the soil surface.

Statistical groups

		Treatment
Most Cover	**Group 1**	**Bare+seed**
	Group 2	Wood Cotton Straw
Least Cover	**Group 3**	**Paper**

Vegetation cover by treatment

Treatment	Div	Veg Cover %
Bare + seed	***Whole***	***97.5***
Bare +seed	Toe	98.0
Bare +seed	Top	97.0
Wood	***Whole***	***83.8***
Wood	Toe	87.5
Wood	Top	80.0
Cotton	***Whole***	***76.9***
Cotton	Toe	78.0
Cotton	Top	75.8
Straw	***Whole***	***74.3***
Straw	Toe	77.3
Straw	Top	71.3
Paper	***Whole***	***57.4***
Paper	Toe	60.0
Paper	Top	54.8

Although the **Bare+seed** control**, Wood, Cotton, Straw** treatments all produced greater than 70% vegetation cover, the seeded natives were nearly absent from observed live cover. Causes were likely those observed during previous experiments: seed buried too deeply by mulch leading to inappropriate light cues for germination; inappropriate temperature regime for germination; and desiccation pre- and post-germination. RS10 ran during the summer when the seed of many cool-season species are typically obligately dormant because high and low temperatures are too warm, a cue for the seed of native species adapted to a summer-dry climate that available water is likely inadequate for growth past germination.

Figure 3-1 shows box plots of average total plant cover at the soil surface over whole box, toe half, and top half.

Table 3-1 list all plant species observed in one or more treatment or control boxes when vegetation cover assessments were recorded in January 2010.

Figure 3-2 shows photos of treatment boxes at week one, six, twelve, and twenty-two.

Figure 3-1. Box plots of vegetation cover: average over box, toe half, and top half.

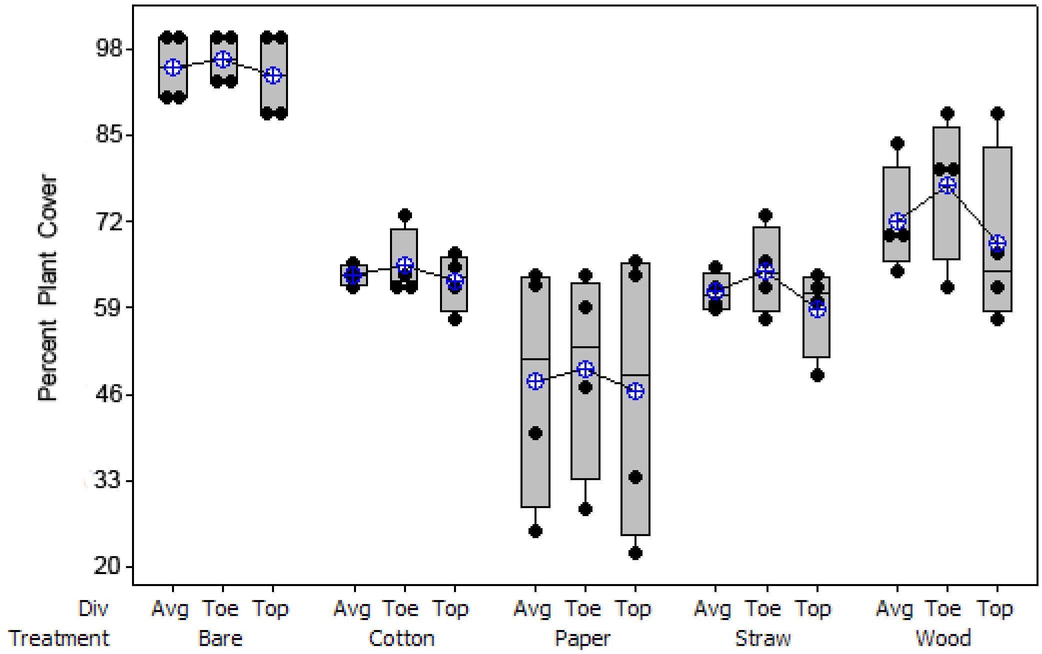
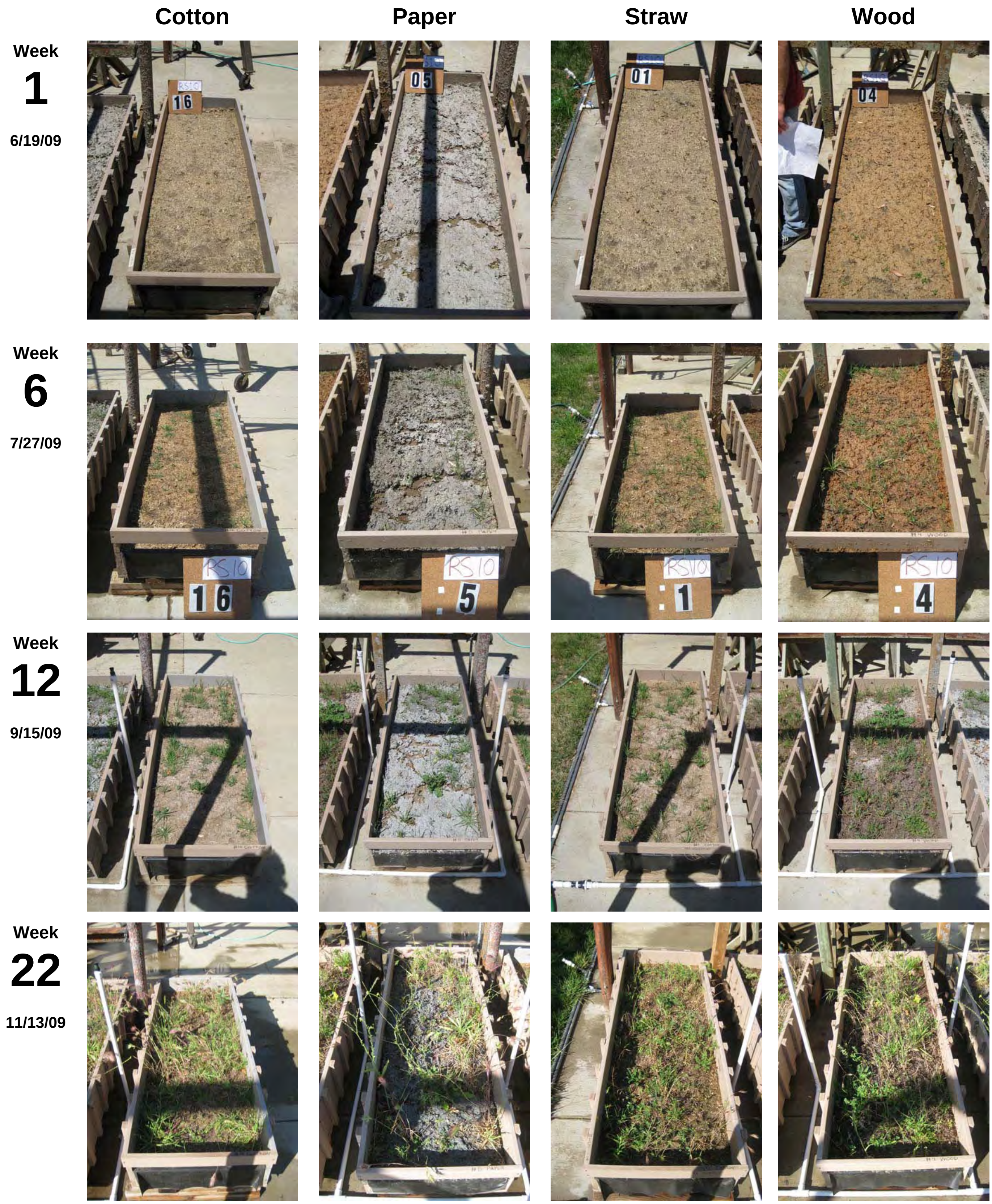


Table 3-1. Plant species observed in one or more treatment or control boxes.

