AN EVALUATION OF COMPOST AND FERTILIZER TO PROMOTE REVEGETATION OF REHABILITATED ROAD SURFACES

REDWOOD NATIONAL PARK
RESEARCH AND DEVELOPMENT

POPENOE, J. and R. MARTIN

TECHNICAL REPORT

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25

WATERSHED REHABILITATION

In 1978, under authorization of P.L. 95-250, Redwood National Park initiated a program of watershed rehabilitation within the Redwood Creek basin. The goals of the program are to reduce sources of man-induced erosion and to restore naturally functioning redwood and related ecosystems on logged lands within the park.

COMPOSTING

Redwood National Park operates a compost facility at Wolf Creek to treat wastes generated in the park from chemical toilets and septic tanks. Composting disposes of sewage effluent and provides a by-product with potential for soil improvement.

NOTICE

This is a preliminary report with initial finding from field trials of compost for watershed rehabilitation. Conclusions may be revised or updated as new information is learned.

AN EVALUATION OF COMPOST AND FERTILIZER
TO PROMOTE REVEGETATION OF REHABILITATED ROAD SURFACES

Redwood National Park
Technical Report 25

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ABSTRACT

As part of its watershed rehabilitation program, Redwood National Park is removing many abandoned, deteriorating roads. Some reshaped roads contain a high proportion of subsoils slow to revegetate. Compost and fertilizer tablets were investigated as ways to encourage native plant growth on one of the harsher sites. One-year-old redwoods averaging 160 mm tall were outplanted in January 1985. In January 1990, controls averaged 288 mm, redwoods with fertilizer tablets 451 mm, redwoods with incorporated compost 848 mm and redwoods with fertilizer tablets and compost 930 mm. Fertilizer tablets accelerated growth most strongly the first year and had no effect by the third year. Compost increased growth for four years. By 1988 the compost-treated areas also had greater cover of natural colonizers with taller individuals. Compost did not affect growth of outplanted, nitrogen-fixing red alders. The chief limitations of compost were the high cost of application and the small quantities available. The greatest need and most cost-effective use of park compost may be in landscaping.

INTRODUCTION

Purpose

This report describes field trials of compost to restore damaged soils on a rehabilitation site. The field trials were designed to evaluate use of park-generated compost in watershed rehabilitation.

Background

Since its expansion in 1978, Redwood National Park has completed many rehabilitation projects aimed at correcting impacts of road building and logging in the Redwood Creek watershed. In each project area, drainages have been restored and abandoned, deteriorating roads removed by ripping the surface and reshaping to an outslope that disperses runoff. Straw has been spread and conifers planted on sites bared by earth-moving. Loss of topsoil has slowed growth on some of the sites. Compost was envisioned as a way to amend damaged soils and correct for topsoil loss.

The source of compost envisioned was Redwood National Park's static pile compost facility at Wolf Creek. This facility was built primarily to treat wastes generated in the park from chemical toilets and septic tanks. Composting and recycling were considered environmentally preferable to alternative disposal through municipal waste treatment plants or sanitary landfills. The piles at Wolf Creek are built from wood waste. The wood waste absorbs sewage effluent and acts as an energy source for composting micro-organisms. High temperatures achieved during composting kill most pathogens which may have been in the effluent. A six-month curing kills any remaining pathogens, making the material safe for land application (Sacklin 1982). Although the compost at Wolf Creek may be recycled almost indefinitely, a portion may be exported for use as a soil ammendment.

