TAHOMA SOIL BOXES SITE REPORT

May 2008

INTRODUCTION

This report describes monitoring and results for the Tahoma Soil Boxes. The Tahoma Soil Boxes are located on the west shore of Lake Tahoe, in Tahoma, California (Figure 1). Twelve soil boxes were constructed at the Hogan residence in Tahoma in 2003. Each box is roughly three feet (1 m) by three feet wide and approximately four feet deep (1.2 m). They are divided into three equally sized, independent sections such that there are three replicates of each treatment (Figure 2). Each box contains locally collected volcanic or granitic soil. Amendment types and rates and the presence of slow release fertilizer (Biosol) varied among boxes. Each box received the same amount and type of native seed.

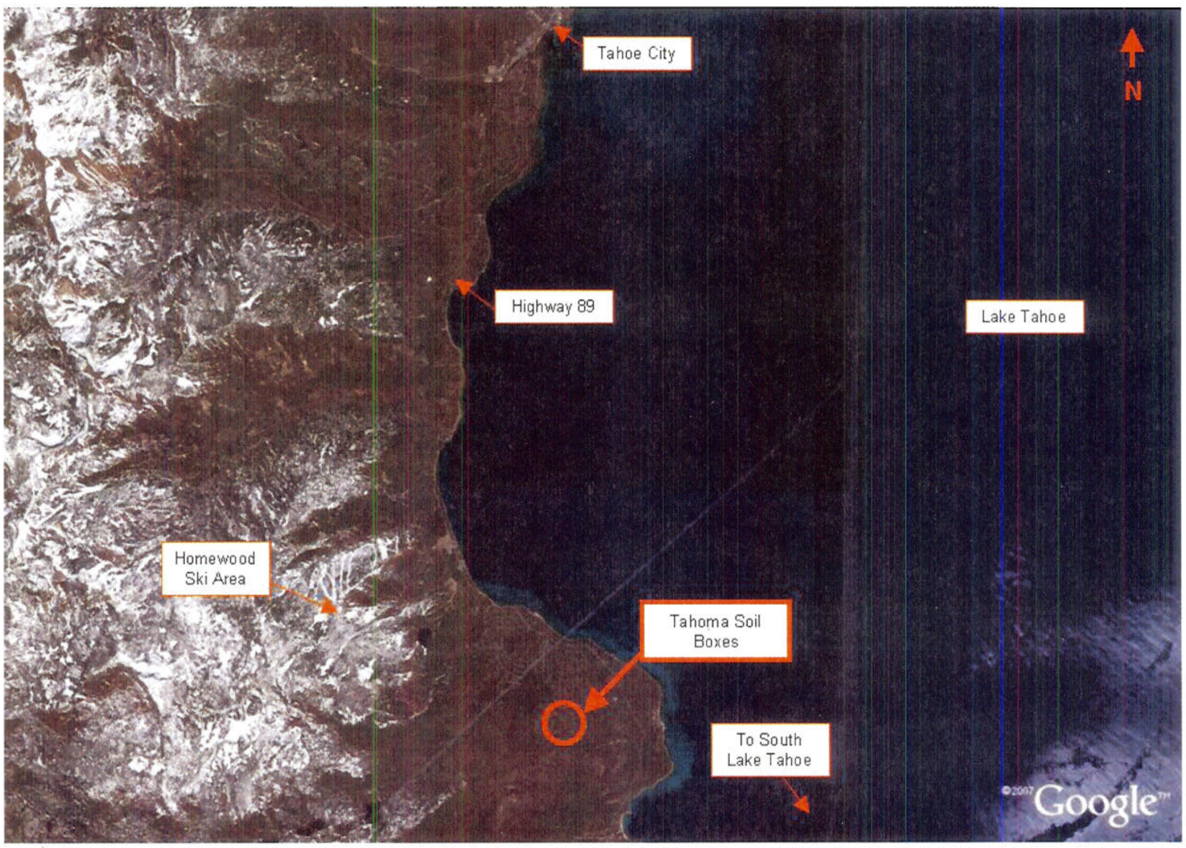


Figure 1. Tahoma Soil Boxes Site Location.

PURPOSE

The soil boxes provided a unique medium for study since each trial and replication is isolated from surrounding trials. In addition to penetrometer, soil moisture, biomass, and plant composition monitoring in 2006, the boxes were deconstructed in 2007 and additional data was collected from distinct layers: root mass, soil nutrient, and soil strength. The data was collected to determine whether differences existed in plant production and composition, soil nutrients levels, root density, and soil strength between five different treatment types. Amendment types and depths and the presence of Biosol varied between the five treatments (Figure 2). All treatments with amendments were tilled, seeded with native species, and mulched with pine needles.

The following research questions were addressed over the four-year monitoring period:

1. Is plant biomass affected by soil type, amendment type, or fertilizer application?
2. Is plant species composition affected by soil type, amendment type, or fertilizer application?
3. Is there a relationship between above ground biomass and root density? Can this difference be measured using the tools and methods employed in this study?
4. Is there a relationship between soil nutrient levels and either above ground biomass or root density?
5. Is there a relationship between root density and soil strength? Is this difference affected by soil type?
6. Is there a measurable difference between root density in volcanic or granitic soils by treatment and/or soil depth?
7. Is there a difference in soil nutrient levels by soil type, treatment type, and depth?
8. Is there a difference in soil density by soil type or treatment types?

SITE DESCRIPTION

Twelve soil boxes were constructed at the Hogan residence in Tahoma, California on the west shore of Lake Tahoe in 2003 (Figure 1). The site elevation is approximately 6,300 feet (1,920 m). The site location is within a moderately dense mixed conifer forest on the edge of a residential neighborhood. During the winter of 2004, box 8 was destroyed by a bear; therefore, 11 boxes were sampled in 2005 and 2006. During the winter of 2006 to 2007, box 10 was partially destroyed; therefore, only one replication could be sampled. The boxes lie on the southeast side of the house, and receive similar amounts of sunlight. Each box was roughly three feet (1 m) by three feet (1 m) wide and approximately four feet (1.2 m) deep. They were divided into three equal sized independent sections such that there are three replicates of each treatment (Figure 2).

TREATMENTS

The boxes were constructed from treated Douglas fir boards, held together with 4 by 4 inch (1.57 by 1.57 cm) Douglas fir posts. They are 3 by 3 feet wide (0.9 by 0.9 m) and at least 3.5 feet (1.1 m) tall. Each box was constructed with two dividers, leaving space for three replicates in each box. Half-inch square hardware cloth was placed in the bottom of each box so that ground-burrowing rodents could not enter the soil boxes. Landscape fabric was stapled to the inside of each box so that soil could not spill out. Soil was loaded into each box using a tractor.

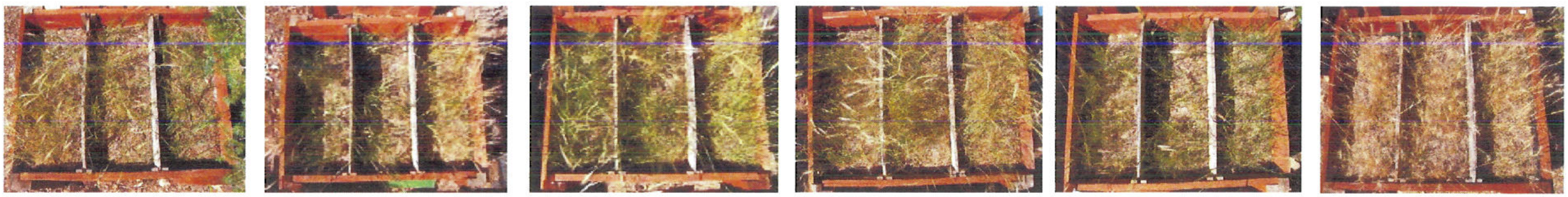
Boxes 4 and 10 were controls and did not receive Biosol fertilizer, compost, or coarse overs. Boxes 1 and 7 received Biosol only, and the rest of the boxes had a combination of coarse overs or compost and Biosol.

Soil Types and Sources

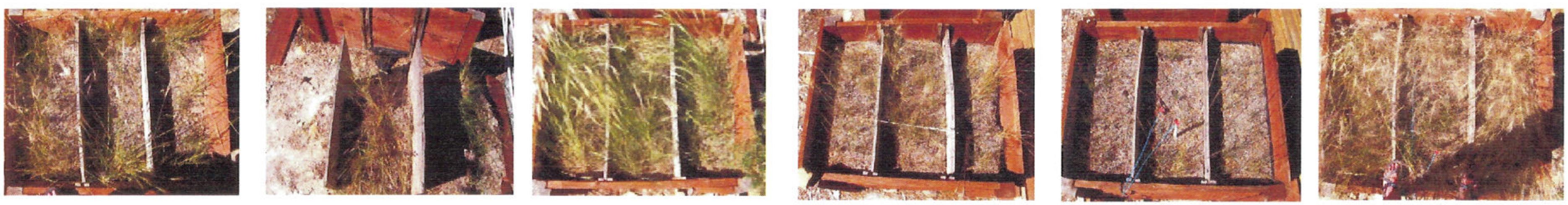
Two soil types commonly found in and around the Tahoe Basin were collected for this experiment. One is a Grus, collected from a cut slope on the west side of Highway 89, just south of the entrance to D.L. Bliss State Park (west shore of Lake Tahoe). This material is exfoliated from parent material and is classified as sand with 89% sand, 4% silt and 7% clay. This soil is referred to in this report as "granitic soil". The other soil collected is of volcanic material parent material from the bottom of the Martis Ski Run at the Northstar-at-Tahoe Ski Resort. It is waste material scraped from a road turn out. Soil particle analysis classified the soil as a sandy clay loam with 47% sand, 24% silt, and 29% clay. This soil is referred to as "volcanic soil" in this report. The amount of raw soil added to each box differed depending on the amount of amendments to be added. Regardless of amendment volume, the soil and amendment combination volume in all boxes was the same prior to tilling, soil settlement, and plant growth. Half the boxes received Grus granitic soil and half received the volcanic soil. The placement of soils in each box was randomized. A sample of each soil load that came in for the construction of the boxes was sent to A&L Laboratories (Modesto, CA) for nutrient analysis (Table 1).

Figure 2. Tahoma Soil Boxes, July, 2006. Layout with Box Number, Soil Type, and Treatment Type. Biosol (fertilizer) spread at a rate of 2000 kg/ha. Box 8 was not sampled in 2005 or 2006. Only one replication of Box 10 was sampled in 2007.

#1 Granitic: 2" Compost + Biosol | #2 Volcanic: 6" Coarse overs + Biosol | #3 Volcanic: 6" Compost + Biosol | #4 Granitic: 6" Compost + Biosol | #5 Volcanic: Biosol | #6 Granitic" 6" Compost + Biosol



#7 Volcanic control | *#8 Granitic: 6" Coarse overs + Biosol* | #9 Volcanic: 6" Compost + Biosol | #10 Granitic: Biosol | #11 Granitic control | #12 Volcanic: 2" Compost + Biosol



* Box 8 was destroyed by bears

Table 1. Initial Soil nutrient data soils boxes, Tahoma CA, 2004.

Sample	TKN	OM	NO_3	P (wb)	P (Na-ext)	K	Mg	Ca	Na	S	Zn	Mn	Fe	Cu	B	pH
VNS13 Volcanic	734	5.1	10	26	16	296	147	786	15	1	0.4	72	22	0.2	0.4	5.9
VNS11 Volcanic	704	4.4	10	26	10	261	131	716	13	1	0.3	54	23	0.1	0.4	5.9
VNS12 Volcanic	677	4.9	10	35	18	256	129	690	23	1	0.3	57	24	0.1	0.2	5.8
VNS14 Volcanic	645	4.1	7	11	8	368	220	1095	36	12	0.5	12	12	2.1	0.2	5.8
DLBG2 Granitic	96	0.4	6	10	7	45	10	168	43	2	0.4	17	20	0.5	0.1	6.3
DLBG1 Granitic	83	0.2	7	9	8	34	10	181	60	3	0.8	15	28	1.5	0.1	6.3

wb = weak bray method, Na-ext = Sodium extractable method

Soil Amendments

Two different soil amendments (compost and coarse overs) were spread at two different depths: 2 inches (5.1 cm) or 6 inches (15.2 cm). Both the compost and coarse overs were obtained from Full Circle Compost (Minden, NV).

Compost

Integrated Tahoe Blend 75% was the selected compost blend from Full Circle Compost. It contains 75% humus fines with a diameter of less than 3/8 inch (1cm) and 25% coarse overs that range in diameter from 3/8 of an inch to 3 inches (7.6 cm). Coarse overs are the woody material that remains after the composting process, after all the fine compost material is screened. Compost was applied at two depths; 2 inches (5.1 cm), with a nitrogen equivalent of approximately 1,784 lbs N/acre (2,000 kg/ha) and 6 inches (15.2 cm), with a nitrogen equivalent of approximately 5,353 lbs N/acre (6,000 kg/ha).

Coarse overs

Coarse overs are the woody materials remaining after the composting process that range in size from 3/8 of an inch (5.1 cm) to 3 inches (7.6 cm). Six inches (15.2cm) of coarse overs were applied at a nitrogen equivalent of approximately 3,500 lbs N/acre (4,000 kg/ha).

Fertilizer

Specific boxes were fertilized at 1,784 lbs of organic Biosol fertilizer/acre (2,000 kg/ha) at a 6% nitrogen content.

Seed

A seed mixture composed of the native bunchgrasses Mountain brome (*Bromus carinatus*), Squirreltail (*Elymus elymoides*), Blue wildrye (*Elymus glaucus*), and Western needlegrass (*Achnatherum occidentalis*) was applied to each box at a rate of 125 1bs/acre (112 kg/ha) (Table 2).

Table 2. Seed mix composition.

