Effective Planting Techniques to Minimize Erosion

Plug Planting
Sod Strips
Hydroseeding
Compost
Jute Netting

Caltrans

CTSW-RT-04-004.69.01

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SECTION 1: PROJECT DESCRIPTION

Need for Project

Vegetation plays a key role in decreasing soil particle detachment and transport from sites where the soil surface has been disturbed by human activities. Vegetation promotes long-term protection of the soil surface by providing leaf cover, which intercepts precipitation, and by establishing roots, which aid soil structure development, thereby increasing infiltration and soil stability. Vegetation also provides a viable alternative to many synthetic means of erosion control, increases species diversity, and increases the aesthetic value of project landscapes.

Native vegetation can be difficult to establish in disturbed soils with increased compaction and competition from aggressive weedy annual vegetation, herein referred to as undesirable vegetation. Successful establishment relies on proper moisture availability, adequate soil structure, and suitable planting techniques.

Goal: To identify vegetation establishment techniques that decrease erosion and improve water quality.

As part of a cooperative effort to improve methods of establishing native vegetation for erosion control and improving water quality, this study was conducted to test the performance of various planting techniques.

Project Goal

This experiment sought to identify and compare vegetation planting techniques that provide immediate soil surface stability and long-term erosion control to reduce soil loss and improve water quality using native vegetation.

Project Objectives

- Identify planting techniques that promote long term establishment of native vegetation.
- Compare the effects of plugs, flats (sod strips), and hydroseed planting techniques on minimizing erosion and improving water quality.
- Ascertain the effects of compost soil amendment on native vegetation cover, species composition, and weedy annual species suppression.

SECTION 2: PROJECT FINDINGS

Introduction

The study provided complex results identifying the planting techniques that may be best suited for establishing vegetation on disturbed soils and improving water quality. The best performing combinations of treatments were identified based on their ability to: produce a high percentage of vegetation cover, increase species diversity, reduce runoff, and decrease sediment yield. A complete analysis of the results and supporting tables, data, and explanations are reported in Section 4.

Water Quality Findings

All treatments decreased runoff and sediment load as compared to control. The following general findings outline the treatments that performed the best for decreasing erosion, increasing infiltration, and improving runoff filtration.

Finding:

Flats on the top and toe performed best for reducing runoff and sediment load.

Flats yielded:	Significantly less runoff than hydroseeding alone or plugs.
Flats reduced:	Runoff by 80 % when compared to control.
Flats removed:	More than 99 % of the amount of sediment produced by control. 99 % of the sediment produced by hydroseeding alone.

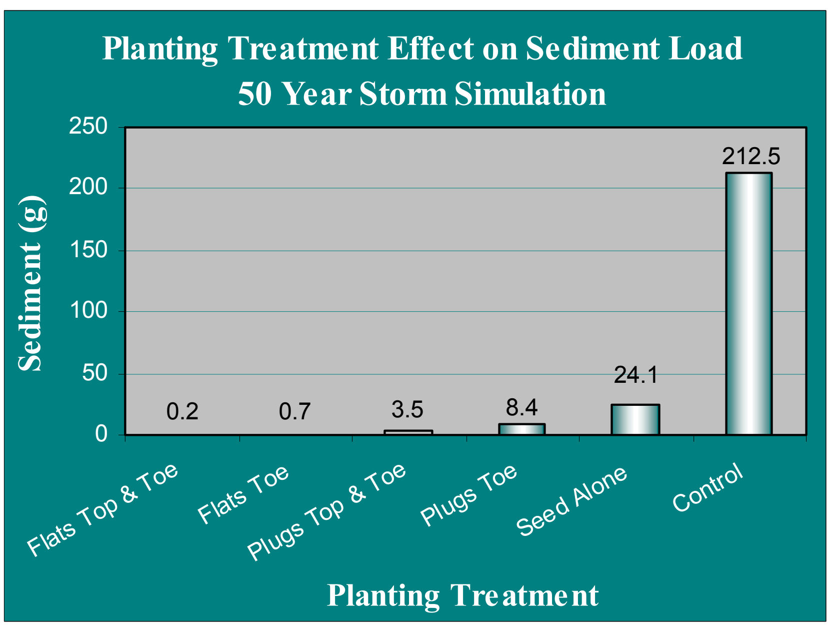

Figure 1. Planting treatment effect on sediment load: 50-year storm simulation

Finding:

Jute and compost with seed on top performed best for water quality.

Jute with seed on compost yielded: Significantly less total runoff.

Jute with seed or compost removed: Significantly more sediment from runoff.

Jute with seed on compost removed: 99.7 % of the sediment produced by control.

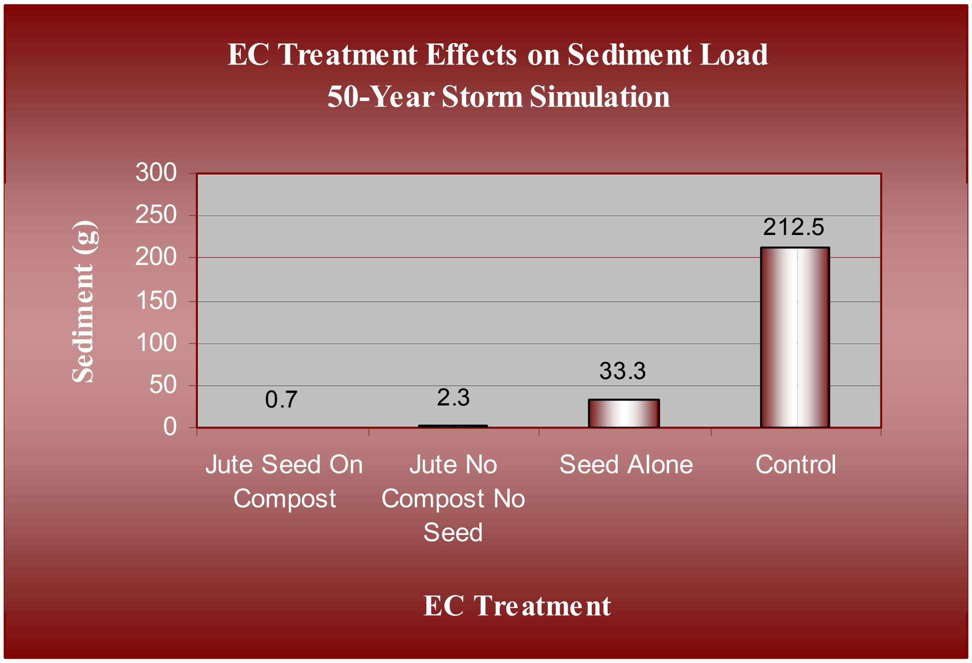

Figure 2. EC treatment effect on sediment load: 50-year storm simulation

Vegetation Cover Findings

Most treatments increased overstory, understory, and total vegetation cover compared to control. The following findings outline treatments that performed the best for increasing desirable overstory and understory cover and increasing total cover. Perennial native species are referred to as desirable and aggressive weedy annual species are referred to as undesirable. Desirable species include: California Brome *(Bromus carinatus)*, Small Fescue *(Festuca microstachys)*, Common Yarrow *(Achillea millefolium)*, Arroyo Lupine *(Lupinus succulentus),* and Purple Needle Grass (*Nassella pulchra*).

> ***Finding:***
>
> ***Jute decreased desirable vegetation when compared to an application with no EC treatment.***

Jute decreased:	Desirable cover in this experiment compared to no EC treatment.
Jute increased:	Overall vegetation cover in the lower portion of the box, suggesting jute does provide a stable environment that intercepts seeds in the runoff and enhances germination.
Jute is still:	The best for establishing vegetation when compared to other EC treatments, such as BFM and gypsum, in past experiments.

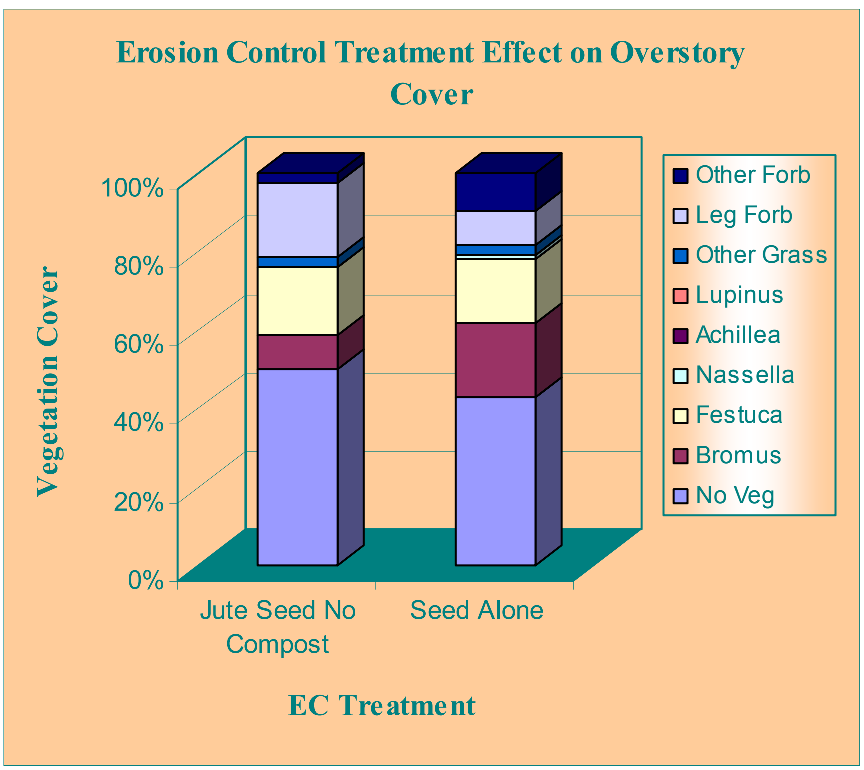

Figure 3. EC treatment effect on overstory cover

Finding:

Compost decreased undesirable cover. Compost inhibited desirable cover if seed was applied under the compost.

Compost (5.08 cm thick) did not change:	Total desirable cover when seed was applied on the compost.
Compost decreased:	Total desirable cover when seed was applied under the compost.
Compost decreased:	Undesirable cover.
Compost slightly increased:	Understory Common Yarrow establishment when seed was applied on the compost.