Scientific Name	Common Name	Seed Bank	Added Seed
Native Perennial Forbs			
Achillea millefolium	Common Yarrow		✓
Native Annual Forbs			
Amsinckia menziesii	Fiddleneck	✓	
Lotus purshianus	Spanish Lotus		✓
Alien Annual Forbs			
Anagallis arevensis	Scarlet Pimpernel	✓	
Brassica nigra	Mustard	✓	
Centaurea solstitialis	Yellow Star Thistle	✓	
Erodium cicutarium	Red Stem Filaree	✓	
Erodium botrys	Broadleaf Filaree	✓	
Lactuca serriola	Prickly Lettuce	✓	
Malva parviflora	Little Mallow	✓	
Marrubium vulgare	White Horehound	✓	
Medicago polymorpha	Bur Clover	✓	
Melilotus indica	Yellow Sweetclover	✓	
Picris echioides	Bristly Ox-Tongue	✓	
Polygonum arenastrum	Oval-Leaf Knotweed	✓	
Sonchus asper	Prickly Sow Thistle	✓	
Alien Annual Grasses			
Avena fatua	Common Wild Oat	✓	
Bromus diandrus	Ripgut Brome	✓	
Bromus rubens	Red Brome	✓	
Bromus hordeaceus	Soft Chess	✓	
Festuca / Vulpia myuros	Rattail Fescue	✓	

Figure 3-2. Photos of treatment boxes at week one, six, twelve, and twenty-two.



3.2 Water Quality

For the array of water quality analyses three controls were run as comparisons with the four fiber treatments:

1. **Bare soil** without fiber mulch or vegetation;
2. soil without a fiber mulch, but having vegetation grown for six months, i.e.,Bare+seed**bank**;
3. soil with a hydroapplied **Compost** mulch about one-inch thick.

Data and analyses for the standard variables are presented first, followed by data and analyses for metals. **Table 3-2** is the complete data matrix for standard water quality variables by treatment.

Total Runoff (RO) in mL

Surface waters that exceed the soil's infiltration rate and depression storage. It includes that portion of precipitation that appears as flow in streams and also includes drainage or flood discharges that leave an area as surface flow or as pipeline flow having reached a channel or pipeline by either surface or subsurface routes.

Total Sediment (TS) in grams

Solid particulate matter, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Turbidity (NTU)

Cloudiness of water quantified by the degree to which light traveling through a water column is scattered by the suspended organic and inorganic particles it contains. The scattering of light increases with a greater suspended load. Turbidity is commonly measured in Nephelometric Turbidity Units (NTU), a unit that measures water quality using a **nephelometer** (Greek: *nephele*, cloud) that assesses turbidity directly by comparing the amount of light transmitted straight through a water sample with the amount scattered at an angle of 90° to one side; this **unitless ratio** determines the turbidity in NTU's. The instrument is calibrated using samples of a standard solution such as **formazin**, a synthetic polymer.

Electrical Conductivity (EC) in **µS/cm**

Measure of the ability of water to carry an electric current. This ability depends on the presence of ions, their concentration, valence, mobility and temperature. EC measurements can give an estimate of the variations in the dissolved mineral content of storm water in relation to receiving waters.

pH

The pH scale is based on $-\log_{10}[H^+]$ and expresses the intensity of an acid or base (alkaline) condition. The pH scale ranges from extreme acids of 1 to extreme bases of 14, with neutral being 7. Units are moles of hydrogen per liter. Extremes of pH can have deleterious effects on biological systems.

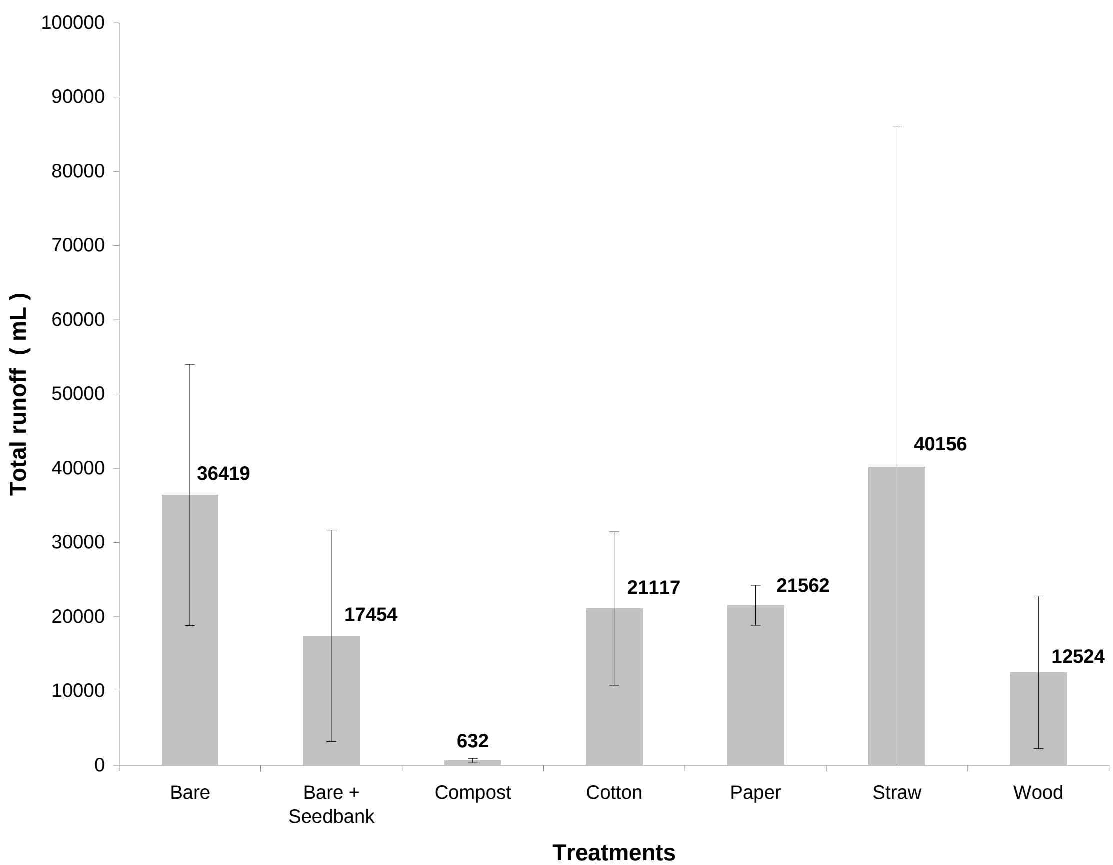
Table 3-2. Data for standard water quality variables by treatment.