Statement of Problem

Roads caused the most severe erosion and revegetation problems existing on logged lands in Redwood National Park (Weaver et al., 1987). The effect on revegetation of constructing and removing roads varies from site to site. The goal in constructing a road in mountainous terrain, whether for logging or any other purpose, is to create a reasonably constant grade. As a general rule, soil is cut from ridges and divides and pushed into hollows and valleys. During watershed rehabilitation, unwanted and potentially erosive roads are removed. Excavation of hollows and stream crossings re-exposes the natural soil profile, leaving topsoil at the surface where it is needed for plant growth. Trees thrive near stream crossings because topsoil is present and sites are relatively moist. In contrast, conditions are particularly harsh where roads were cut through ridges or where soil was removed to quarry rock or build log landings. Deep roadcuts commonly remove all soil and some bedrock and the trees planted there exhibit little growth. Table 1 compares average organic matter (OM) and nitrogen (total N) of native, undisturbed soils, rehabilitated roads and deep roadcuts within the park. Samples from deep roadcuts are lowest in OM and total N. When soils are low in OM and total N, it is reflected in the appearance and growth rate of plants. On deep roadcuts, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco.) have short leaders and branches, sparse foliage and small, yellowish needles.

Table 1. Organic matter and total nitrogen content of surface soil samples (0-15 cm) from deep roadcuts, rehabilitated haul road surfaces and undisturbed forest soils in the lower Redwood Creek Basin, Redwood National Park. Data are presented as the mean ± the 95 percent confidence interval.

Source	Percent OM	Percent total N
Deep roadcuts with stunted, chlorotic (yellowish) Douglas-fir[1]	1.28 ± 0.36	0.063 ± 0.008
Rehabilitated haul road surfaces[2]	2.64 ± 0.31	0.084 ± 0.005
Undisturbed forest soils[3]	8.24 ± 1.59	0.177 ± 0.043

[1] 17 samples, 81-RNP-112 to -128 from east side of Redwood Creek basin.
[2] 48 samples, numbers 714 to 728 from Copper Creek (79-4) and numbers 80-RNP-14 to -49 from W-Line (80-5) Watershed Rehabilitation Units.
[3] Pedons 1 to 14, in Popenoe (1987), Appendix B.

Table 2 shows some data for Douglas-fir on a large roadcut and an adjacent outboard slope along the C-Line road (the shuttle route to the Tall Trees trailhead). Trees on the roadcut were stunted, chlorotic (yellow) and critically low in foliar nitrogen and sulfur. Trees on the outboard slope had healthy, green needles and normal foliar nitrogen and sulfur levels.

Table 2. Douglas-fir needle foliar analysis on samples from chlorotic (yellowish) trees from deep roadcut and healthy trees on adjacent, outboard slope on C-Line road, Redwood National Park.

Element	Chlorotic trees in roadcut		Healthy trees on outboard slope	
	1-year-old needles	New needles	1-year-old needles	New needles
Nitrogen (%)	.62 ± .05 (.51-.72)	.59 ± .05 (.47-.68)	1.25 ± .08 (1.16-1.41)	1.20 ± .09 (1.03-1.39)
Sulfur (%)	.10 ± .02 (.09-.15)	.08 ± .02 (.03-.11)	.17 ± .05 (.15-.23)	.12 ± .03 (.08-.19)

Data are presented as the mean and 95% confidence interval. The range of eight samples is given in parentheses. According to Powers (1976) a nitrogen deficiency is indicated if foliar nitrogen is 1.1 percent or less. Low nitrogen levels cause lowering of foliar sulfur because plants are unable to make sulfur-bearing amino acids.

Physical watershed rehabilitation treatments help in revegetating through-cut ridges because fill material excavated from stream crossings and end-hauled to through-cuts restores depth. Depth is a major requirement for re-establishing conifers. However, fill is mostly sub-surface material, deficient in OM and total N. Conifers are still limited by

1) lack of soil moisture (drought),
2) low nitrogen availability (infertility) and
3) lack of soil oxygen (poor aeration).

Evaluation of compost to supply OM and total N for deficient soils began in 1981 with greenhouse experiments using commercially prepared material (Sacklin et al., 1984). In 1983, a field trial of commercially available compost was initiated using coast redwood (*Sequoia sempervirens* D. Don Endl.). In 1984, compost from the Wolf Creek facility at Redwood was ready for field use. It was applied at a site and trees were planted early in 1985. Results of these field trials are the primary topic of this report.

