Stormwater infiltration relative to hydrologic soil group, compost, and vegetation

Rainfall Simulation Experiment 11

Roadside Erosion Control and Management Study

State of California
Department of Transportation
Division of Design
Stormwater Program
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Erosion Control	Compost
Water Quality	Caltrans SSP 20-055 Compost Blanket
Infiltration	Caltrans SSP 20-056 Compost (Incorporate)

Executive Summary

Rainfall simulation experiment 11 was designed to compare stormwater infiltration among four different subsoils of four different Hydrologic Soil Groups (HSG's) treated according to Caltrans Standard Special Provisions (SSPs) for Erosion Control: 20-055 Compost Blanket; 20-056 Compost (Incorporate); and 20-049 Seeding.

The primary goal of RS11 was to ascertain whether incorporated compost and root penetration by seeded native pioneer plants combined to provide statistically significant greater water infiltration compared with the same soil with incorporated compost alone, covered by a compost blanket, or bare without compost or vegetation.

RS11 was designed as a two-factor analysis of variance (ANOVA) for each variable with Hydrologic Soil Group (HSG), and compost application as factors. Factors were HSG (4 levels: A-sandy loam, B-sandy clay loam, C-clay loam, D-clay), Compost (4 levels: None, Compost Blanket, Compost Incorporated, Compost Incorporated and Vegetation). Measured response variables were: Total Infiltration (TI) in mL, Total Sediment (TS) in grams, Suspended Sediment Concentration (SSC) in ppm, and Turbidity in NTUs.

Test boxes measured 6x2x1 ft, constructed of polyvinyl chloride lumber and food-grade plastic. Soils were all from San Luis Obispo County. Bulk density and porosity were measured from dry soil samples and compared with values from construction site soils along SR46 east of Paso Robles. Compost was US Compost Council certified to be heat-sanitized and weed free, with at least 50% of the mix exhibiting particle size less than 1/2" inch according to Caltrans specifications for erosion control. The seed mix consisted 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 during the winter-spring growing season. For the vegetated test boxes, cover was assessed prior to rainfall simulation using a modified Daubenmire percent cover method to ensure that all boxes exhibited at least 80% uniform cover over the soil surface.

All test boxes were set at a 2:1 H:V (50%, 27º) slope during rainfall simulations. Simulated rainfall was delivered by two Norton Ladder-type variable-sweep, pressurized nozzle rainfall simulators. Coefficient of uniformity measured for both simulators was at least 85%. Preliminary data from RS11 simulations showed that twice the 85th percentile storm (0.4 in/hr) generated no measurable runoff, nor infiltration to a depth of 9 inches, in the allotted 112 minutes. An additional 2.0 inches for 1 hour was applied to match the total precipitation amounts applied in previous RS designs that used a 100th percentile storm for San Luis Obispo. This amounted to a total of 2.76 inches of rainfall over 172 minutes, which resulted in runoff, or infiltration to a 9 inch depth, or both, for all hydrologic soil groups. All soils were dry at the time of the experiment to represent an autumn-winter first major storm scenario.

As shown within this experiment, twice the 85th percentile 24-hour rainfall rate and quantity produced no measurable runoff across all treatments. At over 3.5 times the 85th percentile 24-hour total rainfall (2.76 inches compressed into three-hours, a 100th percentile, 500+ year event), the following results emerged for infiltration across the HSG representatives tested:

HSG A Sandy Loam

- Compost Blanket provided no benefit for any measured variable;
- Compost Incorporated (No Veg) and Compost Incorporated + Veg both negatively affected infiltration quantity, but positively affected infiltration time as water that did reach depth did so more rapidly;
- Compost Incorporated + Veg exhibited the best results combining only slight decrease in infiltration quantity with significant decrease in infiltration time;

HSG B Sandy Clay Loam

- Compost Blanket provided significant increase in infiltration quantity, but significant decrease in infiltration time;
- Compost Incorporated (No Veg) produced only slight increase in infiltration quantity, but did not decrease infiltration time;
- Compost Incorporated + Veg exhibited the best results combining significant increase in infiltration quantity with no decrease in already rapid infiltration time;

HSG C Clay Loam

- Compost Blanket and Compost Incorporated (No Veg) provided significant increase in infiltration quantity, but significant decrease in infiltration time;
- Compost Incorporated + Veg exhibited the best results combining significant increase in infiltration quantity with no decrease in already rapid infiltration time;

HSG D Clay

- Compost Blanket and Compost Incorporated (No Veg) provided no significant increase in infiltration quantity, or decrease in infiltration time;
- Compost Incorporated + Veg exhibited the best results combining no decrease in already excellent infiltration quantity with significant decrease in infiltration time.

Across all HSG representatives tested, Compost Incorporated + Veg performed best by either increasing Total Infiltration (TI) while decreasing Infiltration Time (IT), Total Sediment (TS), Suspended Sediment Concentration (SSC), and Turbidity (NTU), or by not adversely affecting already good to excellent performance for these same variables by Bare Soil Controls.

Where appropriate, a likely best-case scenario for both shorter and longer term erosion control and stormwater infiltration is the incorporation of certified compost together with site-appropriate vegetation. Where appropriate and necessary, a certified compost blanket may provide added protection before vegetation has emerged and grown sufficient aerial cover to protect the soil surface from raindrop splash and from overland flow at the soil surface.

Contents

1 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 ten rainfall simulation experiments (Caltrans 2001, 2002, 2004, 2005a, 2005b, 2007a, 2007b, 2010a).

This report presents the design and results of the eleventh rainfall simulation experiment (RS11) completed by this research program.

1.2 Experiment Topic

1.2.1 Goal

The primary goal of RS11 was to ascertain whether incorporated compost and root penetration by seeded native pioneer plants combined to provide statistically significant greater water infiltration compared with the same soil covered by a compost blanket, with compost incorporated, or bare without compost or vegetation.

RS11 was designed to compare stormwater infiltration among four different subsoils of four different Hydrologic Soil Groups (HSG's) treated according to Caltrans Standard Special Provisions (SSPs) for Erosion Control:

- 20-055 Compost Blanket
- 20-056 Compost (Incorporate)
- 20-049 Seeding.

1.2.2 Background

Caltrans has applied to the California State Water Resources Control Board (CSWRCB 2011) for a renewed statewide storm water permit to discharge storm water and permitted non-storm water to waters of the United States under the National Pollutant Discharge Elimination System (NPDES) permit program. As part of proposed compliance requirements, Caltrans would design all storm water BMPs to infiltrate, harvest and re-use, or evapotranspire, all storm water runoff volume generated from a local-site 85th percentile 24-hour storm event.

To meet this general goal, Caltrans would employ a number of Low Impact Develop (LID) principles with the goal of mimicking pre-project hydrology:

- conserve natural areas, to the extent feasible, including existing trees, stream buffer areas, vegetation and soils;

- minimize the impervious footprint of the project;
- minimize disturbances to natural drainages;
- design and construct pervious areas to effectively receive runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slope and other pertinent factors;
- implement landscape and soil-based BMPs such as compost-amended soils, biofiltration strips, and bioretention;
- use climate-appropriate landscaping that minimizes irrigation and runoff, promotes surface infiltration, and minimizes the use of pesticides and fertilizers; and
- design all landscapes to comply with the California Department of Water Resources Water Efficient Landscape Ordinance, or, if applicable, any more stringent local water conservation ordinance.

2 Methods and Materials

2.1 Experimental design

Model

A two-way Analysis of Variance (ANOVA) for each variable with Hydrologic Soil Group representative soil type and Treatment as factors.

	Factor	
Level	**HSG**	**Treatment**
1	A: Sandy Loam	none
2	B: Sandy Clay Loam	Blanket (3in compost on 9in soil)
3	C: Clay Loam	Incorporated (3in compost into 9in soil)
4	D: Clay	Incorporated + Vegetation at > 80% cover

Replication

	HSG				
Treatment	***A***	***B***	***C***	***D***	
none	2	2	2	2	*8*
Compost Blanket	2	2	2	2	*8*
Compost Incorporated (No Veg)	2	2	2	2	*8*
Compost Incorporated + Veg	4	4	4	4	*16*
	10	*10*	*10*	*10*	*40*

Note Regarding Unequal Replication

The RS11 design approved in June 2010 sought to compare a Compost Incorporated + Vegetation treatment *only* with bare soil control, using representative soils of the four HSGs. This design used 16 treatment test boxes [4 soils x 1 treatment x 4 replications], plus 8 control test boxes [4 soils x 1 bare soil control x 2 replications], for a total of 24 test boxes. The Compost Incorporated (No Vegetation) and Compost Blanket treatments were added to provide comparative data using an additional 16 treatment test boxes [4 soils x 2 treatments x 2 replications]. Thus, a total of 40 test boxes were used for RS11. An ANOVA design using 4 replicates for all treatments would have been best, but would have required either 56 test boxes, or a coordinated sequential reuse of test boxes to achieve 56 test box simulations. ANOVA designs using unequal sample sizes are common, especially in field studies. But, heteroscedasticity (inequality of sample variances), a fundamental violation of ANOVA assumptions, is more likely from small and unequal samples.

Measured variables

Variable	**Units**
Total Infiltration (TI)	mL
Infiltration Time to 9 inch Depth (IT)	minutes
Total Sediment (TS)	grams
Suspended Sediment Concentration (SSC)	ppm
Turbidity	NTU

Constants during rainfall simulations

test box size: 6x2x1 ft

test box slope: 2:1 H:V, 50%, 27º

test box aspect: south

2.2 Materials

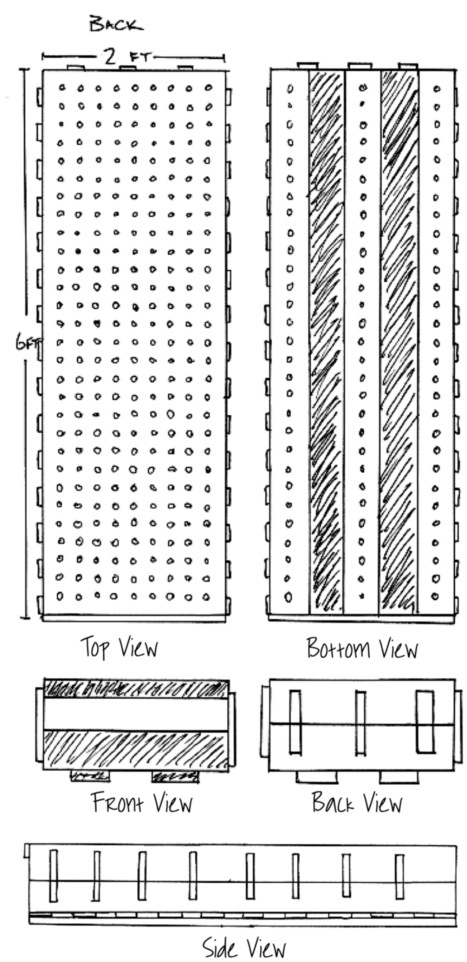
2.2.1 Site set-up

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. Test boxes were set at a 2:1 H:V (50%, 27º) slope during simulations.

2.2.2 Test boxes

Test boxes measured 6x2x1 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.

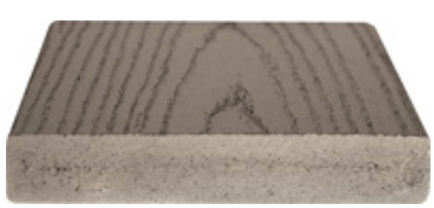


Box Sides:

- 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 types

The USDA recognizes four hydrologic soil groups, or HSGs (A,B,C,D), that, along with land use, management practices, and hydrologic conditions, determine a soil's associated runoff curve number used to estimate direct runoff from rainfall (USDA-NRCS 2007).

Soils were originally assigned to hydrologic soil groups based on measured rainfall, runoff, and infiltrometer data (Musgrave 1955). Now, Hydrologic Soil Groups are determined by three factors: 1) depth to impermeable layer; 2) depth to high water table; 3) K_{sat} for the least transmissive layer.when there is no impermeable layer within 40 inches (100 cm) from the soil surface. Beyond the depth to water or impermeable layer, the soil properties then control the saturated flow of water. Additionally, for an HSG B in the context of road construction, compaction may bump it into group C or D. However, this is difficult to predict because a new k_{sat} valueis required following compaction. HSG's are best identified at a more regional level and specific soil series. The groupings below in **Table 2-1** indicate the condition and expected K_{sat} for each HSG. Note that the soil conditions stated for each HSG are for natural soils with good structure and not post-construction soils compacted to 90%.

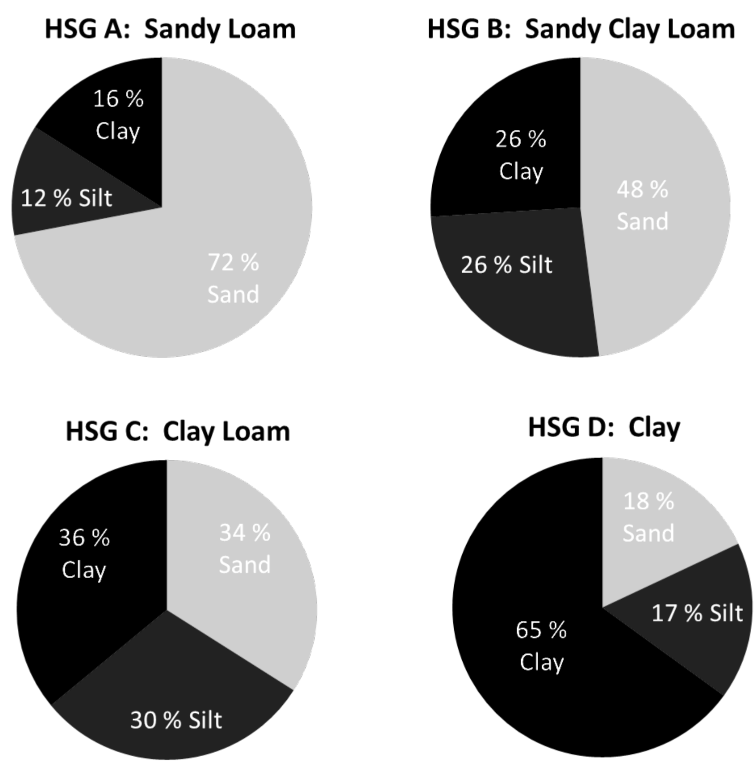
Table 2-1. A synopsis of hydrologic soil group classification

	Hydrologic Soil Group			
	A	**B**	**C**	**D**
Soil Type	loamy sands, sandy loams, loams, silt loams	loams, silt loams, silts, sandy clay loams	clay loams, clays, silty clays, sandy clays	clays, silty clays, sandy clays; .
Underlying Rock	granitic, > 35 % rock fragments	unpredictable	unpredictable	unpredictable
Sand	> 90%	50-90%	< 50%	< 50%
Clay	< 10%	10-20%	20-40%	> 40%
Infiltration in ppt / hr	1.00–8.30	0.50–1.00	0.17–0.27	0.02–0.10
Saturated Hydraulic Conductivity (Ksat)	> 1.42 inches/hour when deep; >5.62 when shallow	0.57 to 1.42 inches/hour when deep; 1.42 to 5.67 inches/hour when shallow	0.06 to 0.57 inches/hour when deep; 0.14 to 1.42 inches/hour when shallow	< 0.06 inches/hour when deep; <0.14 inches/hour when shallow
Runoff potential	low runoff and high infiltration potential when saturated	moderately low runoff and moderately high infiltration potential when saturated	moderately high runoff and moderately low infiltration potential when saturated	high runoff potential and low infiltration when saturated
Erosion potential on slopes when saturated	low to high, if poorly structured	low to moderate	moderate to high	high, owing to water weight; these soils can have high shrink-swell potential and develop deep cracks

Soil groups A and B, high in sand and gravel, have the highest infiltration rates and are typically the best candidate soils for directed infiltration facilities, unless compacted during construction, or through surface traffic. Soil groups C and D, higher in clay, are usually more appropriate for detention basins. Group D includes clay soils with very slow infiltration rate, high shrink-swell potential, high runoff potential; soils in a permanent high water table, and shallow soils over nearly impervious material (Ventura Countywide Stormwater Quality Management Program 2001). All soils with an impermeable layer at less than 20 inches (50 cm) and water table within 24 inches (60 cm) are group D soils

Soils representing one of four Hydrologic Soil Groups (HSGs) were collected from four sites in San Luis Obispo County. Particle size analyses to ascertain soil texture followed the Bouyoucos hydrometer method (Bouyoucos 1936, 1962). Soil was compacted in test boxes to at least 90% (calculated from bulk density), as typically required for construction fill (Caltrans 2002).

HSG	Texture	% Sand	% Silt	% Clay	X_Longitude	Y_Latitude	Site
A	sandy loam	72	12	16	120^{0} 32.9'	35^{0} 25.3'	roadside
B	sandy clay loam	48	26	26	120^{0} 40.6'	35^{0} 18.6'	old compost pile
C	clay loam	34	30	36	120^{0} 40.5'	35^{0} 18.6'	agricultural field
D	clay	18	17	65	120^{0} 39.5'	35^{0} 20.1'	canyon slope



2.2.4 Test soil bulk density

Bulk densities were not measured in the boxes prior to the simulation due to the effect that a removed sample would have on the topography of the soil surface and on the associated removal of vegetation in the vegetated boxes. Bulk density measurement following the simulation would prove erroneous as an indicator for pre-storm conditions as the soil structure is destroyed and soil is translocated. Changes in bulk density in the non-vegetated boxes would not be observed to the same extent in vegetated and natural settings due to the presence of organic and inorganic cementation agents, roots, etc., that stabilize soil aggregates. Mixing and preparation of test soils removes much of these agents allowing water to easily destroy any soil structural units. This process will decrease bulk density, increase total pore space, and increase infiltration rates.