Species	% in mix	Portion Viable	Pure Live Seed (PLS)
Mountain brome	29.01	0.87	25.2
Squirreltail	26.56	0.95	25.2
Blue wild rye	24.58	0.77	18.9
Western needlegrass	12.62	0.75	9.5
Total	92.77*		78.9

* the remainder is inert material.

Mulch

Pine needles, from the Caltrans storage yard near the south shore of Lake Tahoe, were used as surface mulch in the soil boxes. The pine needles were applied on the surface of each soil box to an approximate depth of 2 inches (5 cm).

Additional Treatment Information

Aeration/Tilling

After either compost or coarse overs were applied to the soil surface, each replicate was hand tilled to a minimum depth of 18 inches (46 cm) using a sharp shooter shovel.

Irrigation

Boxes 10, 11, and 12 received some over-spray from Hogan's garden irrigation in 2004. Additional germination was not noted at these boxes, and this irrigation was not present in 2005 and 2006. None of the other boxes received irrigation.

MONITORING METHODS

Cover and Biomass Sampling

Plant biomass was sampled at the Tahoma soil boxes in August of 2005, 2006 and 2007. The above ground plant biomass was clipped according to normal protocols.[1] The biomass was placed in paper bags and air dried before weighing. In 2005 and 2006, photos were taken of each of the 12 soil boxes prior to sampling. In 2006 and 2007, total foliar cover and cover composition by species was estimated ocularly.

Soil Physical Conditions

Soil Density

The penetrometer depth to resistance (DTR) is often used as an index of soil density because a denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10 cm).[2]

Soil density measurements were collected in 2005, 2006, and 2007 with a cone penetrometer. The cone penetrometer, which had a ½ inch diameter tip was pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (2,411 kPa) was reached (Figure 3 and Figure 4). The depth, in inches, at that pressure was recorded as the depth to refusal (DTR).

Soil Moisture

In 2006, a hydrometer was used to measure volumetric soil moisture content at a depth of 4.7 inches (12 cm). Nine measurements of soil density and soil moisture were recorded per box; three per replication. In 2007, the hydrometer was used to sample each layer during deconstruction (see soil strength section).

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[1] Hogan, Michael. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. 2003. South Lake Tahoe, CA, Lahontan Regional Water Quality Control Board

[2] Grismer, M. Simulated Rainfall Evaluation at Sun River and Mt Bachelor Highways, Oregon. Unpublished.

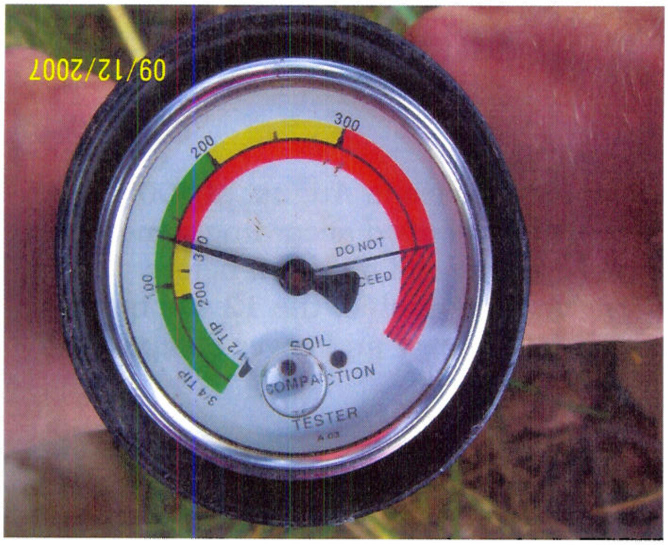

Figure 3. Cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 4. Conducting cone penetrometer readings in the field. The same tool was used to sample the soil boxes.

Soil Strength

Soil strength was measured in 2007, when the boxes were dismantled. The depth of soil per box varied from 33 to 44 inches (84 to 112 cm) since different levels of settling occurred. There were between three and four soil layers per box. Lower soil layers were 9 to 11 inches (23 to 28 cm) deep. The top layer varied in depth from 3 to 9 inches (7.6 to 23 cm), depending the degree of settling. Soil moisture and soil shear strength were recorded in each box for each replication by soil layer (Figure 5, Figure 6 and Figure 7). Three measurements of soil shear strength and soil moisture were taken for each replication at each layer making 9 measurements per soil layer: 3 per replication.

To measure soil strength, the hand-held shear vane with 1.5 inch (38 mm) long blades was pushed into the soil to a depth of 3 inches (76 mm). The shear vane was then turned until the soil could no longer resist the force exerted by the blades and the soil structure either fractured or deformed. This force was then recorded as the "shear stress" in kilopascals (kPa). The shear vane only records shear strength values up to 40 kPa. When the soil resisted this force greater than 40 kPa, it was notes that the actual value exceeded 40 kPa.

Figure 5. Conducting soil moisture readings.

Figure 6. Shear vane soil shear strength tester in use.

Figure 7. Shear vane, side view.

This method of determining shear strength has been used regularly in agricultural soils and various laboratory tests.[3] This method of testing soil shear strength has not been applied to many forest soils. If the soil was too compacted to insert either the shear vane or the soil moisture probe without damaging the instruments, data was not collected. This commonly occurred in layers 3 and 4 at a depth of 24 and 36 inches for volcanic soils and a depth of 36 inches for granitic soils. At the top layer, all mulch or loose organic material was moved aside before sampling.

Soil Nutrient and Root Density Sampling

Soil samples were collected for nutrient and root density analysis. In most cases, the top three to four inches (7.6 to 10.2 cm) were sampled to determine if there was a difference in nutrient levels within this top layer. The remaining soil sample layers were between 9 and 11 inches (23 to 28 cm) deep (Figure 8 and Figure 9). The exact depth of each layer was noted during sampling as well as any important characteristics such as the presence of roots, fungus or other visible soil flora or fauna, woody organic material, rocks, or visible soil moisture. Three equally sized soil samples totaling at least 122 cubic inches (2 liters) were collected for soil nutrient analysis from each replication. Once dried, each soil nutrient sample was sieved to remove any material larger than 0.08 inches (2 mm) in diameter, and sent to A&L Laboratories for S3C nutrient sampling, total Kjeldahl nitrogen (TKN), and organic matter analysis.

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[3] Tengbeh, G.T. 1993. The Effect of Grass Roots on Shear Strength Variations with Moisture Content. *Soil Technology*. Vol. 6. pp. 287-295.

Figure 8. Granitic soil layer at 22 inches deep. The top 2 layers have been removed.

Figure 9. Root and soil moisture profile in volcanic soil monolith, 33 inches deep, This box was divided into three layers for sampling.

During the soil nutrient sampling, an additional 122 cubic inches (2 liters) of soil, in three discrete samples, were collected for root density sampling. For each root density sample, the exact soil volume was recorded to calculate the root density per unit volume. Soil volume rather than weight was measured because volume remains constant with increasing soil moisture, while weight increases with increasing soil moisture.[4] The soil collected for sampling root density was then passed through a 0.08 inch (2 mm) and 0.04 inch (1 mm) sieve, removing any organic material, large fragments, fungal material, and roots. Soil clods were manually broken up before roots were extracted.

The methods used for extracting roots generally followed those employed by Tengbeh.[5] Root extraction methods varied slightly depending on the amount of soil clods present in the sample. In soils that had few clods, roots were removed from the dry soil, which passed through a 0.0083 inch (212 µm) sieve. Small clods were manually broken up to ensure roots in the clods were removed. The roots, which were fine to medium in size, were removed with tweezers and set aside to soak. The soaking dislodged any fine particles or fungus remaining on the roots. After drying, the roots were weighed. Removal of very fine roots that could not be picked up with a tweezers was not practical. In soils with many clods, some roots were removed from dry soil, but most roots were removed after the soil was saturated and the clods dissolved. Roots were then soaked to remove fine particles or fungus and dried.

All roots were dried at air temperature for at least a week before being weighed. Roots were weighed using a Mettler Toledo AE240 balance to an accuracy of 1 milligram. Each sample was placed on a weighing boat, and the balance was

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[4] Tengbeh, G.T. 1993. The Effect of Grass Roots on Shear Strength Variations with Moisture Content. *Soil Technology.* Vol. 6. pp. 287-295.

[5] Ibid. pp. 287-295.

zeroed between each measurement. Photos of several root samples prepared for weighing are shown below (Figure 10, Figure 11, and Figure 12).

Figure 10. Root sample 5R3L1, collected from box 5, a volcanic soil with 2,000 kg/ha of Biosol and no organic amendment, at a depth of 0 – 11 inches.

Figure 11. Root sample 5R3L2, collected from the same box at a depth of 12 – 23 inches.

Figure 12. Root sample 5R3L3, collected from the same box at a depth of 24 – 35 inches.

Statistical Analysis

Several different statistical tests were used to determine differences among treatments. The type of test employed depended on the number of variables tested and the normality of the data. Initially, an Analysis of Variance (ANOVA) was used to investigate differences between groups of data. An ANOVA sorts data by groups (example amendment type - tub grindings, compost, or no amendment). ANOVA is typically used with three or more groups.[6]

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[6] Zar, J.H. Biostatistical Analysis 4th Edition 1999. Prentice Hall Press, Upper Saddle River, New Jersey.

If a difference was detected using the ANOVA test, the student's t-test or the Mann-Whitney test was used to further investigate differences between two sub-groups or sample sets within the larger group. The Mann-Whitney test is a non-parametric test that can be applied to data sets with non-normal distributions. Non-normal distributions are common within small data sets. Some of the sample sizes for the Tahoma soil boxes were small (n = 3), making it necessary to use a non-parametric test. Linear regression was used to investigate possible relationships between variables along a continuum, such as plant biomass and soil nutrient levels. Significant results are presented in the tables below.

RESULTS

Biomass

This section presents results that were common to both granitic and volcanic soils. Each soil type will then be considered separately in the sections following this one.

Volcanic soils produced at least twice the biomass than granitic soils (Figure 15, Figure 16 and Table 3). The average biomass for granitic soils was 37 grams, while the average biomass of volcanic soils was 86 grams. This suggests separate target plant cover levels for each soil type.

Above ground biomass was not correlated with root biomass in either granitic or volcanic soils (Figure 13 and Figure 14). Therefore, biomass or plant cover cannot be used as an indicator of soil strength provided by plant roots. Plant cover, which is currently used as a measure of treatment success, therefore, cannot be used as the sole indicator of overall soil condition or strength.

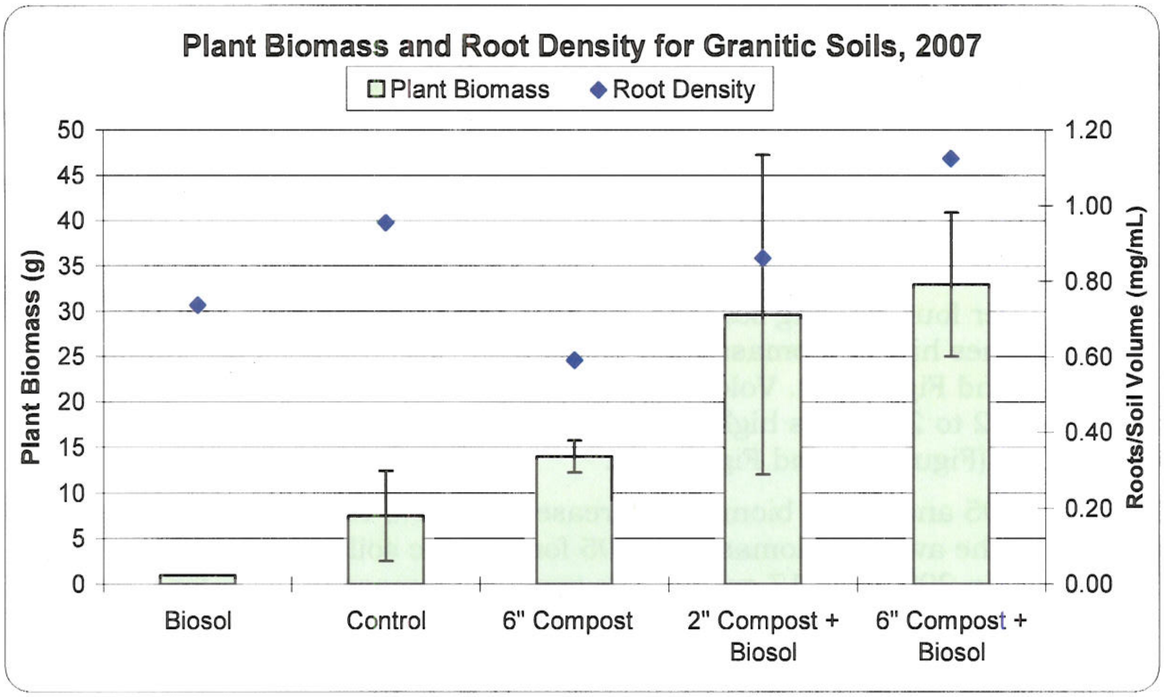

Figure 13. Plant Biomass and Root Density for Granitic Soils, 2007. A pattern was not observed between biomass and root density. Root density is averaged over all soil layers.