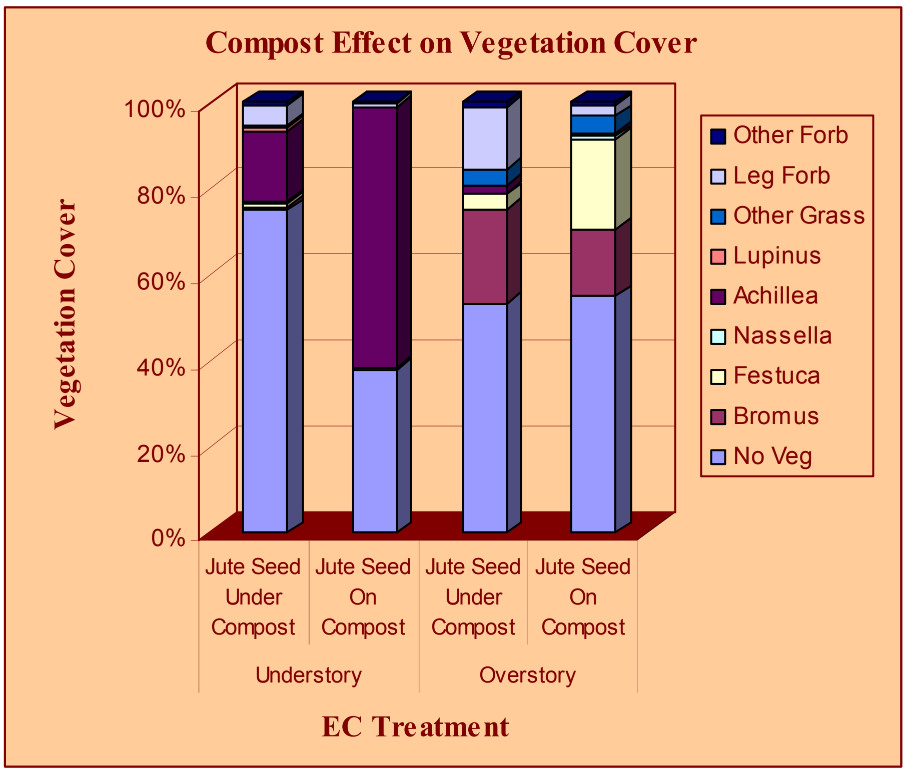

Figure 4. Compost effect on vegetation cover

Finding:

Hydroseeding alone produced the most overstory cover. Hydroseeding on compost produced the most understory cover.

Hydroseeding alone produced: More than 60 % overstory cover.

Seeding on compost produced: More than 65 % understory cover.

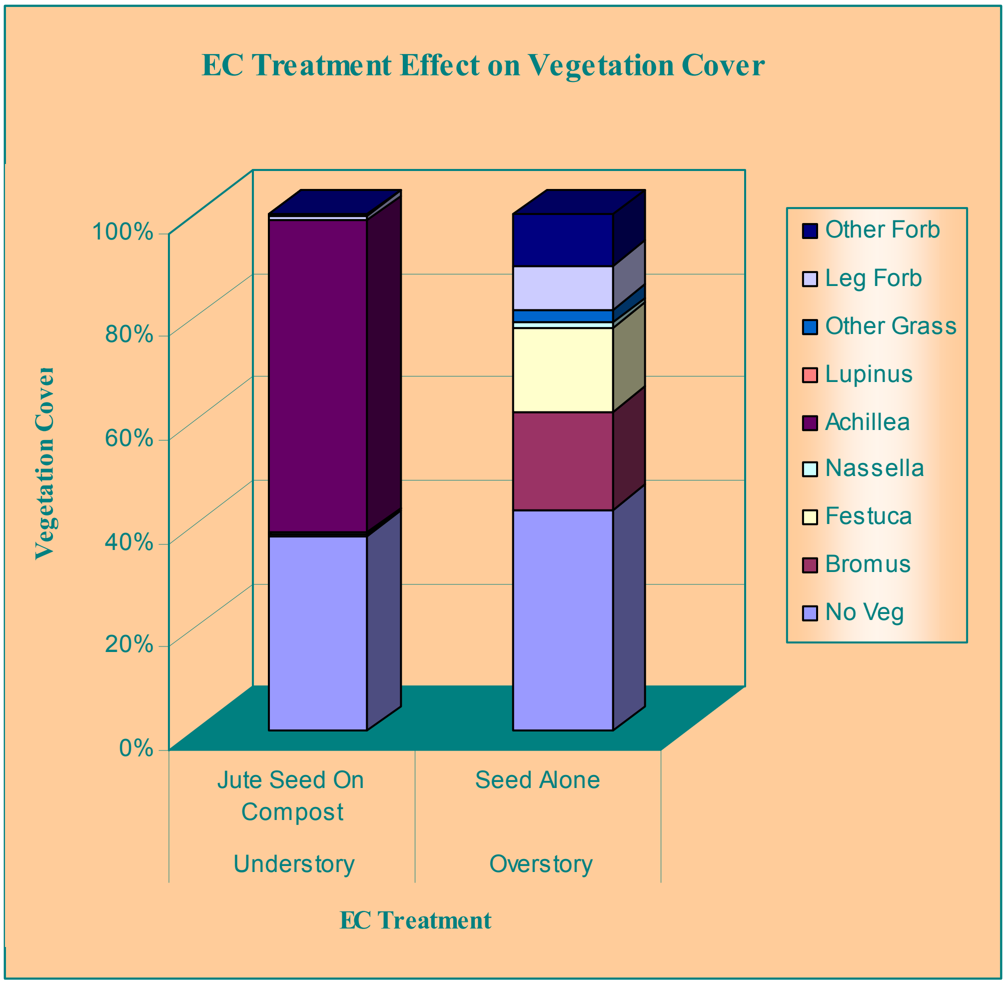

Figure 5. EC treatment effect on vegetation cover

Finding:

Flats on the top and toe with hydroseeding alone produced the most total vegetation cover.

Flats with hydroseeding produced: 92 % total vegetation cover.

Control yielded: 59 % total vegetation cover, all of which was undesirable invasive vegetation.

Jute with seed under compost produced: 44 % total cover when combined with flats on the toe, and 48 % total cover when combined with plugs on the toe.

Table 1. Treatment Combination Results for Total Vegetation Cover

	Seed Alone	Plugs Toe	Plugs Top & Toe	Flats Toe	Flats Top & Toe	Control
Jute Seed Under Compost	63 %	**48 %**	65 %	**44 %**	65 %	n/a
Jute Seed On Compost	63 %	64 %	75 %	68 %	76 %	n/a
Jute Seed No Compost	58 %	73 %	84 %	70 %	69 %	n/a
Jute No Compost No Seed	47 %	66 %	63 %	57 %	53 %	n/a
Seed Alone	69 %	71 %	83 %	62 %	**92 %**	n/a
Control	n/a	n/a	n/a	n/a	n/a	**59 %**

Finding:

The sediment yield increased as understory cover decreased. No clear direct relationship was found between overstory vegetation and sediment yield.

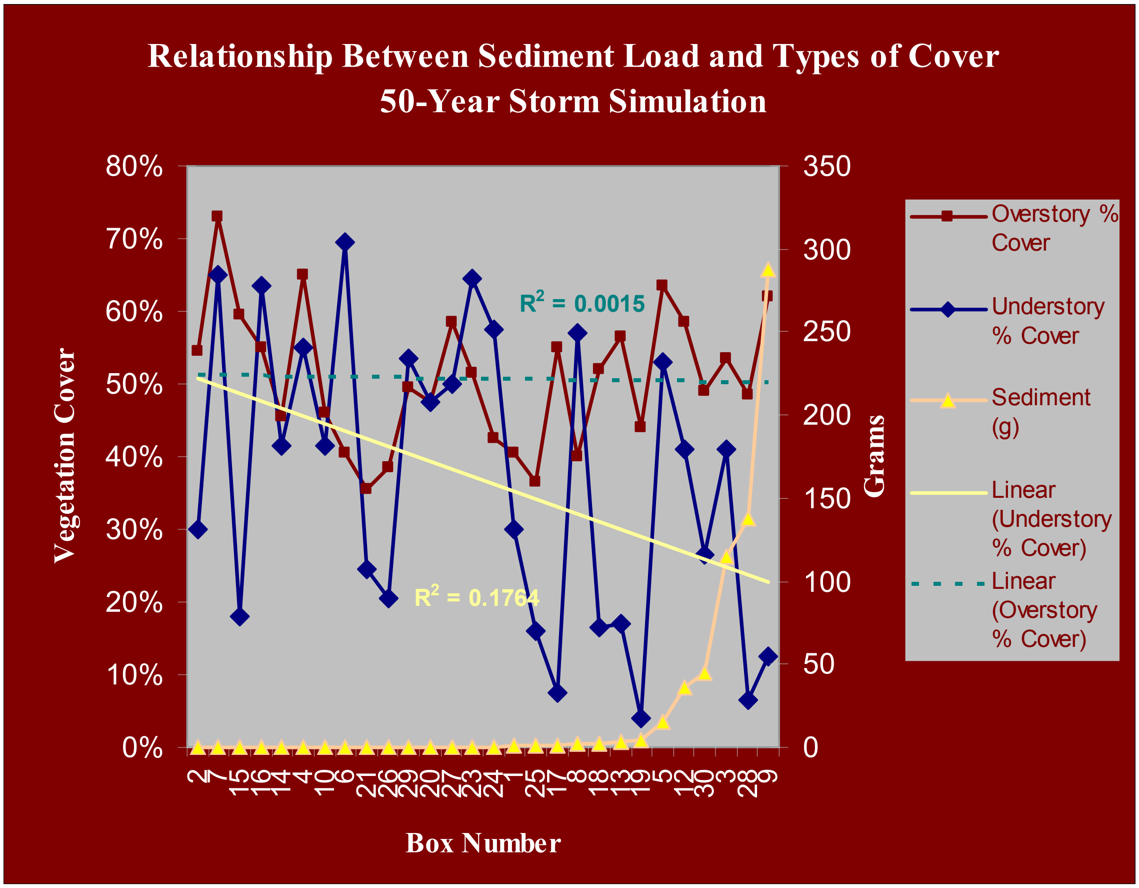

Figure 6. Relationship between sediment load and types of cover: 50 year storm simulation

SECTION 3: PROJECT DESIGN

Introduction

Treatments were applied to erosion test boxes to compare flats, plugs, hydroseed, jute, and compost applications by measuring the effect of each on water quality and vegetation establishment. The boxes were subjected to natural and simulated rainfall.