This total pore space can be related to the amount of water a soil could hold or conversely the degree to which a soil is compacted and pore space is reduced (Lal and Shukla 2004). Ideally, a soil's bulk density in natural conditions without excess compaction is simply determined by texture. Sandy soils have an average bulk density of 1.60 g/cm3, silty soils are about 1.40 g/cm3, loamy soils are about 1.33 g/cm3, and clayey soils have an average bulk density of 1.10 g/cm3 (USDA NRCS 2008). As stated before the erodibility factors for these soils are 0.05 to 0.2, 0.45 to 0.65, 0.25 to 0.45, and 0.05 to 0.15 respectively (USDA RUSLE 2001). These K-factors do not directly correlate with the bulk densities of the soils due to variances in aggregate stability, soil texture, clay type, carbonates, humus content, fungi, roots, individual pore size, and water retention. To accurately relate bulk density to soil erodibility or even soil hydraulic conductivity, the correlation should be made within similar textural and biochemical classes so as to not introduce variability based on factors outside of pore compaction and bulk density. Reported data shows that hydraulic conductivity only correlates with bulk density under the confines of similar textural classes and type (Chu-Agor et al. 2008).

2.2.5 Test soil compaction

The relative compaction of a soil will vary depending on variety of factors. Organic matter content, moisture content, texture, vegetation and other factors affect how much a soil can be compacted. These factors typically vary markedly even within a few feet. Thus, relative compaction is a poor meausre of bulk density, or potential erodibility. No standard method exists for measuring relative soil compaction in a roadside erosion control setting. Although Caltrans uses California Test 216 (Caltrans 2005c) to measure relative compaction as the ratio of the in-place wet density of a soil or aggregate to the test maximum wet density of the same soil or aggregate when compacted, for RS11 a static cone penetrometer measuring psi was used because it provides an easier way to rapidly make multiple samples under varied conditions. Tests using cotton plants showed that root penetration ceased at 300 psi (Penn State ARCE 2002).

2.2.5.1 Field reference values

Reference values were obtained from two sites along SR46 east of Paso Robles in San Luis Obispo County. The purpose was to compare relative compaction of actual Caltrans construction sites one year post-construction and newly compacted to the test boxes used for RS11. A standard depth of 4 inches was used for each sample taken to compensate for areas with shallow soils or laboratory conditions.

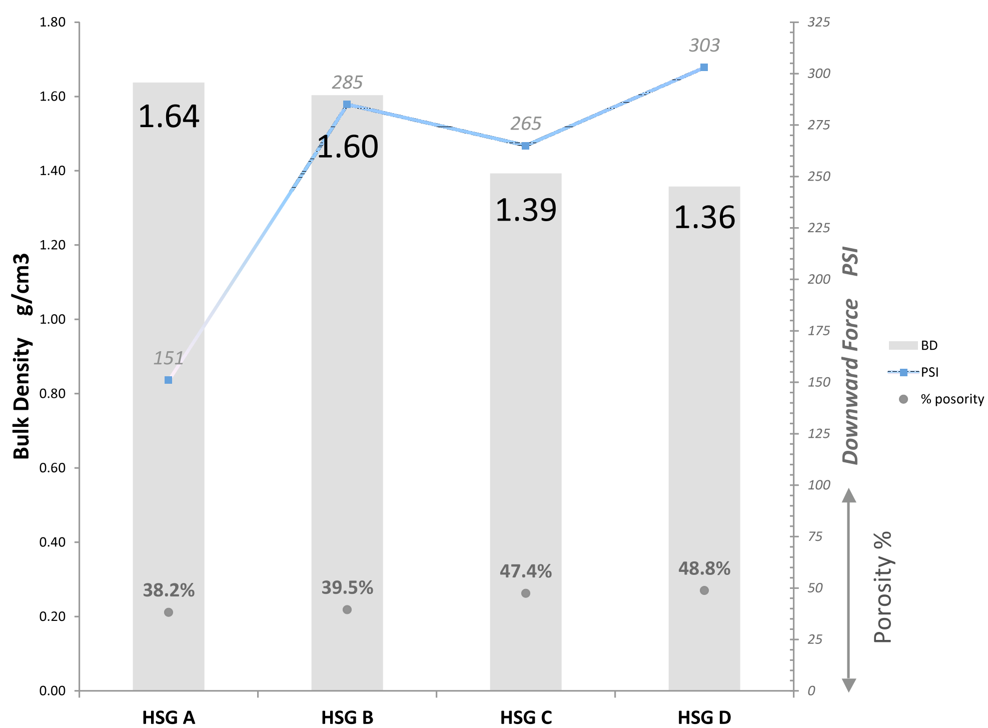
Site 1 was a two-year-old construction site that has revegetated to 60-75 % cover over the past year and has evidence of ground squirrel activity. The average psi reading obtained was 199.9 ± 78.4 owing to root channels and more organic matter in the soil. However, we had trouble taking accurate readings due to the stonyness of the soil. These stony areas will impede infiltration and give a false higher representation of the bulk density and relative compaction of the soil and a lower soil porosity.

Site 2 was a newly tractor-compacted large slope without vegetation. Compaction across this slope varied such that within a one-foot radius the maximum downward force reading could vary by 200 psi, demonstrating that uniform compaction is unlikely owing to micro topography along the slope. The average PSI reading obtained was 432.9 ± 105.

2.2.5.2 Test box values

Each of the four HSG soils were packed dry into test boxes. Four samples were obtained to measure bulk density using the ring method, and four samples were obtained to measure compaction using a static cone penetrometer. Results show bulk density decreasing as the soils become finer. The decrease in bulk density from HSG A to HSG B is less than expected, but the PSI data explains that. Since HSG B was much more compactable, the bulk density was greater.

HSG	Sample	BD	% Posority	PSI
A	1	1.72	35.22	152
A	2	1.59	39.93	140
A	3	1.67	36.91	136
A	4	1.57	40.78	176
A Average		***1.64***	***38.21***	***151***
B	1	1.65	37.60	294
B	2	1.56	41.31	320
B	3	1.59	39.93	296
B	4	1.61	39.08	230
B Average		***1.60***	***39.48***	***285***
C	1	1.39	47.66	234
C	2	1.40	47.19	286
C	3	1.41	46.66	294



2.2.6 Compost

Compost was from the Engel & Gray Regional Compost Facility in Santa Maria, California. Compost was composed of agricultural waste, food waste, and bio-solids, and US Compost Council certified to be heat-sanitized and weed free, with at least 50% of the mix exhibiting particle size less than 1/2" inch according to Caltrans specifications for erosion control.

2.2.7 Test box preparation

All test boxes were filled with approximately 10368 cubic inches (= 72 in *L* x 24 in *W* x 6 in *D*, = 6 cubic feet, = 0.222 cubic yard, = 0.167 cubic meter) of soil, or soil plus compost. Both the Compost Blanket and Compost Incorporated treatments used the same ratio of 3 parts soil (4.5 cubic feet) to 1 part compost (1.5 cubic feet).

Bare Soil Control
Test boxes were filled to an even 6 inch depth with a nearly homogeneous subsample from stockpiles of each HSG representative test soil, then compacted to near 90%.

Compost Blanket Treatment
Test boxes were with filled with 4.5 cubic feet of soil to an even 4.5 inch depth, then compacted to near 90%. On top of the soil, a 1.5 cubic feet of compost was added forming a 1.5 inch layer.

Compost Incorporated Treatment
Test boxes were with filled with a homogeneous mixture of test soil and compost to an even 6 inch depth, then compacted to near 90%.

2.2.8 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 during the winter-spring growing season.

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	Forb	Spanish Lotus	*Lotus purshianus*	4	8
				36	**180**

2.2.9 Vegetation cover

For the vegetated test boxes, cover was assessed prior to rainfall simulation using a modified Daubenmire percent cover method (Interagency Technical Team 1996) to ensure that all boxes exhibited at least 80% uniform cover over the soil surface. Over all test boxes, cover at 90 days from seeding was largely native Small Fescue, *Festuca* [*Vulpia*] *reflexa sensu stricto* (sold as *Festuca* [*Vulpia*] *microstachys sensu amplo*), with lesser amounts of the other seeded species.

2.2.10 Simulated rainfall

2.2.10.1 Simulators and uniformity tests

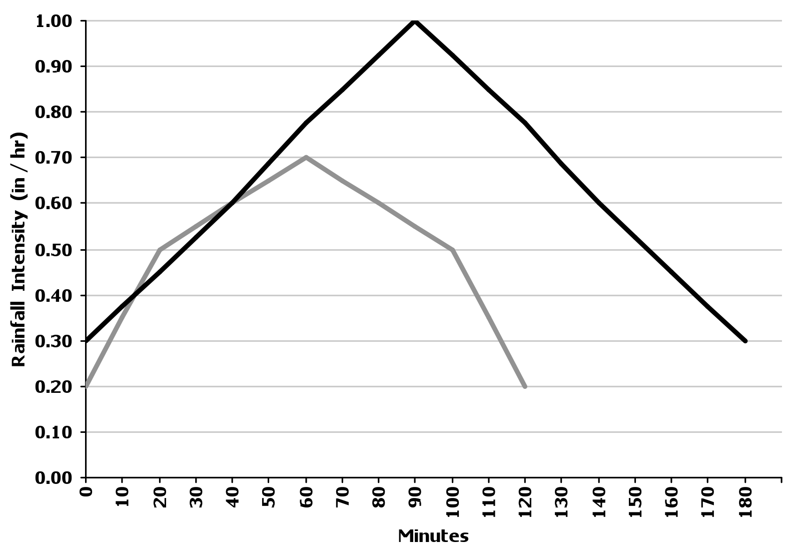
Simulated rainfall was delivered by two Norton Ladder-type variable sweep, pressurized nozzle rainfall simulators developed at the USDA Erosion Research Center at Purdue University and manufactured by Advanced Design and Machine, Clarks Hill, IN.

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 at least 85%.

2.2.10.2 Designed storms

Past rainfall simulation (Caltrans 2001, 2002, 2004, 2005a, 2005b, 2007a, 2010a) and overland flow (Caltrans 2007b) experiments, involving compost blankets or incorporated compost, demonstrated significant reductions in Total Runoff, Total Sediment, and Turbidity, along with increased Electrical Conductivity and acidification.

Previous rainfall simulations used designed storms intended to mimic 10-year to 50-year probability storm events to test treatment effectiveness under near worst-case scenarios. These designed storms used intensity values (inches per hour) exceeding the 0.19 inch/hour 85th percentile 24-hour storm event for Cal Poly State University, San Luis Obispo (from BasinSizer 2007), where these simulations were run.



RS11 intended to simulate a 0.19 inch/hour 85th percentile 24-hour storm event of 0.75 inches total for Cal Poly State University, San Luis Obispo. However, the lowest intensity possible from the Norton Simulators available is 0.4 inch/hour, twice the 85th percentile intensity equal to the Excess Volumetric Rate, as designated in the statewide discharge permit guidelines (CSWRCB 2011).

Preliminary data from RS11 simulations showed that twice the 85th percentile storm (0.4 in/hr) generated no measurable runoff, nor infiltration to a depth of 9 inches, in the allotted 112 minutes. An additional 2.0 inches for 1 hour was applied to match the total precipitation amounts applied in previous RS designs that used a 100th percentile storm for San Luis Obispo (BasinSizer 2007). This amounted to a total of 2.76 inches of rainfall over 172 minutes, which resulted in runoff, or infiltration to a 9 inch depth, or both, for all hydrologic soil groups.

Thus, simulated rainfall was applied on a pair of test boxes at the following rates and durations per rain event (BasinSizer 2007 data for San Luis Obispo).

Storm Percentile	Safety Factor	Rainfall Rate	Duration	Rainfall Total			
CASQA	CASQA	inches / hr	minutes	inches	gal / ft^2	gal / test box	mL / test box
85th	2.0	0.4	112	0.76	0.47	5.69	21522
100th	2.0	2.0	60	2.00	1.25	14.96	56636
			172	2.76	1.72	20.65	78157

? gal per ft^2 = 1 in of rain

area:	1ft^2 = 12in L x 12in W = 144 in^2
volume:	144 in^2 x 1 in H = 144 in^3
constant:	231 in^3/gal water
gal per ft^2:	144 in^3 ÷ 231 in^3/gal = **0.6234** gal

All locations exhibiting 24-hr Rainfall Intensities ≈ 0.4 inch per hour are in Southern California, in lower to mid-montane elevations of the Santa Lucia, Santa Ynez, Santa Monica, San Gabriel, San Bernardino, and Cuyamaca Mountains, and rank as 90th or 95th percentile storm events there.

Station	ID	Percentile	Intensity inch/hr
BOULDER CREEK LOCAT RAN	1005	95	0.39
CARPINTERIA RESERVOIR	1540	95	0.39
CRESTLINE FIRE STATION	2164	95	0.40
GIBRALTAR DAM 2	3402	90	0.39
LECHUZA PTRL ST FC352B	4867	95	0.39
NEWHALL S FC32CE	6162	95	0.39
PINE MOUNTAIN INN	6910	95	0.40
RUNNING SPRINGS 1 E	7600	95	0.40
SAN GABRIEL DAM FC425B	7779	95	0.39
SAN MARCOS PASS	7859	90	0.39
SANTA MARGARITA BOOST	7933	95	0.40

To place these Cal Poly State University rates into a statewide context, **Figure 1** shows locations in California of 85th Percentile 24-hr Rainfall Intensity ≥ 0.19 inch per hour (BasinSizer 2007). **Figure 2** shows average rainfall intensity of 85th Percentile 24-hr storm events (BasinSizer 2007).

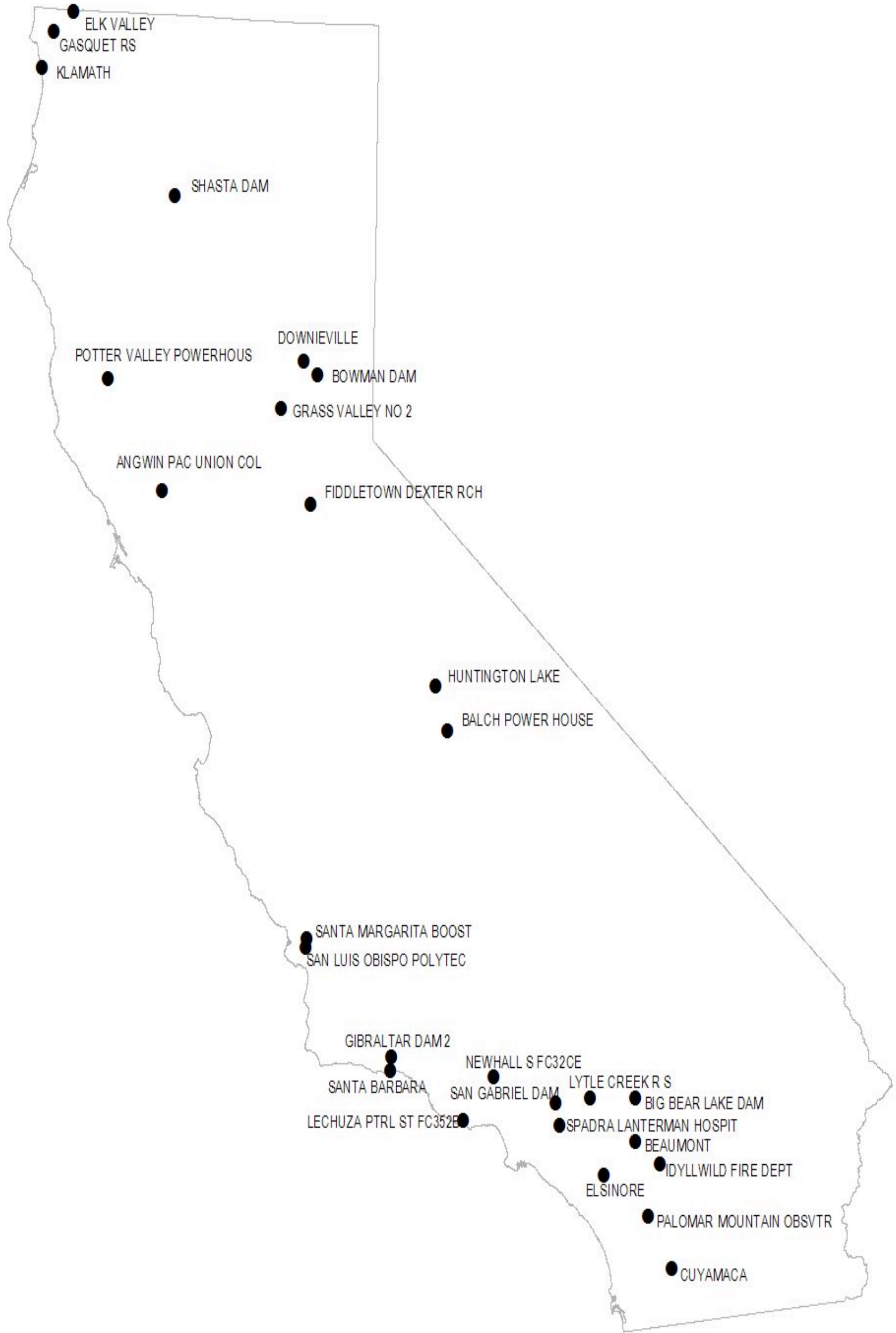


Figure 2-1. Locations of 85th Percentile 24-hr Rainfall Intensity ≥ 0.19 inch per hour.