Treatment	Total Runoff (ml)	Total Sediment (g)	Sediment Conc. (mg/L)	Turbidity (NTU)	EC (µS/cm)	pH
Bare	36419	1113.8	38851	5840	227	7.17
Bare+seedbank	17454	9.3	524	329	127	6.56
Compost	632	0.4	769	12.6	268	6.05
Cotton	21117	17.9	967	484	33	5.30
Paper	21562	9.7	465	239	89	5.63
Straw	40156	29.2	873	405	35	6.05
Wood	12524	4.1	1765	194	58	5.58

3.2.1 Total Runoff (RO)

The hydomulched **Compost** treatment produced significantly less total runoff than all other treatments, with nearly twenty times less runoff than **Wood** fiber, the next-best performer. The **Cotton**, **Paper**, and **Straw** treatments were not significantly different from one another or from the **Bare+seedbank**, or **Bare** controls, although **Straw** produced nearly twice the amount of runoff than the **Cotton** or **Paper** treatments.

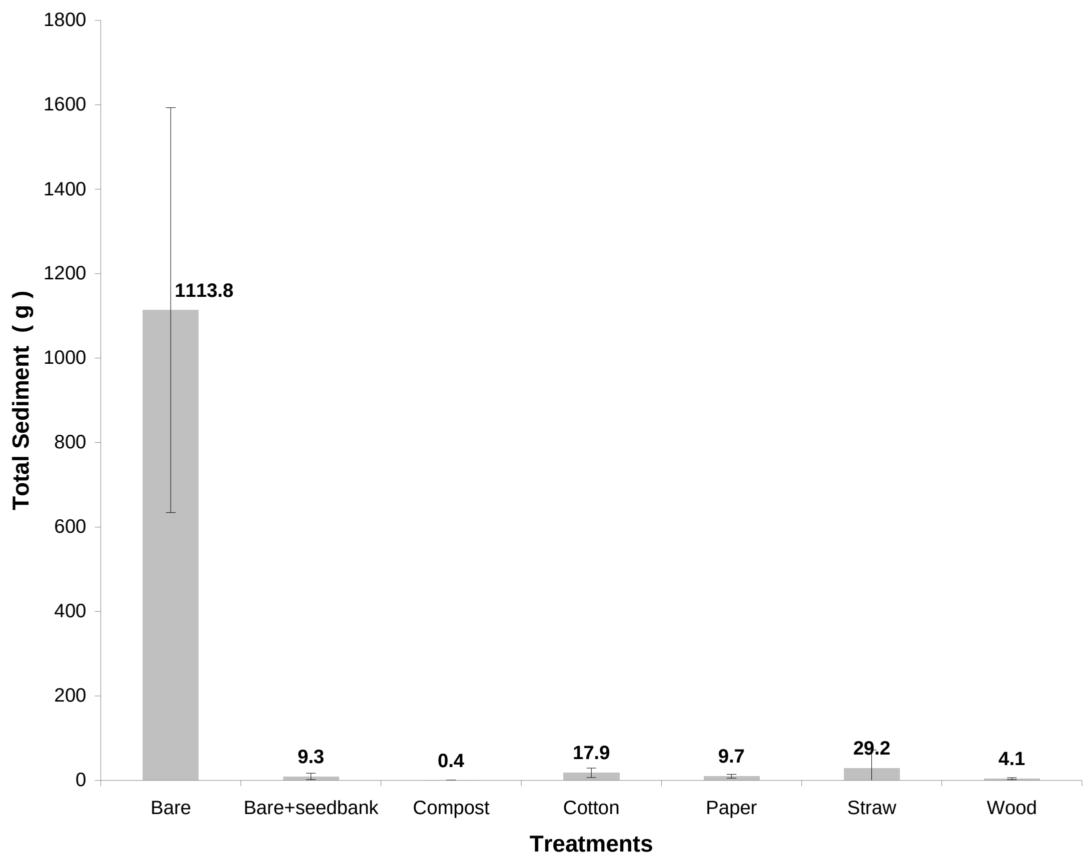
		Treatment	**Total Runoff (mL)**
High RO	**Group 1**	Straw	40156
		Bare	36419
		Paper	21562
		Cotton	21117
		Bare+seed	17454
		Wood	12524
Low RO	**Group 2**	**Compost**	632



3.2.2 Total Sediment (TS)

Again, the **Compost** control performed the best, and, together with **Wood** andBare+seed, was significantly different from **Cotton**, **Paper**, and **Straw**, also collectively siginificantly different from the **Bare** control that produced significantly more sediment than all other treatments.

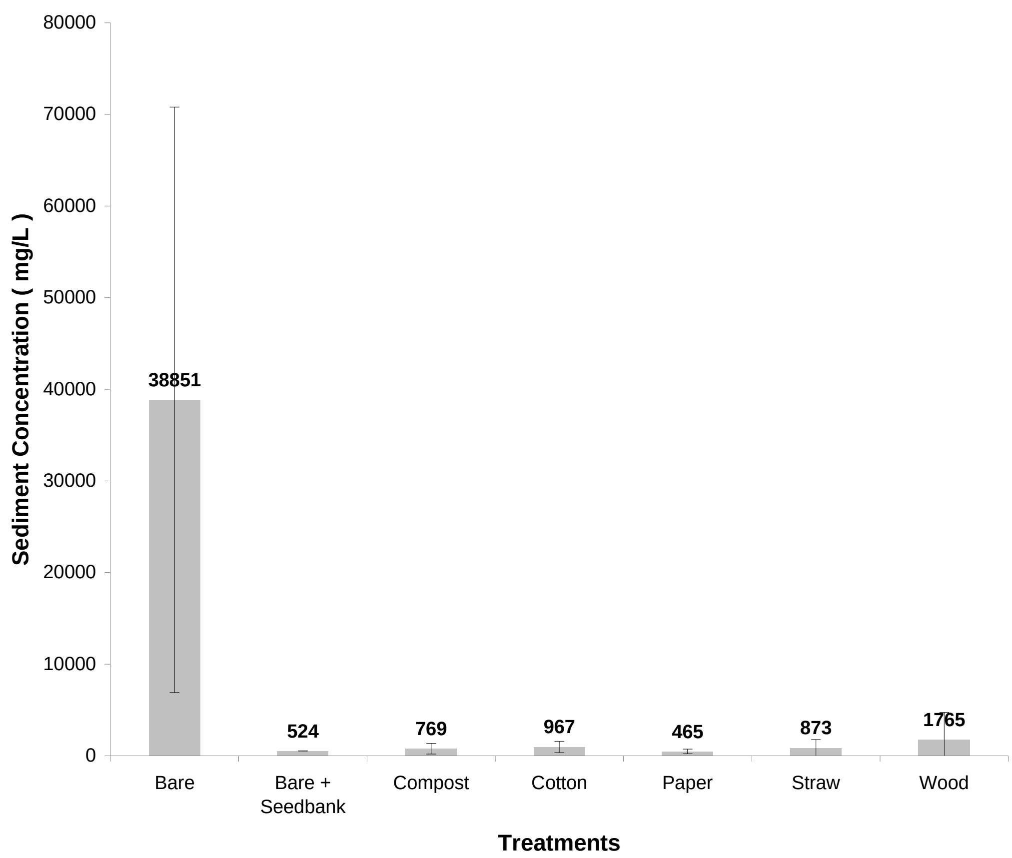
		Treatment	**Total Sediment (g)**
High TS	**Group 1**	Bare	1113.8
	Group 2	Straw	29.2
		Cotton	17.9
		Paper	9.7
Low TS	**Group 3**	Bare+seed	9.3
		Wood	4.1
		Compost	**0.4**



3.2.3 Sediment Concentration (SC)

The **Bare** control produced significantly more sediment concentration than all other treatments. Their was no significant difference among all other treatments or controls.