Box Design

A total of 32 erosion test boxes, each measuring 2.0 m x 0.6 m x 0.3 m, were filled with clay loam soil typical of fill material used on construction sites (Figure 7). The soil was compacted to 90 % to emulate Caltrans construction standards. Supports were used to position the boxes at a 2H:1V slope throughout the experiment.

Each box had a randomly assigned position under the box transport system. Vinyl gutters were used to collect runoff from the base of each box and convey runoff into a 7.5 L plastic container. A rectangular piece of synthetic pond liner was cut and riveted to the vinyl gutter to prevent rainfall from directly entering the collection system.

Figure 7. Erosion test boxes

Physical Erosion Control Treatments

Erosion control treatments included jute netting on combinations of compost and hydromulch with or without seed (Table 2). The 2.54 cm (1.0 in) jute netting used is standard and was purchased at a local supply company. It was secured to the boxes with standard netting staples. The compost consisted of humified, decomposed organic material and was applied to the soil surface at a depth of 5.08 cm (2.0 in).

Table 2. Erosion Control Treatments

EC1	Jute with seed under 5.08 cm (2.0 in) compost
EC2	Jute with seed on top of 5.08 cm (2.0 in) compost
EC3	Jute with seed on top (no compost)
EC4	Jute with no seed (no compost)
EC5	Seed only (no jute)

Vegetation Planting Treatments

Planting treatments included a hydroseed mix applied in combination with plugs or mixed flats of California Brome (*Bromus carinatus*) and Common Yarrow *(Achillea millefolium)* applied on the top and toe or the toe only of the slopes (Table 3). The flats

(Figure 8) and plugs (Figure 9) were composed of 50 % of each species. Twenty plugs were installed in an area equal to the size of the flats, which measured 0.25 m x 0.5 m, or 0.125 m^2 (1.35 ft^2). The erosion test boxes were placed in a random order prior to hydroseeding. The hydroseeded mix included only native plants (Table 4). The hydroseed mix also included wood fiber mulch applied at a rate of 400 lbs/acre to carry the seed in the hydroseeding process.

Table 3. Seeding/Planting Treatments

S1	Hydroseed alone
S2	Hydroseed; plugs on toe
S3	Hydroseed; plugs on top and toe
S4	Hydroseed; flats on toe
S5	Hydroseed; flats on top and toe

Table 4. Hydroseed Mix

50%	*Bromus carinatus* (California Brome)
25%	*Festuca microstachys* (Small Fescue)
20%	*Achillea millefolium* (Common Yarrow)
5%	*Lupinus succulentus* (Arroyo Lupine)

Figure 8. Sod strip/flat setup

Figure 9. Plugs setup

Natural Rainfall

Throughout the experiment, natural rainfall was permitted to fall on the boxes. In total, data for six natural storms and one simulated storm were collected (Table 5). The simulated storm was 3.81 cm (1.5 in) of rain over 1.5 hours, roughly equivalent to a 50-year storm for the central coast of California.

Natural rainfall was measured and recorded by a weather station (Figure 10) and backup rain gauges onsite. Additional data was available from a California Irrigation Management Information System (CIMIS) station and a National Oceanic and Atmospheric Administration (NOAA, 2003) station on campus.

Figure 10.Weather station

Table 5. Applied Storms

Collection Date	Storm Duration	Rainfall cm	in
12/21/02	Dec. 19-21, 2002	5.08	2.00
12/30/02	Dec. 27-29, 2002	3.56	1.40
02/14/03	Feb. 11-13, 2003	5.08	2.00
02/26/03	Feb. 24-25, 2003	1.58	0.62
02/28/03	Feb. 27, 2003	1.48	0.57
03/04/03	Mar. 03, 2003	1.07	0.42
05/13/03	1.5 hr Simulation	3.81	1.50

Simulated Rainfall

For simulation purposes, two Norton Ladder variable sweep rainfall simulators were used (Figure 11). The industrial spray nozzles were pressurized to 41 kPa (6 psi), and produced drop sizes averaging 2.25 mm (0.09 in) diameter. The drop size corresponded to the average drop size of erosive storms in the Midwest region of the United States. Drop size along the Pacific Coast is frequently smaller, but actual measurement data and analysis have not been published.

The nozzles oscillated side-to-side by a cam driven by a small motor. The intensity of simulated rainfall was determined by the number of times the nozzles of the boom swept past the box opening. The frequency and duration of oscillations were altered during each simulation to mimic the theoretical hydrograph of a storm. The simulators were tested before simulations began and yielded 95 % uniformity. The simulators returned unused rain to the water supply.

Figure 11. Rainfall simulators

Water Quality Analysis

Runoff was analyzed for sediment load, pH, and salt concentration. The total water runoff was calculated by subtracting the sediment and container weight from the original total collection weight. The total sediment included the evaporated sediment weight. Sediment concentration (mg/L) was calculated from the total runoff and total sediment values. Salt concentration (electrical conductivity) and pH were measured using a pH/EC/TDS/Temperature meter built by Hanna Instruments, Inc., for each collection following natural and simulated storm events.

Total solids were analyzed using a procedure that combined methods described by ASTM D3977-97 (ASTM, 2002) and EPA Method 160.2 (EPA, 2001). After collection of each weighed runoff sample, samples received 10-20 ml 1 M $AlCl_3$, a common water treatment flocculant. Any remaining sediment on the walls or bottom of the storage container was rinsed into an evaporating dish to be oven dried. The container with sediment was oven dried at 115^0 C for 24-48 hours and then weighed.

Vegetation Cover Analysis

To analyze the effects of planting technique, jute netting, and compost application on vegetation establishment, plant cover was observed directly prior to simulations. Aerial plant cover was the most logical variable to study due to the ability of plant parts to intercept raindrops before striking the soil surface. Government agencies use aerial cover as a standard to determine adequate soil surface protection and compliance with environmental regulations.

Point intercept is the oldest, most objective, and most repeatable procedure for measuring plant cover. For this method, the observer projects a small point from above onto vegetation and soil surfaces (BLM, 1996). Each contact is termed a "hit" for each category of plant species, soil surface litter, rock, or bare soil.

For this experiment, a modified point-transect method was used. A 600 mm length of 20 mm square stock (wood) was notched along the length of each angled face at 25 mm intervals. Along each face 10 positions were selected using random number tables to produce four different point position arrays. The ends of the stock were fixed to the position and allowed to rotate so that the bar was held parallel, approximately 25 mm above the soil surface.

Each soil test box was divided into an upper and a lower half to assess differences in plant cover between the two halves due to gravitational water flow and water retention at the toe of the box. Positions were marked every decimeter along the rails of each box and were selected using computer-generated random number tables to establish unique positions for each box. Positions selected for the upper half were used for the lower half of the same box. Randomly generated numbers were also used to establish sample points along each transect, yielding 100 observations per box.

For each observation the presence or absence of overstory and understory cover was recorded. Overstory cover included grass-like species that grew vertically, whereas understory species were those that lay prostrate or flat on the soil surface. The species were identified and then grouped into desirable or undesirable species. Desirable species included those that were a part of the planting treatments (Table 3). Undesirable plants included weedy annual grasses, forbs, and legumes that germinated from the existing seed bank.

Plant identifications were made based on the observer's knowledge of the flora. One trained botanist observed the vegetation throughout the duration of the study to decrease variability in sampling.

Statistical Analysis

Water runoff, sediment load in the runoff, and sediment concentration in the runoff were analyzed (after a normalization transformation, if needed) using analysis of variance (ANOVA). Tukey post-hoc multiple comparisons were used to identify differences between individual treatments.

Vegetation cover was analyzed using baseline-category logistic regression (also called polychotomus or nominal logistic regression).

Percent cover was measured in each box-half by determining the presence and type of cover for each of 50 points. If the presence or absence of desirable or undesirable plant matter is considered at each sampled location as the response variable of interest, then this is related to the experimental factors (Montogomery, 1991). Logistic regression is a method by which one can model the presence of plant matter at any point in the box as a function of erosion control treatment, vegetation planting technique, and other factors.

Trend Analysis

To analyze data trends, runoff, and sediment yield measurements were totaled and averaged for boxes with the same planting or erosion control treatment. The boxes were compared to boxes with other treatments and figures were generated to show differences. Totals were analyzed for the 50-year simulated event.

Trends in vegetation cover data were analyzed by calculating percent cover of each recorded species for each treatment. Comparisons were made regarding each individual treatment combination, percent cover yielded by each treatment, and species composition produced by each treatment.

SECTION 4: PROJECT RESULTS AND DISCUSSION

Water Quality

Planting Treatment Effects

Planting treatments had varied effects on overall water quality. For all storms, natural and simulated, flats planted on the toe yielded significantly less total runoff than hydroseeding alone or plugs on the toe only. There was no significant difference among the other planting treatments for runoff. There were no significant differences in total sediment load yield for planting treatments (p=.639). Planting treatment showed no significant effect on sediment concentration (p=.477).

For the 50-year simulated storm event, trends showed flats or hydroseeding alone reduced runoff by 80 % when compared to control (Figure 12). Flats on the top and toe yielded 82 % less runoff than plugs on the top and toe.