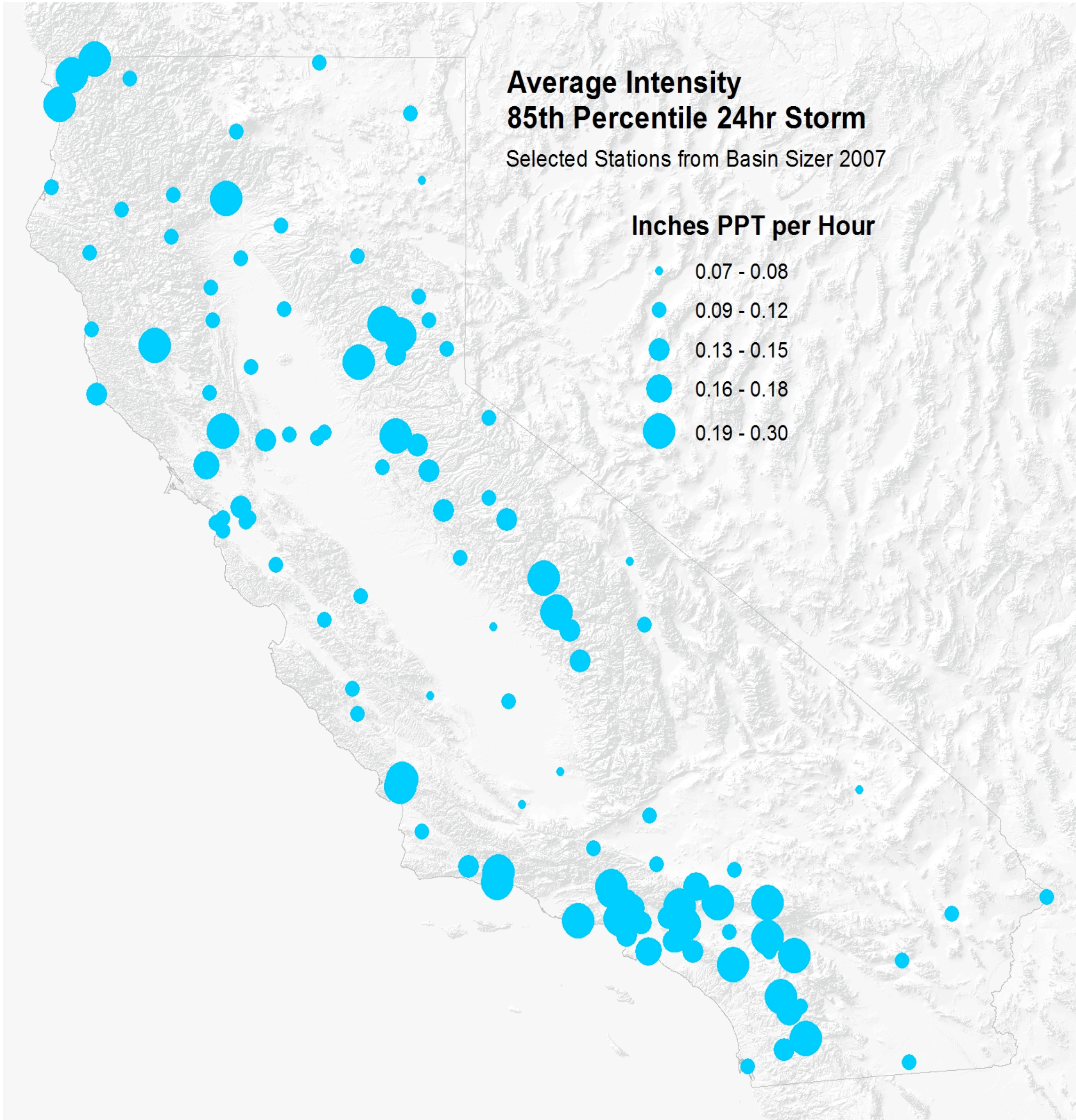


Figure 2-2. Average Intensity of 85th Percentile 24hr Storm Events in California.

2.3 Data collection and analyses

2.3.1 Variables measured

Total Infiltration (TI) in mL

Infiltration is the flow of water into soil pores or small openings owing to gravity and capillary action even against the force of gravity. Soil texture, soil structure, vegetation cover, root penetration, pre-existing water in a soil, soil temperature, and rainfall intensity are all factors affecting infiltration rate and total infiltration. The amount of surface water that exceeds a soil's infiltration rate and depression storage constitute Total Runoff. Total Infiltration (mL) is calculated by subtracting Total Runoff (mL) from a known quantity of water applied during a rainfall event.

Infiltration Time to 9 inch Depth (IT) in minutes

How quickly stormwater infiltrates a column of soil to depth is critical for both runoff reduction from slopes, and for adequate sizing of stormwater retention basins to prevent or slow spillage beyond. For the test boxes, Infiltration Time to 9 inch Depth (IT) is measured by timing when water first begins to appear and drip (breakthrough) from the bottom of the 9 inch soil layer in each test box. For RS11, each simulation event required 172 minutes, so the time to breakthrough was recorded. Observations were not continued beyond 172 minutes.

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.

Suspended Sediment Concentration (SSC) in ppm

High suspended solid levels affect the clarity of water, causing decreased sunlight penetration, decreased aquatic plant growth, and decreased oxygen available to fish and other aquatic animals. Suspended Sediment Concentration (SSC) is measured using American Society for Testing and Materials D3977-97 (2007) Standard Test Methods for Determining Sediment Concentration in Water Samples (ASTM 2007), now preferred over Total Suspended Solids (TSS) analysis (EPA Method 160. 2) owing to demonstrated greater accuracy (Gray at al. 2000), especially for runoff from the 12ft^2 test boxes where the relatively small sizes of entire samples (~0. 5L to 3. 5L) lend themselves to analysis in their entirety.

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.

2.3.2 Runoff data collection

Total Runoff was quantified and analysed for sediment load. 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 $AlCl_3$, 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 Runoff was calculated by subtracting the sediment and container weight from the original total collection weight. Total Infiltration was calculated by subtracting Total Runoff from the total rainfall applied during each rainfall simulator event. Total Sediment included the evaporated sediment weight. Suspended Sediment Concentration (mg/L converted to ppm) was calculated from the Total Runoff and Total Sediment values.

2.3.3 Runoff data analyses

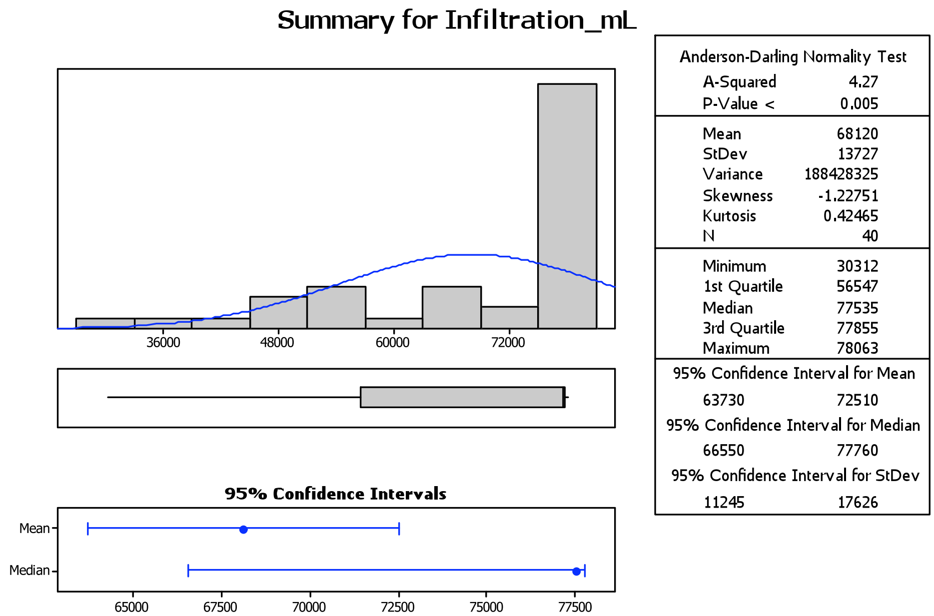
Water quality variables were analysed using Fixed Factor Analysis of Variance (ANOVA) after a natural log (*ln*) normalization transformation as an attempt to achieve homogeneity of variances for all responses, a required assumption of any ANOVA (Zar 1984). Post comparisons of treatment means used Bonferroni, Dunnet and Sidak methods**.**

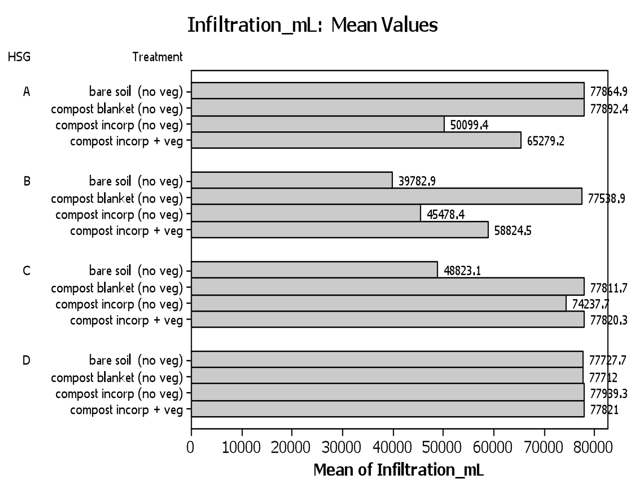
3 Results and Analyses

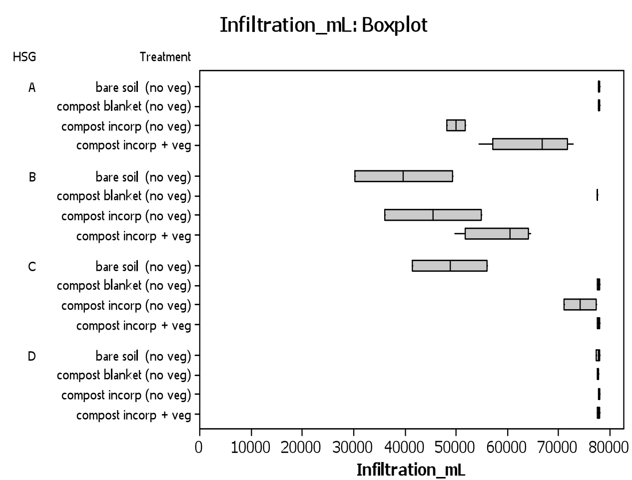
3.1 Total Infiltration (TI)

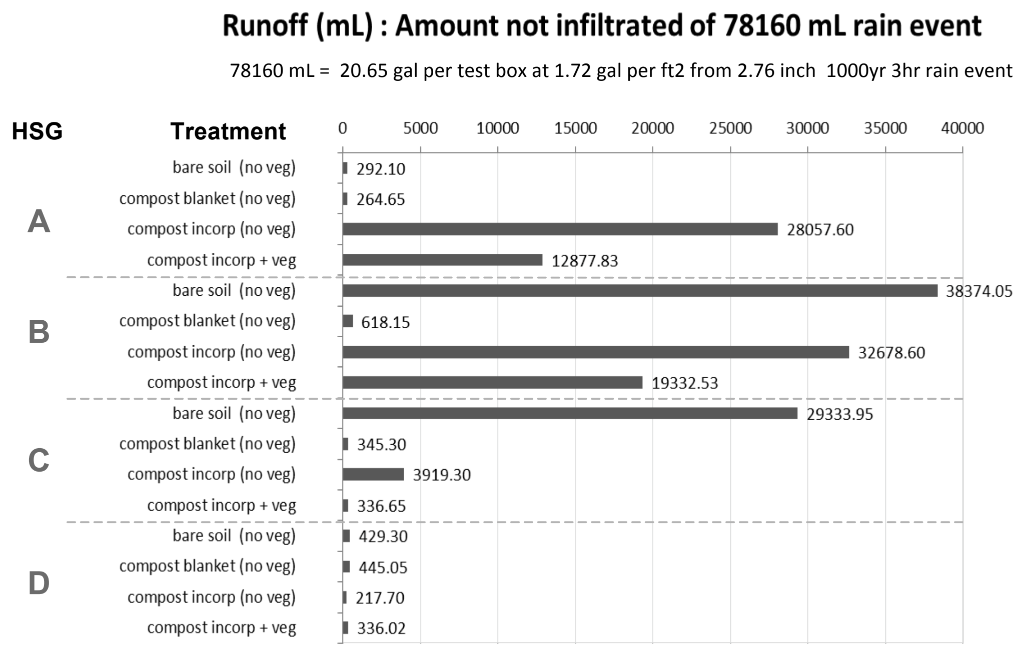
3.1.1 Descriptive Statistics

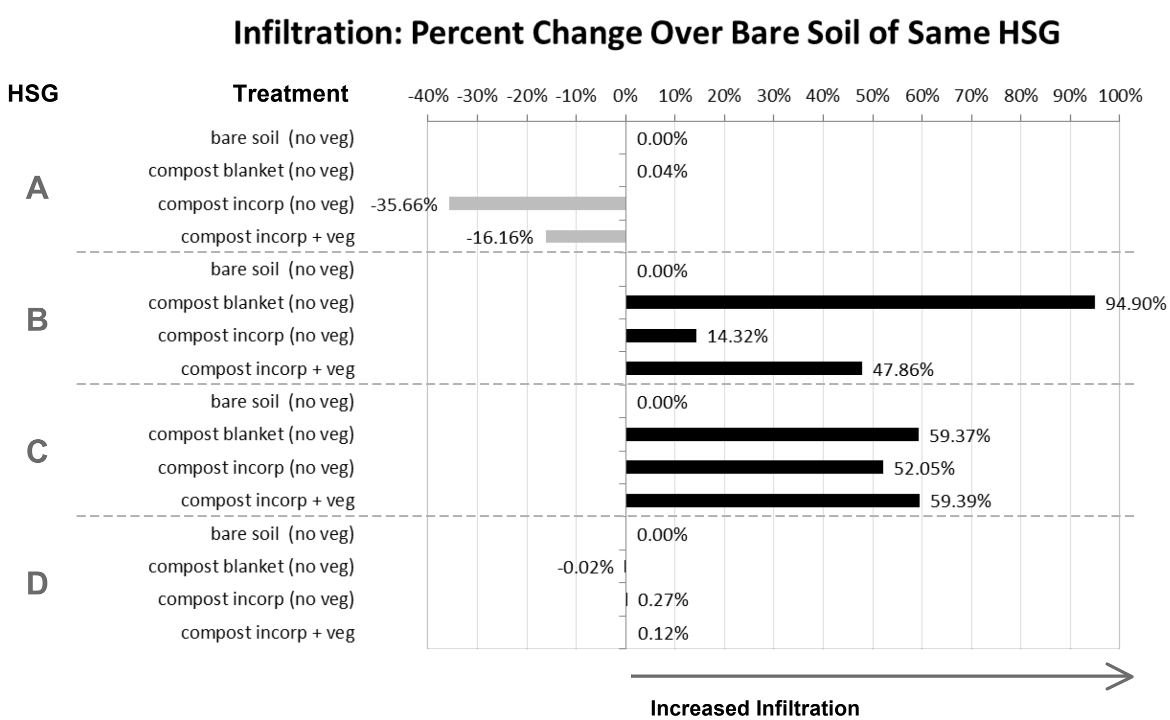
Total Infiltration (TI) data exhibit a non-normal (Anderson-Darling $p = < 0.005$), bimodal distribution with the highest values mostly from the Compost Blanket treatments across all HSGs, but this pattern is punctuated with Compost Incorporated treatments, and even bare soil on HSG A.








Runoff (mL) : Amount not infiltrated of 78160 mL rain event
78160 mL = 20.65 gal per test box at 1.72 gal per ft2 from 2.76 inch 1000yr 3hr rain event
HSG
Treatment
0
5000
10000
15000
20000
25000
30000
35000
40000
A
bare soil (no veg) 292.10
compost blanket (no veg) 264.65
compost incorp (no veg) 28057.60
compost incorp + veg 12877.83
B
bare soil (no veg) 38374.05
compost blanket (no veg) 618.15
compost incorp (no veg) 32678.60
compost incorp + veg 19332.53
C
bare soil (no veg) 29333.95
compost blanket (no veg) 345.30
compost incorp (no veg) 3919.30
compost incorp + veg 336.65
D
bare soil (no veg) 429.30
compost blanket (no veg) 445.05
compost incorp (no veg) 217.70
compost incorp + veg 336.02


Infiltration: Percent Change Over Bare Soil of Same HSG
HSG
Treatment
-40% -30% -20% -10% 0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
A
bare soil (no veg) 0.00%
compost blanket (no veg) 0.04%
compost incorp (no veg) -35.66%
compost incorp + veg -16.16%
B
bare soil (no veg) 0.00%
compost blanket (no veg) 94.90%
compost incorp (no veg) 14.32%
compost incorp + veg 47.86%
C
bare soil (no veg) 0.00%
compost blanket (no veg) 59.37%
compost incorp (no veg) 52.05%
compost incorp + veg 59.39%
D
bare soil (no veg) 0.00%
compost blanket (no veg) -0.02%
compost incorp (no veg) 0.27%
compost incorp + veg 0.12%
Increased Infiltration

3.1.2 Homogeneity of Variances

Bartlett's and Levene's Tests both produce significant *p* values, thus, homogeneity of variances is be rejected and a basic assumption of ANOVA is violated likely owing to the small sample sizes.