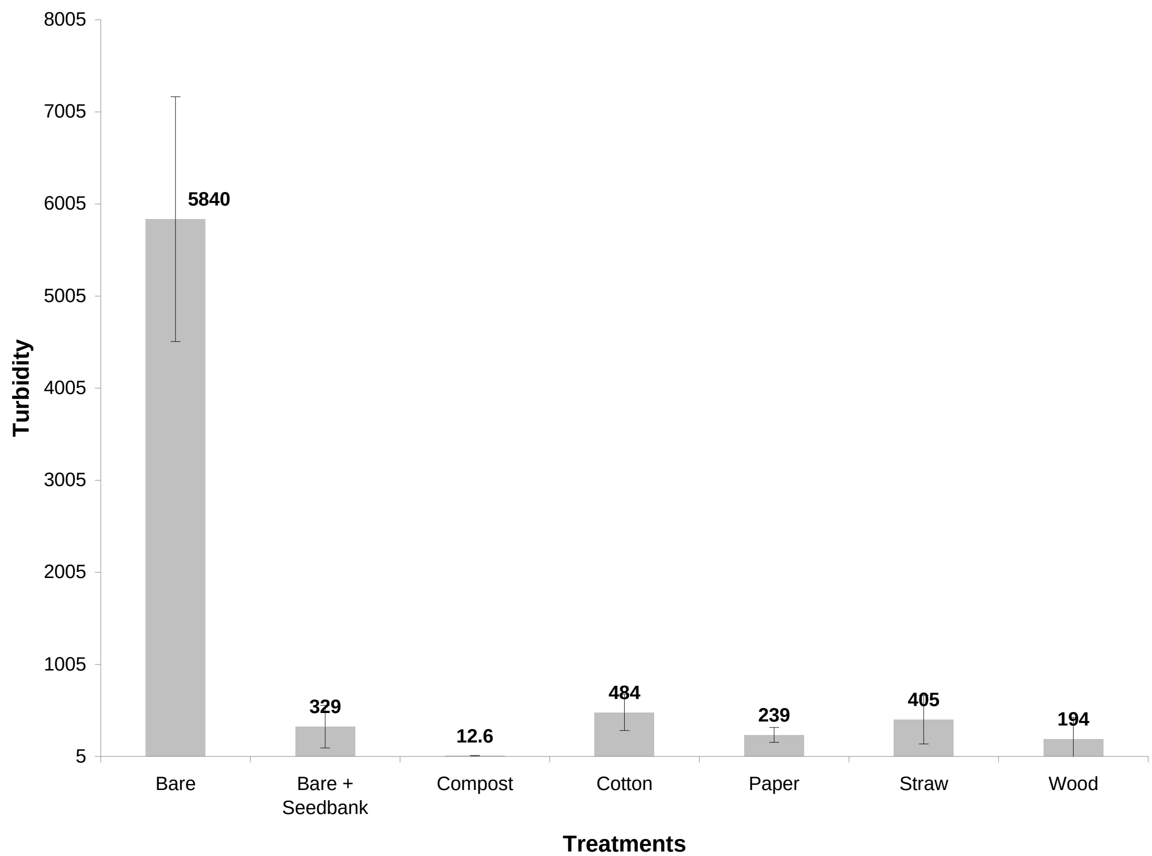
	Treatment	**Sediment Conc (mg/L)**
High SC Group 1	Bare	**38851**
Low SC Group 2	Wood	1765
	Cotton	967
	Straw	873
	Compost	769
	Bare+seed	524
	Paper	465



3.2.4 Turbidity (NTU)

The **Bare** control produced significantly more turbidity than all other treatments, the **Compost** control produced significantly less turbidity than all other treatments. Their was no significant difference among all other treatments or the **Bare+seed** control.

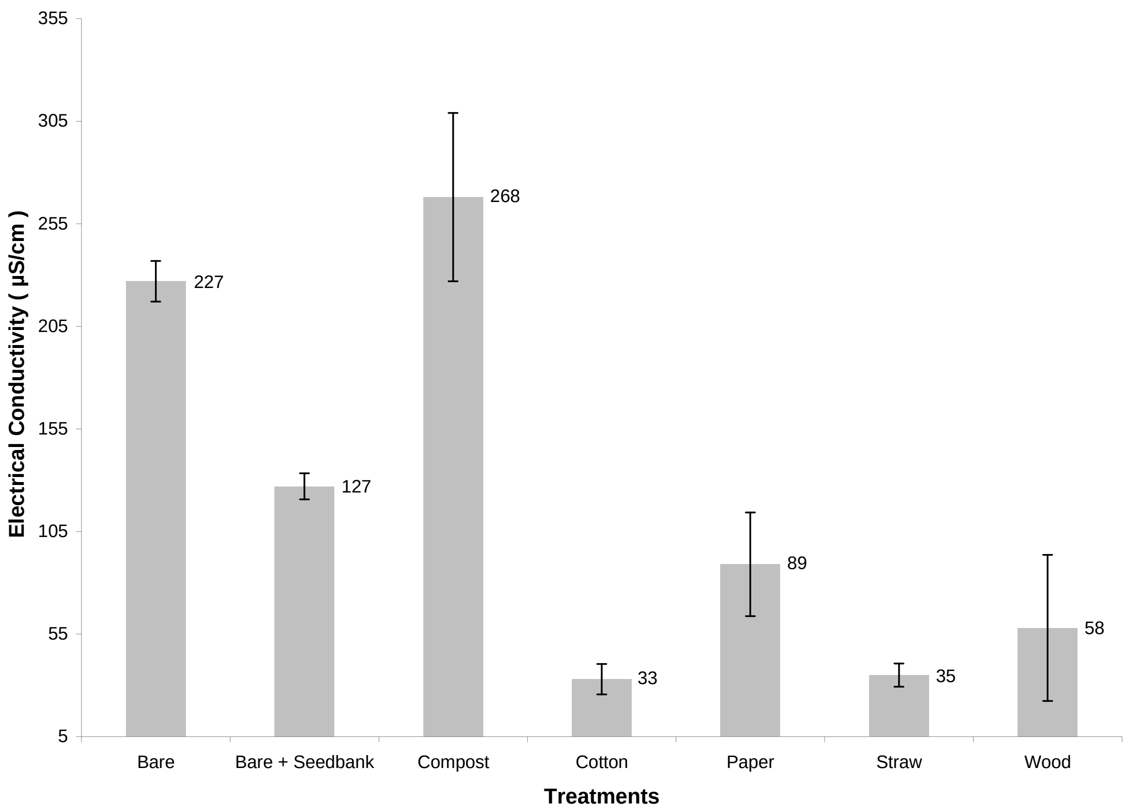
		Treatment	NTU
High NTU	Group 1	Bare	5840
		Cotton	484
		Straw	405
		Bare+seed	329
		Paper	239
		Wood	194
Low NTU	Group 3	**Compost**	**13**



3.2.5 Electrical Conductivity (EC)

The **Bare** control and the **Compost** control produced significantly more EC than all other treatments, while the **Straw** and **Cotton** treatments produced significantly less EC than all other treatments.