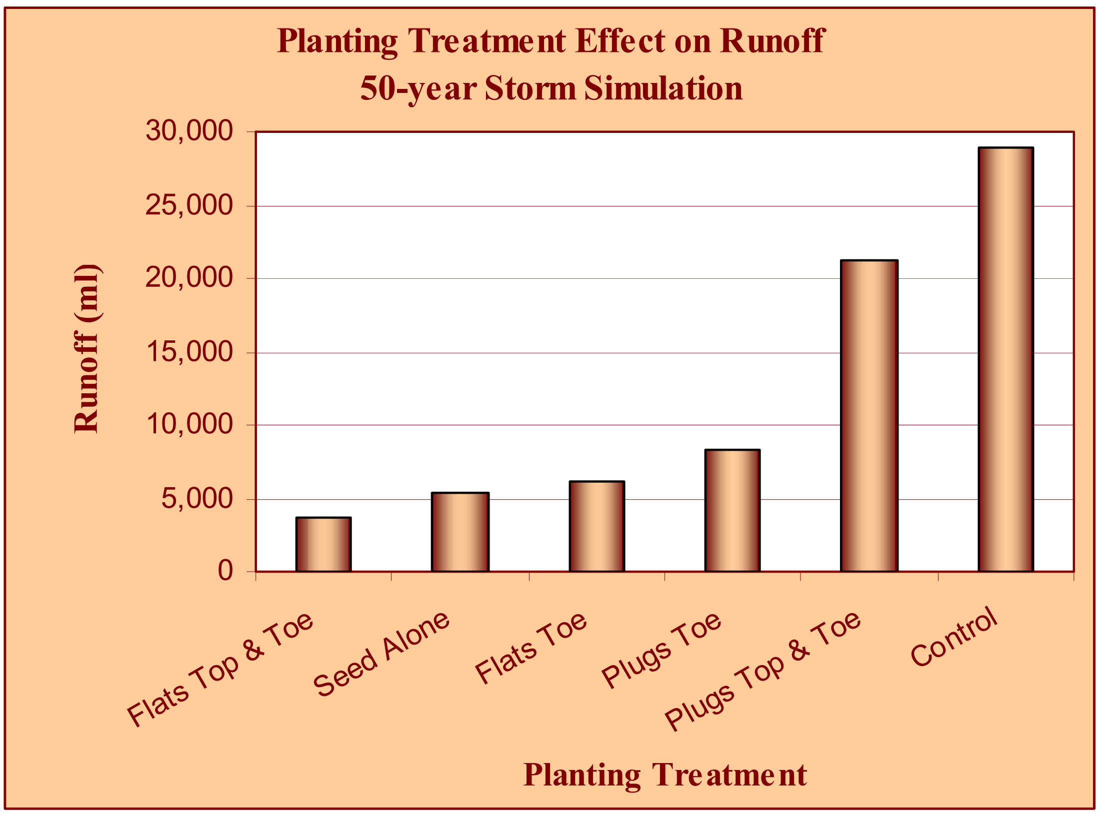

Figure 12. Planting treatment effect on runoff: 50-year storm simulation

Trends also indicate that flats on the top and toe, or the toe only, removed more than 99 % of the amount of sediment produced by control during a 50-year storm event (Figure 13). Furthermore, flats removed up to 99 % of the sediment produced by boxes treated with hydroseeding alone. Overall, planting treatments increased infiltration of rainfall.

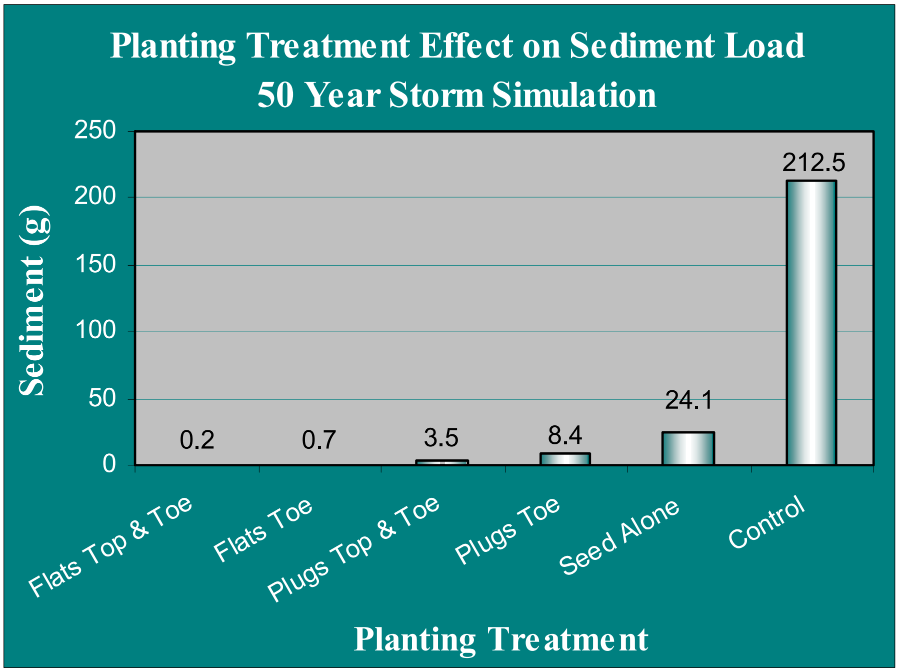

Figure 13. Planting treatment effect on sediment load: 50-year storm simulation

Erosion Control Treatment Effects

Erosion control treatments affected runoff ($p<.001$), sediment load ($p<.001$), and sediment concentration ($p=.042$). Jute with seed on compost yielded significantly less total runoff compared to all other erosion control treatments. Jute with compost and/or seed removed significantly more sediment from runoff than no seed and/or no compost. No individual treatments were identified as significantly different.

Trends show that for a 50-year storm event simulation, boxes treated with jute and seed on compost produced, on average, 0.3 % of the sediment produced by control (Figure 14). The treatment also removed 98 % more sediment than seed alone.

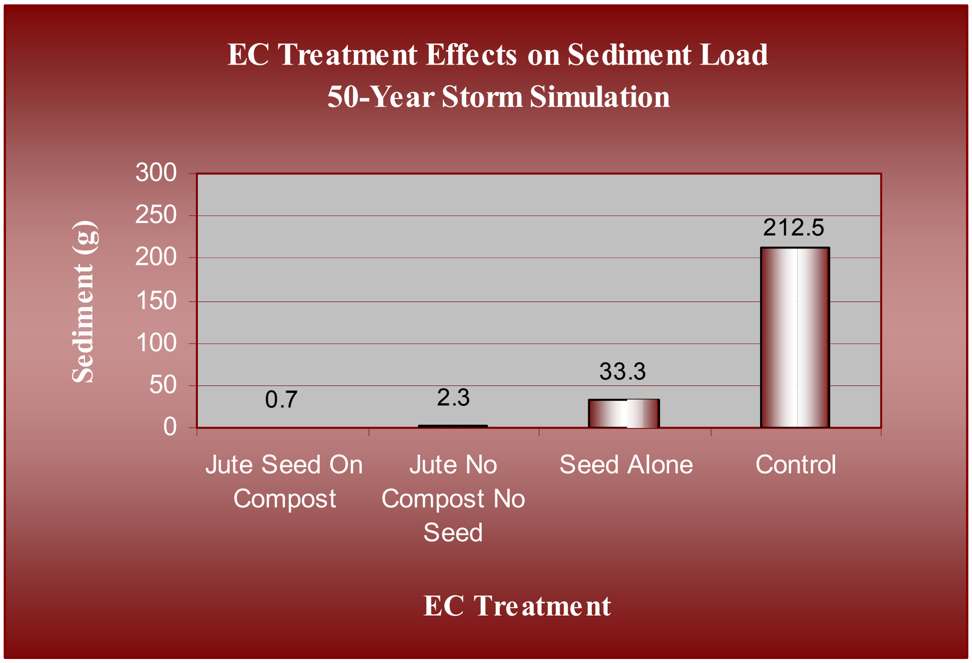

Figure 14. EC treatment effect on sediment load: 50-year storm simulation

EC treatment also affected pH levels and salt concentrations for all storms (Figure 15). Higher pH and salt concentrations were detected in the runoff from boxes treated with compost, but the levels were not harmful to plant growth (Smith, 2002).

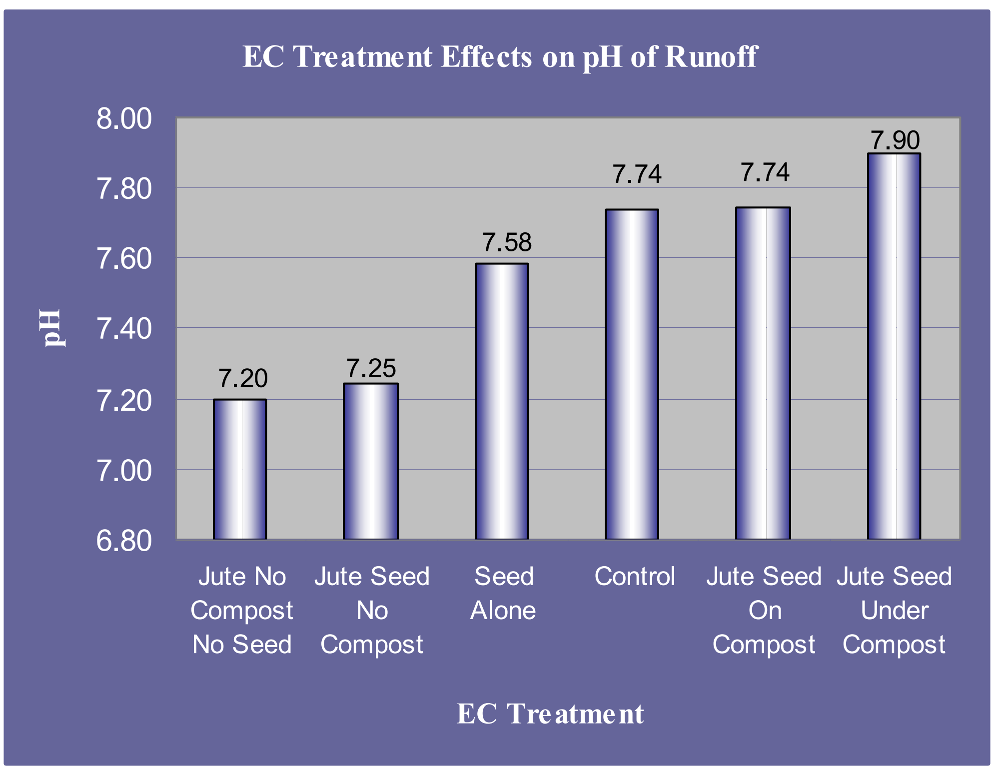

Figure 15. EC treatment effect on pH of runoff

Vegetation

Overstory Cover Response

The upper portion of the box produced significantly lower cover of both desirable ($p<.001$) and undesirable plants ($p<.001$) compared to the lower portion of the box (Table 6). On average, jute significantly decreased desirable cover ($p<.001$). Jute had no noticeable effect on undesirable cover ($p=.535$); however the use of jute limited the cover in the upper portion and increased the cover in the lower portion of the box ($p=.025$).