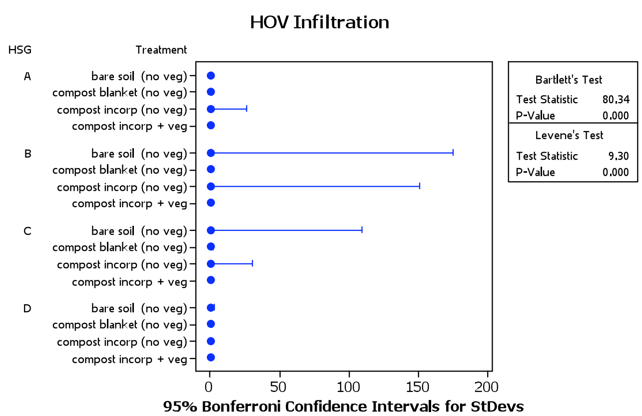
Test for Equal Variances: Infiltration_In versus HSG, Treatment

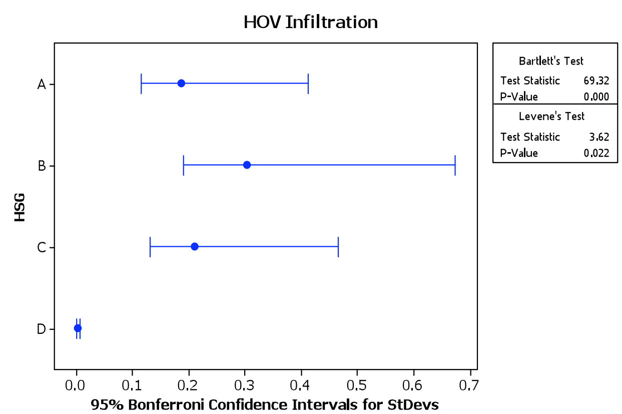
95% Bonferroni confidence intervals for standard deviations

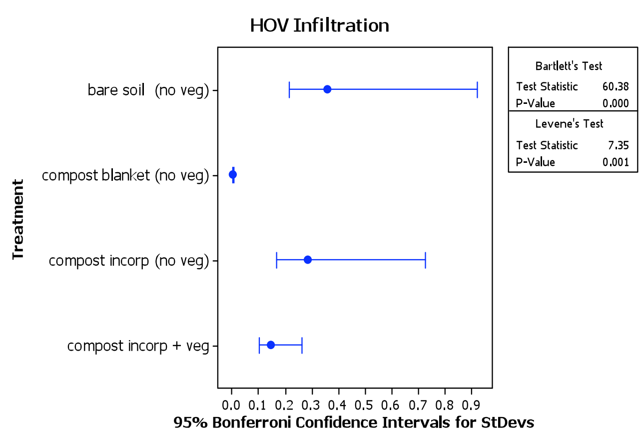
HSG	Treatment	N	Lower	StDev	Upper
A	bare soil (no veg)	2	0.000477	0.001509	0.771
A	compost blanket (no veg)	2	0.000941	0.002975	1.519
A	compost incorp (no veg)	2	0.016151	0.051084	26.086
A	compost incorp + veg	4	0.055687	0.125843	1.204
B	bare soil (no veg)	2	0.108536	0.343280	175.295
B	compost blanket (no veg)	2	0.000169	0.000535	0.273
B	compost incorp (no veg)	2	0.093285	0.295042	150.662
B	compost incorp + veg	4	0.052295	0.118178	1.131
C	bare soil (no veg)	2	0.067586	0.213762	109.157
C	compost blanket (no veg)	2	0.001446	0.004575	2.336
C	compost incorp (no veg)	2	0.018659	0.059016	30.136
C	compost incorp + veg	4	0.001120	0.002530	0.024
D	bare soil (no veg)	2	0.001910	0.006042	3.086
D	compost blanket (no veg)	2	0.000554	0.001753	0.895
D	compost incorp (no veg)	2	0.000118	0.000374	0.191
D	compost incorp + veg	4	0.001054	0.002382	0.023

Bartlett's Test (Normal Distribution)
Test statistic = 80.34, p-value = 0.000

Levene's Test (Any Continuous Distribution)
Test statistic = 9.30, p-value = 0.000







3.1.3 Analysis of Variance

Both HSG and Treatment main effects, and their interaction, are significant at $p < 0.5$. R-Squared explains about 85% of the variation predicted by the model factors.

3.1.3.1 Main Effects

Main Effects plots and Multiple Comparison Tests show that

- HSGs C (high) and D (highest) are significantly different from HSGs A (mean) and B (lowest).
- Compost Blanket (highest) and Compost Incorporated + Veg (high) are significantly different from Compost Incorporated (low) and Bare (lowest).

3.1.3.2 Interactions

Interaction plots and Multiple Comparison Tests show that

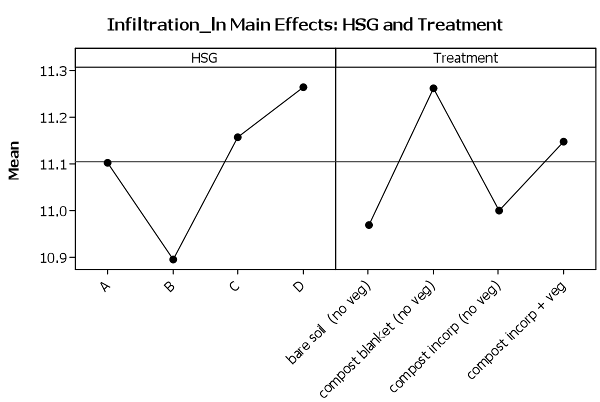
- Overall interaction between HSG and Compost application is significant.
- Compost Blanket increases infiltration significantly on HSGs A, B, and C.
- Compost Incorporated increases infiltration significantly on HSG C.
- Compost Incorporated + Veg increases infiltration significantly on HSGs B and C.

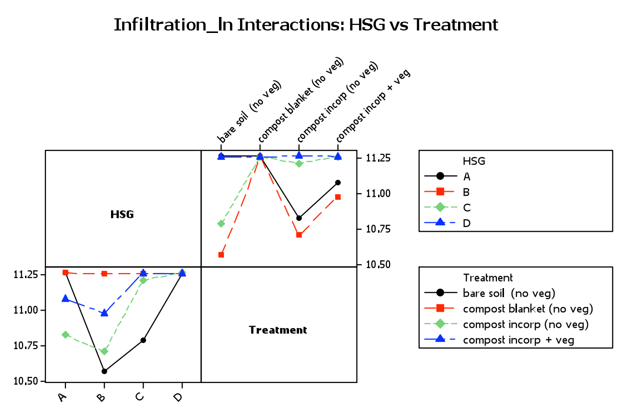
Analysis of Variance for Total Infiltration, using Adjusted SS for Tests

Factor	Type	Levels	Values
HSG	fixed	4	A, B, C, D
Treatment	fixed	4	bare soil (no veg), compost blanket (no veg), compost incorp (no veg), compost incorp + veg

Source	DF	Seq SS	Adj SS	Adj MS	F	P
HSG	3	0.71166	0.70893	0.23631	16.38	0.000
Treatment	3	0.45953	0.45953	0.15318	10.62	0.000
HSG*Treatment	9	0.74042	0.74042	0.08227	5.70	0.000
Error	24	0.34619	0.34619	0.01442		
Total	39	2.25780				

S = 0.120103 R-Sq = 84.67% R-Sq(adj) = 75.08%





3.1.3.3 Multiple Comparisons

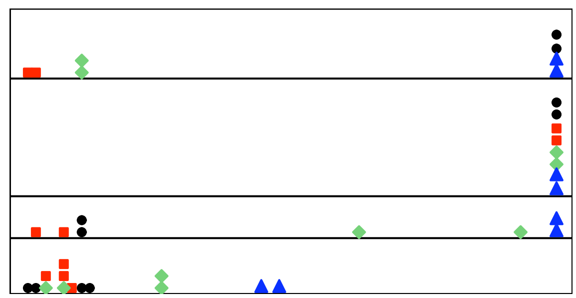
Both Compost Blanket and Compost Incorporated + Veg increase infiltration significantly more than the Bare Soil control.

```
Grouping Information Using Bonferroni Method and 95.0% Confidence

Treatment                      N  Mean  Grouping
bare soil  (no veg) (control)  8  11.0  A
compost incorp (no veg)        8  11.0  A
compost incorp + veg          16  11.1
compost blanket (no veg)       8  11.3


Bonferroni 95.0% Simultaneous Confidence Intervals
Response Variable Infiltration
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

Treatment                   Lower   Center   Upper
compost blanket (no veg)   0.1390  0.29353  0.4481
compost incorp (no veg)   -0.1215  0.03301  0.1876
compost incorp + veg       0.0441  0.17797  0.3118

Treatment                 --------+---------+---------+--------
compost blanket (no veg)                   (--------*---------)
compost incorp (no veg)   (---------*---------)
compost incorp + veg                  (-------*-------)
                          --------+---------+---------+--------
                               0.00      0.16      0.32

Bonferroni Simultaneous Tests
Response Variable Infiltration
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

                          Difference       SE of           Adjusted
Treatment                   of Means  Difference  T-Value   P-Value
compost blanket (no veg)     0.29353     0.06005   4.8880    0.0002 *
compost incorp + veg         0.17797     0.05201   3.4221    0.0067 *
compost incorp (no veg)      0.03301     0.06005   0.5498    1.0000

Grouping Information Using Dunnett Method and 95.0% Confidence

Treatment                      N  Mean  Grouping
bare soil  (no veg) (control)  8  11.0  A
compost incorp (no veg)        8  11.0  A
compost incorp + veg          16  11.1
compost blanket (no veg)       8  11.3


Dunnett 95.0% Simultaneous Confidence Intervals
Response Variable Infiltration
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

Treatment                   Lower   Center   Upper
compost blanket (no veg)   0.1438  0.29353  0.4433
compost incorp (no veg)   -0.1167  0.03301  0.1827
compost incorp + veg       0.0483  0.17797  0.3076

Treatment                 -------+---------+---------+---------
compost blanket (no veg)                  (--------*---------)
compost incorp (no veg)   (--------*--------)
compost incorp + veg                 (-------*-------)
                          -------+---------+---------+---------
                              0.00      0.16      0.32


Dunnett Simultaneous Tests
Response Variable Infiltration
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

                          Difference       SE of           Adjusted
Treatment                   of Means  Difference  T-Value   P-Value
compost blanket (no veg)     0.29353     0.06005   4.8880    0.0002 *
compost incorp + veg         0.17797     0.05201   3.4221    0.0060 *
compost incorp (no veg)      0.03301     0.06005   0.5498    0.8964
```

3.2 Infiltration Time (IT)

3.2.1 Descriptive Statistics

Infiltration Time to 9 inch Depth (IT) data exhibit a bimodal non-normal (Anderson-Darling $p = < 0.005$), distribution with the values skewed toward the maximum 172 minute time by HSG A and D Bare Soil Controls and all eight Compost Blanket treatments across all HSGs; the Compost Incorporated (No Veg) treatment on HSG D also ran the maximum time with no breakthrough. Observations were not continued past 172 minutes so actual breakthrough times for each replicate are not available.

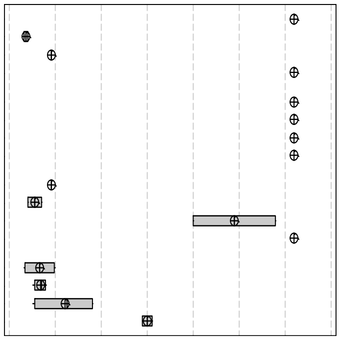


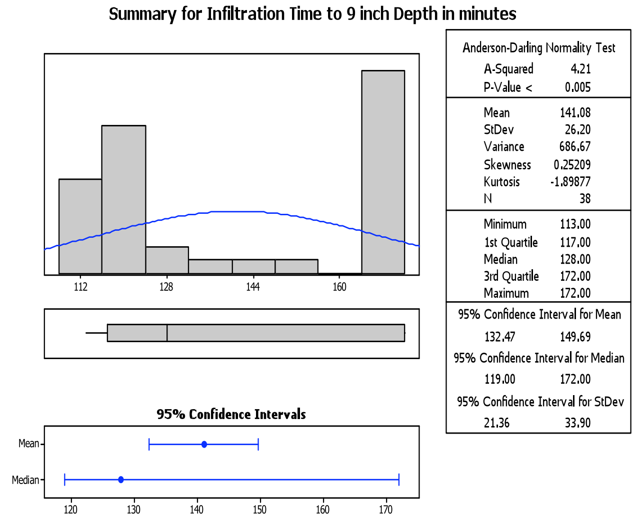
Treatment by HSG

HSG	Treatment	Minutes
A	Bare Soil Control	172
A	Bare Soil Control	172
A	Compost Blanket (No Veg)	172
A	Compost Blanket (No Veg)	172
A	Compost Incorporated (No Veg)	119
A	Compost Incorporated (No Veg)	119
A	Compost Incorporated + Veg	119
A	Compost Incorporated + Veg	113
A	Compost Incorporated + Veg	114
A	Compost Incorporated + Veg	120
B	Bare Soil Control	114
B	Bare Soil Control	113
B	Compost Blanket (No Veg)	172
B	Compost Blanket (No Veg)	172
B	Compost Incorporated (No Veg)	114
B	Compost Incorporated (No Veg)	117
B	Compost Incorporated + Veg	117
B	Compost Incorporated + Veg	117
B	Compost Incorporated + Veg	115
B	Compost Incorporated + Veg	118
C	Bare Soil Control	119
C	Bare Soil Control	119
C	Compost Blanket (No Veg)	172
C	Compost Blanket (No Veg)	172
C	Compost Incorporated (No Veg)	168
C	Compost Incorporated (No Veg)	150
C	Compost Incorporated + Veg	115
C	Compost Incorporated + Veg	117
C	Compost Incorporated + Veg	128
C	Compost Incorporated + Veg	128
D	Bare Soil Control	172
D	Bare Soil Control	172
D	Compost Blanket (No Veg)	172
D	Compost Blanket (No Veg)	172
D	Compost Incorporated (No Veg)	172
D	Compost Incorporated (No Veg)	172
D	Compost Incorporated + Veg	139
D	Compost Incorporated + Veg	141
D	Compost Incorporated + Veg	*
D	Compost Incorporated + Veg	*

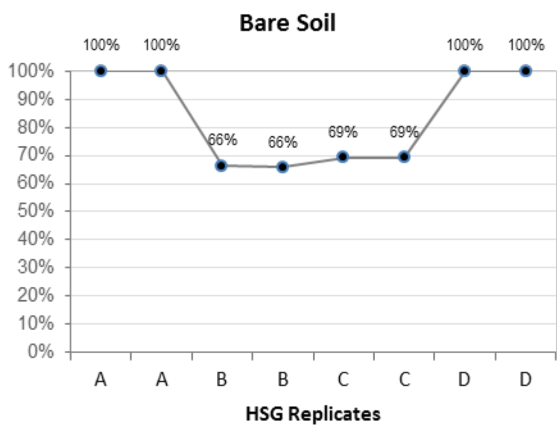
HSG by Treatment

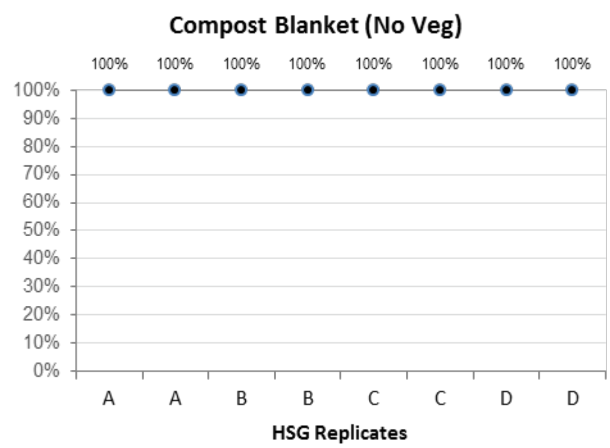
Treatment	HSG	Minutes
Bare Soil Control	A	172
Bare Soil Control	A	172
Bare Soil Control	B	113
Bare Soil Control	B	114
Bare Soil Control	C	119
Bare Soil Control	C	119
Bare Soil Control	D	172
Bare Soil Control	D	172
Compost Blanket (No Veg)	A	172
Compost Blanket (No Veg)	A	172
Compost Blanket (No Veg)	B	172
Compost Blanket (No Veg)	B	172
Compost Blanket (No Veg)	C	172
Compost Blanket (No Veg)	C	172
Compost Blanket (No Veg)	D	172
Compost Blanket (No Veg)	D	172
Compost Incorporated (No Veg)	A	119
Compost Incorporated (No Veg)	A	119
Compost Incorporated (No Veg)	B	114
Compost Incorporated (No Veg)	B	117
Compost Incorporated (No Veg)	C	150
Compost Incorporated (No Veg)	C	168
Compost Incorporated (No Veg)	D	172
Compost Incorporated (No Veg)	D	172
Compost Incorporated + Veg	A	113
Compost Incorporated + Veg	A	114
Compost Incorporated + Veg	A	119
Compost Incorporated + Veg	A	120
Compost Incorporated + Veg	B	115
Compost Incorporated + Veg	B	117
Compost Incorporated + Veg	B	117
Compost Incorporated + Veg	B	118
Compost Incorporated + Veg	C	115
Compost Incorporated + Veg	C	117
Compost Incorporated + Veg	C	128
Compost Incorporated + Veg	C	128
Compost Incorporated + Veg	D	139
Compost Incorporated + Veg	D	141
Compost Incorporated + Veg	D	*
Compost Incorporated + Veg	D	*

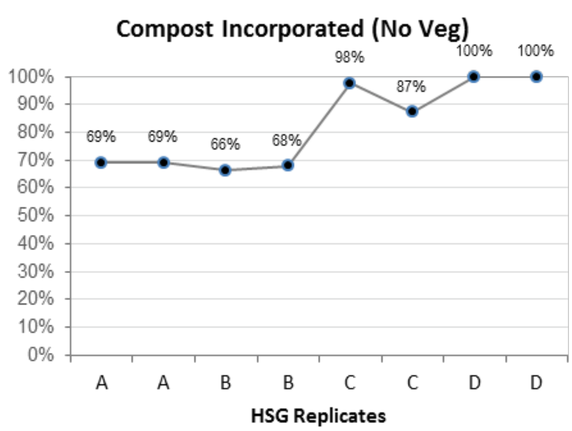


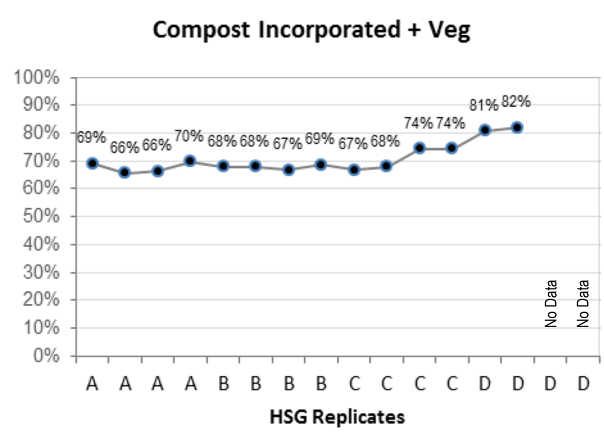


Breakthrough Time Values as Percentages of Total 172 minute simulation









3.2.2 Homogeneity of Variances

At $p < 0.5$, Bartlett's Test is nearly significant, and Levene's Test is significant; thus, homogeneity of variances is rejected and a basic assumption of ANOVA is violated likely owing to the small sample sizes and strong departure from-normality.