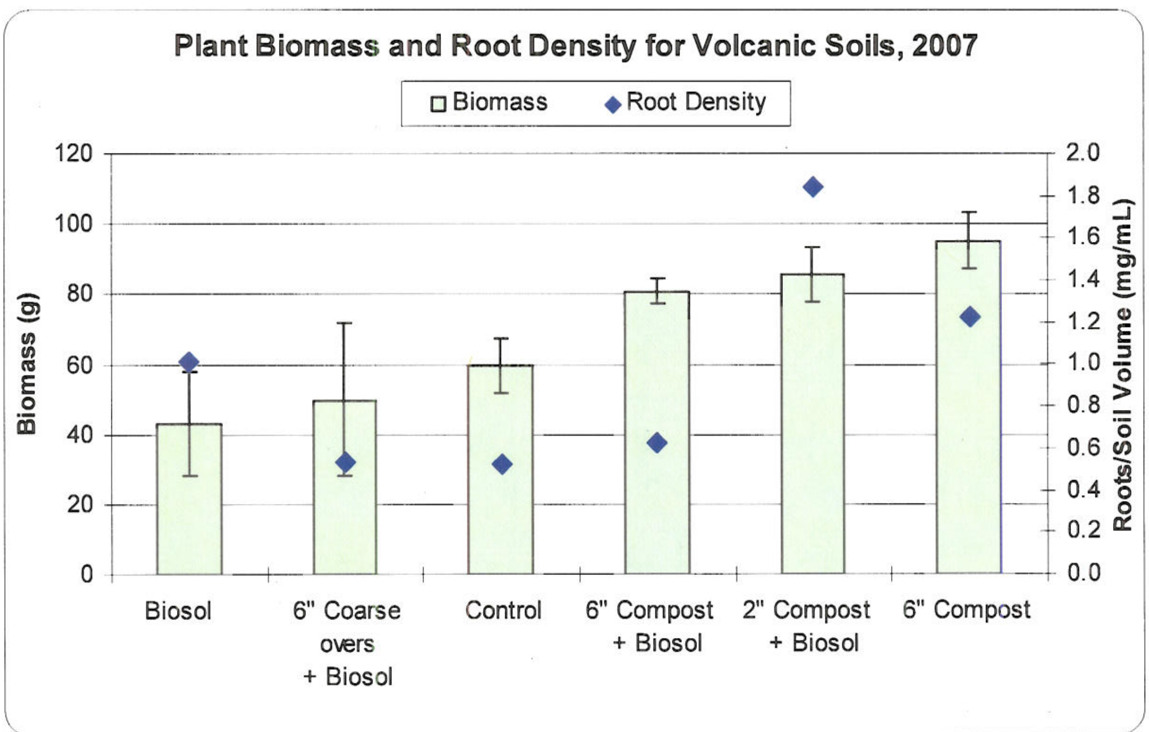

Figure 14. Plant Biomass and Root Density for Volcanic Soils, 2007. The two treatments that produced the highest biomass had the highest root density. Root density is averaged over all soil layers.

Over 3 seasons, granitic soils amended with compost resulted in an average of 1.5 times higher plant biomass than at the control (Figure 15 and Table 3). Volcanic soils amended with compost or coarse overs had and an average of 4 times higher plant biomass than at the control (Figure 16 and Table 3). The three year average biomass for treated granitic boxes was 43 grams, while the control supported 10 grams of biomass. The three year average biomass for treated volcanic boxes was 91 grams, while the average biomass for the control was 61 grams.

In 2007, after four growing seasons, granitic soil amended with compost had 7.5 to 33 times higher biomass than boxes with Biosol, but no amendment (Figure 13 and Figure 15). Volcanic soils amended with compost or coarse overs had 1.2 to 2.2 times higher biomass than boxes with Biosol, but no amendment (Figure 14 and Figure 16).

Between 2005 and 2007, biomass decreased from 1.6 to 3.1 times at all of the soil boxes. The average biomass in 2005 for granitic soils was 52 grams, while the average in 2007 was 17 grams. The average biomass in 2005 for volcanic soils was 110 grams, which decreased to 69 grams in 2007.

With both soil types, the addition of fertilizer (Biosol) alone resulted in high second year plant biomass followed by a decline in biomass over the three sampling years (Figure 15 and Figure 16). This decline was greatest for granitic treatments with Biosol only. Granitic soil boxes with Biosol only had 14 times higher plant cover in the second year compared to the control.

In 2007, after four growing seasons, Biosol only treatments produced 1.4 to 8 times less biomass than the control in both volcanic and granitic soils. The granitic control produced 8 grams of biomass, while the granitic Biosol only treatment produced 1 gram of biomass. The volcanic control produced 60 grams of biomass, while the granitic Biosol only treatment produced 43 grams of Biomass.

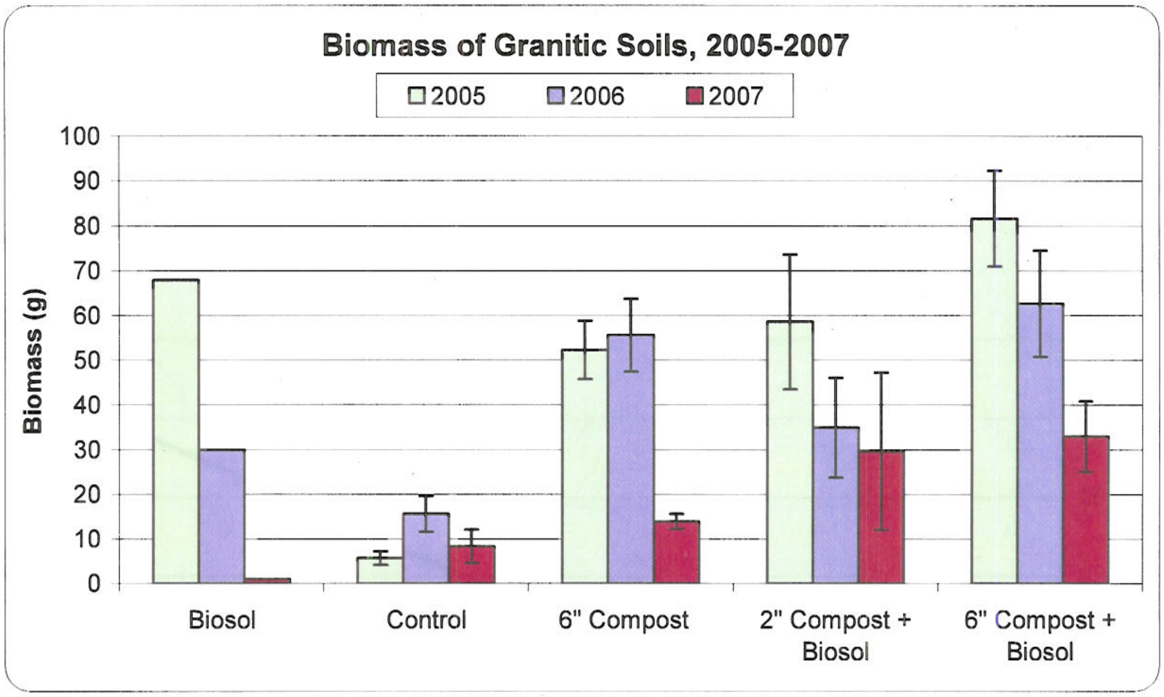

Figure 15. Biomass of Granitic Soils, 2005-2007. In all years, all treatments had higher biomass than the control, except for the Biosol only treatment in 2007. There is a sharp decline in biomass for the Biosol only treatment. Error bars denote one standard deviation above and below the mean. Only one replication of the Biosol box was intact, therefore, a standard deviation was not calculated for this plot.

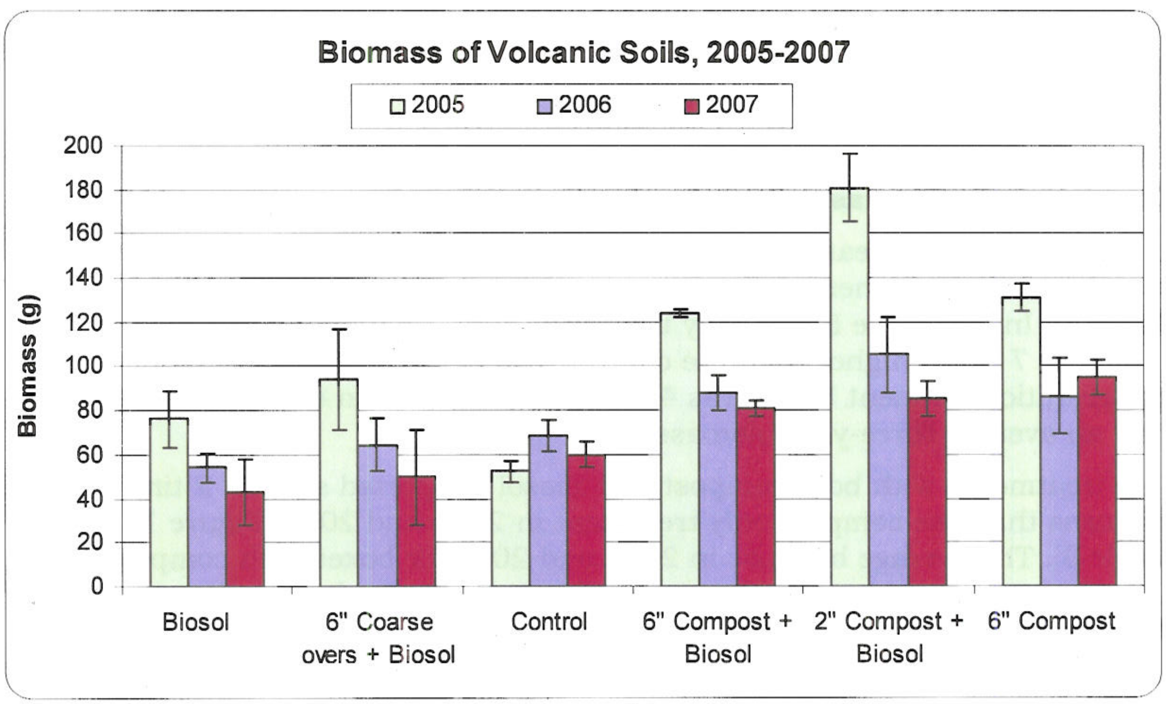

Figure 16. Biomass of Volcanic Soils, 2005-2007. Regardless of treatment, volcanic soils produced at least 50% more biomass than granitic soils. Error bars denote one standard deviation above and below the mean. Graph sorted by 2007 biomass.

As shown by linear regression, higher soil nitrogen levels were correlated with greater plant biomass in both granitic and volcanic soils in 2007 (Figure 17). This supports previous work which linked soil nitrogen to vegetation response in disturbed sites.[7]

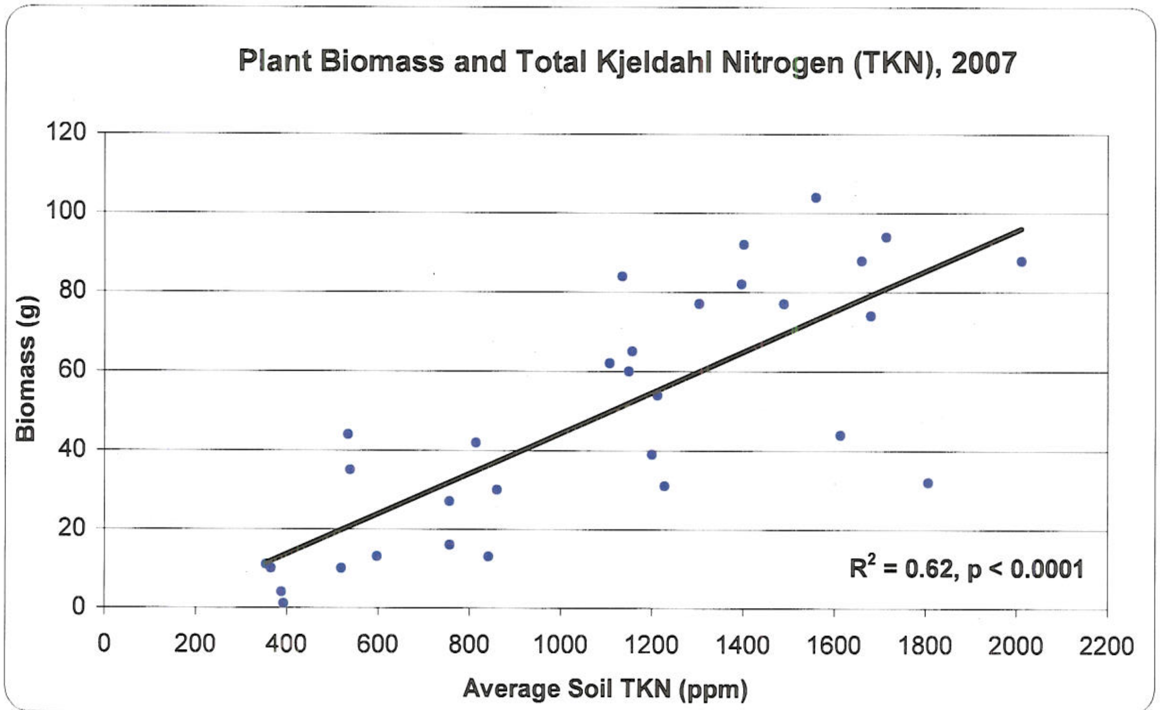

Figure 17. Plant Biomass Related to Total Kjeldahl Nitrogen (TKN) 2007. Plant biomass increases with increasing TKN (R^2 = 0.62 and $p < 0.0001$).

Granitic Soils Biomass

Second and fourth season biomass (2005 and 2007) in the granitic soil boxes was 2 to 8 times higher in all treatments than at the control (Figure 15 and Table 3). In 2005, the Biosol only treatment supported among the highest biomass, 7 times higher than the control. The three-year average biomass for the granitic treatment boxes was 43 grams, compared to the control plot, which had an average three-year biomass of 10 grams.

The treatments with both compost and Biosol supported at least 2 times more biomass than the compost only treatment in 2005 and 2007 (Figure 15 and Table 3). The average biomass in 2005 and 2007 for boxes with compost and Biosol was 51 grams, while the compost only treatment had an average biomass of 14 grams.

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[7] Claassen, V. P. and Hogan, M. P. Soil Nutrients Associated with Revegetation of Disturbed Sites in the Lake Tahoe Basin. Restoration Ecology. 2002 Jun; 10(2):195-203.