In planning the field trials, a number of practical questions were addressed: How effective are compost and fertilizer at restoring growth of redwoods and other native plants to normal levels? How quickly do compost and fertilizer break down and lose their effectiveness after application on a rehabilitation site? How does compost affect patterns of naturally invading plants? How much do compost and fertilizer cost to apply? What are the most effective and cost-effective methods of application?

In addressing these concerns, it was borne in mind that Redwood National Park has a policy of respecting natural processes and using them to advantage in watershed rehabilitation. Landslides are a natural process that strips soil and results in low surface OM and total N. Landslides are rapidly colonized by red alders (*Alnus rubra* Bong.). Red alders have actively N-fixing actinomycetes associated with their roots. They produce nitrogen at a more-or-less constant rate after reaching about 10 years age. Using linear regression, Bormann and DeBell (1981) estimated that 35 Kg ha^{-1} total N is produced annually in the upper 20 cm of mineral soil. Soils on watershed rehabilitation sites average 30 percent rock fragments and have bulk densities of 1.25 g/cm^3 in the fine earth fraction. Calculated from the soil test standpoint, red alders increase total N by .002 percent of the fine earth dry weight per year. At this rate, red alders restore total N of stripped soils to normal levels in from 40 to 60 years. There is no rate in the literature for red alders younger than 10 years. However, it is thought that the constant rate for older trees is determined by the rate of photosynthesis which is light limited. If so, alders would reach their maximum rate of total N production with crown closure at an age of approximately 3 years. Red alders have great potential for both natural and mediated recovery of damaged soils. Therefore, the park's compost trials were designed with alders in all treatments. Possible effects of alders in controls were compared to alders with fertilizer and compost.

METHODS

Field Trial 1

Field procedure. This trial was established as a pilot experiment on February 2, 1983, on the former C-20 Road. The site is a gently NW-facing slope near the top of a ridge. The regolith is reworked subsoil, road rock and crushed bedrock. The road was outsloped and mulched with straw. Test plants were one-year-old (1-0) containerized redwoods, protected in vexar mesh tubes to prevent browsing. Vexar tubes were remove in January, 1989. Alders were planted 60 cm (2 ft) south of each redwood to provide shade and fix nitrogen. Treatments were

1. Control (tags #301-325)
2. Fertilizer tablet (tags #326-350)
3. Commercial compost + fertilizer tablet (tags #351-368)
4. Topsoil + fertilizer tablet (tags #369-378).

The four treatments were interspersed at random over the experimental site. The fertilizer was a 21 g Agriform tablet (20-10-5) placed 10 cm (4 in) deep, 10 cm (4 in) uphill from the treated redwood, just after it was planted. The compost treatment consisted of 0.9 liter (1 quart) of purchased compost (ammoniated sawdust) mixed with 1.9 liters (2 quarts) of subsoil placed in a planting hole 30 cm (12 in) deep. The topsoil treatment consisted of 2.8 liters (3 quarts) of soil collected from the surface 15 cm (6 in) at sites in old-growth redwood forest. The height and girth of each tree was measured initially and again annually, thereafter. Height was measured from the ground surface to the tip of the highest shoot. Girth was measured near the base between the first and second node. Foliage color was recorded on August 17, 1983 using Munsell color charts for plant tissues. Colors were summarized by hue. Hues 5YR and 7.5YR were called "bronze", 2.5Y and 5Y were called "yellow", 2.5GY was called "yellowish green" and 5GY and 7.5GY were called "green".