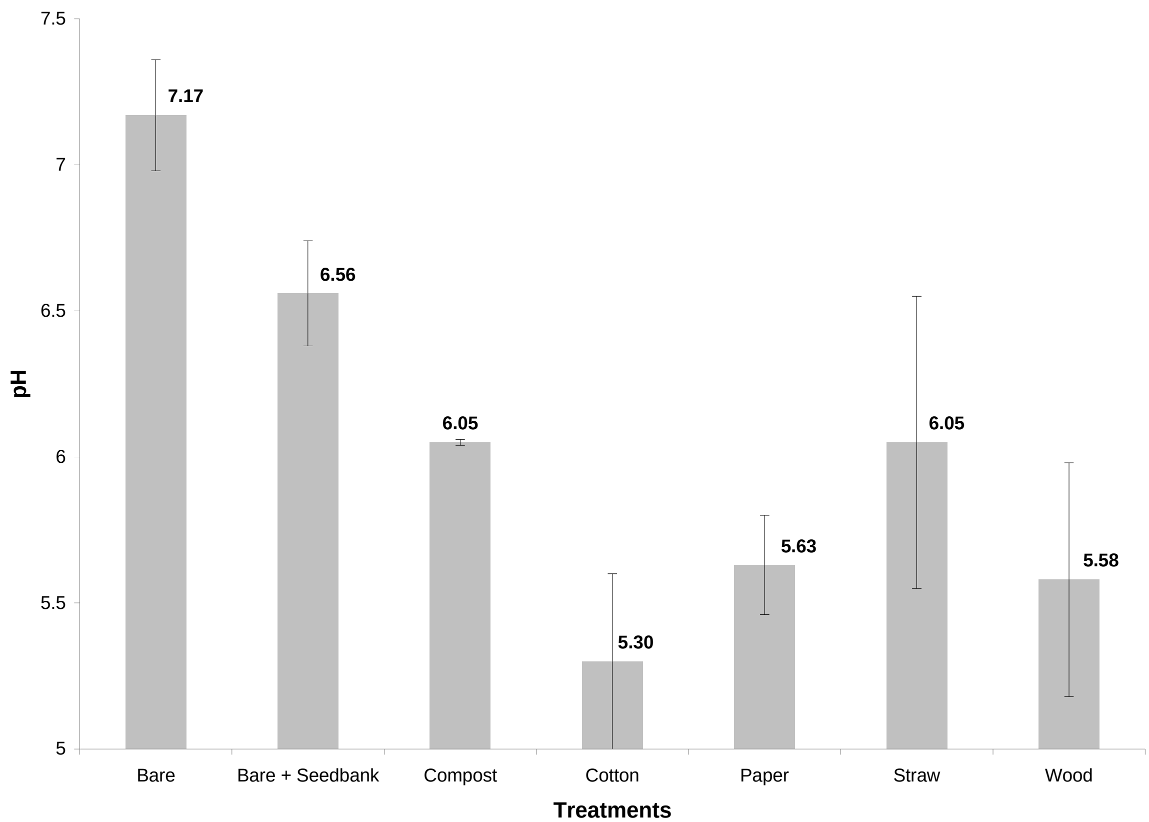
		Treatment	EC (µS/cm)
High EC	**Group 1**	Compost	268
		Bare	227
	Group 2	Bare+seed	127
		Paper	89
		Wood	58
Low EC	**Group 3**	Straw	35
		Cotton	33



3.2.6 pH

The **Bare** control and the **Bare+seed** control exhibited significantly higher pH than all other treatments or the **Compost** control, while the **Cotton** treatment produced significantly lower pH than all other treatments. Their was no significant difference among all other treatments.

		Treatment	pH
High pH	Group 1	Bare	7.17
		Bare+seed	6.56
	Group 2	Compost	6.05
		Straw	6.05
		Paper	5.63
		Wood	5.58
Low pH	Group 3	Cotton	5.30



3.2.7 Metals

Trace quantities of many metals are necessary for biological growth and may naturally occur in runoff. Most metals, however, have numeric water quality standards because of their toxicity to aquatic organisms at high concentrations. Toxicity of some metals is inversely related to water hardness. The numeric water quality standards for cadmium, chromium, copper, lead, nickel, silver and zinc are hardness-dependent. Copper, lead and zinc are the metals most commonly found in highway runoff.

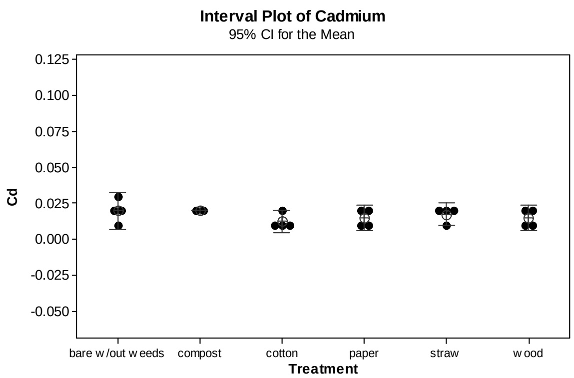
RS10 analysed quantities of cadmium, copper, nickel, lead, and zinc in sediment. **Figure 3-3** shows interval plots of metals (PPM) by treatment with 95% confidence limits. **All metals were in quantities at or below MDL limits.** In the ANOVA of metals by fiber treatment, lead was the only metal to exhibit significant lower quantity in the **Compost** control. No other significant differences were announced for all other metals data for any fiber treatment or control.

Number	Relative Atomic Mass	Symbol	Ions	Metal	MDL
48	112.41	Cd	Cd+, Cd++	**Cadmium**	**0.027**
29	63.56	Cu	Cu+, Cu++	**Copper**	**0.117**
28	58.69	Ni	Ni++, Ni+++	**Nickel**	**0.018**
82	207.20	Pb	Pb++, Pb++++	**Lead**	**0.026**
30	65.39	Zn	Zn++	**Zinc**	**0.143**