In the fourth growing season (2007), treatments with compost or compost and Biosol maintained plant biomass that was 1.7 to 4.1 times higher than the biomass at the control and up to 15 times higher than the treatment with Biosol only (Figure 15 and Table 3). The average biomass in 2007 for the compost treatment boxes was 26 grams, while the control box had an average biomass of 8 grams. In 2007, biomass in the Biosol only treatment dropped below that of the control. However, only one intact replication made it impossible to determine the statistical significance of this difference.

Volcanic Soil Biomass

In 2005 and 2006, biomass for all volcanic treatments equaled or exceeded that of the control by an average of 1.6 times (Table 3 and Figure 16). The two-year average biomass for treated volcanic soils was 100 grams, while the two-year average for the control was 61 grams. The magnitude of this difference was not as great as for the granitic soils, which in some cases had over 10 times more biomass than the control (Figure 15).

In 2005, the treatment with 2 inches of compost and Biosol produced 1.7 times more biomass than the other treatments, 1.4 to 1.5 times more biomass than the 6 inch compost boxes, and 3 times higher than the control (Table 3 and Figure 16.). The average biomass for the 2 inches of compost and Biosol treatment was 181 grams, compared to the average for the other treatments, which was 107 grams, and the 6 inch compost treatment, which ranged from 124 to 131 grams. The average biomass from the control was 60 grams.

The compost treatments produced up to 1.6 times more biomass than the control in 2007 (Figure 16.). The compost only treatment produced an average biomass of 87 grams, while the control box had an average biomass of 60 grams, and the other treatments had an average biomass of 47 grams.

In volcanic soils, average biomass at boxes with compost was 1.4 times higher during all growing seasons than biomass at boxes with coarse overs (98 grams compared to 70 grams, Figure 16)

In 2007, in volcanic soils, biomass at boxes with Biosol only was 1.2 to 2 times lower than at boxes with Biosol and an amendment (Figure 14).

Table 3. Results of Statistical Tests for Biomass

Test	Variables and Factors tested	Test statistic*
Student t -test	2005 Biomass (n=31) vs. 2006 Biomass (n=31)	t = 4.348
Student t -test	2005 Biomass (n=31) vs. 2007 Biomass (n=31)	t = 6.629
Student t -test	2006 Biomass (n=31) vs. 2007 Biomass (n=31)	t = 4.313
ANOVA	2007 Biomass Soil Type	$F_{1,29} = 24.7$
ANOVA	2006 Biomass Soil Type	$F_{1,29} = 24.7$
Linear regression	2006 Biomass (n=31) vs. 2007 Biomass (n=31)	$R^2 = 0.65$
ANOVA	2006 Biomass Granitic Soils by Treatment	$F_{3,8} = 8.38$
ANOVA	2006 Biomass Volcanic Soils by Treatment	$F_{5,12} = 7.2$
ANOVA	2007 Biomass Granitic Soils by Treatment	$F_{3,8} = 3.53$**
Mann-Whitney	2006 Biomass Granitic Control (n = 3) vs. Biomass Granitic Treated (n=9)	U = 27
Mann-Whitney	2006 Biomass Granitic 2K B&C (n=3) vs. Biomass Granitic 6K B&C (n=3)	U = 9 **
Mann-Whitney	2006 Biomass Granitic 2K B&C (n=3) vs. Biomass Granitic 6K Compost (n=3)	U = 9 **
Mann-Whitney	2007 Biomass Volcanic Soils no compost (n = 9) vs. Biomass compost (n=9)	U = 81
Mann-Whitney	2007 Biomass Granitic Soils Compost and Biosol (n=6) vs. No Biosol (n=6)	U = 31.5†
Mann-Whitney	2006 Biomass Volcanic Soils no compost (n = 9) vs. Biomass compost (n=9)	U = 78.5

* Results are significant at > 99% † Results are significant at > 95% ** Results significant at > 90%

Species Composition

Ocular estimates of plant cover and above ground plant biomass were positively correlated; indicating that at the soil boxes, ocular estimation of foliar cover is a surrogate for plant biomass measurement (Figure 18 and Figure 19).

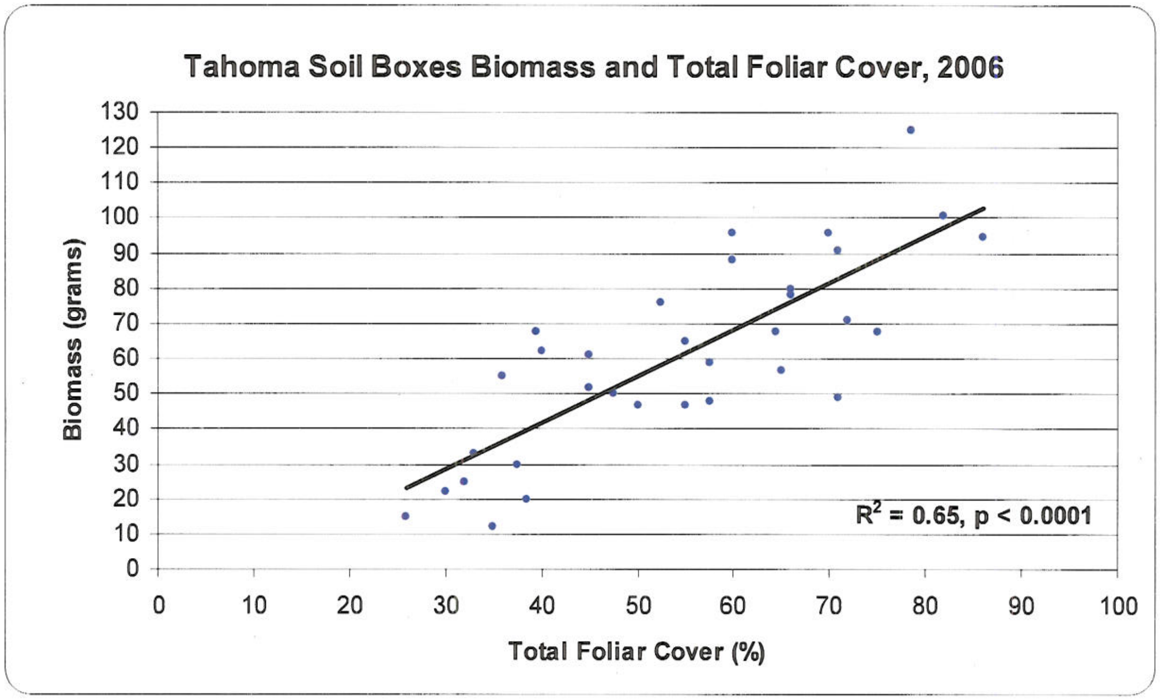

Figure 18. Soil Boxes Biomass and Total Foliar Cover, 2006. The variability in foliar cover is well correlated to the variability in biomass, indicating that estimated foliar cover may be a good surrogate measurement for biomass ($R^2 = 0.65$, $p < 0.0001$.

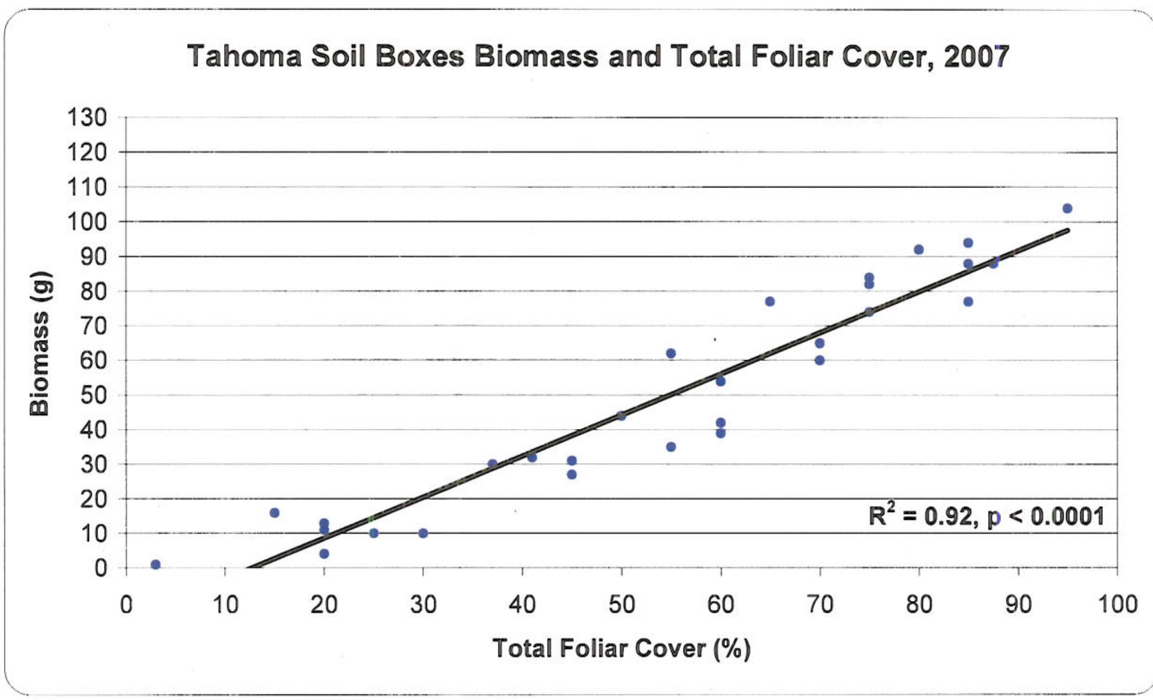

Figure 19. Tahoma Soil Boxes Biomass and Total Foliar Cover, 2007. The variability in foliar cover is well correlated to the variability in biomass, indicating that foliar cover may be a good surrogate measurement for biomass ($R^2 = 0.92$, $p < 0.00001$).

Granitic boxes with 6 inches of compost had plant cover that was 1.3 to 1.9 times higher than boxes with 2 inches of compost in 2006, and similar plant cover to boxes with 2 inches of compost in 2007 (Figure 20 and Figure 21).

In 2006 and 2007, plant cover on volcanic soils with 2 inches of compost was higher than or similar to plant cover on volcanic soils with 6 inches of compost. Plant cover was greater than 75% on boxes with both compost depths (Figure 20 and Figure 21).

The volcanic boxes with 2 inches of compost had 1.5 to 2.8 times higher overall root density when compared to boxes with 6 inches of compost (Figure 14).

In 2007, in volcanic boxes, plant cover at the boxes with Biosol only was 1 to 1.6 times lower than at boxes with Biosol and an amendment (Figure 21).

Squirreltail (*Elymus elymoides*), which composed 30 to 100% of plant cover was the most well-established seeded species in both granitic and volcanic soils across treatments (Figure 20 and Figure 21).

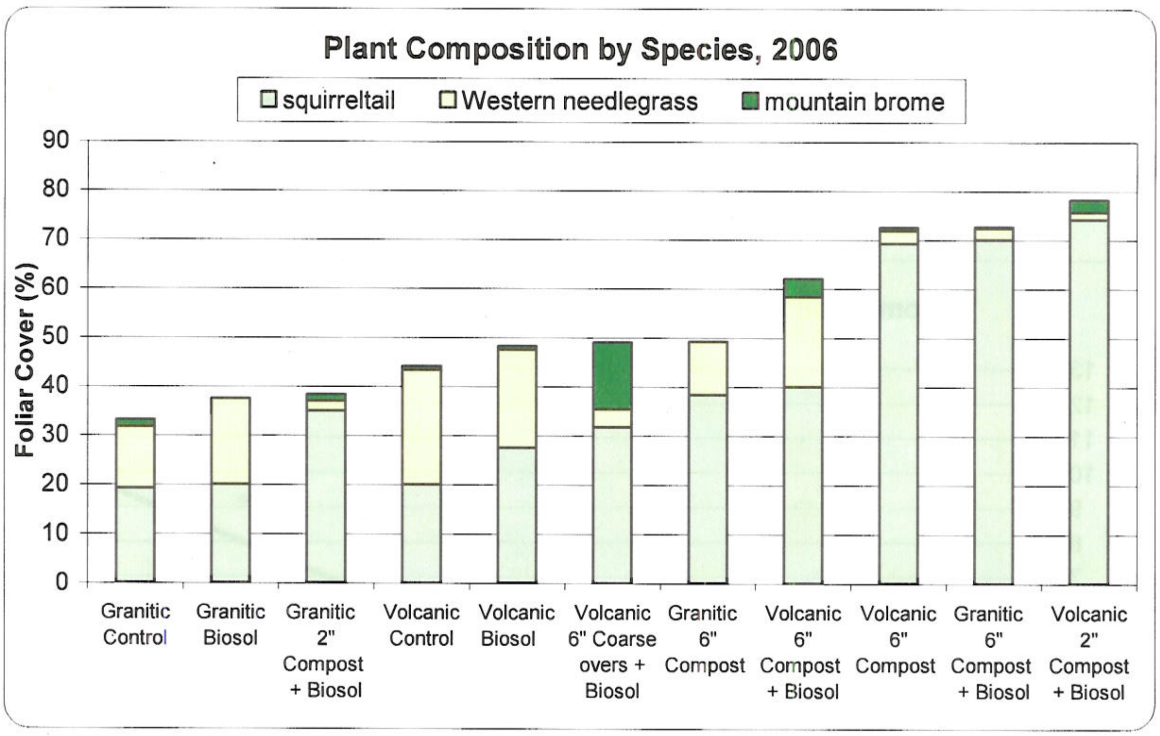

Figure 20. Plant composition by Species, 2006. Squirreltail is the dominant grass for most treatments regardless of soil type. There is a higher proportion of Western needlegrass in boxes with lower nutrient inputs. Overall cover is higher in volcanic soils.