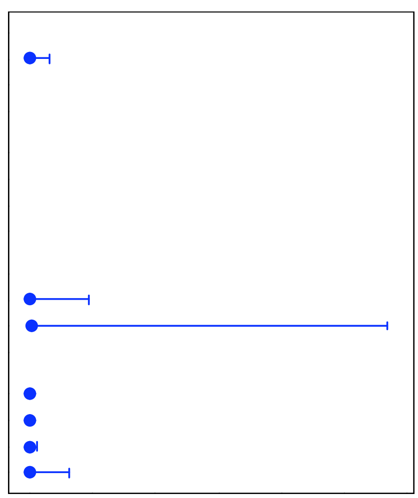
Test for Equal Variances: Minutes versus Treatment, HSG

95% Bonferroni confidence intervals for standard deviations

Treatment	HSG	N	Lower	StDev	Upper
Bare Soil Control	A	2	*	0.0000	*
Bare Soil Control	B	2	0.24268	0.7071	157.97
Bare Soil Control	C	2	*	0.0000	*
Bare Soil Control	D	2	*	0.0000	*
Compost Blanket (No Veg)	A	2	*	0.0000	*
Compost Blanket (No Veg)	B	2	*	0.0000	*
Compost Blanket (No Veg)	C	2	*	0.0000	*
Compost Blanket (No Veg)	D	2	*	0.0000	*
Compost Incorporated (No Veg)	A	2	*	0.0000	*
Compost Incorporated (No Veg)	B	2	0.72804	2.1213	473.92
Compost Incorporated (No Veg)	C	2	4.36826	12.7279	2843.51
Compost Incorporated (No Veg)	D	2	*	0.0000	*
Compost Incorporated + Veg	A	4	1.65192	3.5119	25.45
Compost Incorporated + Veg	B	4	0.59188	1.2583	9.12
Compost Incorporated + Veg	C	4	3.28144	6.9761	50.55
Compost Incorporated + Veg	D	2	0.48536	1.4142	315.95

Bartlett's Test (Normal Distribution)
Test statistic = 12.48, p-value = 0.052

Levene's Test (Any Continuous Distribution)
Test statistic = 53.63, p-value = 0.000



3.2.3 Analysis of Variance

Both HSG and Treatment main effects, and their interaction, are significant at ***p*** < 0.5. R-Squared explains about 99% of the variation predicted by the model factors.

3.2.3.1 Main Effects

Main Effects plots and Multiple Comparison Tests show that

- HSGs B (shortest time) and D (longest time) are significantly different from HSGs A (mean time) and C (mean time).
- Compost Incorporated + Veg (shortest time) and Compost Blanket (longest time) are significantly different from Compost Incorporated (mean time) and Bare Soil (mean time).

3.2.3.2 Interactions

Interaction plots and Multiple Comparison Tests show that

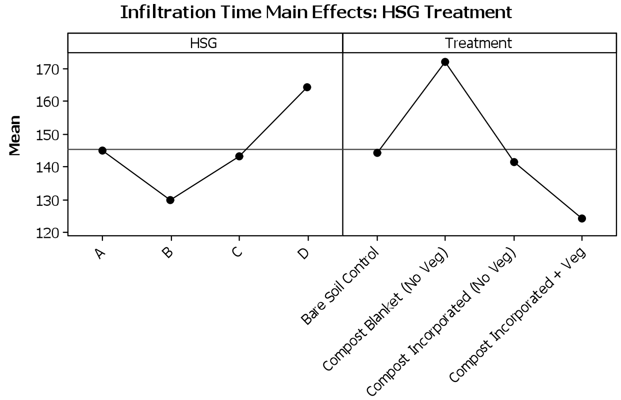
- Overall interaction between HSG and Compost application is significant.
- Compost Blanket increases infiltration time significantly on HSGs B and C.
- Compost Incorporated increases infiltration time significantly on HSG C.
- Compost Incorporated decreases infiltration time significantly on HSG A.
- Compost Incorporated + Veg decreases infiltration time significantly on HSGs A and D.

Factor	Type	Levels	Values
HSG	fixed	4	A, B, C, D
Treatment	fixed	4	Bare Soil Control, Compost Blanket (No Veg), Compost Incorporated (No Veg), Compost Incorporated + Veg

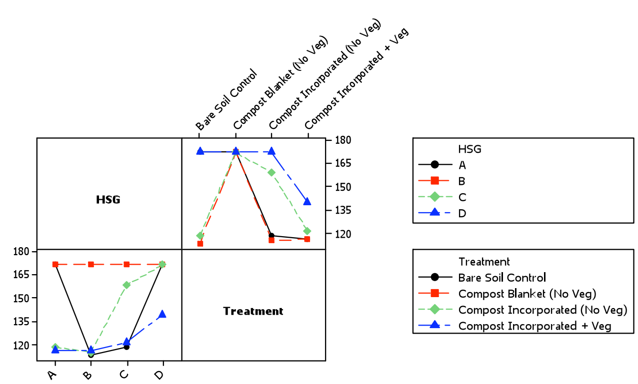
Source	DF	Seq SS	Adj SS	Adj MS	F	P
HSG	3	6300.7	5136.4	1712.1	105.58	0.000 *
Treatment	3	11583.1	11463.3	3821.1	235.64	0.000 *
HSG*Treatment	9	7166.3	7166.3	796.3	49.10	0.000 *
Error	22	356.7	356.7	16.2		
Total	37	25406.8				

S = 4.02690 R-Sq = 98.60% R-Sq(adj) = 97.64%

Infiltration Time Main Effects: HSG Treatment



Infiltration Time Interaction HSG Treatment



3.2.3.3 Multiple Comparisons

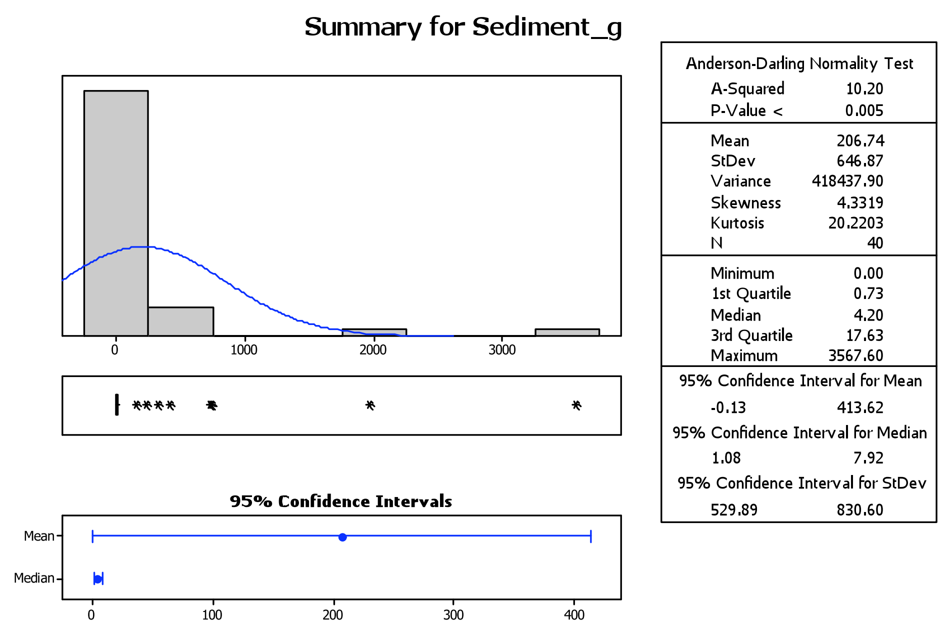
Both Compost Incorporated + Veg (shortest time) and Compost Blanket (longest time) are significantly different from Compost Incorporated (mean time) and Bare Soil (mean time)

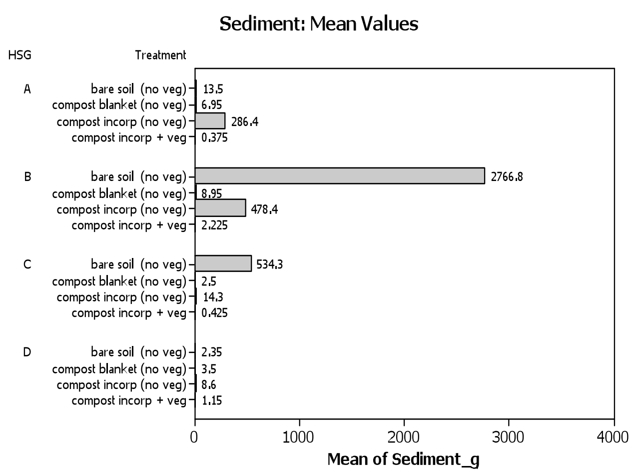
```
Grouping Information Using Bonferroni Method and 95.0% Confidence

Treatment                       N   Mean  Grouping
Bare Soil Control (control)     8  144.1  A
Compost Blanket (No Veg)        8  172.0
Compost Incorporated (No Veg)   8  141.4  A
Compost Incorporated + Veg     14  123.8

Bonferroni 95.0% Simultaneous Confidence Intervals
Response Variable Minutes
Comparisons with Control Level
Treatment = Bare Soil Control  subtracted from:

Treatment                       Lower  Center   Upper
Compost Blanket (No Veg)        22.66   27.87   33.09
Compost Incorporated (No Veg)   -7.97   -2.75    2.47
Compost Incorporated + Veg     -25.02  -20.31  -15.61

Treatment                      ------+---------+---------+---------+
Compost Blanket (No Veg)                                   (--*---)
Compost Incorporated (No Veg)             (--*---)
Compost Incorporated + Veg     (--*--)
                               ------+---------+---------+---------+
                                   -16         0        16        32

Bonferroni Simultaneous Tests
Response Variable Minutes
Comparisons with Control Level
Treatment = Bare Soil Control  subtracted from:

                               Difference       SE of           Adjusted
Treatment                        of Means  Difference  T-Value   P-Value
Compost Blanket (No Veg)            27.87       2.013    13.84    0.0000 *
Compost Incorporated (No Veg)       -2.75       2.013    -1.37    0.5574
Compost Incorporated + Veg         -20.31       1.815   -11.19    0.0000 *


Grouping Information Using Dunnett Method and 95.0% Confidence

Treatment                       N   Mean  Grouping
Bare Soil Control (control)     8  144.1  A
Compost Blanket (No Veg)        8  172.0
Compost Incorporated (No Veg)   8  141.4  A
Compost Incorporated + Veg     14  123.8

Dunnett 95.0% Simultaneous Confidence Intervals
Response Variable Minutes
Comparisons with Control Level
Treatment = Bare Soil Control  subtracted from:

Treatment                       Lower  Center   Upper
Compost Blanket (No Veg)        22.82   27.87   32.93
Compost Incorporated (No Veg)   -7.81   -2.75    2.31
Compost Incorporated + Veg     -24.87  -20.31  -15.75

Treatment                      ------+---------+---------+---------+
Compost Blanket (No Veg)                                   (--*---)
Compost Incorporated (No Veg)             (--*--)
Compost Incorporated + Veg     (--*--)
                               ------+---------+---------+---------+
                                   -16         0        16        32

Dunnett Simultaneous Tests
Response Variable Minutes
Comparisons with Control Level
Treatment = Bare Soil Control  subtracted from:

                               Difference       SE of           Adjusted
Treatment                        of Means  Difference  T-Value   P-Value
Compost Blanket (No Veg)            27.87       2.013    13.84    0.0000 *
Compost Incorporated (No Veg)       -2.75       2.013    -1.37    0.3922
Compost Incorporated + Veg         -20.31       1.815   -11.19    0.0000 *
```

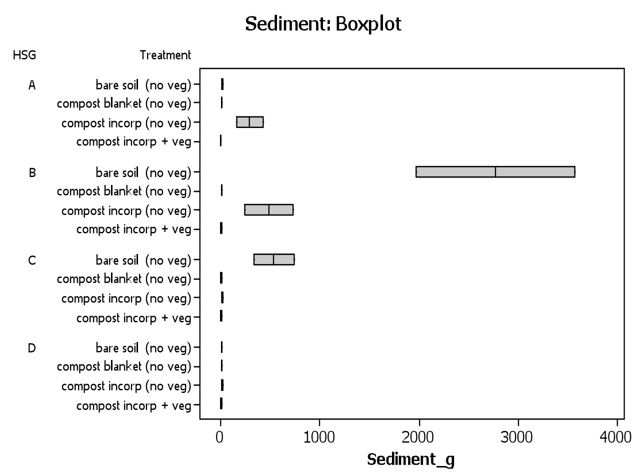
3.3 Total Sediment (TS)

3.3.1 Descriptive Statistics

Total Sediment (TS) data exhibit a non-normal (Anderson-Darling $p = < 0.005$), bimodal distribution with the highest values mostly from HSGs B and C Bare Soil, but also from the Compost Incorporated treatments on HSG A.







3.3.2 Homogeneity of Variances

Bartlett's and Levene's Tests are both non-significant, thus, homogeneity of variances cannot be rejected and ANOVA can proceed.

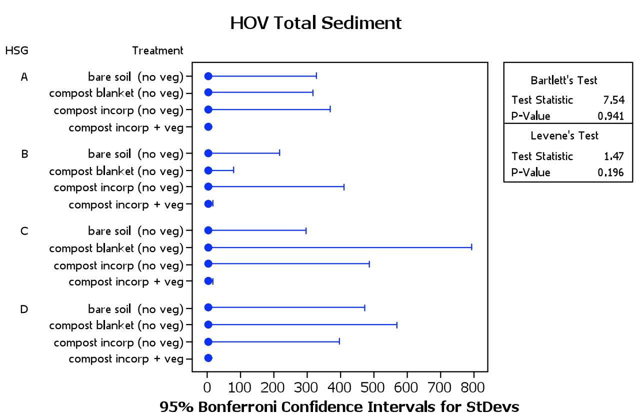
Test for Equal Variances: Total Sediment_ln versus HSG, Treatment

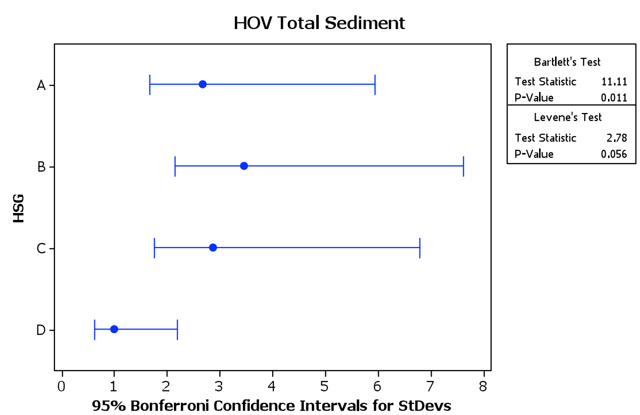
95% Bonferroni confidence intervals for standard deviations

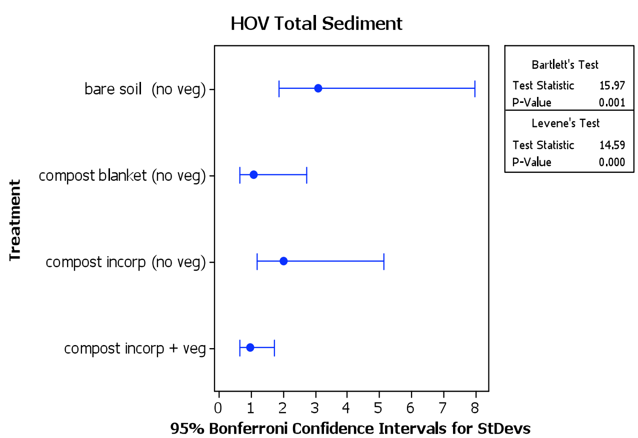
HSG	Treatment	N	Lower	StDev	Upper
A	bare soil (no veg)	2	0.201388	0.63695	325.258
A	compost blanket (no veg)	2	0.194815	0.61617	314.642
A	compost incorp (no veg)	2	0.227054	0.71813	366.710
A	compost incorp + veg	4	0.268349	0.60642	5.802
B	bare soil (no veg)	2	0.133222	0.42136	215.165
B	compost blanket (no veg)	2	0.047642	0.15068	76.946
B	compost incorp (no veg)	2	0.253283	0.80109	409.072
B	compost incorp + veg	4	0.636377	1.43809	13.759
C	bare soil (no veg)	2	0.182282	0.57653	294.400
C	compost blanket (no veg)	2	0.491232	1.55368	793.378
C	compost incorp (no veg)	2	0.301239	0.95276	486.524
C	compost incorp + veg	3	0.216273	0.54975	13.902
D	bare soil (no veg)	2	0.292502	0.92513	472.413
D	compost blanket (no veg)	2	0.352241	1.11408	568.898
D	compost incorp (no veg)	2	0.245615	0.77683	396.687
D	compost incorp + veg	4	0.226260	0.51130	4.892

Bartlett's Test (Normal Distribution)
Test statistic = 7.54, p-value = 0.941

Levene's Test (Any Continuous Distribution)
Test statistic = 1.47, p-value = 0.196







3.3.3 Analysis of Variance

Both HSG and Treatment main effects, and their interaction, are significant at ***p*** < 0.5. R-Squared explains about 94% of the variation predicted by the model factors.