Data analysis. The statistical procedure for Field Trial 1 was a repeated-measures analysis of variance (ANOVA) on estimated relative growth rates using SPSS PC+ statistical software (Norusis 1988). The procedure is listed in Appendix A. The null hypothesis was that treatments did not affect growth during the six years of measurement. A repeated-measures design was selected because of its sensitivity both to changes in response over time and differential changes in response among treatments over time. Treatment (Control, Fertilizer, Compost + Fertilizer, Soil + Fertilizer) was a between-subjects factor. Year and the treatment-year interaction were analyzed as within-subjects factors. Significance levels were adjusted to maintain α = .05 for the whole experiment (Bray and Maxwell 1985). With three F values, critical α = .05/3 for individual F statistics. When an F statistic was significant, the next step was to examine years individually. Critical α's for individual years were adjusted by the number of years, so α = .05/6 for individual F statistics. Duncan's Multiple Range Test was used to distinguish which treatments differed in growth within individual years.

Relative growth, measured from time t_{i-1} to t_i is defined as

$$R_i = \frac{\ln(W_i) - \ln(W_{i-1})}{t_i - t_{i-1}} = \frac{\ln(W_i / W_{i-1})}{t_i - t_{i-1}}$$

where $\ln(W_i)$ is the natural logarithm of the weight of an individual at time t_i (Evans 1972). Since the trees are measured annually, R_i is measured in years^{-1}. The weight ratios which define R_i were estimated from allometric measurements (girth and height) of the trees, assuming that biomass is proportional to volume, which is proportional, in turn, to girth squared times height (g^2h) (Yoder, et al. 1988). Individual relative growth rate estimates were

$$R_i = \ln(g_i^2 h_i / (g_{i-1}^2 h_{i-1}))$$

where $t_i - t_{i-1} = 1$ is the interval (one year) between the girth and height measurements. Use of relative growth rates simplified data interpretation in two ways. First, R_i replaced two measurements, g_i and h_i. Second, the formula included a log transformation. In most plant growth studies the variance in sizes among plants increases as the plants grow. If treatments have different means, they are likely to have different variances. The most common method of equalizing variances is a log transformation.

Field Trial 2

Field procedure. This trial was also established on a ridge on the former C-20 Road about 25 m (80 ft) south of Field Trial 1. It was intended as a full-scale evaluation of park-generated compost for use in watershed rehabilitation. This site is on a through-cut, narrow ridge. The regolith is subsoil, road rock and crushed bedrock. The site was prepared on July 5, 1984, by ripping and re-shaping the former road surface to a gentle, slightly convex, SW-facing slope. On July 6, approximately 115 m^3 (150 cu yds) of compost were incorporated into the ground on three test plots. A D7 tractor first pushed the compost on a track below the test plots. Next, 61 cm (2 ft) of earth was excavated from each plot. Earth from the hole was bladed together with the compost as shown in Figure 1. Finally, the mixture was pushed back into the hole. Three piles of compost went into three plots. Plots 1, 3 and 5 received compost. The treated plots were each 6.1 m (20 ft) wide and 10 m (33 ft) long, with a 6.7 m (22 ft) space between them. Care was taken not to contaminate spaces between with compost, so they could be used as control plots. Plots 2, 4 and 6 were the controls (without compost). Because the compost was pushed from the storage location over loose ground, it became mixed and somewhat diluted with earth in transit. Plot 1 was closest to the storage location. It had the shortest push and appeared to receive the highest concentration of compost. Plot 5 was furthest and appeared to receive the most diluted compost. Later, the entire experimental area was mulched with straw at a rate of two tons per acre. Figure 2 shows the layout of the field plots.

Figure 1. Bulldozer mixing compost into ground.