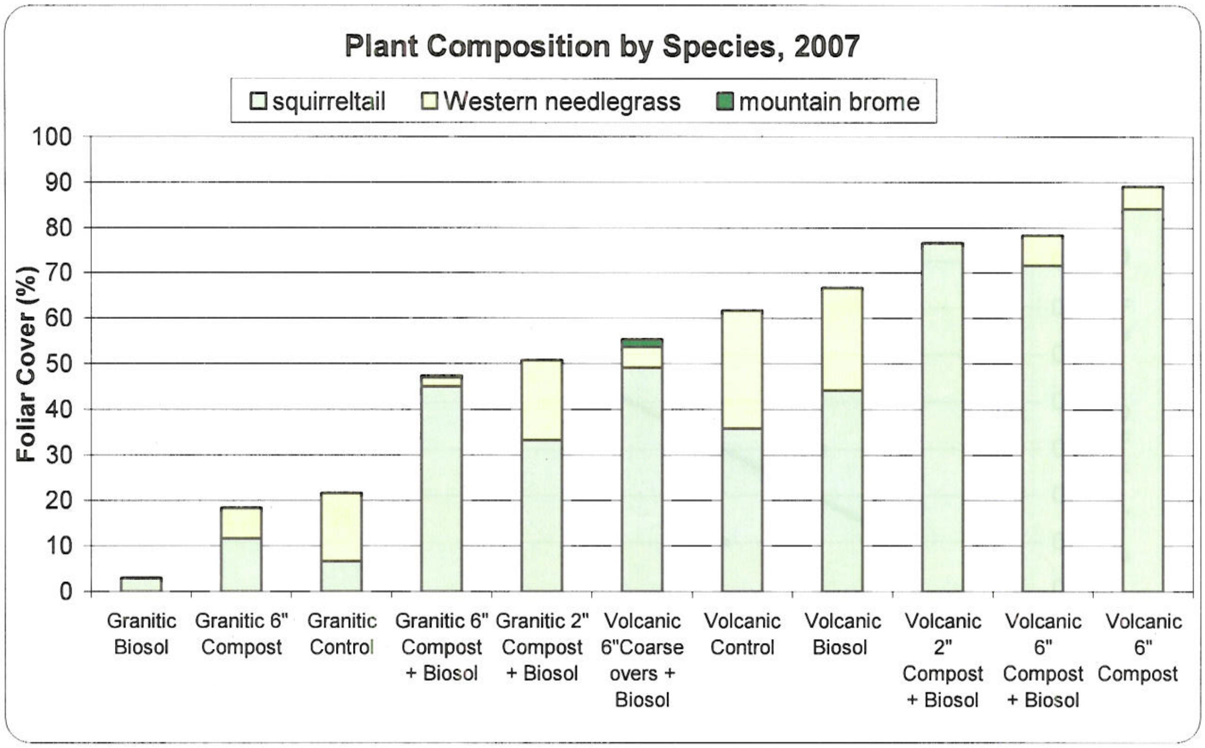

Figure 21. Plant composition by Species, 2007. Squirreltail is the dominant grass for most treatments regardless of soil type. There is a higher proportion of Western needlegrass in boxes with lower nutrient inputs. Overall cover is higher in volcanic soils.

Cover by squirreltail increased as total soil nitrogen (TKN) increased (Figure 22). In 2006 and 2007, squirreltail grass cover was highest in boxes with higher nutrient inputs (Figure 20 and Figure 21). In the granitic soils, cover by squirreltail grass was highest in the box with 6 inches of compost and Biosol. Cover by squirreltail was 70% in 2006 and 45% in 2007 at the 6 inches of compost and Biosol box (Figure 20 and Figure 21). Cover by squirreltail in the granitic control was 20% in 2006 and 11% in 2007, while for the treatment with Biosol only it was 20% in 2006 and 2% in 2007. In volcanic soils, cover by squirreltail was highest in treatments with 6 inches of compost, greater than 40% in 2006 and greater than 80% in 2007.

In granitic soils with nitrogen levels less than 400 ppm and volcanic soils with TKN less than 1,200 ppm, Western needlegrass cover equaled or exceeded that of squirreltail, suggesting that needlegrass is well suited for sites with moderate to low soil nutrients(Figure 20, Figure 21, and Figure 23). Cover by Western needlegrass was highest in the treatments with low nutrient input. In 2006, both granitic and volcanic soils with Biosol only had the highest cover by Western needlegrass (greater than 15%).

Mountain brome and blue wild rye did not compose more than 5% of the total plant cover, and therefore will not be further discussed.

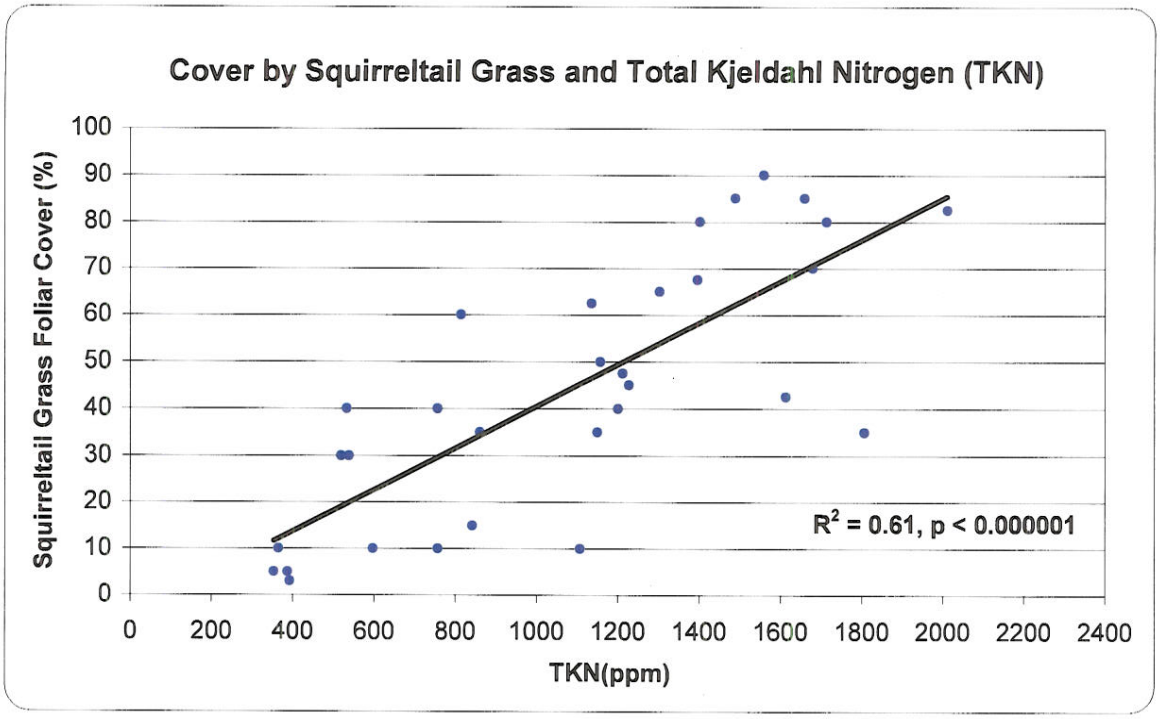

Figure 22. Cover by Squirreltail Grass and Total Kjeldahl Nitrogen (TKN). Cover by squirreltail grass increased with increasing TKN ($R^2 = 0.61$, $p < 0.000001$).

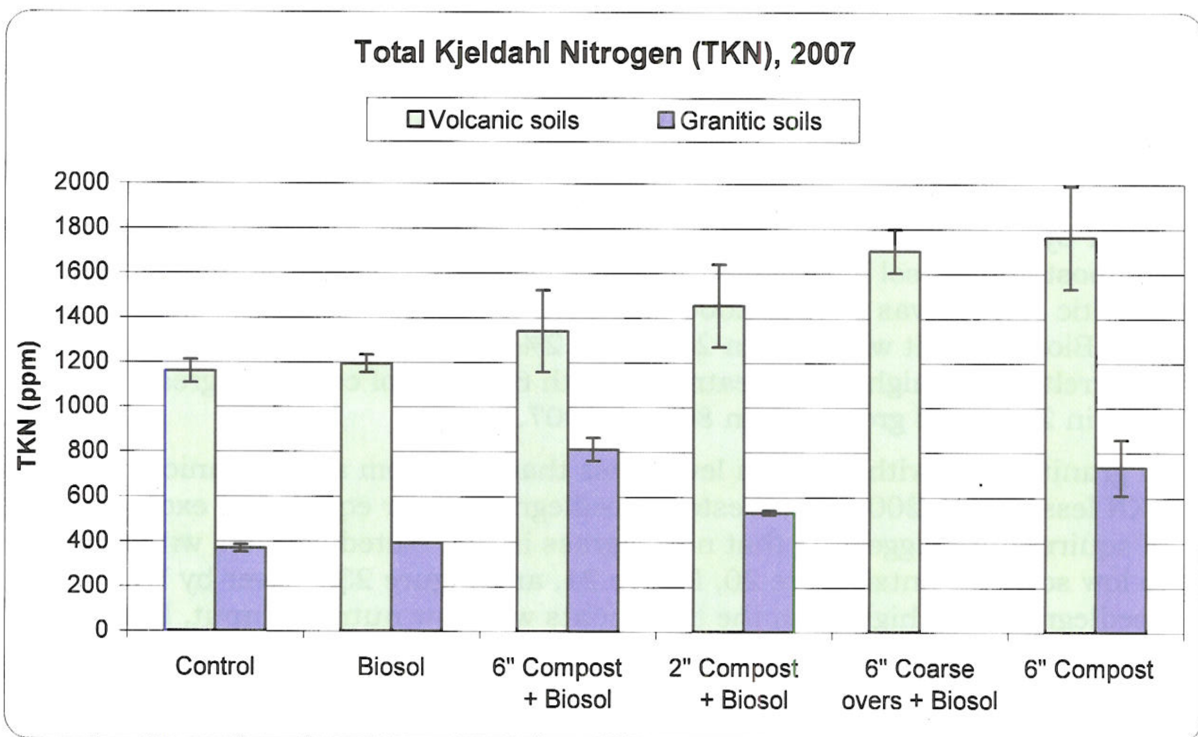

Figure 23. Total Kjeldahl Nitrogen (TKN), 2007. Treatments with Biosol alone had the lowest TKN.

Soil Characteristics

Soil Density

Regardless of treatment, volcanic soils are 3 to 12 times denser than granitic soils (Figure 24). The average penetrometer DTR for granitic soils is 27 inches, compared with the average DTR for volcanic soils of 4.3 inches. Granitic soils have fewer silt and clay size particles (less than 11%) as compared to between 20 and 40% in volcanic soils. These finer particles tend to adhere and form dense soil clods, which lead to shallower penetrometer DTRs.

Soil density in volcanic soils decreased with the addition of an organic amendment. This decrease was greatest (50%) with a higher amount of amendment (Figure 24). There was no difference in the density of granitic soils with or without an organic amendment added.

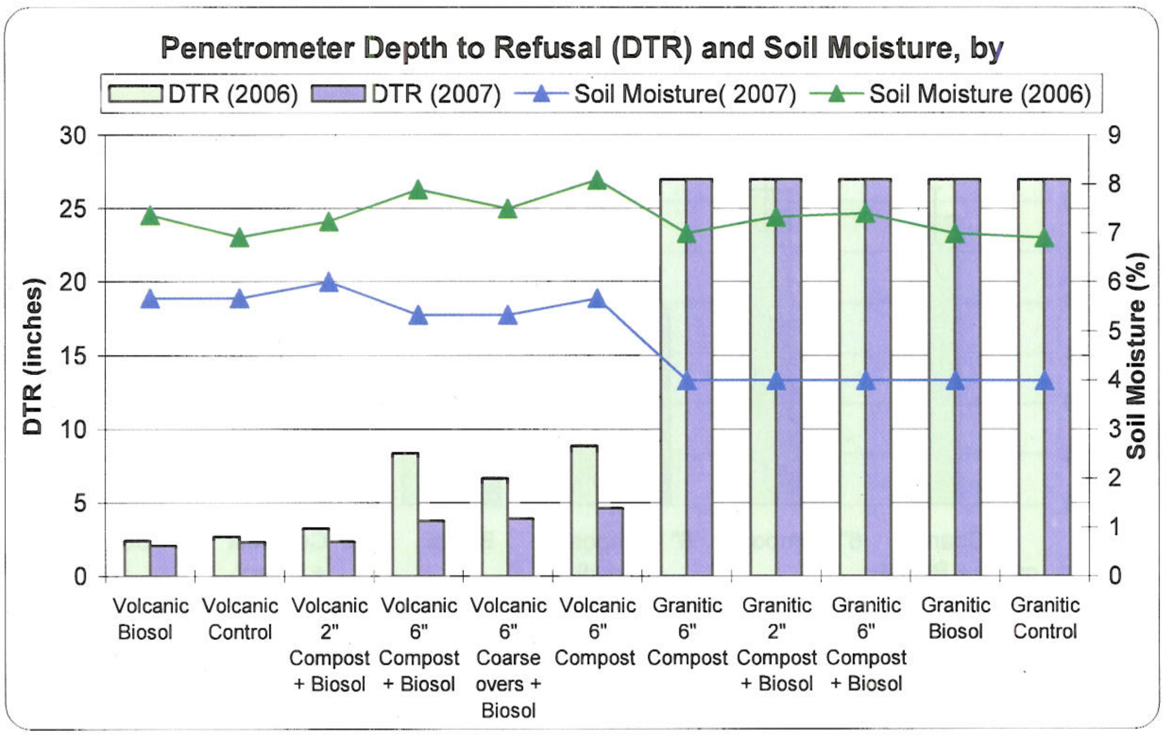

Figure 24. Penetrometer Depth to Refusal (DTR) and Soil Moisture, 2006-2007. DTRs for granitic soils are much deeper than for volcanic soils. Volcanic soils with the higher amendment rate had the deepest DTRs.