The use of compost had no noticeable effect on desirable cover ($p=.859$), but reduced undesirable cover ($p<.001$). For boxes with hydroseed beneath compost, the desirable cover did not significantly change ($p=.060$), but undesirable cover increased ($p<.001$). The effect of compost on desirable cover depended on the box division ($p<.001$). The upper portion of the box with compost decreased desirable cover. Similarly, the effect of compost on the undesirable cover depended on box-division ($p=.002$) and the upper portion of the box with compost decreased undesirable plant cover.

On average, hydroseeding, with other treatments, increased desirable cover ($p<.001$) and decreased undesirable cover ($p<.001$). In the upper portion of the box, hydroseeding had a stronger beneficial effect on desirable cover than in the lower portion of the box ($p=.048$). Similarly, hydroseeding had a stronger negative effect on the undesirable species in the upper portion of the box than in the lower portion ($p<.001$).

The use of flats compared to plugs lowered the desirable cover ($p<.001$) but did not affect the undesirable species ($p=.428$). Planting the top and toe increased both the undesirable ($p=.002$) and desirable cover ($p=.036$). On average, hydroseeding alone did not affect either the desirable ($p=.374$) or undesirable cover ($p=.724$). However, hydroseeding alone did increase the desirable cover in the upper portion of the box ($p=.048$). Overall overstory cover increased over time; however, the increase occurred in the first month.

Table 6. Treatment Effects on Overstory Cover*

Overstory Cover	Desirable Cover		Undesirable Cover	
Treatment Type	Upper Slope	Lower Slope	Upper Slope	Lower Slope
EC Jute	↓	↓	↓	↑
EC Compost	↓	↔	↓↓	↓
EC Seed Under Compost	↔	↔	↑	↑
EC Hydroseeding	↑↑	↑	↓↓	↓
S Hydroseeding Alone	↑	↔	↔	↔
S Flats	↑	↑	↑	↑
S Plugs	↑	↑	↑	↑
Lower vs. Upper Box	↓	↑	↓	↑
Time	↑	↑	↑	↑

↑: Increases Cover ↓: Decreases Cover ↓↓ or ↑↑: Stronger Effect ↔:No Noticeable Effect

*Table 6 serves as a guide to the statistical results for this experiment. It should be read horizontally to determine the effect of applying a particular treatment to bare soil. Individual sites should be evaluated prior to applications.

Overstory Species Composition

Trend analysis demonstrates species composition of overstory cover was strongly affected by the presence of an erosion control treatment. The control boxes that received no treatments yielded no desirable cover of native grasses or forbs (Figure 16). Overall, jute and seed on compost; jute, seed and no compost; and hydroseed alone produced the most desirable species. Hydroseed alone produced roughly 60 % cover in the overstory (note that this percentage does not include the understory cover observed). Small Fescue (*Festuca microstachys*) did well when applied on compost or with no compost. California Brome did well in all treatments, and was able to thrive when seeded under compost (20 % coverage of total ground, and roughly 50 % of the total vegetation cover), indicating the species' ability to germinate through thick mulches.

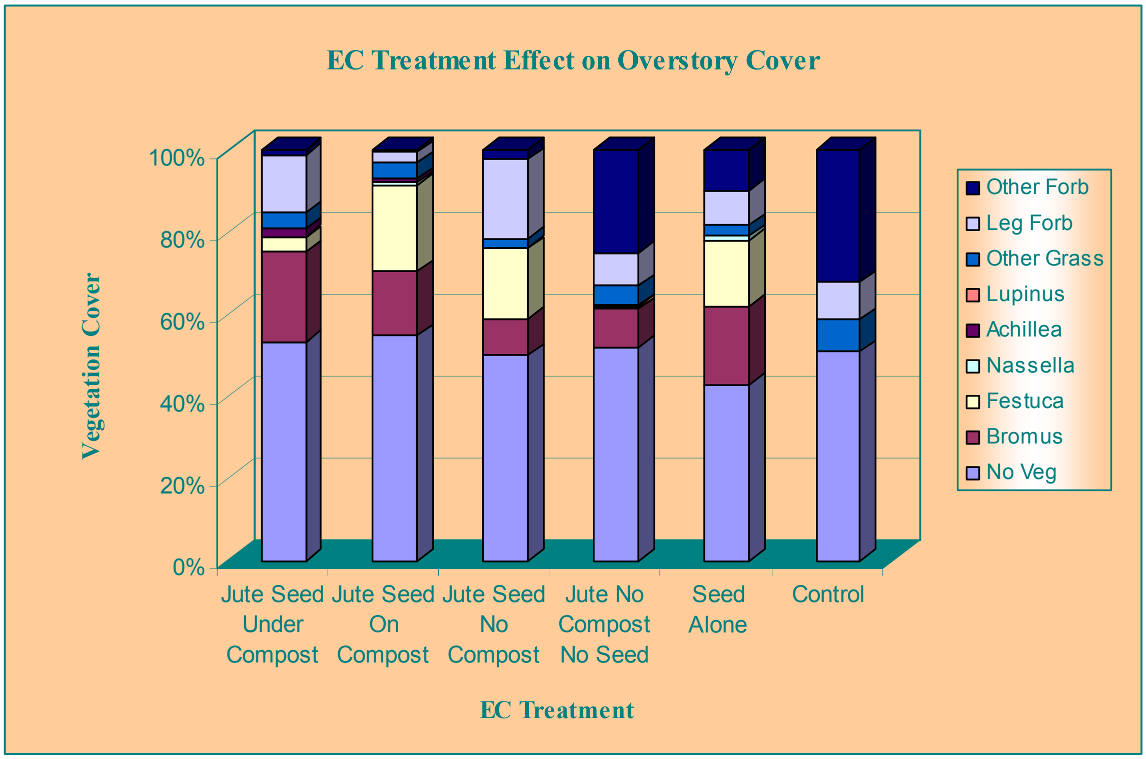

Figure 16. EC treatment effect on overstory cover

Based on trend analysis, planting treatments affected the overstory species composition. Starting plants as plugs increased the overstory cover of California Brome, demonstrating that more vigorous individual plants were established by plug planting methods (Figure 17). Boxes treated with plugs also produced the least amount of bare ground, yielding 60 % overstory cover, which included a large percentage of undesirable species.

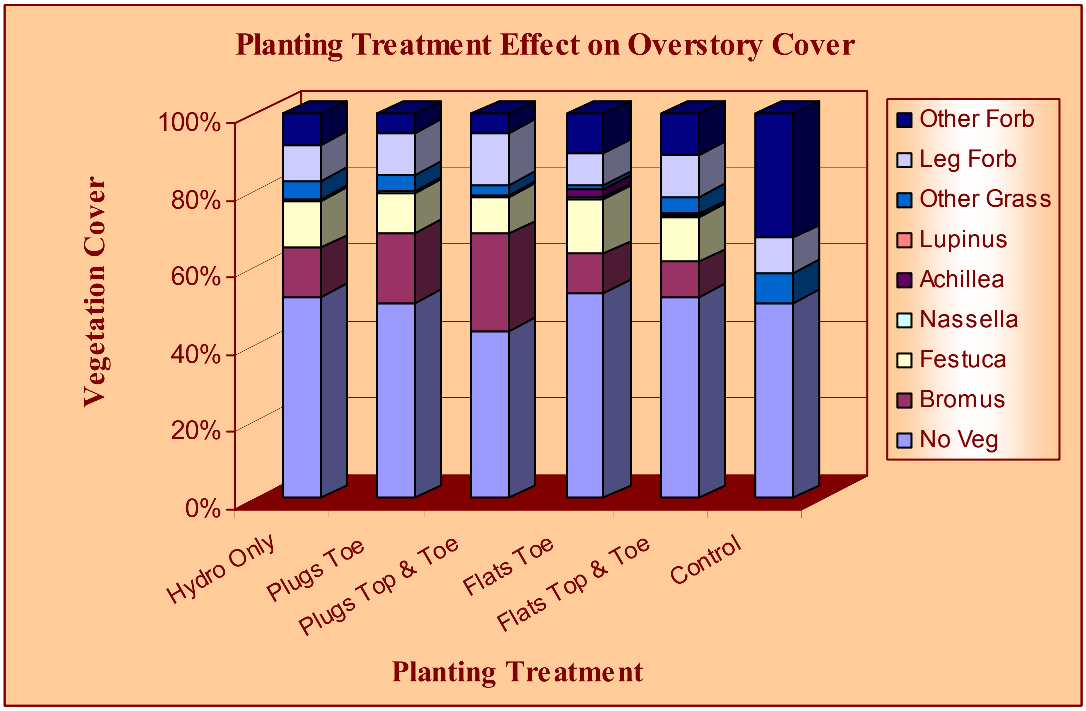

Figure 17. Planting treatment effect on overstory cover

Understory Cover Response

The upper portion of the box had significantly lower desirable cover ($p<.001$), but the undesirable cover was not significantly different ($p=.395$) (Table 7). Jute appeared to have no effect on desirable understory cover ($p=.298$), but reduced undesirable cover ($p=.005$). However, in the upper portion of the box, jute yielded lower desirable cover ($p=.007$).

On average, compost reduced desirable understory cover ($p=.041$), but had no effect on undesirable cover ($p=.370$). Compost had a greater effect on desirable species in the lower portion of the box than in the upper portion of the box ($p<.001$). Seeding under the compost significantly decreased the desirable cover ($p<.001$), but did not significantly increase undesirable cover ($p=.248$). However, in the upper portion of the box, seeding under the compost produced more desirable cover than in the lower portion of the box ($p<.001$).

Hydroseeding, as an erosion control treatment, significantly increased desirable cover ($p<.001$), but did not significantly affect undesirable cover ($p=.293$).

Flats and plugs on the top and toe increased both the desirable ($p<.001$) and undesirable cover ($p=.001$). Where flats were planted, as opposed to plugs, desirable cover increased ($p<.001$). Hydroseeding alone produced less desirable cover in the lower portion of the box ($p<.001$) as compared to flats and plugs but did not significantly affect undesirable cover ($p=.080$). Overall understory cover increased over time; however, the increase appeared to occur during the first month.