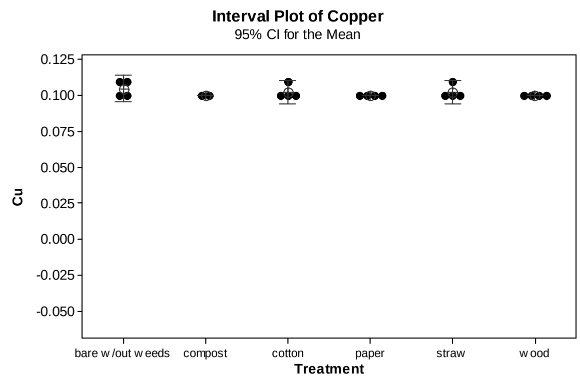
Sample	Treatment	Cadmium	Copper	Nickel	Lead	Zinc
				PPM		
48	Bare w/out weeds	**0.02**	**0.11**	~~0.00~~	**0.02**	**0.02**
49	Bare w/out weeds	**0.01**	**0.11**	**0.01**	**0.01**	**0.02**
52	Bare w/out weeds	**0.02**	**0.10**	**0.02**	**0.01**	**0.01**
54	Bare w/out weeds	**0.03**	**0.10**	**0.01**	**0.01**	**0.01**
42	Compost	**0.02**	**0.10**	~~0.00~~	~~0.00~~	**0.03**
44	Compost	**0.02**	**0.10**	**0.01**	~~0.00~~	**0.04**
26	Cotton	**0.01**	**0.11**	0.00	**0.01**	**0.04**
31	Cotton	**0.01**	**0.10**	**0.01**	**0.01**	**0.02**
32	Cotton	**0.02**	**0.10**	**0.01**	**0.01**	**0.03**
35	Cotton	**0.01**	**0.10**	~~0.00~~	**0.01**	**0.02**
14	Paper	**0.01**	**0.10**	~~0.00~~	**0.02**	**0.04**
16	Paper	**0.01**	**0.10**	~~0.00~~	**0.02**	**0.02**
51	Paper	**0.02**	**0.10**	**0.01**	**0.01**	**0.01**
53	Paper	**0.02**	**0.10**	**0.01**	**0.01**	**0.01**
19	Straw	**0.01**	**0.10**	~~0.00~~	**0.02**	**0.03**
24	Straw	**0.02**	**0.10**	~~0.00~~	**0.01**	**0.02**
37	Straw	**0.02**	**0.10**	**0.02**	**0.02**	**0.02**
38	Straw	**0.02**	**0.11**	~~0.00~~	**0.01**	**0.01**
7	Wood	**0.01**	**0.10**	**0.01**	**0.01**	**0.06**
8	Wood	**0.01**	**0.10**	**0.01**	~~0.00~~	**0.03**
23	Wood	**0.02**	**0.10**	**0.01**	**0.01**	**0.02**
25	Wood	**0.02**	**0.10**	**0.01**	**0.01**	**0.04**

Figure 3-3. Interval plots of metals (PPM) by treatment with 95% confidence limits.

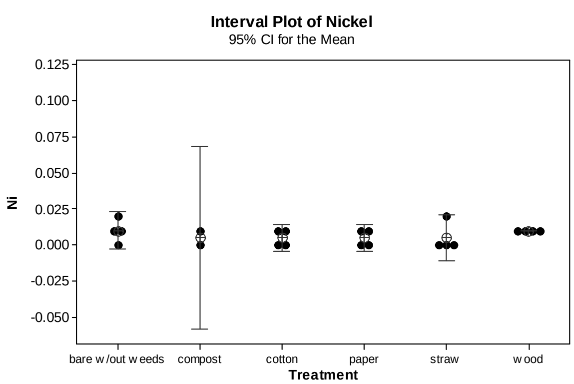
Cadmium MDL= 0.027



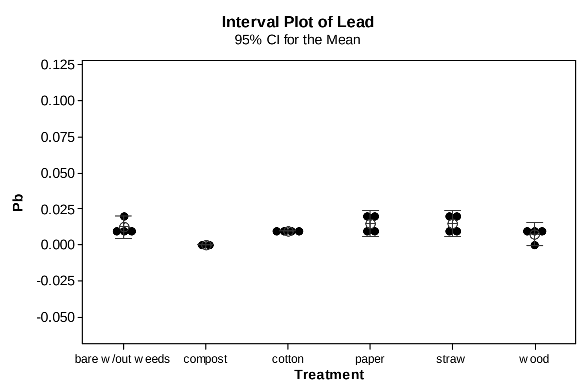
Copper MDL= 0.117



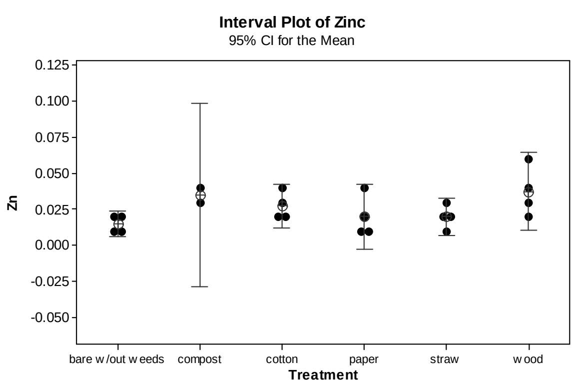
Nickel MDL= 0.018



Lead MDL= 0.026



Zinc MDL= 0.143



General Linear Model: Cd, Cu, Ni, Pb, Zn, versus Treatment

Factor	Type	Levels	Values
Treatment	fixed	6	bare w/out weeds, compost, cotton, paper, straw, wood

Analysis of Variance for Cd, using Adjusted SS for Tests

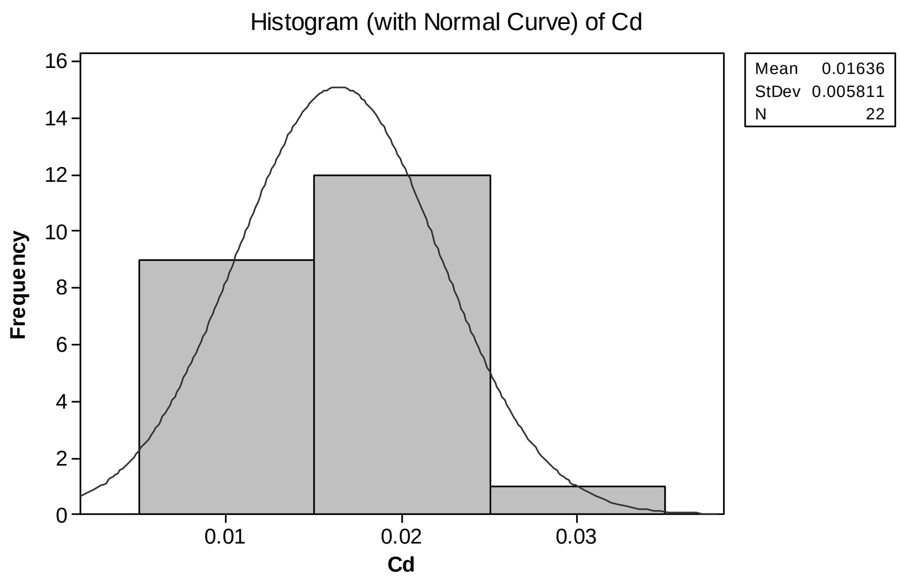
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	5	0.0001591	0.0001591	0.0000318	0.93	0.490
Error	16	0.0005500	0.0005500	0.0000344		
Total	21	0.0007091				

S = 0.00586302   R-Sq = 22.44%   R-Sq(adj) = 0.00%

Descriptive Statistics: Cd

Variable	Total Count	Mean	StDev	Variance	Minimum	Median	Maximum	Mode
Cd	22	0.01636	0.00581	0.00003	0.01000	0.02000	0.03000	0.02