3.3.3.1 Main Effects

Main Effects plots and Multiple Comparison Tests show that

- HSG B (high) is significantly different from HSGs A and C (mean) and D (lowest).
- Bare Soil (highest) and Compost Incorporated (high) are significantly different from Compost Blanket (low) and Compost Incorporated + Veg (lowest).

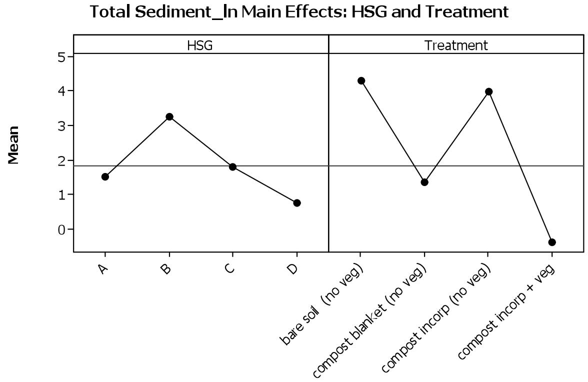
3.3.3.2 Interactions

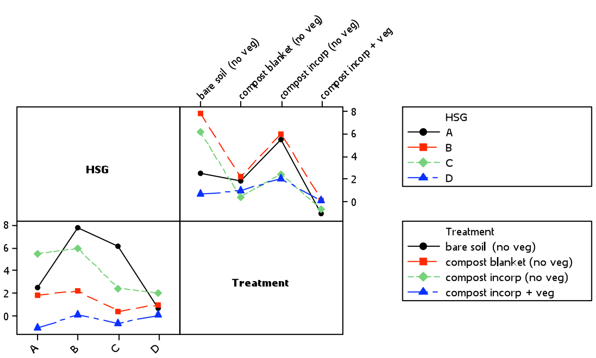
Interaction plots and Multiple Comparison Tests show that

- Overall interaction between HSG and Compost application is significant.
- Compost Blanket decreases sediment significantly on HSGs A, B, and C.
- Compost Incorporated + Veg decreases sediment significantly on HSGs A, B, and C.
- Compost Incorporated alone increases sediment significantly on HSGs A and B.

Analysis of Variance for ln Total Sediment, using Adjusted SS for Tests

```
Factor     Type   Levels  Values
HSG        fixed       4  A, B, C, D
Treatment  fixed       4  bare soil  (no veg), compost blanket (no veg),
                          compost incorp (no veg), compost incorp + veg

Source         DF   Seq SS   Adj SS  Adj MS      F      P
HSG             3   33.184   45.849  15.283  20.44  0.000
Treatment       3  163.487  162.891  54.297  72.63  0.000
HSG*Treatment   9   65.820   65.820   7.313   9.78  0.000
Error          23   17.194   17.194   0.748
Total          38  279.685

S = 0.864616   R-Sq = 93.85%   R-Sq(adj) = 89.84%
```





3.3.3.3 Multiple Comparisons

Both Compost Blanket and Compost Incorporated + Veg decrease Total Sediment significantly more than the Bare Soil control and Compost Incorporated.

```
Grouping Information Using Bonferroni Method and 95.0% Confidence

Treatment                       N  Mean  Grouping
bare soil  (no veg) (control)   8   4.3  A
compost incorp (no veg)         8   4.0  A
compost blanket (no veg)        8   1.4
compost incorp + veg           15  -0.4


Bonferroni 95.0% Simultaneous Confidence Intervals
Response Variable Sediment
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

Treatment                  Lower  Center   Upper
compost blanket (no veg)  -4.074  -2.958  -1.842
compost incorp (no veg)   -1.424  -0.308   0.808
compost incorp + veg      -5.700  -4.720  -3.740

Treatment                 ---------+---------+---------+-------
compost blanket (no veg)           (----*-----)
compost incorp (no veg)                        (----*-----)
compost incorp + veg      (----*----)
                          ---------+---------+---------+-------
                                -4.0      -2.0       0.0


Bonferroni Simultaneous Tests
Response Variable Sediment
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

                          Difference       SE of           Adjusted
Treatment                   of Means  Difference  T-Value   P-Value
compost blanket (no veg)      -2.958      0.4323    -6.84    0.0000
compost incorp + veg          -4.720      0.3796   -12.44    0.0000
compost incorp (no veg)       -0.308      0.4323    -0.71    1.0000


Grouping Information Using Sidak Method and 95.0% Confidence

Treatment                       N  Mean  Grouping
bare soil  (no veg) (control)   8   4.3  A
compost incorp (no veg)         8   4.0  A
compost blanket (no veg)        8   1.4
compost incorp + veg           15  -0.4

Means not labeled with letter A are significantly different from control
level
     mean.


Sidak 95.0% Simultaneous Confidence Intervals
Response Variable Sediment
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

Treatment                  Lower  Center   Upper
compost blanket (no veg)  -4.071  -2.958  -1.845
compost incorp (no veg)   -1.421  -0.308   0.805
compost incorp + veg      -5.697  -4.720  -3.743

Treatment                 --------+---------+---------+--------
compost blanket (no veg)          (----*-----)
compost incorp (no veg)                       (----*-----)
compost incorp + veg      (---*----)
                          --------+---------+---------+--------
                               -4.0      -2.0       0.0


Sidak Simultaneous Tests
Response Variable Sediment
Comparisons with Control Level
```

Treatment = bare soil (no veg) subtracted from:

Treatment	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
compost blanket (no veg)	-2.958	0.4323	-6.84	0.0000
compost incorp + veg	-4.720	0.3796	-12.44	0.0000
compost incorp (no veg)	-0.308	0.4323	-0.71	0.8620

Grouping Information Using Dunnett Method and 95.0% Confidence

Treatment	N	Mean	Grouping
bare soil (no veg) (control)	8	4.3	A
compost incorp (no veg)	8	4.0	A
compost blanket (no veg)	8	1.4	
compost incorp + veg	15	-0.4	

Dunnett 95.0% Simultaneous Confidence Intervals
Response Variable Sediment
Comparisons with Control Level
Treatment = bare soil (no veg) subtracted from:

Treatment	Lower	Center	Upper
compost blanket (no veg)	-4.040	-2.958	-1.876
compost incorp (no veg)	-1.390	-0.308	0.774
compost incorp + veg	-5.670	-4.720	-3.771

```
Treatment                 --------+---------+---------+--------
compost blanket (no veg)          (----*-----)
compost incorp (no veg)                        (----*-----)
compost incorp + veg      (---*----)
                          --------+---------+---------+--------
                               -4.0      -2.0       0.0
```

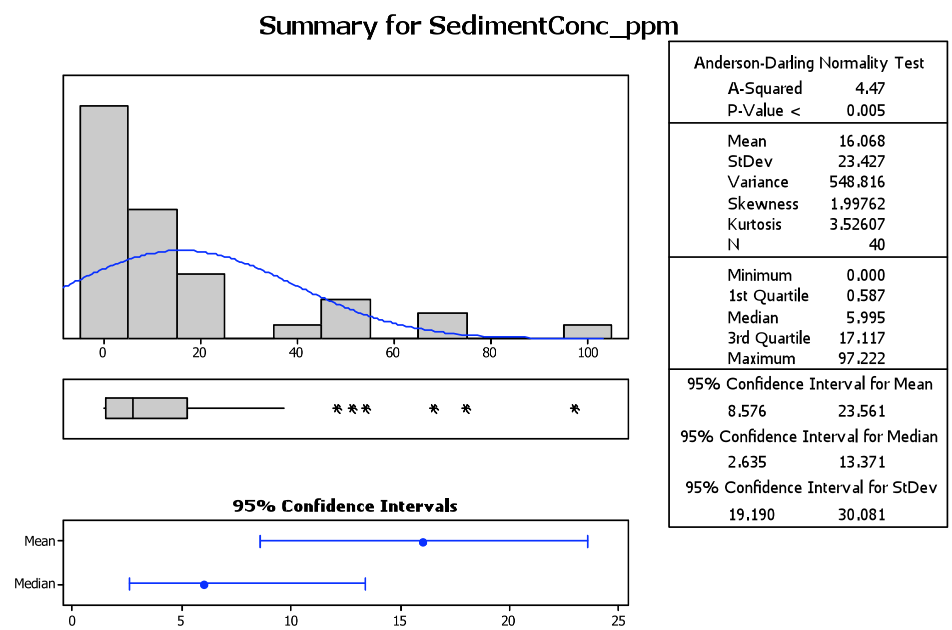
Dunnett Simultaneous Tests
Response Variable Sediment
Comparisons with Control Level
Treatment = bare soil (no veg) subtracted from:

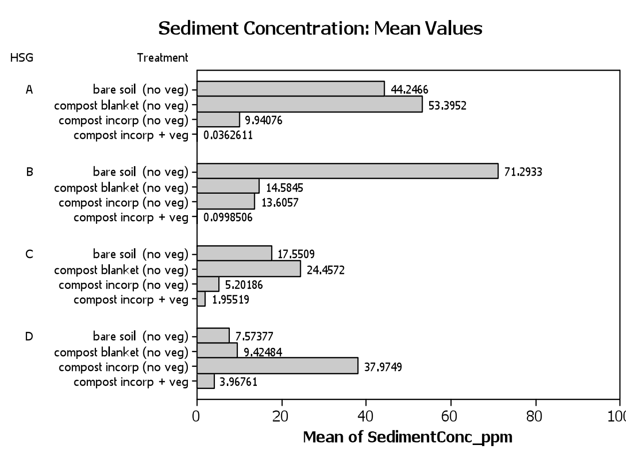
Treatment	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
compost blanket (no veg)	-2.958	0.4323	-6.84	0.0000
compost incorp + veg	-4.720	0.3796	-12.44	0.0000
compost incorp (no veg)	-0.308	0.4323	-0.71	0.8087

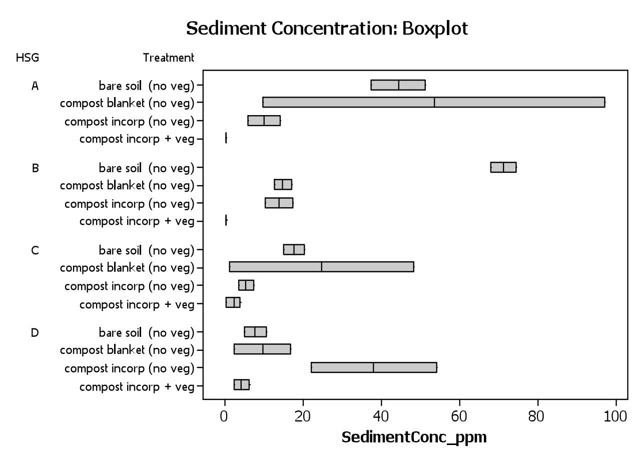
3.4 Suspended Sediment Concentration (SSC)

3.4.1 Descriptive Statistics

Suspended Sediment Concentration (SSC) data exhibit a non-normal (Anderson-Darling $p = < 0.005$), bimodal distribution with the highest values mostly from HSGs A and B Bare Soil, but also from the Compost Blanket treatments on HSG A, and the Compost Incorporated treatment on HSG D.







3.4.2 Homogeneity of Variances

Bartlett's Test is not significant, but Levene's Test is significant. Because the data distribution is not normal Levene's Test should be used; thus, homogeneity of variances is rejected and ANOVA is somewhat suspect.

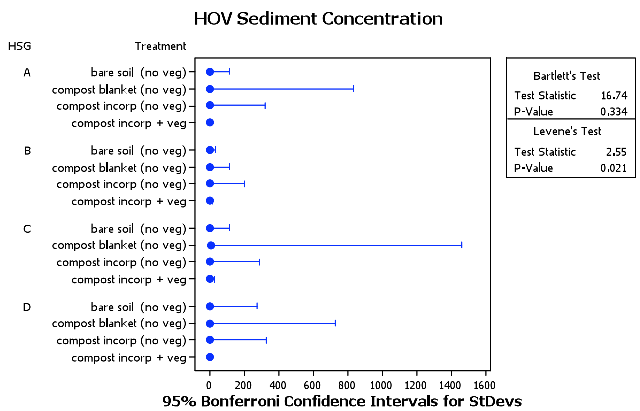
Test for Equal Variances: Sediment Concentration_ln versus HSG, Treatment

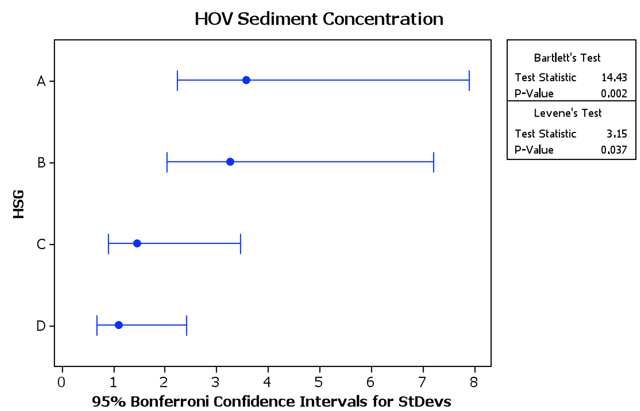
95% Bonferroni confidence intervals for standard deviations

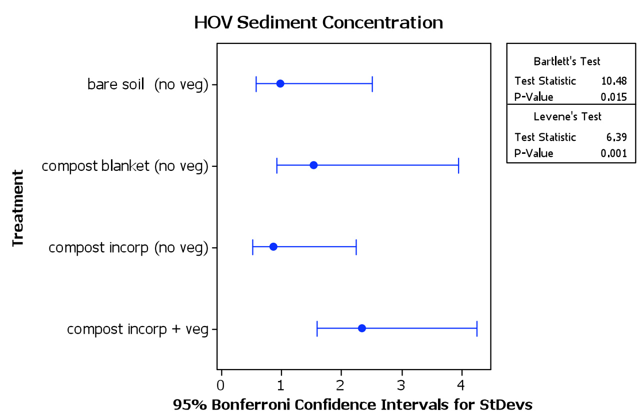
HSG	Treatment	N	Lower	StDev	Upper
A	bare soil (no veg)	2	0.070572	0.22321	113.98
A	compost blanket (no veg)	2	0.518355	1.63946	837.18
A	compost incorp (no veg)	2	0.198187	0.62683	320.09
A	compost incorp + veg	4	0.332930	0.75236	7.20
B	bare soil (no veg)	2	0.020533	0.06494	33.16
B	compost blanket (no veg)	2	0.068886	0.21787	111.26
B	compost incorp (no veg)	2	0.121635	0.38471	196.45
B	compost incorp + veg	4	0.595130	1.34488	12.87
C	bare soil (no veg)	2	0.068231	0.21580	110.20
C	compost blanket (no veg)	2	0.905477	2.86386	1462.42
C	compost incorp (no veg)	2	0.177824	0.56243	287.20
C	compost incorp + veg	3	0.450450	1.14502	28.96
D	bare soil (no veg)	2	0.167690	0.53037	270.83
D	compost blanket (no veg)	2	0.450598	1.42516	727.75
D	compost incorp (no veg)	2	0.203177	0.64261	328.15
D	compost incorp + veg	4	0.262744	0.59375	5.68

Bartlett's Test (Normal Distribution)
Test statistic = 16.74, p-value = 0.334

Levene's Test (Any Continuous Distribution)
Test statistic = 2.55, p-value = 0.021







3.4.3 Analysis of Variance

The HSG main effect is not significant, but the Treatment main effect, and the interaction between HSG and Treatment, are both significant at $p < 0.5$. R-Squared explains about 90% of the variation predicted by the model factors.