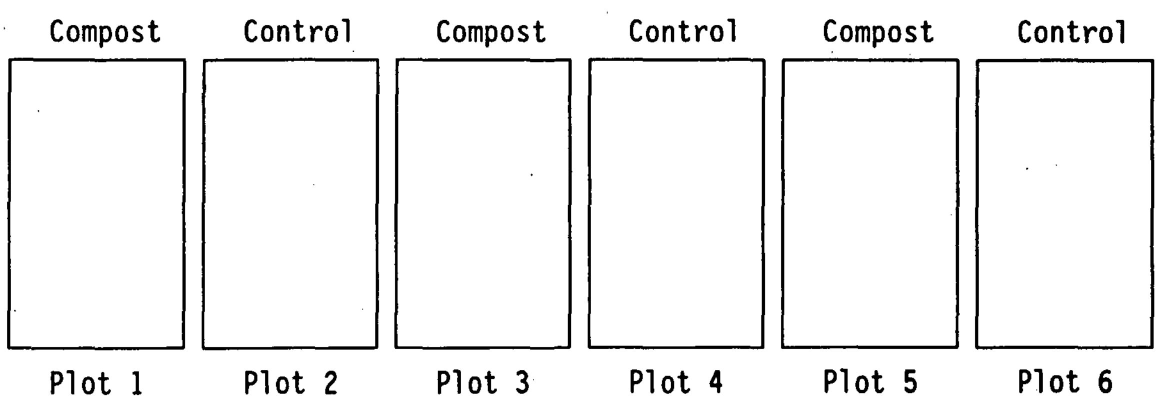

Figure 2. Plot layout in Field Trial 2. North is to left side of figure.

Trees were planted January 15-21, 1985. There were 144 one-year-old (1-0) redwoods and 288 alders within the six plots, 24 redwoods and 48 alders per plot. An additional 106 redwoods and 250 alders were planted around plots to minimize edge effects and fill in the nose of the ridge with trees. Spacing of redwoods was 1.5 m (5 ft). It was kept uniform in order to postpone competitive interactions and reduce variance. Redwoods were planted in 4 rows of six trees each and protected against browsing by vexar mesh tubes. Vexar tubes were removed in January, 1989. Two alders were planted near to each redwood, one 0.46 m (1.5 ft) south and the other 0.46 m (1.5 ft) east of the redwood tree. Figure 3 shows how the site looked just after it was planted. In this experiment, both species were measured. All 144 redwoods were measured and 144 alders, those in rows 2 and 3 in each plot, were measured. Height was measured from the ground surface to the tip of the highest shoot. Girth was measured near the base between the first and second node. Redwoods in odd numbered rows were fertilized with a 21 g Agriform fertilizer tablet (20--10-5), on January 21, 1986. The one-year delay in fertilization allowed adjustment for initial growth rates using analysis of covariance (Woolens and White 1988). Trees were measured at the start of the experiment and once-a-year thereafter during winter dormancy.

An inventory of natural colonization was conducted from May 24 to June 7, 1988. This inventory consisted of 25 randomly located samples per plot, a total of 150 sample points. A rectangular, 20 cm x 50 cm Daubenmire frame was placed at each point. Species were identified, counts and heights of woody species measured and cover classes of grasses, forbs, woody species and bare ground recorded. Standard Daubenmire cover classes were used for recording data in the field (Bonham 1989). However, during tabulation, some of the Daubenmire cover classes were combined to simplify data display, as follows:

Class	Range recorded	Range tabulated
1	0- 5	0- 5
2	5- 25	5- 25
3	25- 50	25- 75
4	50- 75	
5	75- 95	75-100
6	95-100	

Soil samples were collected in January 1985 and January 1990. Each sample consisted of thirty 1.9 cm (0.75 in) diameter cores, to a depth of 15 cm (6 in), taken from a split-tube sampler from evenly distributed points within plots. A mix of thirty cores was used to decrease within-plot variability and improve the estimate of the plot mean. Two samples of thirty cores were taken from each plot. Samples were allowed to dry at room temperature and passed through a 2 mm sieve before shipping them to a laboratory. Organic matter (OM), total nitrogen (total N) and mineralizable nitrogen (mineralizable N) were determined by CH2M Hill in

Figure 3. Field Trial 2 just after planting in February 1985.

Redding, California. Duplicate analyses were requested. Additional, one-time baseline tests on the 1985 samples included pH, exchangeable bases, cation exchange capacity (by ammonium acetate extraction at pH 7), phosphorus (by acid-fluoride extraction), ammonium and nitrate ions. These analyses were performed by the Soil Testing Laboratory, Oregon State University, Corvallis, Oregon, as described in Berg and Gardner (1978).