Soil Strength

The soil strength of tilled soils was similar to that measured at native sites with undisturbed soil. Soil strength measured in volcanic soil at a native area near the Truckee Bypass in Truckee was 31.5 kPa. This is similar to the average shear strength measured in volcanic soil at the Tahoma soil boxes, which ranged from 28 to 38 kPa (Figure 25). Soil strength measured in undisturbed soil near the Meyer's Airport in Meyers, California was slightly higher (21 kPa) than values in granitic soil at the Tahoma soil boxes, which ranged from 12 to 19 kPa (Figure 25).

Soil type had the greatest effect on soil strength, with volcanic soils exhibiting an average of 2.5 times higher shear strength values than granitic soils (Figure 25). The average soil strength for granitic soils was 14.1 kPa, while the average for volcanic soils was 34.7 kPa.

There was no relationship between soil strength and root density for either soil type at any depth. It may be that a relationship between root density and soil strength would be more apparent at higher soil moisture because the soil matrix looses strength with increasing soil moisture.

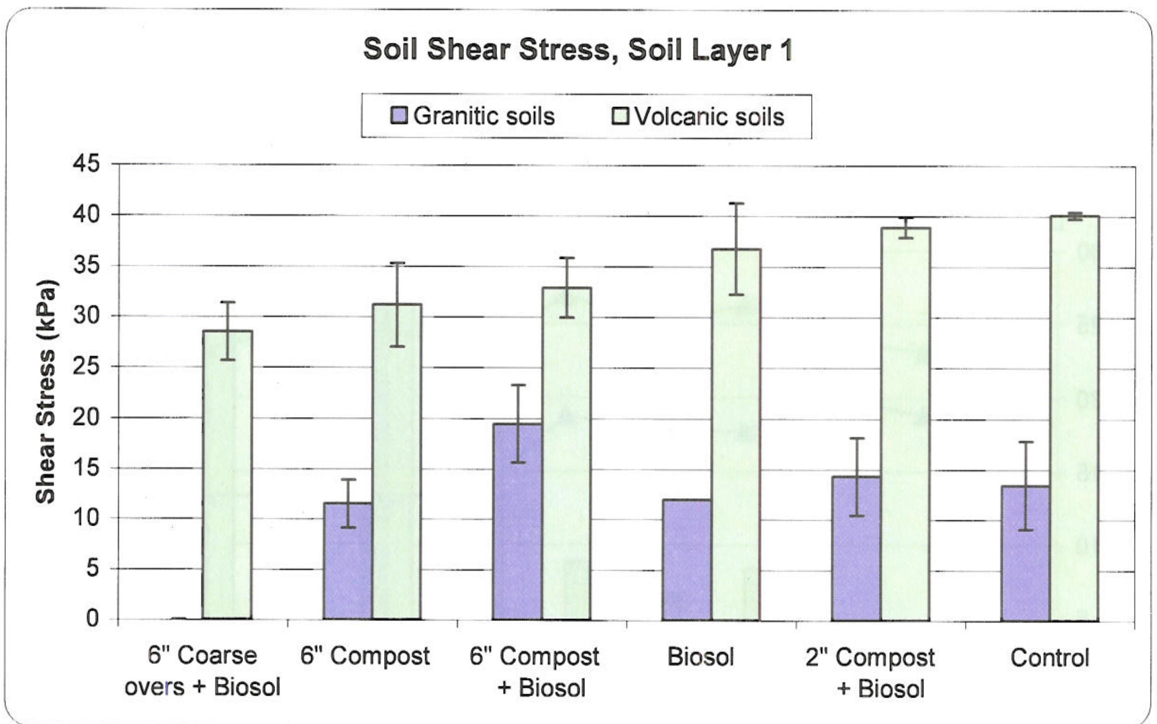

Figure 25. Soil Shear Strength, Soil Layer 1. Volcanic soils with 6 organic amendment had lower shear strength values. Granitic soils did not exhibit a trend by treatment type. Layer 1 (0-11).

Root Density

For both soil types, root density was 2 to 3 times greater in the upper 22 inches of the soil when compared to below 23 inches (Figure 26, Figure 27, and Figure 28). The average root density in the upper 22 inches of soil was 0.38 mg/mL, while below that, the average was 0.10 mg/mL.

Volcanic soils had higher root density in the top 11 inches, 0.48 mg/ml, than granitic soils, 0.37 mg/mL (Figure 26).

Volcanic Root Density

Volcanic soils treated with compost had 3.4 times higher root density at 23 inches and deeper than treatments without compost (Figure 28). The root density at 23 inches and deeper was 0.16 mg/mL for soil boxes with compost and 0.05 mg/mL for boxes without compost.

The volcanic treatment with Biosol only had the highest proportion of roots in the upper 11 inches when compared to other treatments (Figure 28). Greater than 70% of total root mass was present in the top 11 inches, while an average of 30-54% of the total root mass was present in the top 11 inches of the other treatments.

The volcanic soil box with 2 inches of compost had 1.4 to 3.3 times higher overall root density when compared to boxes with 6 inches of compost (Figure 28). The root density in the soil with 2 inches of compost was 1.84 mg/mL, compared to 0.62 to 1.22 mg/mL for soil with 6 inches of compost.

Granitic Root Density

A variation in root density between treatments was not observed in granitic soils (Figure 27).

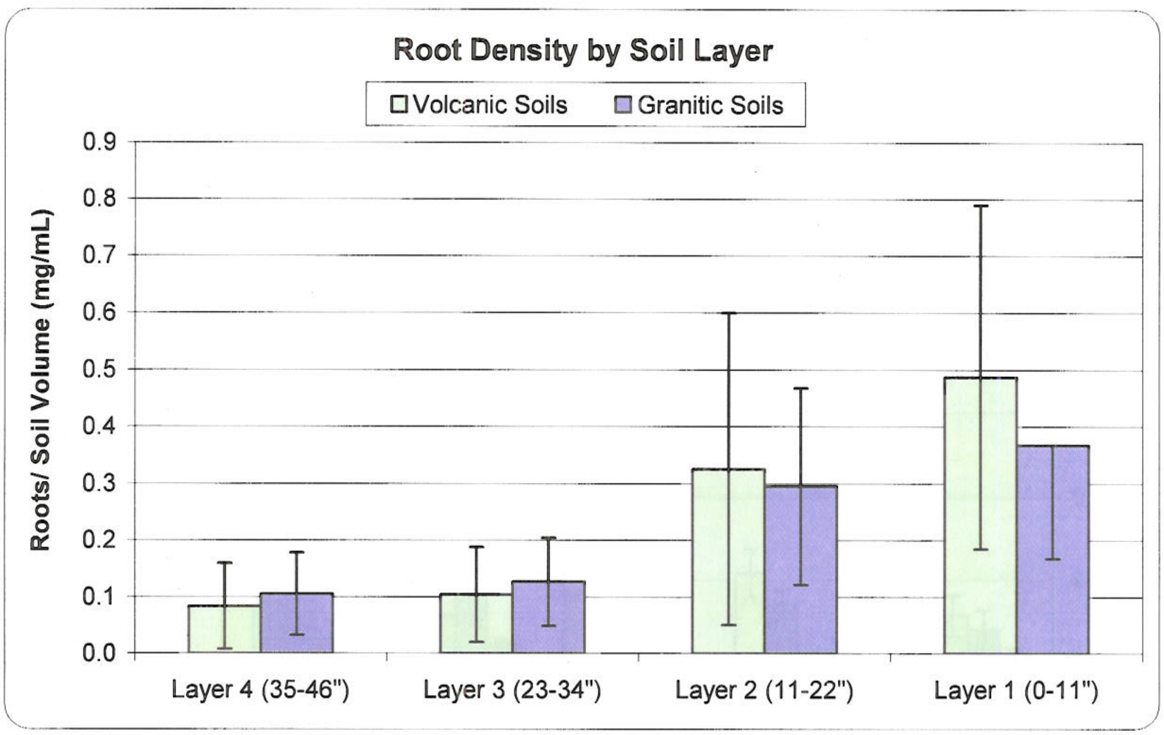

Figure 26. Root Density by Soil Layer. There was higher root density in layers 1 and 2 (0 to-22) than in layers 3 and 4 (23 to 44) for both soil types. Volcanic soils had higher root density in the top 11 inches than granitic soils.

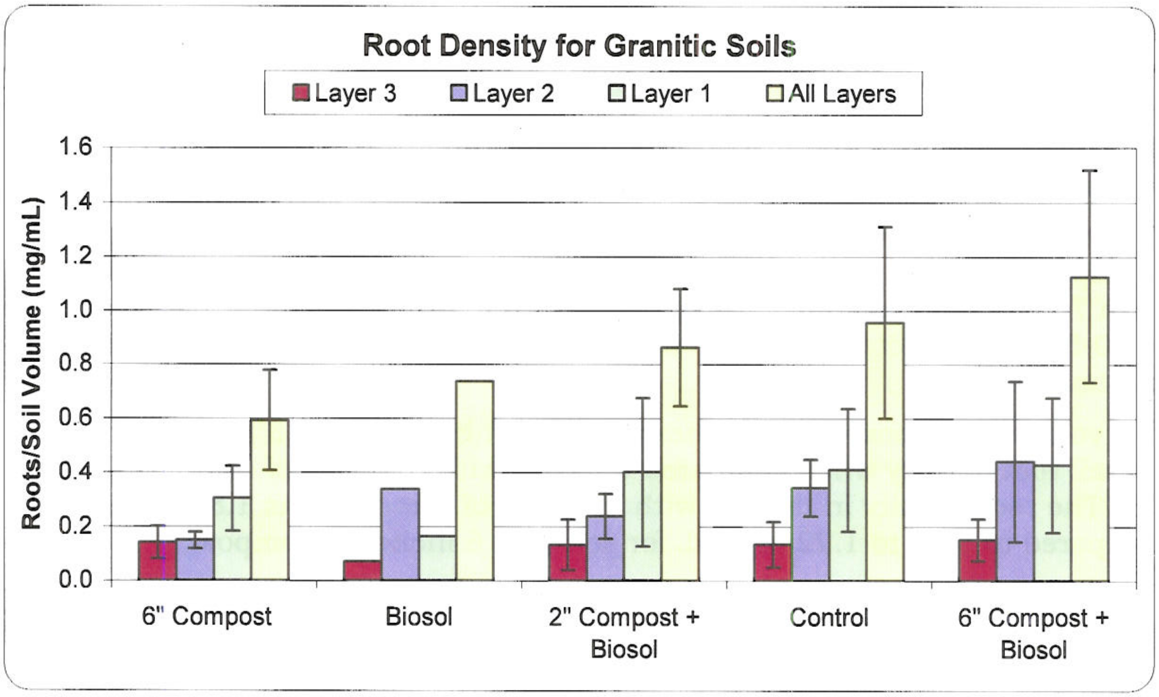

Figure 27. Root Density for Granitic Soils. There was little difference in root density by treatment for granitic soils. Layer depths: Layer 1 (0-11), Layer 2 (11-22), Layer 3 (23-34), Layer 4 (35-46).

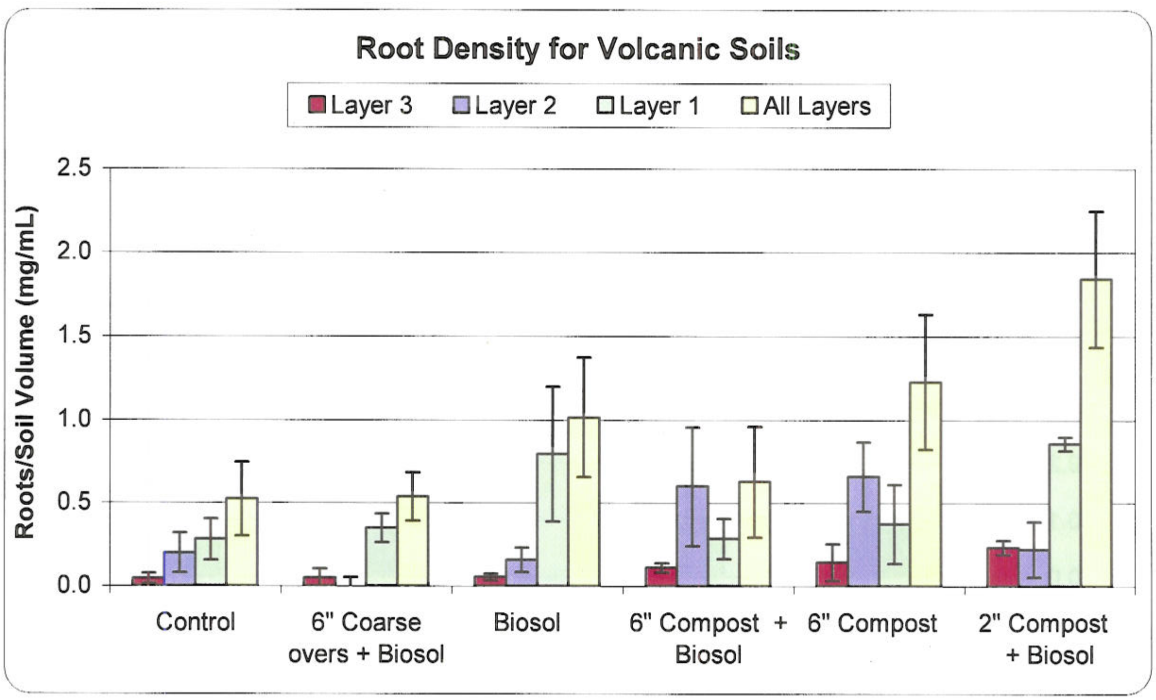

Figure 28. Root Density for Volcanic Soils. There was higher root density in layer 3 (greater than 22 inches depth) in treatments with compost added. Layer depths: Layer 1 (0-11), Layer 2 (11-22), Layer 3 (23-34).