3.4.3.1 Main Effects

Main Effects plots and Multiple Comparison Tests show that

- HSGs are not significantly different.
- Compost Incorporated + Veg (lowest) is significantly different from all other treatments.

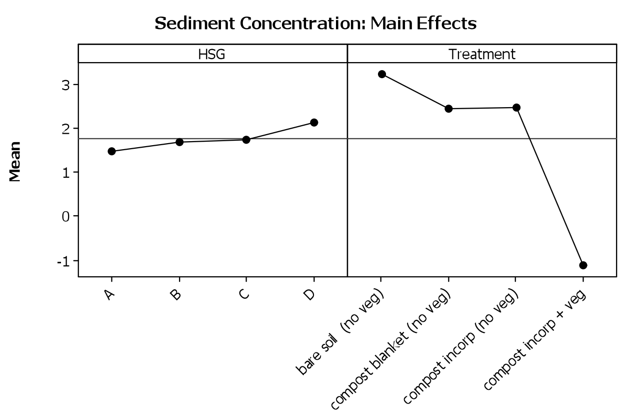
3.4.3.2 Interactions

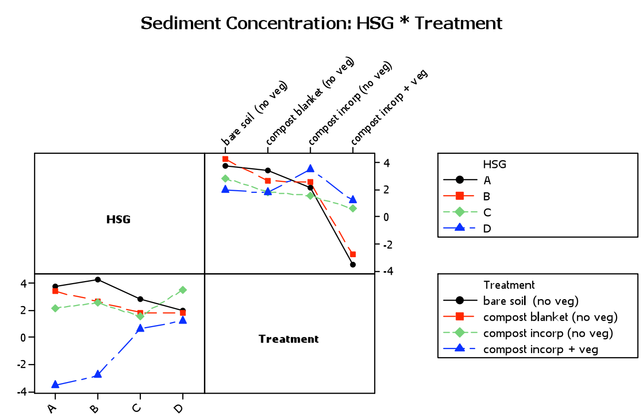
Interaction plots and Multiple Comparison Tests show that

- Overall interaction between HSG and Compost application is significant.
- Compost Incorporated + Veg decreases sediment concentrationsignificantly on HSGs A and B.

Analysis of Variance for Sediment Concentration, using Adjusted SS for Tests

```
Factor     Type   Levels  Values
HSG        fixed       4  A, B, C, D
Treatment  fixed       4  bare soil  (no veg), compost blanket (no veg),
                          compost incorp (no veg), compost incorp + veg

Source          DF   Seq SS   Adj SS  Adj MS      F      P
HSG              3   14.439    2.166   0.722   0.65  0.589
Treatment        3  144.740  136.577  45.526  41.18  0.000
HSG*Treatment    9   67.215   67.215   7.468   6.76  0.000
Error           23   25.424   25.424   1.105
Total           38  251.818


S = 1.05138   R-Sq = 89.90%   R-Sq(adj) = 83.32%
```





3.4.3.3 Multiple Comparisons

Compost Incorporated + Veg decrease Suspended Sediment Concentration significantly more than the Bare Soil control and other treatments.

```
Grouping Information Using Bonferroni Method and 95.0% Confidence

Treatment                       N  Mean  Grouping
bare soil  (no veg) (control)   8   3.2  A
compost incorp (no veg)         8   2.5  A
compost blanket (no veg)        8   2.4  A
compost incorp + veg           15  -1.1  A


Bonferroni 95.0% Simultaneous Confidence Intervals
Response Variable SedimentConc_ln
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

                                  Difference
Treatment                  Lower    of Means
compost blanket (no veg)  -1.969      -0.779
compost incorp (no veg)   -1.932      -0.742
compost incorp + veg      -5.373      -4.328


Treatment                 -------+---------+---------+---------
compost blanket (no veg)                   (-----*-------------
compost incorp (no veg)                    (-----*-------------
compost incorp + veg      (----*-------------------------------
                          -------+---------+---------+---------
                              -4.0      -2.0       0.0


Bonferroni Simultaneous Tests
Response Variable SedimentConc_ln
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

                          Difference       SE of            Adjusted
Treatment                   of Means  Difference  T-Value    P-Value
compost blanket (no veg)      -0.779      0.5257   -1.482      1.000
compost incorp (no veg)       -0.742      0.5257   -1.412      1.000
compost incorp + veg          -4.328      0.4615   -9.377      1.000


Grouping Information Using Sidak Method and 95.0% Confidence

Treatment                       N  Mean  Grouping
bare soil  (no veg) (control)   8   3.2  A
compost incorp (no veg)         8   2.5  A
compost blanket (no veg)        8   2.4  A
compost incorp + veg           15  -1.1  A


Sidak 95.0% Simultaneous Confidence Intervals
Response Variable SedimentConc_ln
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

                                  Difference
Treatment                  Lower    of Means
compost blanket (no veg)  -1.965      -0.779
compost incorp (no veg)   -1.928      -0.742
compost incorp + veg      -5.369      -4.328


Treatment                 -------+---------+---------+---------
compost blanket (no veg)                   (-----*-------------
compost incorp (no veg)                    (-----*-------------
compost incorp + veg      (----*-------------------------------
                          -------+---------+---------+---------
                              -4.0      -2.0       0.0


Sidak Simultaneous Tests
```

Response Variable SedimentConc_ln
Comparisons with Control Level
Treatment = bare soil (no veg) subtracted from:

Treatment	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
compost blanket (no veg)	-0.779	0.5257	-1.482	0.9996
compost incorp (no veg)	-0.742	0.5257	-1.412	0.9994
compost incorp + veg	-4.328	0.4615	-9.377	1.0000

Grouping Information Using Dunnett Method and 95.0% Confidence

Treatment	N	Mean	Grouping
bare soil (no veg) (control)	8	3.2	A
compost incorp (no veg)	8	2.5	A
compost blanket (no veg)	8	2.4	A
compost incorp + veg	15	-1.1	A

Dunnett 95.0% Simultaneous Confidence Intervals
Response Variable SedimentConc_ln
Comparisons with Control Level
Treatment = bare soil (no veg) subtracted from:

Treatment	Lower	Difference of Means
compost blanket (no veg)	-1.915	-0.779
compost incorp (no veg)	-1.878	-0.742
compost incorp + veg	-5.325	-4.328

```
Treatment                 -------+---------+---------+---------
compost blanket (no veg)                  (-----*-------------
compost incorp (no veg)                    (----*-------------
compost incorp + veg      (----*-------------------------------
                          -------+---------+---------+---------
                              -4.0      -2.0       0.0
```

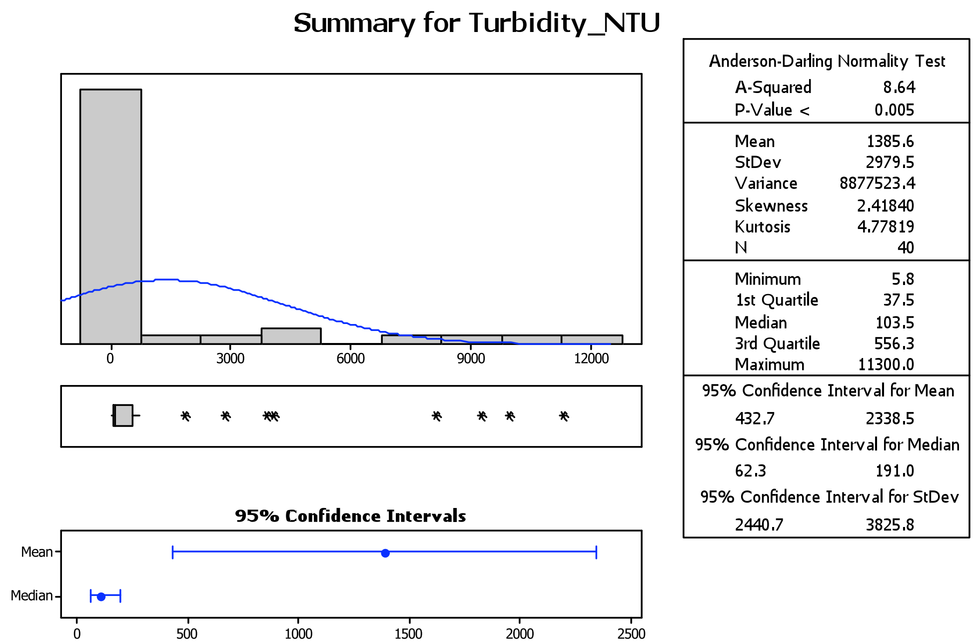
Dunnett Simultaneous Tests
Response Variable SedimentConc_ln
Comparisons with Control Level
Treatment = bare soil (no veg) subtracted from:

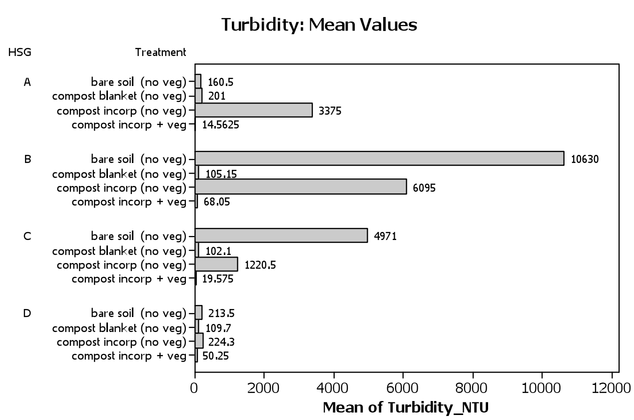
Treatment	Difference of Means	SE of Difference	T-Value	Adjusted P-Value
compost blanket (no veg)	-0.779	0.5257	-1.482	0.9873
compost incorp (no veg)	-0.742	0.5257	-1.412	0.9847
compost incorp + veg	-4.328	0.4615	-9.377	1.0000

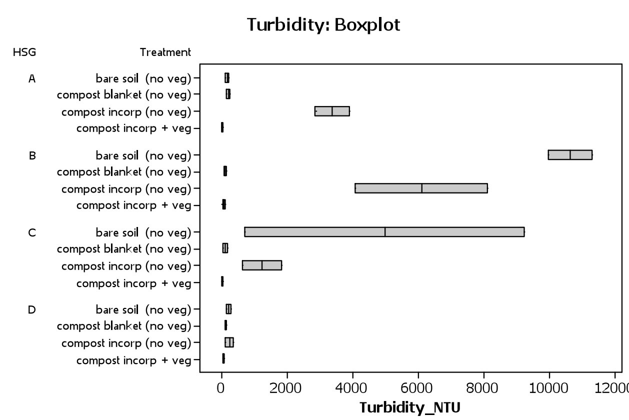
3.5 Turbidity (NTU)

3.5.1 Descriptive Statistics

Turbidity (NTU) data exhibit a non-normal (Anderson-Darling $p = < 0.005$) distribution with the highest values mostly from the Bare Soil HSGs B and C, Compost Incorporated on HSGs A and B.





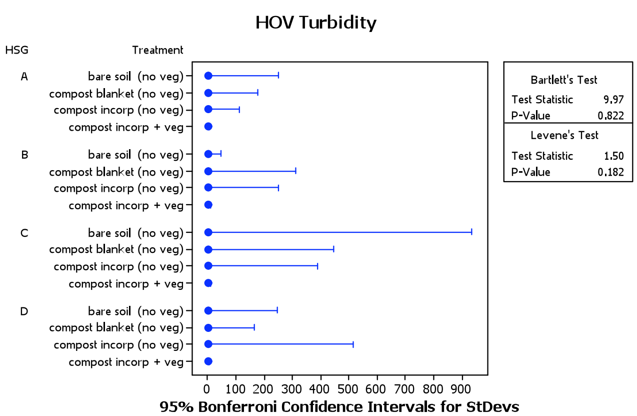


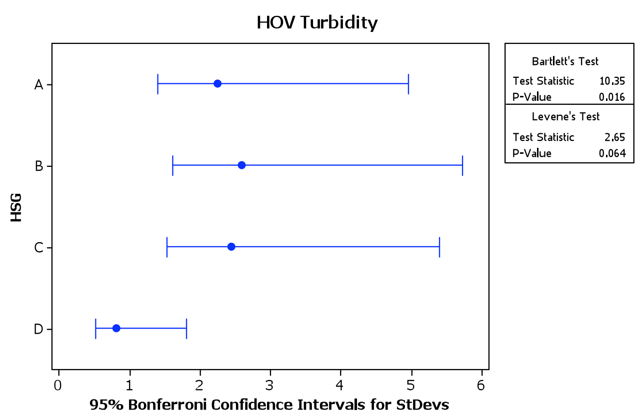
3.5.2 Homogeneity of Variances

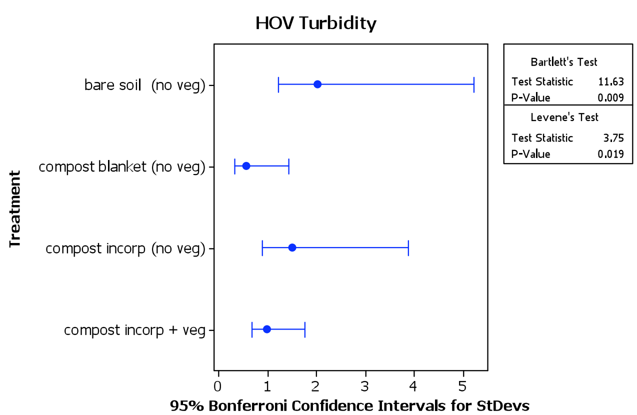
Both Bartlett's and Levene's Tests are non-significant, thus, homogeneity of variances cannot be rejected and ANOVA can proceed.

Test for Equal Variances: Turbidity_In versus HSG, Treatment

```
95% Bonferroni confidence intervals for standard deviations

HSG                 Treatment  N     Lower    StDev    Upper
  A       bare soil  (no veg)  2  0.154967  0.49013  250.283
  A  compost blanket (no veg)  2  0.108880  0.34437  175.850
  A   compost incorp (no veg)  2  0.068765  0.21749  111.061
  A      compost incorp + veg  4  0.304362  0.68780    6.581
  B       bare soil  (no veg)  2  0.028221  0.08926   45.579
  B  compost blanket (no veg)  2  0.193443  0.61182  312.425
  B   compost incorp (no veg)  2  0.155242  0.49100  250.727
  B      compost incorp + veg  4  0.451324  1.01990    9.758
  C       bare soil  (no veg)  2  0.579666  1.83338  936.207
  C  compost blanket (no veg)  2  0.274904  0.86947  443.993
  C   compost incorp (no veg)  2  0.240394  0.76032  388.256
  C      compost incorp + veg  4  0.411761  0.93050    8.903
  D       bare soil  (no veg)  2  0.151052  0.47775  243.961
  D  compost blanket (no veg)  2  0.100715  0.31854  162.663
  D   compost incorp (no veg)  2  0.319779  1.01140  516.469
  D      compost incorp + veg  4  0.203081  0.45892    4.391

Bartlett's Test (Normal Distribution)
Test statistic = 9.97, p-value = 0.822

Levene's Test (Any Continuous Distribution)
Test statistic = 1.50, p-value = 0.182
```







3.5.3 Analysis of Variance

Both HSG and Treatment main effects, and their interaction, are significant at ***p*** < 0.5. R-Squared explains about 92% of the variation predicted by the model factors.

3.5.3.1 Main Effects

Main Effects plots and Multiple Comparison Tests show that

- HSG B (higher) is significantly different from other HSGs.
- Compost Blanket (low) and Compost Incorporated + Veg (lowest) are significantly different from Bare Soil (high) and Compost Incorporated (highest).

3.5.3.2 Interactions

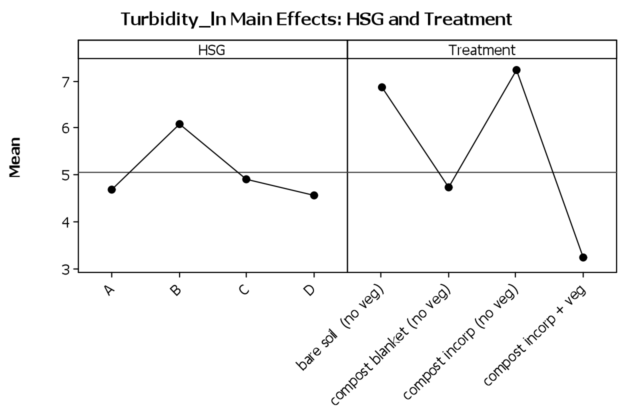
Interaction plots and Multiple Comparison Tests show that

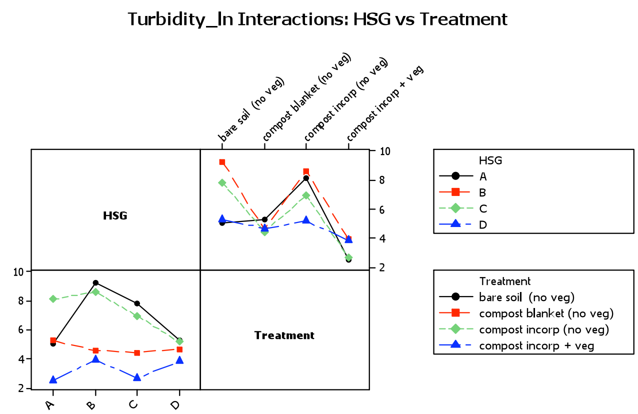
- Overall interaction between HSG and Compost application is significant.
- Compost Blanket and Compost Incorporated + Veg decrease turbidity significantly across all HSGs.