Data analysis. Growth of redwoods and alders was evaluated statistically using repeated-measures ANOVAs on relative growth rates, R_i, as described in Field Trial 1. The procedure is listed in Appendix B. The null hypothesis was that treatments did not affect growth during the years of measurement. Factors for redwood were compost, fertilizer, and year, along with the two-way and three-way interactions. Compost and fertilizer were between-subjects factors. Year was analyzed as a within-subjects factor. Significance levels were adjusted to maintain $\alpha = .05$ for the whole experiment (Bray and Maxwell 1985). With seven F values, critical $\alpha = .05/7$ for individual F statistics. When an F statistic was significant, the next step was to examine years individually. In individual years, there was an F value each for compost, fertilizer and the compost-fertilizer interaction. Critical α's for individual years were adjusted by 5 years x 3 F values = 15, so $\alpha = .05/15$ for individual F statistics. Duncan's Multiple Range Test was used to distinguish which treatments differed in growth within individual years. Redwood growth was examined also, on an exploratory basis, by analysis of covariance (ANCOVA), as suggested by Woolens and White (1988). In this analysis, growth in 1985 was the covariate. Growth from 1986 to 1990 was the dependent variable and compost, fertilizer and year were factors. With removal of protecting vexar mesh tubes in 1989, the potential for browsing increased. Evidence of browsing was noted. Effects of browsing are described and analyzed in Appendix C.

Factors for alder were compost and year. Compost was a between-subjects factor. Year and the compost-year interaction were analyzed as a within-subjects factors. For alders, with three F values, critical $\alpha = .05/3$ for individual F statistics. Had an F statistic been significant, the next step would have been to examine years individually, as with the redwoods.

Soil data were analyzed and pooled hierarchically. The 48 laboratory runs for OM, total N and mineralizable N were duplicates nested within the 24 field samples. The field samples were nested within the 6 plots from each of two years. Residuals calculated within samples and within plot-years are tabulated in Appendix B. Means at the plot-year level were calculated and used in a factorial multivariate repeated-measures analysis of variance. OM, total N and mineralizable N were the multiple dependent variables. Log transformations were used to minimize differences in variance among treatments. The multivariate null hypothesis was that compost did not affect OM, total N and mineralizable N and that they did not change over time. Compost was a between-subjects factor. Year was a within-subjects factor. Including the interaction, there were three F values. To keep $\alpha = .05$ for the whole experiment, critical $\alpha = .05/3$ was used for multivariate F statistics. When multivariate statistics differed, the next step was a univariate analysis of similar design for each soil test. Three soil tests (OM, total N and mineralizable N) x three F statistics = 9. Therefore, with adjustment, critical α = .05/9 for the univariate F statistics.

Multiple linear regression was used to compare tree growth and soil properties, allowing for different levels of compost among treated plots. The five-year response to compost was inferred from the regression of mean plot relative growth rates of unfertilized trees on mean plot levels of total N, OM and mineralizable N. The regression slope measured the response to soil conditions and the X intercept measured the threshold minimum soil test level needed for growth, given the specific environment (light, climate, drainage, etc.) found on the site during the trial period. It was anticipated that the three soil tests would be highly correlated with one another. Therefore, the soil tests were added stepwise to the regression only if they produced a significant reduction in the residual sum of squares. It was thought that a fertilizer response might vary with soil conditions. The pattern of response in redwoods to compost with fertilizer was inferred from the regression of mean plot relative growth rates of fertilized trees. The Y distance between regression lines was interpreted as the response to fertilizer under the specific soil test conditions at each point on the X axis. The difference in regression slopes measured the interaction between soil conditions and fertilizer response.

RESULTS

Alders

Alders averaged 0.17 m tall and 2.2 mm in diameter between the first and second node when planted. After four years, they averaged 3.70 m tall and 50.9 mm in diameter. Of the 144 trees planted, 130 survived in 1988 after four years. There was no significant difference in growth or survival of alders due to compost. Alders were larger toward the uphill (eastern) side of the plots. The largest alders were near the northeast corner of the experimental area.