Table 4. Results of Statistical Tests for Soil Characteristics

Test	Variables and Factors tested	Test statistic*
ANOVA	Organic Matter Layer 1 by Soil Type	$F_{1,29} = 11.2$*
ANOVA	Percentage of Roots Layer 1 by Soil Type	$F_{1,29} = 2.9$ **
ANOVA	Percentage of Roots Layer 3 & 4 by Soil Type	$F_{1,29} = 3.7$**
Student's t-test	Root Density Layer 1 Volcanic (n=18) > Granitic (n=13)	t = -1.2†
Mann-Whitney	Root Density Layers 3 & 4 Volcanic (n=27) < Granitic (n=22)	U = 373†
ANOVA	Shear Strength Layer 1 by Soil Type	$F_{1,29} = 139$*
ANOVA	Shear Strength Layer 1 Granitic Soils by Treatment Type	$F_{4,8} = 2.03$†
ANOVA	Shear Strength Layer 1 Volcanic Soils by Treatment Type	$F_{5,12} = 6.8$*
Mann-Whitney	2007 DTR Granitic Soils (n=5) >. Volcanic Soils (n=6)	U = 30*
Mann-Whitney	2006 DTR Granitic Soils (n=5) > Volcanic Soils (n=6)	U = 30*
ANOVA	Percentage of Roots Layer 1 in Volcanic Soil by Treatment	$F_{5,12} = 4.8$ *
ANOVA	Percentage of Roots Layer 3 in Volcanic Soils by Treatment	$F_{5,12} = 5.12$*
Mann-Whitney	Root Density Layer 3 in Volcanic Soils with Compost (n=9) > without Compost (n= 9)	U = 75*
Mann-Whitney	Percent of Roots Layer 1 in Volcanic Soils with Biosol (n=12) > without Biosol (n= 6)	U = 54*
ANOVA	TKN Volcanic Soils by Layer	$F_{2,51} = 12.18$*
ANOVA	TKN Granitic Soils by Layer	$F_{3,44} = 8.9$*
ANOVA	Root Density by Layer Granitic Soils	$F_{3,45} = 9.3$*
ANOVA	Root Density by Layer Volcanic Soils	$F_{3,59} = 11.2$*
ANOVA	Percentage of Roots Layer 3 & 4 in Granitic Soils by Treatment Type	$F_{4,8} = 5.4$ **
Mann-Whitney	Organic matter Layer 1 for Granitic Soils with Compost (n=9) > without Compost (n=4)	U = 36*
ANOVA	TKN Layer 1 by Treatment Granitic Soils	$F_{4,8} = 11.768$
ANOVA	Average TKN by Treatment Granitic Soils	$F_{4,43} = 4.2$*
Mann-Whitney	TKN Layer 1 for Granitic Soils with Compost (n=9) > without Compost (n=4)	U = 36*
Student's t-test	TKN All Layers for Granitic Soils with Compost (n=32) > without Compost (n=16)	t = 4.6*
ANOVA	Average TKN by Treatment Volcanic Soils	$F_{5,48} = 3.439$*
Student's t-test	TKN All Layers for Volcanic Soils with Amendment (n=44) > without Amendment (n=19)	t = 4.2*
Mann- Whitney	TKN Layer 1 for Volcanic Soils with Amendment (n=12) > without Amendment (n=6)	U = 72*
ANOVA	TKN Layer 1 by Treatment Volcanic Soils	$F_{5,12} = 4.77$*

*Results are significant at > 99%, **Results are significant at 90, †Results are significant at 80%.

Soil Nutrients

After 3 seasons, in the top 11 inches of granitic and volcanic soils, boxes with compost had higher TKN than the control boxes. The average soil TKN for granitic boxes with compost (1,101 ppm) was 2.7 times higher than the average TKN for the granitic control (408 ppm). The average TKN for the volcanic boxes with compost (2,209 ppm) was 1.8 times higher than the volcanic control (1,236 ppm, Figure 30 and Figure 31).

Regardless of treatment, the TKN in top 11 inches of volcanic soils was 2.3 times higher than in the top 11 inches of granitic soil (Figure 29). The average TKN in volcanic soils was 1,890 ppm, while the average TKN in granitic soil was 830 ppm.

The average organic matter in the top 11 inches was an average of 3.6 times greater in volcanic soils than in granitic soils (Figure 29). The average organic matter was 6.5% in volcanic soils compared to 1.8% in granitic soils.

In both soil types, TKN and organic matter values recorded above 11 inches were higher 1.5 to 1.8 times than those recorded at below 11 inches (Figure 30 and Figure 31). TKN in volcanic soils was 1.5 times higher above 11 inches than below 11 inches. The average TKN above 11 inches was 1,881 ppm, while the average TKN below 11 inches was 1,230 ppm. In granitic soils, TKN was 1.8 times higher in the top 11 inches versus below 11 inches. The average TKN above 11 inches was 830 ppm, compared to 451 ppm below 11 inches.

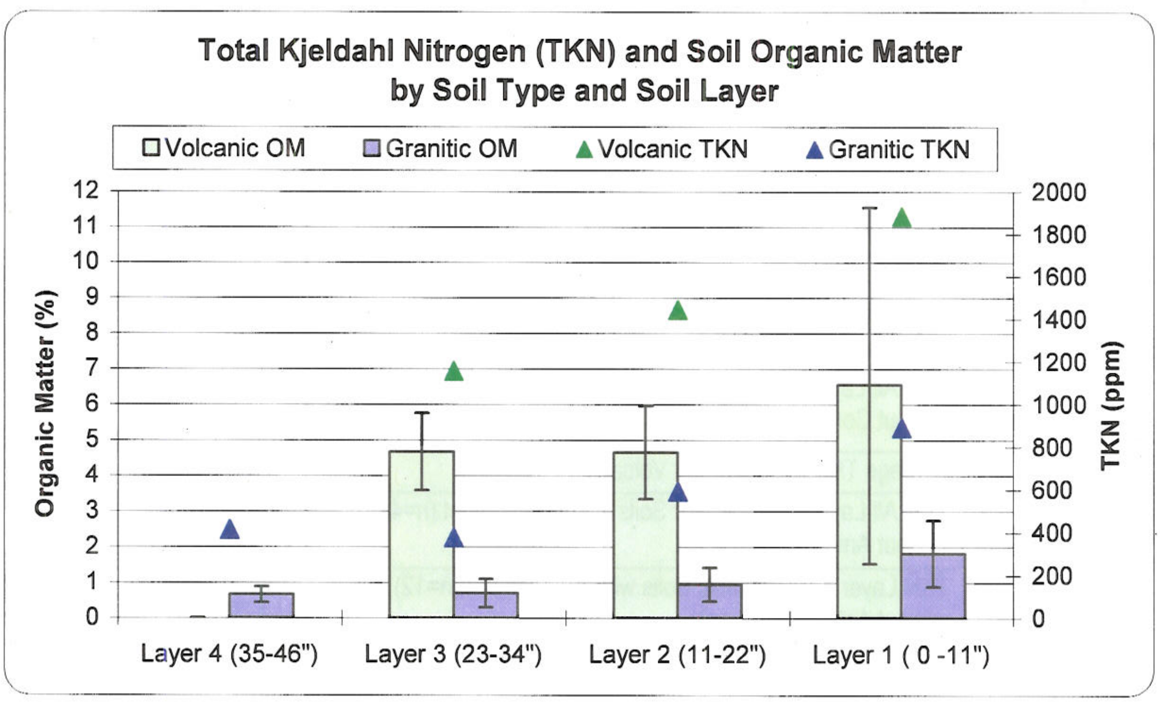

Figure 29. Total Kjeldahl Nitrogen (TKN) and Organic Matter by Soil Type and Soil Layer. There is a significant decrease in TKN and organic matter with depth. Volcanic soils had at least 2 times higher TKN concentrations and percent organic matter (OM).

Volcanic Soil Nutrients

In the top 11 inches of volcanic soil boxes with an amendment, TKN was an average of 1.8 times higher than in boxes without an amendment. Treatments with an amendment had average TKN levels in the top soil layer greater than of 2,209 ppm, while treatments without an amendment added had average TKN of 1,225 ppm (Table 4 and Figure 31). Volcanic treatments with 6 inches of compost (no Biosol) had the highest TKN level, 1,874 ppm, averaged over all layers. When all soil boxes with compost are considered, soil with 2 inches of compost had similar TKN levels to soil with 6 inches of compost.

Granitic Soil Nutrients

In granitic soils amended with compost, total Kjeldahl nitrogen in the top 11 inches was an average of 2.6 times higher than soils without compost. Boxes with compost had an average of 1,101 ppm in the top 11 inches, compared to boxes without compost, which had an average TKN of 245 ppm (Figure 30.).

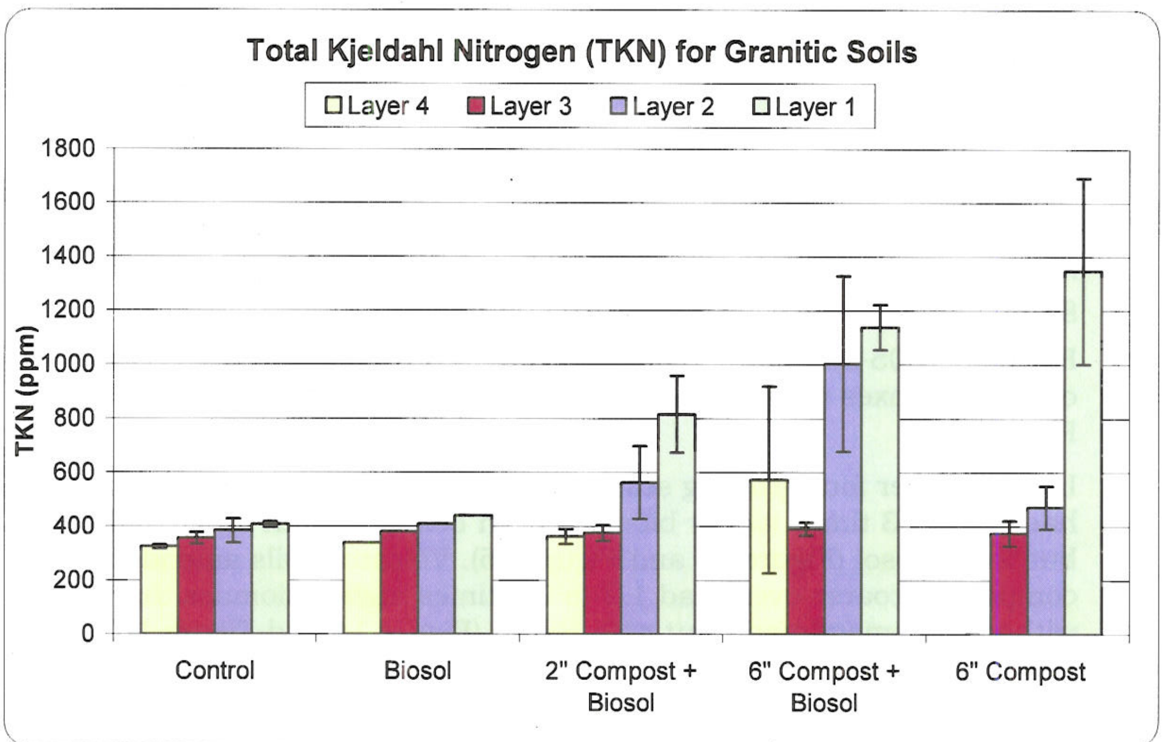

Figure 30. Total Kjeldahl Nitrogen (TKN) for Granitic Soils. TKN is higher within the first layer of soil with and without compost. Layer depths: Layer 1 (0-11), Layer 2 (11-22), Layer 3 (23-34), Layer 4 (35-46).

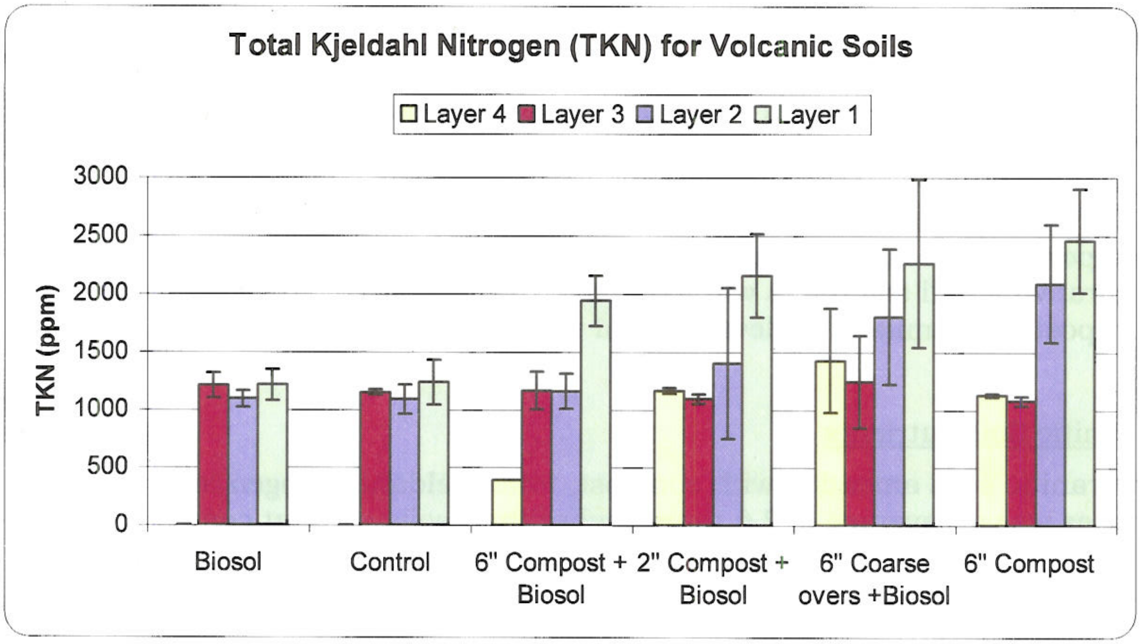

Figure 31. Total Kjeldahl Nitrogen (TKN) by Layer and Treatment for Volcanic Soils. There is higher TKN within the first layer for boxes with an organic amendment. Layer depths: Layer 1 (0-11), Layer 2 (11-22), Layer 3 (23-34), Layer 4 (35-46).