Table 7. Treatment Effects on Understory Cover*

Understory Cover	Desirable Cover		Undesirable Cover	
Treatment Type	Upper Slope	Lower Slope	Upper Slope	Lower Slope
EC Jute	↔	↓	↓	↓
EC Compost	↓↓	↓	↔	↔
EC Seed Under Compost	↓	↓↓	↔	↔
EC Hydroseeding	↑	↑	↔	↔
S Hydroseeding Alone	↔	↓	↔	↔
S Flats	↑↑	↑↑	↑	↑
S Plugs	↑	↑	↑	↑
Upper vs. Lower Box	↓	↑	↔	↔
Time	↑	↑	↑	↑

↑: Increases Cover ↓: Decreases Cover ↓↓ **or** ↑↑: Strong Effect ↔: No Noticeable Effect

*Table 7 serves as a guide to the statistical results for this experiment. It should be read horizontally to determine the effect of applying a particular treatment to bare soil. Individual sites should be evaluated prior to applications.

Understory Species Composition

Trend analysis indicates erosion control treatments affect the understory species composition (Figure 18). Control yielded NO vegetation at the understory level, demonstrating the need to seed desirable species to gain direct soil surface protection. Common Yarrow established best when seeded on compost, but performed well with no compost. Throughout all treatments, Common Yarrow dominated the species composition for the understory, covering up to 65 % of the soil surface.

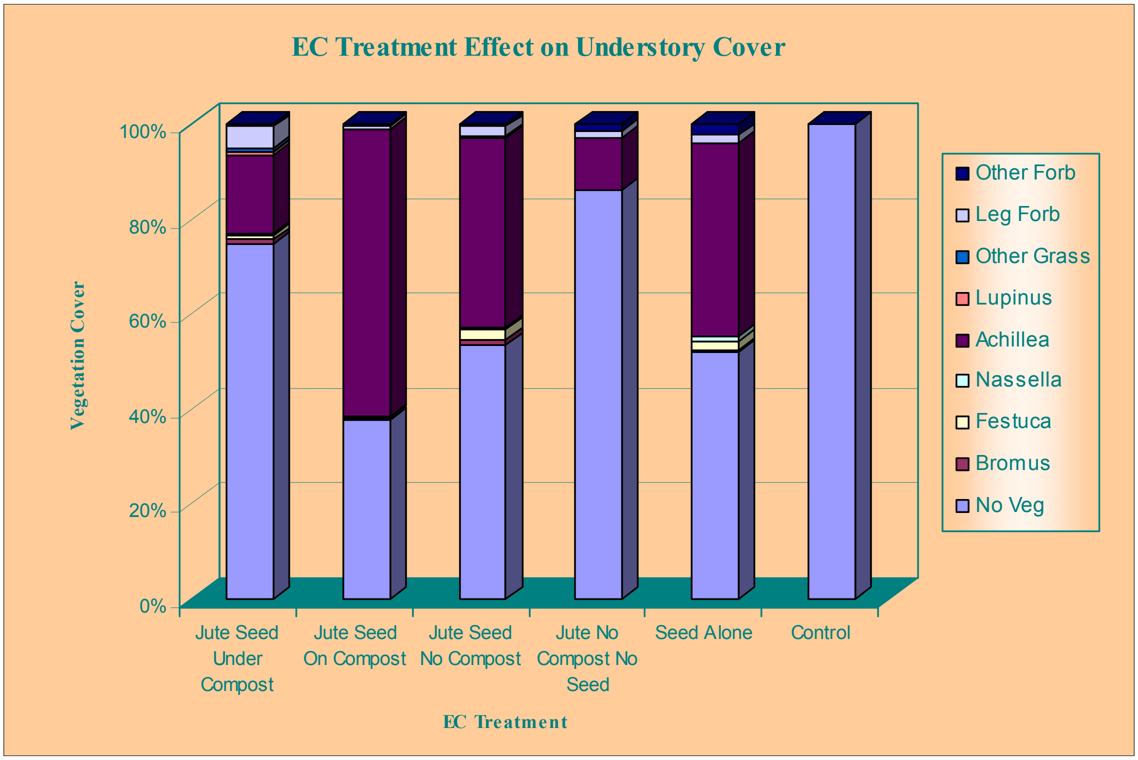

Figure 18. EC treatment effect on understory cover

Trend analysis indicates planting technique affected understory species composition; though not as dramatically as erosion control treatment. Flats on the top and toe produced the most cover (55 %), with plugs on the top and toe following (45 %) (Figure 19). Flats on the toe and plugs on the toe each produced 40 % vegetation cover. Hydroseeding alone produced 35 % vegetation cover, while control produced no understory cover. Common Yarrow grows readily in flats, which allows the plants to form a mat of vegetation over the soil surface.

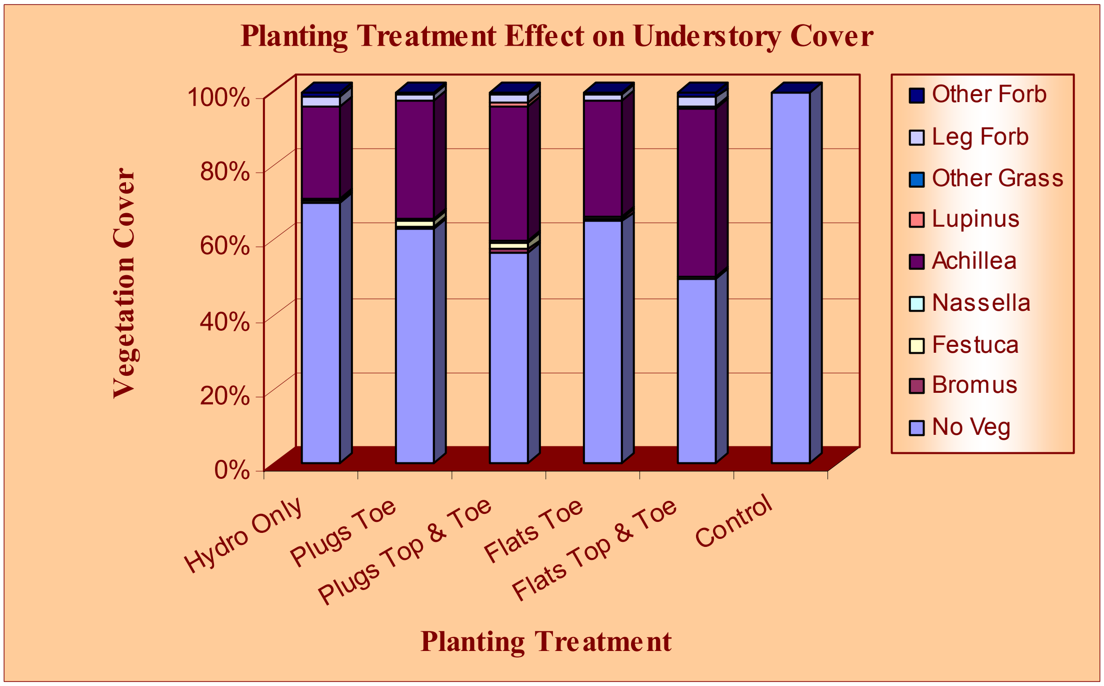

Figure 19. Planting treatment effect on understory cover

Overall Vegetation Cover

The interactions between erosion control treatments and planting techniques were extremely complex. Trend analysis demonstrated each combination produced at least 40 % cover, with seed alone and flats on the top and toe together producing the most overall cover at 92 % (Table 8, Figure 20). The second best combination was plugs on the top and toe and jute with seed and no compost together producing 84 % cover. Jute with seed under compost produced 44 % cover when combined with flats on the toe, and 48 % when combined with plugs on the toe, again demonstrating that thick applications of fiber, mulch, or compost may have inhibited the germination of plants in this experiment. Control yielded 59 % cover, which is better than some of the combinations of treatments. This cover, however, consisted of mainly undesirable plants, and no understory cover.

Table 8. Treatment Combination Results for Total Vegetation Cover

	Hydro Only	Plugs Toe	Plugs Top & Toe	Flats Toe	Flats Top & Toe	Control
Jute Seed Under Compost	63 %	48 %	65 %	44 %	65 %	n/a
Jute Seed On Compost	63 %	64 %	75 %	68 %	76 %	n/a
Jute Seed No Compost	58 %	73 %	84 %	70 %	69 %	n/a
Jute No Compost No Seed	47 %	66 %	63 %	57 %	53 %	n/a
Seed Alone	69 %	71 %	83 %	62 %	92 %	n/a
Control	n/a	n/a	n/a	n/a	n/a	59 %

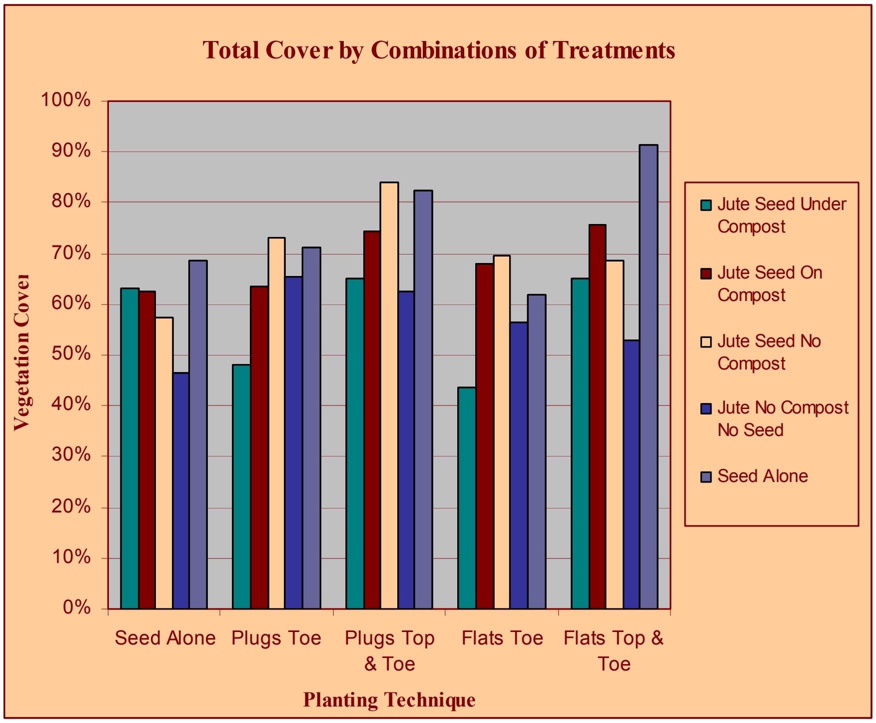

Figure 20. Overall cover by combinations of treatments

The sediment load increased as understory cover decreased (Figure 21). There appeared to be no clear direct relationship between overstory vegetation and sediment load. This suggests that although overstory cover is important for soil protection, understory cover has a more positive effect on soil stability and sediment filtration.