Variable	N for Mode	Skewness	Kurtosis
Cd	12	0.21	-0.62



Analysis of Variance for Cu, using Adjusted SS for Tests

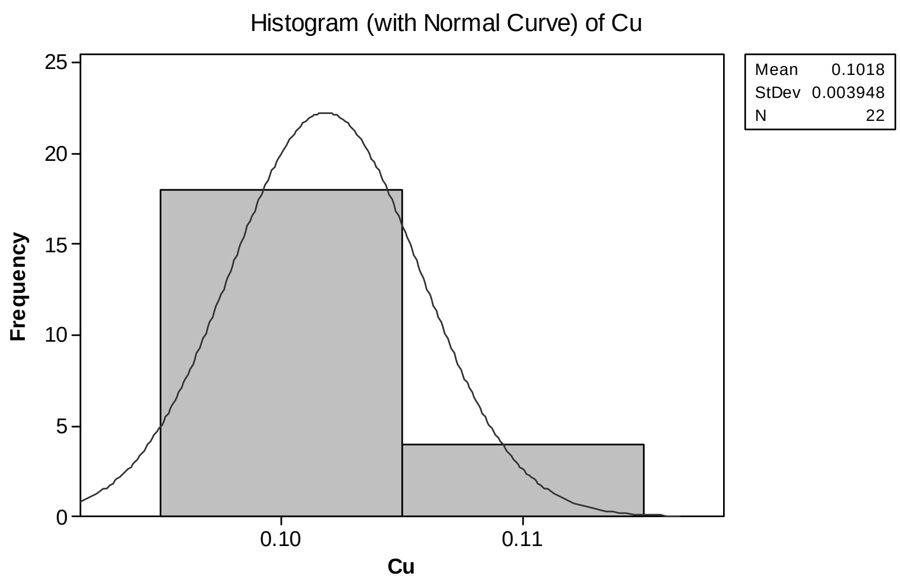
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	5	0.0000773	0.0000773	0.0000155	0.99	0.455
Error	16	0.0002500	0.0002500	0.0000156		
Total	21	0.0003273				

S = 0.00395285   R-Sq = 23.61%   R-Sq(adj) = 0.00%

Descriptive Statistics: Cu

Variable	Total Count	Mean	StDev	Variance	Minimum	Median	Maximum	Mode
Cu	22	0.10182	0.00395	0.000016	0.10000	0.10000	0.11000	0.1

Variable	N for Mode	Skewness	Kurtosis
Cu	18	1.77	1.25



Analysis of Variance for Ni, using Adjusted SS for Tests

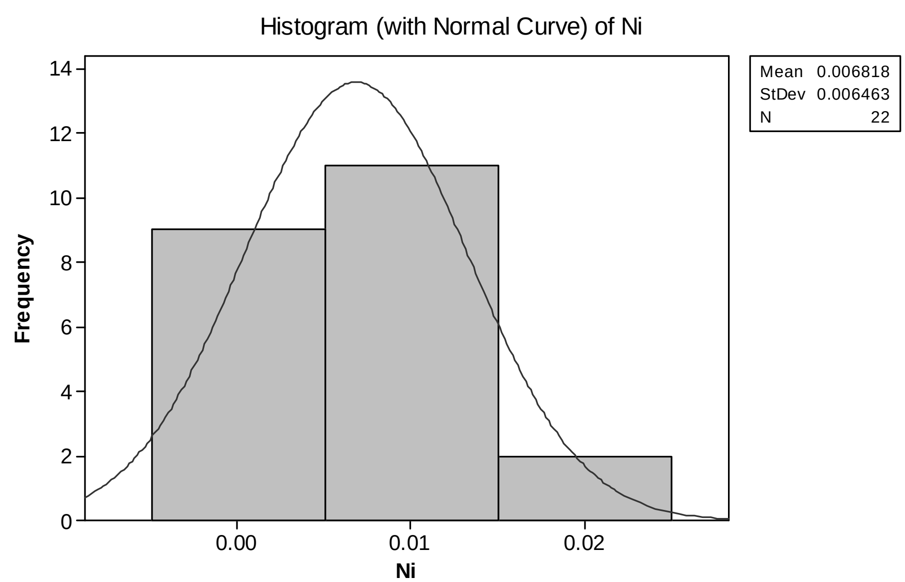
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	5	0.0001273	0.0001273	0.0000255	0.54	0.741
Error	16	0.0007500	0.0007500	0.0000469		
Total	21	0.0008773				

S = 0.00684653   R-Sq = 14.51%   R-Sq(adj) = 0.00%

Descriptive Statistics: Ni

Variable	Total Count	Mean	StDev	Variance	Minimum	Median	Maximum	Mode
Ni	22	0.00682	0.00646	0.00004	0.00000	0.01000	0.02000	0.01

Variable	N for Mode	Skewness	Kurtosis
Ni	11	0.40	-0.54



Analysis of Variance for Pb, using Adjusted SS for Tests

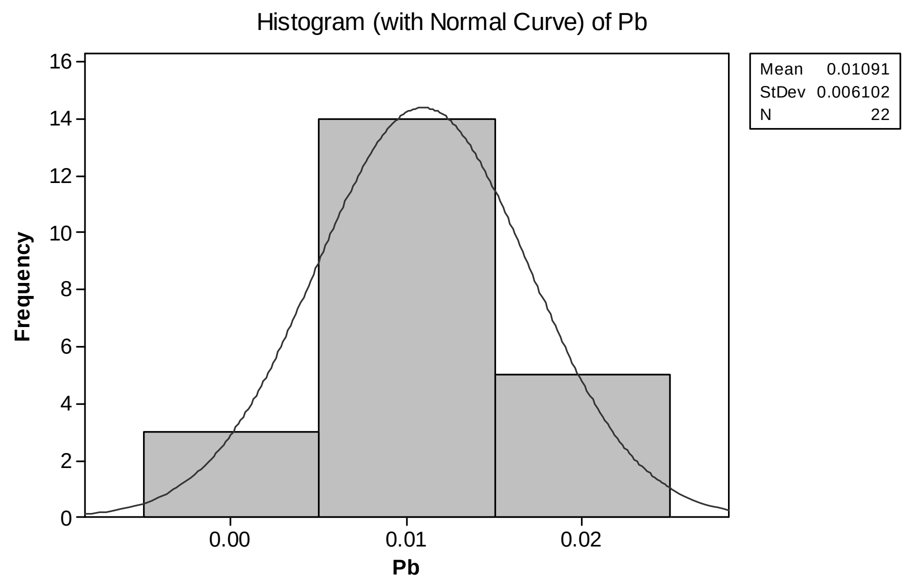
```
Source      DF     Seq SS     Adj SS      Adj MS     F      P
Treatment    5  0.0004318  0.0004318  0.0000864  3.95  0.016
Error       16  0.0003500  0.0003500  0.0000219
Total       21  0.0007818
```

← significant at 0.05 level

```
S = 0.00467707   R-Sq = 55.23%   R-Sq(adj) = 41.24%


Level             N      Mean     StDev
bare w/out weeds  4  0.012500  0.005000
compost           2  0.000000  0.000000
cotton            4  0.010000  0.000000
paper             4  0.015000  0.005774
straw             4  0.015000  0.005774
wood              4  0.007500  0.005000


                  Individual 95% CIs For Mean Based on Pooled StDev
Level                ---------+---------+---------+---------
bare w/out weeds                         (------*------)
compost              (---------*---------)
cotton                                (------*------)
paper                                       (------*-------)
straw                                       (------*-------)
wood                               (------*------)
                     ---------+---------+---------+---------
                  -0.0070    0.0000    0.0070    0.0140

Pooled StDev = 0.004677
```