CONCLUSIONS

Biomass

- Above ground biomass was not correlated with root biomass in either granitic or volcanic soils (Figure 13 and Figure 14).
- Between 2005 and 2007, biomass decreased from 1.6 to 3.1 times at all of the soil boxes with both granitic and volcanic soils (Figure 15 and Figure 16).
- In 2007, after four growing seasons, granitic soil amended with compost had 7.5 to 33 times higher biomass than boxes without an amendment, but with Biosol (Figure 13 and Figure 15). Volcanic soils amended with compost or coarse overs had 1.2 to 2.2 times higher biomass than boxes without an amendment, but with Biosol (Figure 14 and Figure 16).
- Over 3 seasons, in granitic and volcanic soils, boxes amended with compost or coarse overs resulted in higher average biomass than at the control. In granitic soil boxes with amendments, the biomass was 1.5 times higher than the biomass at the control, while in volcanic soil, amended soils had an average of 4 times higher biomass than the control (Figure 15, and Figure 16, and Table 3).
- As shown by linear regression, higher soil nitrogen levels were correlated with greater plant biomass in both granitic and volcanic soils in 2007 (Figure 17).

Granitic Biomass

- Second and fourth season biomass (2005 and 2007 in the granitic soil boxes was 2 to 8 times higher in all treatments when compared to the control (Figure 15 and Table 3).
- In the fourth growing season (2007), treatments with compost or compost and Biosol, in granitic soils, maintained plant biomass that was 1.7 to 4.1 times higher than the biomass at the control (Figure 15 and Table 3).
- In granitic soils, the treatments with both compost and Biosol supported at least 2 times more biomass than the compost only treatment in 2005 and 2007 (Figure 15 and Table 3).
- Granitic soil boxes with Biosol only had 14 times higher plant cover in the second year compared to the control.

Volcanic Biomass

- In 2005 and 2006, biomass for all volcanic treatments equaled or exceeded that of the control by an average of 1.6 times (Figure 16).
- In 2005, in volcanic soils, the treatment with 2 inches of compost and Biosol produced 1.7 times more biomass than the other treatments, 1.4 to 1.5 times more biomass than the 6 inch compost boxes, and 3 times more biomass than the control (Table 3 and Figure 16.).
- The compost treatments in volcanic soils produced up to 1.6 times more biomass than the control in 2007 (Figure 16.).
- In 2006 and 2007, plant cover in volcanic soils was higher than or similar to plant cover at the boxes with 6 inches of compost. Plant cover for boxes with both depths was greater than 75%.
- In volcanic soils, average biomass in boxes with compost was 1.4 times higher during all growing seasons than biomass in the boxes with coarse overs (98 grams compared to 70 grams) (Figure 16).
- In 2007, in volcanic soils, biomass in the boxes with Biosol only was 1.2 to 2 times lower than in the boxes with Biosol and an amendment (Figure 14).

Species composition

- Ocular estimates of plant cover and above ground plant biomass were positively correlated, indicating that at the soil boxes, ocular estimation of foliar cover is a surrogate for plant biomass (Figure 18 and Figure 19).
- Squirreltail (*Elymus elymoides*), which composed 30% to 100% of plant cover was the most well-established seeded species in both granitic and volcanic soils across treatments (Figure 20 and Figure 21).

- Cover by squirreltail increased as total soil nitrogen (TKN) increased (Figure 22).
- In granitic soils with nitrogen levels less than 400 ppm and volcanic soils with TKN less than 1,200 ppm, Western needlegrass cover equaled or exceeded that of squirreltail, suggesting that needlegrass is well suited for sites with moderate to low soil nutrients (Figure 20, Figure 21, and Figure 23).

Granitic Composition

- Granitic soils with 6 inches of compost had plant cover that was 1.3 to 1.9 times higher than the boxes with 2 inches of compost in 2006, and similar plant cover to the box with 2 inches of compost in 2007 (Figure 20 and Figure 21).

Volcanic Composition

- Volcanic soils with 2 inches of compost had plant cover that was higher than or similar to plant cover in volcanic boxes with 6 inches of compost (Figure 20 and Figure 21).
- In 2007, in volcanic soils, plant cover at the boxes with Biosol only was 1 to 1.6 times lower than at the boxes with Biosol and an amendment (Figure 21).
- In volcanic soils, foliar plant cover at boxes amended with compost was 1.2 to 1.6 times higher in 2006 and 1.4 to 1.6 times higher in 2007 when compared to boxes amended with coarse overs (Figure 20 and Figure 21)

Soil Density

- Regardless of treatment, volcanic soils are 3 to 12 times denser than granitic soils (Figure 24).
- Soil density in volcanic soils decreased with the addition of an organic amendment. This decrease was greatest (50%) with a higher amount of amendment (Figure 24).

Shear Strength

- The soil strength of tilled soils was similar to that measured at native sites with undisturbed soil.
- Soil type had the greatest effect on soil strength, with volcanic soils exhibiting an average of 2.5 times higher shear strength values than granitic soils (Figure 25).
- There was no relationship between soil strength and root density for either soil type at any depth.

Root Density

- For both soil types, root density was 2 to 3 times greater in the upper 22 inches of the soil when compared to below 23 inches (Figure 26, Figure 27, and Figure 28)
- Volcanic soils had higher root density in the top 11 inches, 0.48 mg/ml, than granitic soils, 0.37 mg/mL (Figure 26).
- Volcanic soils treated with compost had 3.4 times higher root density at 23 inches and deeper than treatments without compost (Figure 28).
- The volcanic treatment with Biosol only had the highest proportion of roots in the upper 11 inches when compared to the other treatments (Figure 28).
- The volcanic soils with 2 inches of compost had 1.4 to 3.3 times higher overall root density when compared to boxes with 6 inches of compost (Figure 14).

Soil Nutrients

- After 3 seasons, in the top 11 inches of granitic and volcanic soils, boxes with compost had higher TKN than the control boxes
- The average organic matter in the top 11 inches was 3.6 times greater in volcanic soils than in granitic soils (Figure 29).
- In both soil types, TKN and organic matter values recorded above 11 inches were higher 1.5 to 1.8 times than those recorded at below 11 inches (Figure 30 and Figure 31).

Granitic Nutrients

- In granitic soils amended with compost, total Kjeldahl nitrogen in the top 11 inches was an average of 2.6 times higher than in boxes without compost.

Volcanic Nutrients

- Regardless of treatment, the TKN in top 11 inches of volcanic soils was 2.3 times higher than in the top 11 inches of granitic soil (Figure 29).
- In the top 11 inches of volcanic soil boxes with an amendment, TKN was an average of 1.8 times higher than in boxes without an amendment.
- Volcanic treatments with 6 inches of compost had the highest TKN level, 1,874 ppm, averaged over all layers

RECOMMENDATIONS

Granitic soil

These recommendations are for granitic soils with less than 11% silt and clay particles, low initial soil nitrogen (less than 400 ppm) and organic matter (less than 2%) in sites located at 6,300 feet (1,920 m) above sea level with moderate solar exposure and no source of aggressive annual plant species.

Tilling: 18 inches

Amendment: compost composed of 25% coarse material (coarse overs) to a depth of 6 inches.

Biosol: applied at a rate of 1,784 lbs/acre (2,000 kg/ha)

Seed: 125 lbs/acre (140 kg/ha) with the following composition:

60% squirreltail
30% Western needlegrass
10% mountain brome

Amendment versus No Amendment

Incorporation of an organic amendment to a depth of 18 inches is recommended for the following reasons. It should be noted that compost with 75% fines and 25% coarse woody material was the only amendment tested in granitic soil due to destruction of the soil box with the coarse overs treatment.

- Over 3 seasons, granitic soils amended with compost resulted in an average of 1.5 times higher plant biomass than the control
- In 2007, after four growing seasons, granitic soils amended with compost had 7.5 to 33 times higher biomass than boxes with Biosol only
- The average soil TKN for granitic soil boxes with compost (1,101 ppm) was 2.7 times higher than the average TKN for the granitic control (408 ppm).

Compost Rate (6 inches versus 2 inches)

Compost, applied to a depth of 6 inches, is recommended over compost applied to 2 inches for the following reasons. Granitic soils with 6 inches of compost exhibited:

- plant cover that was 1.3 to 1.9 times higher than soil boxes with 2 inches of compost in 2006, and similar to plant cover at the soil box with two inches of compost in 2007
- total Kjeldahl nitrogen in the top 11 inches was almost 2 times higher than in boxes with 2 inches of compost

Biosol

Biosol is recommended at a rate of 1,784 lbs/acre (2,000 kg/ha), in combination with an amendment, for the following reasons:

- In 2007, after four growing seasons, Biosol only treatments in granitic soils produced 8 times less biomass than the control. Therefore, Biosol is only recommended in conjunction with an organic amendment.
- The addition of Biosol alone resulted in high second year plant biomass followed by a decline in biomass over the three sampling years (Figure 15). Therefore, Biosol is only recommended in combination with an organic amendment.
- The treatments with both compost and Biosol supported at least 2 times more biomass than the compost treatments without Biosol in 2005 and 2007.

Seed

Seed applied at a rate of 125 lbs/acre (140 kg/ha) with the following composition:

60% squirreltail,
30 % Western needlegrass
10% mountain brome and blue wild rye

is recommended for the following reasons:

- Squirreltail grass was the most successful species, composing 30 – 100% of cover, therefore it is recommended as the dominant species in the mix.
- Squirreltail grass cover increased with increasing inputs of nitrogen in the form of compost and Biosol, which are recommended.
- Blue wild rye and mountain brome did not represent significant plant cover and are only recommended to be 10% of the seed mix.
- Granitic soils with low TKN levels supported less squirreltail and more Western needlegrass than other treatments. Therefore, Western needlegrass should be included in seed mixes at sites with low nutrient inputs or low initial inputs. For example a site amended with a compost that has a high proportion of woody material may not have enough available nitrogen to support other grass species in the first few years.

Volcanic soil

These recommendations are for volcanic soils with less than 50% silt and clay particles, and an initial soil nitrogen (around 1,000 to 1,200 ppm) and organic matter (less than 4%) in sites located at 6,300 feet (1,920 m) with moderate solar exposure and no source of aggressive annual plant species.

Tilling: 18 inches

Amendment: compost composed of 25% coarse material (coarse overs) to a depth of 6 inches.

Biosol: applied at a rate of no more than 1,784 lbs/acre (2,000 kg/ha)

Seed: at least 125 lbs/acre (140 kg/ha) seed with the following composition:

60% squirreltail
20% mountain brome
20% Western needlegrass

Amendment versus No Amendment

Incorporation of an organic amendment (compost or coarse overs) to a depth of 18 inches is recommended for the following reasons:

- Volcanic soils amended with compost or coarse overs had and an average of 4 times higher plant biomass than the control
- Volcanic soils amended with compost or coarse overs had 1.2 to 2.2 times higher biomass than soil boxes with Biosol, but no amendment
- Volcanic soil amended with compost or coarse overs had 1.8 times greater TKN (greater than 1,900 ppm) than treatments without an organic amendment (TKN was less than 1,300 ppm).

Amendment Type (Compost versus Coarse overs)

Compost is recommended over coarse overs because soil boxes with compost exhibited:

- an average biomass that was 1.4 times higher during all growing seasons than biomass in the soil boxes with coarse overs

Compost rate (2 inches versus 6 inches)

A compost depth of 2 inches is recommended over the 6 inch depth for the following reasons. Soil boxes with 2 inches of compost exhibited:

- overall root densities that were 1.4 to 3.3 times denser when compared to boxes with 6 inches of compost
- plant cover that was higher than or similar to plant cover at boxes with 6 inches of compost
- second year biomass that was 1.4 to 1.5 times higher than on 6 inch boxes (181 grams compared to 124 to 131 grams) and similar third and fourth year biomass to boxes with 6 inches of compost
- similar TKN levels to boxes with 6 inches of compost

Biosol

Biosol is recommended, in combination with an amendment, at a rate of 1,784 lbs/acre (2,000 kg/ha) for the following reasons:

- In 2007, biomass at the soil boxes with Biosol only was 1.2 to 2 times lower than at the boxes with Biosol and an amendment. Therefore, it is recommended that Biosol only be applied in conjunction with an amendment.
- In the second growing season, boxes with Biosol only had biomass that was 1.4 times greater than the control (Figure 16)
- The volcanic treatment with compost and Biosol produced the highest biomass for among volcanic soils, which was 3 times higher than the control in the second year (2005).

Seed

Seed_applied at a rate of at least 125 lbs/acre (140 kg/ha) with the following composition:

60% squirreltail
20% mountain brome and blue wild rye
20% Western needlegrass

is recommended for the following reasons:

- Squirreltail grass was the most successful species on volcanic soils, composing 50% – 100% of total plant cover
- Squirreltail grass cover increased with increasing inputs of nitrogen and higher nitrogen inputs are recommended.
- Blue wild rye and mountain brome did not represent significant plant cover and are only recommended to be 20% or less of the seed mix .
- Volcanic soils with low nitrogen inputs supported less squirreltail and more Western needlegrass than other treatments. Therefore, Western needlegrass should be included in seed mixes at sites with low nutrient inputs or low initial inputs. For example, a site amended with a compost that has a high proportion of woody material may not have enough available nitrogen to support other grass species in the first few years.