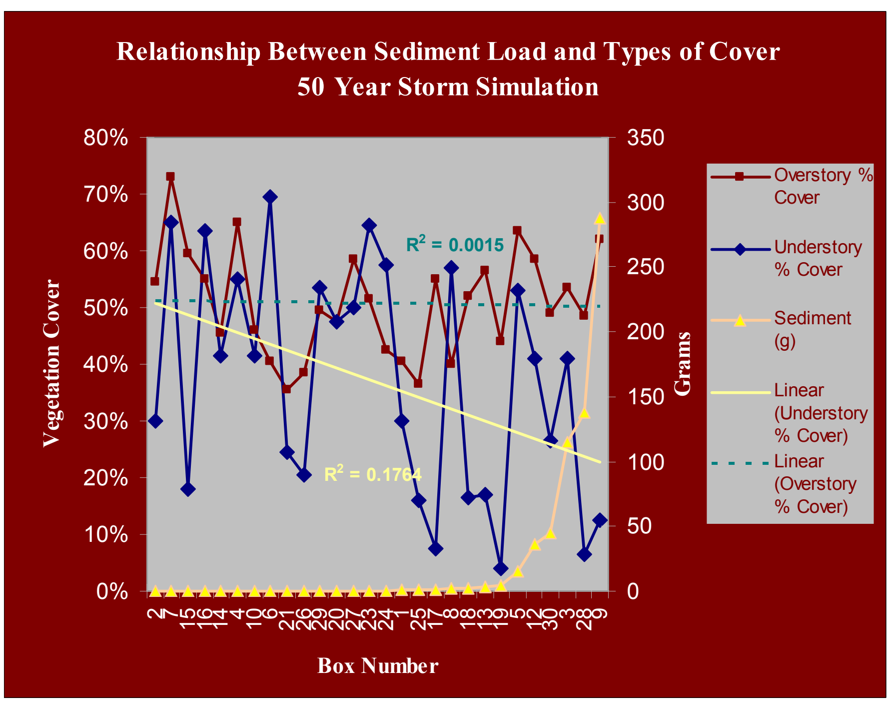

Figure 21. Relationship between sediment load and types of cover: 50-year storm

SECTION 5: CONCLUSION

All treatments improved water quality when compared to control. Jute combined with compost performed well as an erosion control treatment, producing little sediment and runoff. However, jute slightly decreased cover, whether desirable or undesirable. Compost did suppress understory weeds, but did not significantly promote the perennial natives. Weeds were able to compete when the natives were seeded under the compost. The germination of understory Common Yarrow was inhibited when seeded under the compost. This suggests that compost does not provide an advantage to the native plants seeded in this experiment and 5.08 cm (2 in) of material can actually inhibit germination of these species.

Additionally, pH was slightly affected by treatment types and combinations of treatments. Jute alone decreased pH, while compost increased pH. Changes could be important depending on water quality standards of receiving water bodies.

The installation of the native flats and plugs decreased sediment load and runoff, and improved perennial native cover. Flats consistently performed the best, whether planted on the top and toe or toe only, suggesting vigorous vegetation protection on the top and toe of a slope is crucial. Both native and undesirable cover established poorly on the upper portion of the boxes, which should be taken into consideration when establishing vegetation on slopes and planning irrigation regimes. When installed on the top and toe or toe only, plugs performed well and may be beneficial if access to sod is limited for a particular site.

Hydroseeding increased overstory and understory native cover when combined with flats and plugs. Hydroseeding alone decreased native cover. This indicates the pre-started vegetation, such as flats and plugs, offers increased infiltration and soil stability that enhance seed establishment and early plant growth. Results demonstrate that understory cover is critical for decreasing sediment load, however an adequate combination of understory and overstory vegetation is essential for improved water quality.

Flats on the top and toe, when combined with jute netting and hydroseeding applied mid-slope on compost, should perform the best for encouraging native plant establishment and minimizing soil erosion.

Soil conditions at all sites should be evaluated prior to plant installation. Specific species should be researched thoroughly to determine particular water and nutrient requirements. Natives of the particular region should be used, as these species are acclimated to the climate and conditions of the area.

SECTION 6: REFERENCES

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APPENDIX

Water Quality Statistical Analysis

Preliminary analyses suggest analyzing log(Total Water), log(Total Sediment) and log(Sediment Concentration) is more appropriate than direct measurements of Water, Sediment and Concentration. [Residuals were closer to normal … especially true of Total Sediment.]

Total Water

- ANOVA:
  - The two-way ANOVA with natural logarithm as response variable shows:

General Linear Model: logWater versus SeedTTT, ECTTT

Factor	Type	Levels	Values
SeedTTT	fixed	5	1 2 3 4 5
ECTTT	fixed	5	1 2 3 4 5

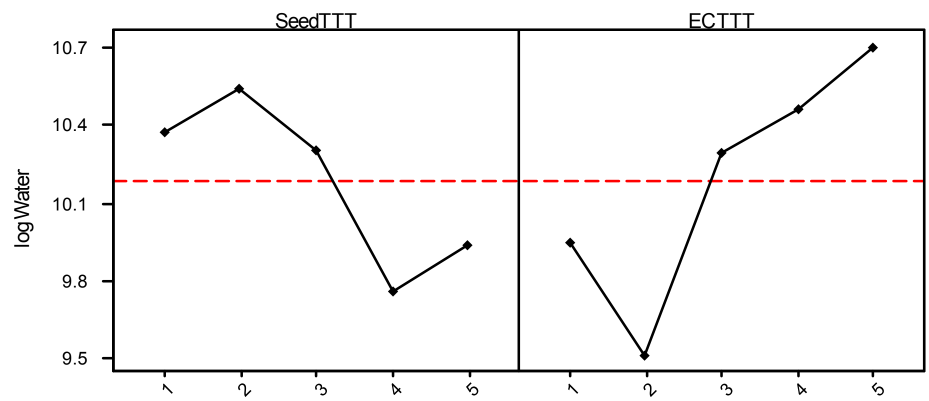
Analysis of Variance for logWater, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SeedTTT	4	2.10322	2.10322	0.52580	5.27	0.007
ECTTT	4	4.35862	4.35862	1.08965	10.92	0.000
Error	16	1.59710	1.59710	0.09982		
Total	24	8.05893				

Which indicates both an effect of seed treatment (p=.007) and of erosion control treatment (p<.001)

- A plot of the main effects:

Main Effects Plot - LS Means for logWater



- Seed Treatment Effect:

  - A Tukey post-hoc multiple comparison shows (at the 5% level) S4 has lower average total water than do S1 and S2.

S4 S5 S3 S1 S2

- EC Treatment Effects:

  - A Tukey post-hoc multiple comparison shows (at the 5% level) EC2 has lower average total water than do EC3, EC4 and EC5. Furthermore, EC1 has lower average total water than does EC5.

EC2 EC1 EC3 EC4 EC5

Total Sediment

- ANOVA
  - A two-way ANOVA with natural logarithm of total sediment as the response variable shows:

General Linear Model: logSediment versus SeedTTT, ECTTT

Factor	Type	Levels	Values
SeedTTT	fixed	5	1 2 3 4 5
ECTTT	fixed	5	1 2 3 4 5

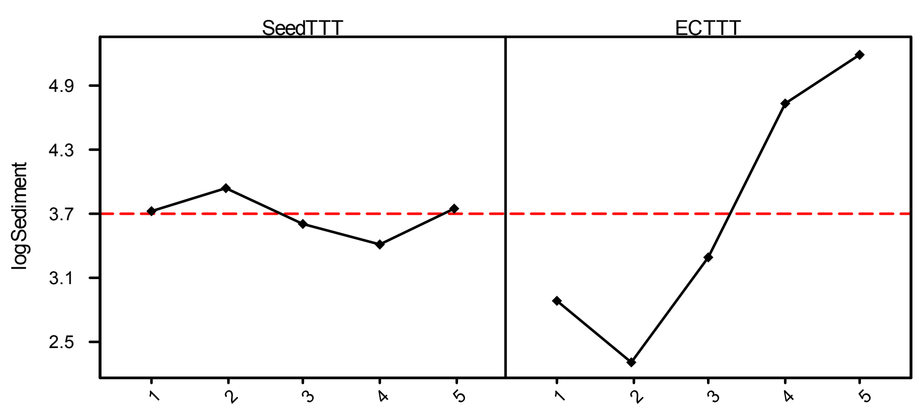
Analysis of Variance for logSedim, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SeedTTT	4	0.7219	0.7219	0.1805	0.64	0.639
ECTTT	4	29.9152	29.9152	7.4788	26.68	0.000
Error	16	4.4848	4.4848	0.2803		
Total	24	35.1219				

which indicates there is an effect of erosion control treatment on total sediment ($p<.001$) but there isn't a statistically significant effect of seed treatment on total sediment ($p=.639$).

  - A main effects plot:

Main Effects Plot - LS Means for logSediment



- EC Treatment Effect:
  - A Tukey post-hoc multiple comparison shows (at the 5% level) shows that erosion control treatments 2, 1 and 3 have lower total sediment than do erosion control treatments 4 and 5.