Factor	Type	Levels	Values
HSG	fixed	4	A, B, C, D
Treatment	fixed	4	bare soil (no veg), compost blanket (no veg), compost incorp (no veg), compost incorp + veg

Source	DF	Seq SS	Adj SS	Adj MS	F	P
HSG	3	14.405	17.070	5.690	9.20	0.000
Treatment	3	117.794	117.794	39.265	63.47	0.000
HSG*Treatment	9	32.744	32.744	3.638	5.88	0.000
Error	24	14.847	14.847	0.619		
Total	39	179.790				

S = 0.786518   R-Sq = 91.74%   R-Sq(adj) = 86.58%





3.5.3.3 Multiple Comparisons

Compost Blanket and Compost Incorporated + Veg decrease turbidity significantly more than the Bare Soil control or Compost Incorporated.

```
Grouping Information Using Bonferroni Method and 95.0% Confidence

Treatment                         N  Mean  Grouping
bare soil  (no veg) (control)     8   6.9  A
compost incorp (no veg)           8   7.2  A
compost blanket (no veg)          8   4.7
compost incorp + veg             16   3.2


Bonferroni 95.0% Simultaneous Confidence Intervals
Response Variable Turbidity
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

Treatment                  Lower  Center   Upper
compost blanket (no veg)  -3.130  -2.118  -1.106
compost incorp (no veg)   -0.642   0.370   1.382
compost incorp + veg      -4.503  -3.627  -2.750

Treatment                 --------+---------+---------+--------
compost blanket (no veg)          (------*-----)
compost incorp (no veg)                           (-----*------)
compost incorp + veg      (----*-----)
                          --------+---------+---------+--------
                               -3.2      -1.6      -0.0


Bonferroni Simultaneous Tests
Response Variable Turbidity
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

                          Difference       SE of           Adjusted
Treatment                   of Means  Difference  T-Value   P-Value
compost blanket (no veg)      -2.118      0.3933    -5.39    0.0000
compost incorp + veg          -3.627      0.3406   -10.65    0.0000
compost incorp (no veg)        0.370      0.3933     0.94    1.0000


Grouping Information Using Sidak Method and 95.0% Confidence

Treatment                         N  Mean  Grouping
bare soil  (no veg) (control)     8   6.9  A
compost incorp (no veg)           8   7.2  A
compost blanket (no veg)          8   4.7
compost incorp + veg             16   3.2


Sidak 95.0% Simultaneous Confidence Intervals
Response Variable Turbidity
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

Treatment                  Lower  Center   Upper
compost blanket (no veg)  -3.128  -2.118  -1.109
compost incorp (no veg)   -0.639   0.370   1.380
compost incorp + veg      -4.500  -3.627  -2.753

Treatment                 --------+---------+---------+--------
compost blanket (no veg)          (------*-----)
compost incorp (no veg)                           (-----*------)
compost incorp + veg      (----*-----)
                          --------+---------+---------+--------
                               -3.2      -1.6      -0.0


Sidak Simultaneous Tests
Response Variable Turbidity
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

                          Difference       SE of           Adjusted
Treatment                   of Means  Difference  T-Value   P-Value
compost blanket (no veg)      -2.118      0.3933    -5.39    0.0000
```

```
compost incorp + veg         -3.627      0.3406   -10.65    0.0000
compost incorp (no veg)       0.370      0.3933     0.94    0.7325


Grouping Information Using Dunnett Method and 95.0% Confidence

Treatment                      N  Mean  Grouping
bare soil  (no veg) (control)  8   6.9  A
compost incorp (no veg)        8   7.2  A
compost blanket (no veg)       8   4.7
compost incorp + veg          16   3.2


Dunnett 95.0% Simultaneous Confidence Intervals
Response Variable Turbidity
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

Treatment                  Lower  Center   Upper
compost blanket (no veg)  -3.099  -2.118  -1.138
compost incorp (no veg)   -0.610   0.370   1.351
compost incorp + veg      -4.476  -3.627  -2.777

Treatment                 --------+---------+---------+--------
compost blanket (no veg)           (-----*-----)
compost incorp (no veg)                             (-----*-----)
compost incorp + veg      (----*-----)
                          --------+---------+---------+--------
                               -3.2      -1.6      -0.0


Dunnett Simultaneous Tests
Response Variable Turbidity
Comparisons with Control Level
Treatment = bare soil  (no veg)  subtracted from:

                          Difference       SE of           Adjusted
Treatment                   of Means  Difference  T-Value   P-Value
compost blanket (no veg)      -2.118      0.3933    -5.39    0.0001
compost incorp + veg          -3.627      0.3406   -10.65    0.0000
compost incorp (no veg)        0.370      0.3933     0.94    0.6574
```

3.6 Summary Results

Compost Blanket significantly increased Total Infiltration and Infiltration Time, and significantly decreased Total Sediment and Turbidity, on HSGs B and C. Compost Blanket provided 95% increased infiltration on HSG B, and 60% increased infiltration on HSG C, compared with Bare Soil controls of the same HSGs. However, Infiltration Time increased also on HSGs B and C such that water had not reached the 9 inch depth by 172 minutes, about a 30% increase over Bare Soil controls. The Bare Soil controls for HSGs A and D had exhibited over 99% infiltration and the maximum Infiltration Time. Thus, Compost Blanket offered little added infiltration benefit.

Compost Incorporated (No Veg) significantly increased Total Infiltration from HSG C (52% increase compared with Bare HSG C), and significantly increased Total Sediment on HSGs A and B. On HSG A, Compost Incorporated (No Veg) **decreased** Total Infiltration by 36% compared with Bare Soil, but also decreased Infiltration Time so that the water that did infiltrate did so more rapidly. The same effect occurred on HSG C. Increased sediment from Compost Incorporated (No Veg) was likely the result of the incorporation process disturbing soil structure of already poorly structured Sandy Loam and Clay Loam soils, exposing more fine particles to rainfall without the benefit of a topical compost blanket or vegetation to reduce the force from drop impacts.

Compost Incorporated + Veg significantly increased Total Infiltration from HSGs B and C, providing 48% increased infiltration on HSG B, and 60% increased infiltration on HSG C, compared with Bare Soil controls of the same HSGs. In addition, HSGs A and D exhibited significantly more rapid Infiltration Time. Compost Incorporated + Veg also significantly decreased Total Sediment and Turbidity across HSGs A, B, and C, and significantly decreased Suspended Sediment Concentration for HSGs A and B.

Table 3.1 presents a summary matrix of results for each variable by treatment within soil type representing a hydrologic soil group. Statistically significant differences (at $p < 0.5$) **from bare soil controls** are indicated by symbols.

Table 3.1 Summary Statistical Significance for Variables by Treatment within Soil Type

HSG	A			B			C			D		
Soil Type	Sandy Loam			Sandy Clay Loam			Clay Loam			Clay		
Compost	Blanket	Incorp	Incorp+Veg	Blanket	Incorp	Incorp+Veg	Blanket	Incorp	Incorp+Veg	Blanket	Incorp	Incorp+Veg
Total Infiltration (TI)		▼		+		+	+	+	+			
Infiltration Time (IT)		▼	▼	+			+	+				▼
Total Sediment (TS)		+	▼	▼		▼	▼	▼	▼			
Sediment Concentration (SSC)			▼			▼						
Turbidity (NTU)		+	▼	▼		▼	▼		▼			

+ statistically significant increase ▼ statistically significant decrease

Table 3.2 is a summary matrix of results for Total Infiltration (TI) and Infiltration Time (IT) by treatment within soil type representing each hydrologic soil group. Statistically significant differences (at $p < 0.5$) **from bare soil controls** are indicated by symbols.

Table 3.2 Total Infiltration (TI) and Infiltration Time (IT) by Treatment within Soil Type

	HSG A Sandy Loam		HSG B Sandy Clay Loam		HSG C Clay Loam		HSG D Clay	
	Total Infiltration	Infiltration Time	Total Infiltration	Infiltration Time	Total Infiltration	Infiltration Time	Total Infiltration	Infiltration Time
Bare Soil Control	**Excellent** over 99 %	**Slow** not to 9 inch depth by 172 minutes	**Fair** about 49 %	**Rapid** to 9 inch depth by 114 minutes	**Fair** about 38 %	**Rapid** to 9 inch depth by 119 minutes	**Excellent** over 99 %	**Slow** not to 9 inch depth by 172 minutes
Compost Blanket	**Excellent** —	**Slow** —	**Excellent** + 95 % increase	**Slow** (+) not to 9 inch depth by 172 minutes	**Good** + 60 % increase	**Slow** (+) not to 9 inch depth by 172 minutes	**Excellent** —	**Slow** —
Compost Incorporated (No Veg)	**Fair** (▼) 36 % reduction	**Rapid** ▼ to 9 inch depth by 119 minutes	**Fair** — 14 % increase	**Rapid** —	**Good** + 52 % increase	**Moderate** (+) to 9 inch depth by 160 minutes	**Excellent** —	**Slow** —
Compost Incorporated + Veg	**Fair** — 16 % reduction	**Rapid** ▼ to 9 inch depth by 119 minutes	**Good** + 48 % increase	**Rapid** —	**Good** + 60 % increase	**Rapid** —	**Excellent** —	**Moderate** ▼ to 9 inch depth by 140 minutes

— Not significantly different from Bare Soil Control

\+ Significant increase from Bare Soil Control

(+) Significant increase from Bare Soil Control, but typically not desired for stormwater control

▼ Significant decrease from Bare Soil Control

(▼) Significant decrease from Bare Soil Control, but typically not desired for stormwater control

The HSG A Bare Soil Control showed excellent total infiltration, but slow infiltration time. Compost Blanket performance was nearly identical to Bare Soil. Compost Incorporated (No Veg) decreased the total infiltration and increased sediment concentration and turbidity. The disturbance necessary to incorporate compost likely exposed more fine particles to raindrop slash and sealed the soil surface, thus decreased infiltration and increased sediment in the runoff. However the soils had excellent infiltration and the compost treatments decreased infiltration time. Compost Incorporated + Veg performed best by reducing infiltration the least while decreasing infiltration time.

The HSG B Bare Soil Control showed fair total infiltration and rapid infiltration time. The use of compost increased total infiltration and the infiltration time remained rapid while the total sediment and turbidity decreased. Compost Incorporated + Veg performed best by increasing infiltration by 48% while decreasing infiltration time.

The HSG C Bare Soil Control showed fair total infiltration and rapid infiltration time. The use of compost increased the total infiltration to good and slowed the infiltration time down while decreasing total sediment. Compost Incorporated + Veg performed best by increasing infiltration by 60% while maintaining rapid infiltration time.

The HSG D Bare Soil Control showed excellent total infiltration for bare and all compost treatments, but with slow infiltration time. There were no differences between the Bare Soil Control and Compost treatments on water quality. Compost Incorporated + Veg performed best by maintaining excellent infiltration while decreasing infiltration time. The HSG D soil did not exhibit high runoff because the soil maintained cracks 2.5 inches deep allowing water to drain through these cracks.

All soils were dry at the time of the experiment to represent an autumn-winter first major storm scenario, as described in our experimental design. These soils represent erosion control treatments of Compost Blanket and Compost Incorporated on a 50% slope where soils are not saturated at the time of rainfall simulation. Thus, the Saturated Hydraulic Conductivity (*Ksat*) values listed in **Table 2-1** were not applicable. The rainfall simulation at the 85^{th} percentile had 100% infiltration and the full 24hr 2 year storm had runoff in all treatments.

RS11 was designed to evaluate 3 surface treatments and evaluate their effectiveness on increasing water infiltration and thus decreasing runoff. The 4 HSG soil types have shrink/swell tendencies that increase from the A soil to the D soil. Therefore the HSG A, sandy soils with macro pores, and D, clay soils with large cracks, tend to have high infiltration rates during initial wetting.

The 3 treatments had significant results for the HSG A, B, and C soils The HSAG D soils may take days for the cracks to close up and therefore did not have significant differences when compared to the bare soil control. The simulated rainfall did not saturate the soils and did not close up the cracks in the HSG D soil.

3.7 Test Box Photos

3.7.1 HSG A: Sandy Loam

HSG A: Bare Soil
post rainfall simulation on 25 Jul 2011

HSG A: Compost Blanket
post rainfall simulation on 18 Jul 2011

HSG A: Compost Incorporated (No Veg)
post rainfall simulation on 5 Jul 2011
Note that "Bare" means no vegetation

HSG A: Compost Incorporated + Veg at 123 days
pre rainfall simulation on 21 Jun 2011
Cover is mostly Festuca microstachys

3.7.2 HSG B: Sandy Clay Loam

HSG B: Bare Soil
post rainfall simulation on 26 Jul 2011

HSG B: Compost Blanket
post rainfall simulation on 19 Jul 2011

No Photo Available

HSG B: Compost Incorporated (No Veg)

HSG B: Compost Incorporated + Veg at 125 days
pre rainfall simulation on 23 Jun 2011
Cover is mostly Festuca microstachys

3.7.3 HSG C: Clay Loam

HSG C: Bare Soil
post rainfall simulation on 28 Jul 2011

HSG C: Compost Blanket
post rainfall simulation on 20 Jul 2011

HSG C: Compost Incorporated (No Veg)
post rainfall simulation on 14 Jul 2011
Note that "Bare" means no vegetation

HSG C: Compost Incorporated + Veg at 132 days
pre rainfall simulation on 30Jun 2011
Cover is mostly Festuca microstachys

3.7.4 HSG D: Clay

HSG D: Bare Soil
post rainfall simulation on 21 Jul 2011

HSG D: Compost Blanket
post rainfall simulation on 21 Jul 2011

HSG D: Compost Incorporated (No Veg)
post rainfall simulation on 21 Jul 2011
Note that "Bare" means no vegetation

HSG D: Compost Incorporated + Veg at 126 days
pre rainfall simulation on 24 Jun 2011
Cover is mostly Festuca microstachys

4 Conclusions

Several important caveats moderate conclusions drawn from this experiment:

- a small sample size of 40 test boxes, and only two or four replicates per soil-treatment combination;
- only one representative of each Hydrologic Soil Group is included;
- Compost Blanket and Compost Incorporated (No Veg) treatments, and Bare Soil Controls, were subjected to rainfall simulation soon after boxes were prepared, but Compost Incorporated + Veg treatments were allowed a six-month growing period before rainfall simulations; thus, time for disturbance effects from compost incorporation to lessen as boxes were irrigated and plant roots penetrated to depth;
- data for all variables are not normally distributed;
- data for Total Infiltration and Infiltration Time exhibit unequal variances making these ANOVAs suspect.

Despite these caveats, past rainfall simulation experiments (Caltrans 2001, 2002, 2004, 2005a, 2005b, 2007a, 2007b, 2010a) and many field trials (e.g., Caltrans 2010c) have demonstrated that Compost Blanket and Compost Incorporated, using certified compost conforming to Caltrans specifications, are effective erosion control treatments with, or without, seeded or live vegetation. As shown within this experiment, twice the 85th percentile 24-hour rainfall rate and quantity produced no measurable runoff across all treatments. At over 3.5 times the 85th percentile 24-hour total rainfall (2.76 inches compressed into three-hours, a 100th percentile, 500+ year event), the following results emerged for infiltration across the HSG representatives tested:

HSG A Sandy Loam

- Compost Blanket provided no benefit for any measured variable;
- Compost Incorporated (No Veg) and Compost Incorporated + Veg both negatively affected infiltration quantity, but positively affected infiltration time as water that did reach depth did so more rapidly;
- **Compost Incorporated + Veg exhibited the best results combining only slight decrease in infiltration quantity with significant decrease in infiltration time;**

HSG B Sandy Clay Loam

- Compost Blanket provided significant increase in infiltration quantity, but significant decrease in infiltration time;
- Compost Incorporated (No Veg) produced only slight increase in infiltration quantity, but did not decrease infiltration time;
- **Compost Incorporated + Veg exhibited the best results combining significant increase in infiltration quantity with no decrease in already rapid infiltration time;**

HSG C Clay Loam

- Compost Blanket and Compost Incorporated (No Veg) provided significant increase in infiltration quantity, but significant decrease in infiltration time;
- **Compost Incorporated + Veg exhibited the best results combining significant increase in infiltration quantity with no decrease in already rapid infiltration time;**

HSG D Clay

- Compost Blanket and Compost Incorporated (No Veg) provided no significant increase in infiltration quantity, or decrease in infiltration time;
- **Compost Incorporated + Veg exhibited the best results combining no decrease in already excellent infiltration quantity with significant decrease in infiltration time.**

Across all HSG representatives tested, Compost Incorporated + Veg performed best by either increasing Total Infiltration (TI) while decreasing Infiltration Time (TI), Total Sediment (TS), Suspended Sediment Concentration (SSC), and Turbidity (NTU), or by not adversely affecting already good to excellent performance for these same variables by Bare Soil Controls.

Where appropriate, a likely best-case scenario for both shorter and longer term erosion control and stormwater infiltration to meet construction permit guidelines is the incorporation of certified compost together with site-appropriate vegetation (Caltrans 2010b, FHA-USDOT 2007). Where appropriate and necessary, a certified compost blanket may provide added protection before vegetation has emerged and grown sufficient aerial cover to protect the soil surface from raindrop splash and from overland flow at the soil surface.

Of course, local project site context and cost factors drive all erosion control design considerations. An overarching goal for any roadside erosion control project is the use of context-dependent, sustainable solutions. No single prescribed treatment could ever meet the needs of every project across diverse California landscapes of approximately 1650 soil series and over 6000 native plant species. Field research studies are recommended to evaluate and verify the data that was developed in this rainfall simulation research.

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