Descriptive Statistics: Pb

```
           Total
Variable   Count     Mean    StDev  Variance  Minimum   Median  Maximum  Mode
Pb            22  0.01091  0.00610   0.00004  0.00000  0.01000  0.02000  0.01

           N for
Variable    Mode  Skewness  Kurtosis
Pb            14     -0.03      0.02
```


Histogram (with Normal Curve) of Pb
Mean 0.01091
StDev 0.006102
N 22
Frequency
16
14
12
10
8
6
4
2
0
0.00
0.01
0.02
Pb

Analysis of Variance for Zn, using Adjusted SS for Tests

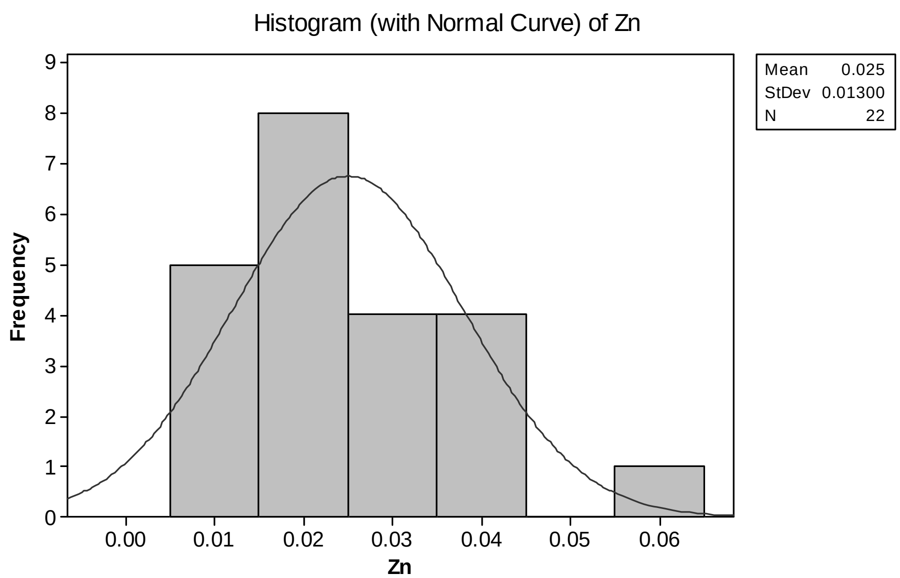
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	5	0.0014500	0.0014500	0.0002900	2.21	0.104
Error	16	0.0021000	0.0021000	0.0001312		
Total	21	0.0035500				

S = 0.0114564   R-Sq = 40.85%   R-Sq(adj) = 22.36%

Descriptive Statistics: Zn

Variable	Total Count	Mean	StDev	Variance	Minimum	Median	Maximum	Mode
Zn	22	0.02500	0.01300	0.00017	0.01000	0.02000	0.06000	0.02

Variable	N for Mode	Skewness	Kurtosis
Zn	8	0.93	0.88



Section 4

Conclusions

4.1 Synopsis

Consistent with past experiments involving fiber and compost treatments (CTSW-RT-04-004.69.01, CTSW-RT-04-069.06.1, CTSW-RT-05-069.06.2), the hydroapplied Compost control outperformed all fiber treatments in all measures except for higher levels of soluble salts that could present osmotic problems for some plants when hydroapplied Compost is used in large quantities as a germination medium.

Among the fiber treatments, **Wood** performed better than **Cotton**, **Straw**, or **Paper** in an overall ranked matrix of variables based on statistical significance and mean values. The matrix combines both water quality measures and greatest production of vegetation cover at the soil surface.

Treatment	***TOTAL SCORE***	Total Runoff (ml)	Total Sediment (g)	Turbidity (NTU)	EC (µS/cm)	pH	Vegetation Cover	Cadmium	Copper	Nickel	Lead	Zinc
Compost	***11***	3	3	3	0	1	0	0	0	0	1	0
Wood	***8***	1	2	2	2	0	1	0	0	0	0	0
Bare+seed	***5***	0	1	0	1	1	2	0	0	0	0	0
Cotton	***4***	0	0	0	3	0	1	0	0	0	0	0
Straw	***4***	-1	0	0	3	1	1	0	0	0	0	0
Paper	***3***	0	1	1	2	0	-1	0	0	0	0	0
Bare	***–2***	-1	-1	-1	0	1	0	0	0	0	0	0

4.1.1 Vegetation Cover

Although the seeded native species were a complete failure in RS10, greater than 70% plant cover at the soil surface was evident in all fiber treatments, except **Paper**, and the **Bare+seedbank** control produced **over 95% plant cover at the soil surface from the soil seedbank alone**. Outcomes from both the **Paper** treatment and the **Bare+seedbank** control hold wider implications for erosion control and roadside vegetation management.

The **Paper** treatment performed well as a sediment control, second to **Wood** of the fiber treatments and 114 times better than **Bare** soil, but the consisitently poor production of vegetation in this experiment, and empirical evidence from past roadside hydroseedings, negate any positive benefits as an erosion control treatment when vegetation establishment is also a goal. However, for project applications where temporary erosion control is required and vegetation production is ***not*** desired, such as a temporary rain-season cover, or as a weed control between planted live container stock, paper hydromulch could be useful.

The **Bare+seedbank** control production of over 95% plant cover at the soil surface from the soil seedbank alone, coupled with good to excellent ratings in water quality [*Runoff*: not significantly different from any fiber treatments; *Sediment*: significantly better than Cotton, Paper, Straw; *Turbidity*: not significantly different from any fiber treatment: *pH*: significantly better than Cotton, Paper, Straw, and Wood; *metals (Cd, Cu, Ni, Pb, Zn)*: not significantly different from any fiber treatment], suggests that the typical mix of alien and native winter-annuals common over much of cismontane California roadsides has the potential to perform as well as or better than the fiber products tested as an erosion control treatment, **if given sufficient water and time to establish over 95% plant cover at the soil surface.** This caveat is an extremely important one as large local variation in sufficient fall to spring precipitation produces large local variation in annual plant cover and density. However, as a parallel to RS8 (Caltrans 2007) where simulated rainfall trials of groundcover cultivars (Iceplants, Ivy, Lantana, Myoporum, Rosemary) showed that these common roadside plantings may be performing storm water treatment as intended, the common roadside annuals also may be performing storm water treatment sufficient to not exceed regulatory limits.

4.1.2 Runoff and Sediment

The hydroapplied Compost control again outperformed all fiber treatments in producing the least total runoff, least sediment, least turbidity, and the lowest lead levels. In next-best to least-best order were Wood, Cotton, Straw, and Paper, although Paper was better than Cotton and Straw in lesser total sediment, sediment concentration, and turbidity.

4.1.3 Metals

All metals were in quantities at or below MDL limits. In the ANOVA of metals by fiber treatment, lead was the only metal to exhibit significant lower quantity in the **Compost** control. No other significant differences were announced for all other metals data for any fiber treatment or control.

Section 5
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