EC2 EC1 EC3 EC4 EC5

Sediment Concentration

- ANOVA
  - A two-way ANOVA with natural logarithm of total sediment as the response variable shows:

General Linear Model: logConcentration versus SeedTTT, ECTTT

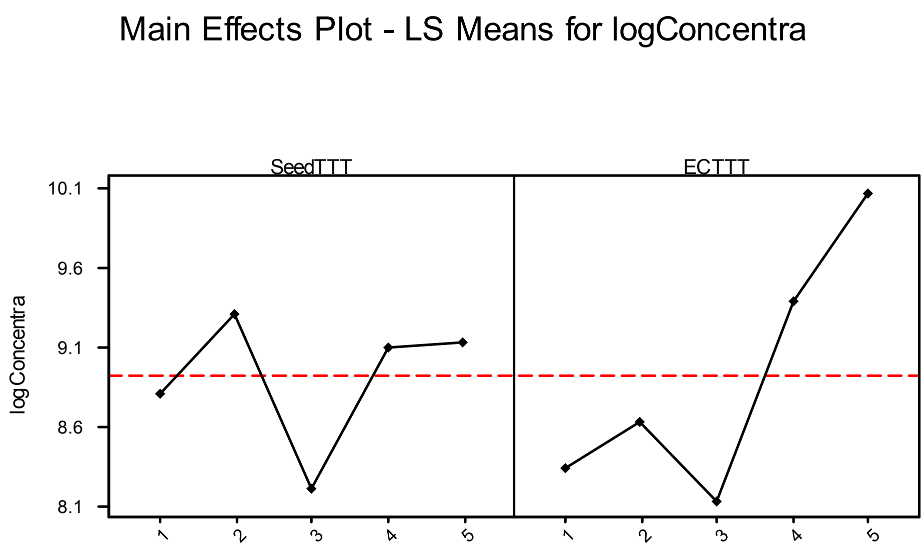
Factor	Type	Levels	Values
SeedTTT	fixed	5	1 2 3 4 5
ECTTT	fixed	5	1 2 3 4 5

Analysis of Variance for logConce, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SeedTTT	4	3.791	3.791	0.948	0.92	0.477
ECTTT	4	13.100	13.100	3.275	3.18	0.042
Error	16	16.502	16.502	1.031		
Total	24	33.392				

There is not a statistically significant effect of seed treatment on runoff concentration (p=.477) but there is for erosion control (p=.042).

  - A main effects plot:



- EC Treatment Effect
  - A Tukey post-hoc multiple comparison shows (at the 5% level) shows no individual differences as statistically significant.

EC3	EC1	EC2	EC4	EC5

Vegetation Cover Analysis

Overstory Statistical Results

Nominal Logistic Regression: O_Results versus Upper, Jute, ...

Response Information

Variable	Value	Count	
O_Result	0	2465	(Reference Event)
	2	1063	
	1	1345	
	Total	4873	

4873 cases were used

127 cases contained missing values

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Logit 1: (2/0)							
Constant	-1.2538	0.1044	-12.01	0.000			
Upper	-0.6800	0.1902	-3.58	0.000	0.51	0.35	0.74
Jute	-0.0782	0.1259	-0.62	0.535	0.92	0.72	1.18
Compost	-0.8537	0.1233	-6.92	0.000	0.43	0.33	0.54
Seeded	-0.4175	0.1121	-3.73	0.000	0.66	0.53	0.82
SeededUn	1.0897	0.1763	6.18	0.000	2.97	2.10	4.20
Flats	-0.07306	0.09221	-0.79	0.428	0.93	0.78	1.11
Top	0.27625	0.08765	3.15	0.002	1.32	1.11	1.57
HydroOnl	0.0437	0.1238	0.35	0.724	1.04	0.82	1.33
Flats*Top	0.0373	0.1840	0.20	0.839	1.04	0.72	1.49
Upper*Jute	-0.5463	0.2432	-2.25	0.025	0.58	0.36	0.93
Upper*Compost	-0.7414	0.2436	-3.04	0.002	0.48	0.30	0.77
Upper*Seeded	-1.2733	0.2180	-5.84	0.000	0.28	0.18	0.43
Upper*SeededUn	0.9138	0.3522	2.59	0.009	2.49	1.25	4.97
Upper*Flats	0.0500	0.1753	0.29	0.775	1.05	0.75	1.48
Upper*Top	-0.2566	0.1753	-1.46	0.143	0.77	0.55	1.09
Upper*HydroOnl	-0.2963	0.2460	-1.20	0.228	0.74	0.46	1.20
Upper*Flats*Top	0.5162	0.3506	1.47	0.141	1.68	0.84	3.33
DaysSinc	0.05326	0.01143	4.66	0.000	1.05	1.03	1.08
d2	-0.0008736	0.0002744	-3.18	0.001	1.00	1.00	1.00

```
Logit 2: (1/0)
Constant           -1.5157     0.1104   -13.73 0.000
Upper              -1.2170     0.2005    -6.07 0.000     0.30     0.20     0.44
Jute               -0.5841     0.1152    -5.07 0.000     0.56     0.44     0.70
Compost             0.0179     0.1010     0.18 0.859     1.02     0.84     1.24
Seeded              1.1920     0.1555     7.67 0.000     3.29     2.43     4.47
SeededUn           -0.2143     0.1138    -1.88 0.060     0.81     0.65     1.01
Flats             -0.55929    0.08772    -6.38 0.000     0.57     0.48     0.68
Top                0.17583    0.08406     2.09 0.036     1.19     1.01     1.41
HydroOnl           -0.1043     0.1172    -0.89 0.374     0.90     0.72     1.13
Flats*Top          -0.7660     0.1753    -4.37 0.000     0.46     0.33     0.66
Upper*Jute         -0.3655     0.2216    -1.65 0.099     0.69     0.45     1.07
Upper*Compost      -1.0261     0.1986    -5.17 0.000     0.36     0.24     0.53
Upper*Seeded        0.6046     0.3062     1.97 0.048     1.83     1.00     3.34
Upper*SeededUn      0.9608     0.2274     4.23 0.000     2.61     1.67     4.08
Upper*Flats        -0.1523     0.1678    -0.91 0.364     0.86     0.62     1.19
Upper*Top           0.3549     0.1678     2.12 0.034     1.43     1.03     1.98
Upper*HydroOnl      0.5175     0.2327     2.22 0.026     1.68     1.06     2.65
Upper*Flats*Top     0.0529     0.3357     0.16 0.875     1.05     0.55     2.04
DaysSinc           0.08545    0.01013     8.43 0.000     1.09     1.07     1.11
d2              -0.0014946  0.0002473    -6.04 0.000     1.00     1.00     1.00

Log-likelihood = -4438.938
Test that all slopes are zero: G = 1181.965, DF = 38, P-Value = 0.000

Goodness-of-Fit Tests

Method      Chi-Square    DF      P
Pearson        618.912   160  0.000
Deviance       663.123   160  0.000
```

Understory Statistical Results

Nominal Logistic Regression: U_Results versus Upper, Jute, ...

Response Information

Variable	Value	Count	
U_Result	0	3020	(Reference Event)
	2	166	
	1	1772	
	Total	4958	

4958 cases were used

42 cases contained missing values

Logistic Regression Table

Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	95% CI Upper
Logit 1: (2/0)							
Constant	-3.5865	0.2470	-14.52	0.000			
Upper	-0.3502	0.4119	-0.85	0.395	0.70	0.31	1.58
Jute	-0.7887	0.2813	-2.80	0.005	0.45	0.26	0.79
Compost	-0.2508	0.2799	-0.90	0.370	0.78	0.45	1.35
Seeded	0.3056	0.2908	1.05	0.293	1.36	0.77	2.40
SeededUn	0.4124	0.3572	1.15	0.248	1.51	0.75	3.04
Flats	-0.0127	0.2181	-0.06	0.954	0.99	0.64	1.51
Top	0.6618	0.2076	3.19	0.001	1.94	1.29	2.91
HydroOnl	0.4932	0.2820	1.75	0.080	1.64	0.94	2.85
Flats*Top	-0.0188	0.4438	-0.04	0.966	0.98	0.41	2.34
Upper*Jute	-0.5030	0.5336	-0.94	0.346	0.60	0.21	1.72
Upper*Compost	-0.4582	0.5450	-0.84	0.400	0.63	0.22	1.84
Upper*Seeded	-0.7521	0.5661	-1.33	0.184	0.47	0.16	1.43
Upper*SeededUn	-0.1547	0.7124	-0.22	0.828	0.86	0.21	3.46
Upper*Flats	0.8165	0.4083	2.00	0.046	2.26	1.02	5.04
Upper*Top	0.0799	0.4150	0.19	0.847	1.08	0.48	2.44
Upper*HydroOnl	0.7939	0.5583	1.42	0.155	2.21	0.74	6.61
Upper*Flats*Top	0.9792	0.8183	1.20	0.231	2.66	0.54	13.24
DaysSinc	0.17775	0.02359	7.54	0.000	1.19	1.14	1.25
d2	-0.0036407	0.0005673	-6.42	0.000	1.00	1.00	1.00

Logit 2: (1/0)

Constant	-1.8198	0.1031	-17.65	0.000			
Upper	-0.8581	0.1836	-4.67	0.000	0.42	0.30	0.61
Jute	-0.1053	0.1011	-1.04	0.298	0.90	0.74	1.10
Compost	-0.19635	0.09600	-2.05	0.041	0.82	0.68	0.99
Seeded	2.0210	0.1314	15.38	0.000	7.55	5.83	9.76
SeededUn	-2.3188	0.1301	-17.83	0.000	0.10	0.08	0.13
Flats	0.02713	0.08254	0.33	0.742	1.03	0.87	1.21
Top	0.63516	0.07939	8.00	0.000	1.89	1.62	2.21
HydroOnl	-0.4697	0.1180	-3.98	0.000	0.63	0.50	0.79
Flats*Top	0.3582	0.1653	2.17	0.030	1.43	1.03	1.98
Upper*Jute	-0.5222	0.1938	-2.69	0.007	0.59	0.41	0.87
Upper*Compost	-1.5290	0.1888	-8.10	0.000	0.22	0.15	0.31
Upper*Seeded	0.1648	0.2585	0.64	0.524	1.18	0.71	1.96
Upper*SeededUn	1.7916	0.2590	6.92	0.000	6.00	3.61	9.97
Upper*Flats	0.0413	0.1575	0.26	0.793	1.04	0.77	1.42
Upper*Top	0.9049	0.1581	5.72	0.000	2.47	1.81	3.37
Upper*HydroOnl	1.0929	0.2326	4.70	0.000	2.98	1.89	4.71
Upper*Flats*Top	0.6712	0.3151	2.13	0.033	1.96	1.06	3.63
DaysSinc	0.068041	0.009848	6.91	0.000	1.07	1.05	1.09
d2	-0.0011614	0.0002387	-4.87	0.000	1.00	1.00	1.00

Log-likelihood = -3052.219

Test that all slopes are zero: G = 1663.992, DF = 38, P-Value = 0.000

Goodness-of-Fit Tests

Method	Chi-Square	DF	P
Pearson	423.081	160	0.000
Deviance	421.546	160	0.000