Redwoods

In Field Trial 1, 76 of the original 78 redwoods survived in 1988, six years after outplanting. In Field Trial 2, 137 of the original 144 survived in 1990, five years after outplanting. Treatments had no significant effect on survival. Growth of redwoods increased both with compost and with fertilizer. Mean height and girth of redwoods in the two trials are plotted in Figures 4 to 7. Figure 8 shows the first-year foliage colors in Field Trial 1. Tables 3 and 4 show the significance levels of ANOVA's for relative growth rates of redwoods. Tables 5 and 6 show relative growth rates by treatment and year. This is a summary of findings for redwoods:

1. Fertilizer tablets increased growth of 1-0 redwoods over controls. The effect was significant the first year after fertilization. There was no significant fertilizer response after the first year.
2. Compost, mixed one third by volume with subsoil, increased growth of redwoods over controls consisting of subsoil alone. Effects lasted more than one year.
   a. In Field Trial 1, begun in 1983 with compost mixed into 2.8-liter (3-qt) planting holes 30 cm (2 ft) deep, growth of 1-0 redwoods increased over controls during the first three years. There was no significant response to compost during years four, five and six.
   b. In Field Trial 2, begun in 1985, with compost mixed to a depth of 60 cm over a large area, growth of 1-0 redwoods increased over controls during the first four years. Response to compost was not significant the fifth year.
3. Precipitation varied from year to year, giving different shapes to the growth curves in the two field trials. Growth rates were high in 1983 during the wet "El Nino", at the start of Field Trial 1. Growth rates were lower in 1985, which had a drier-than-average summer, at the start of Field Trial 2.
4. First-year individual growth rates of redwoods were not significantly correlated with individual growth rates in later years, so an analysis of covariance procedure offered no advantage and was not pursued.

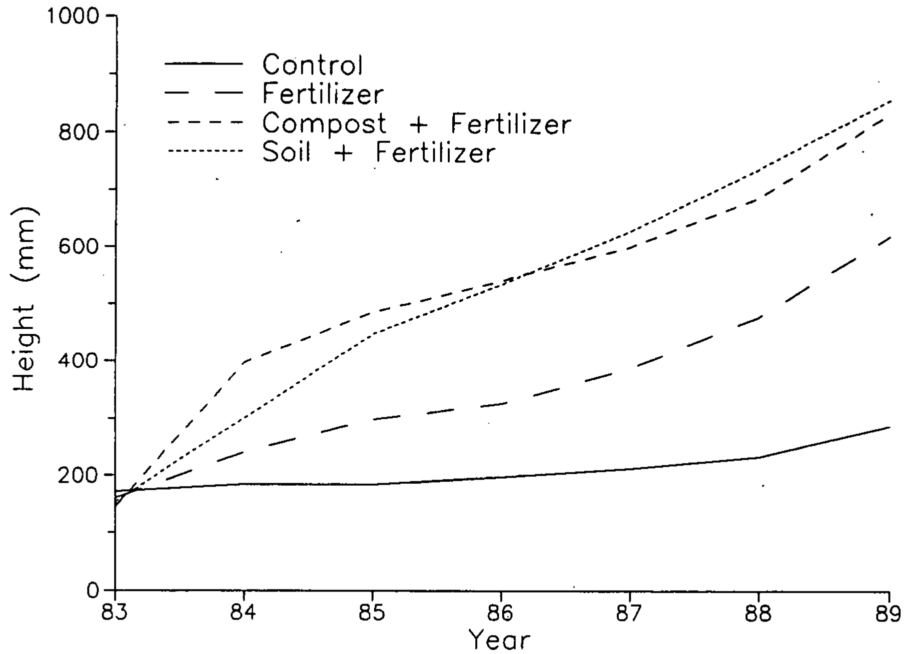

Figure 4. Redwood height in Field Trial 1.

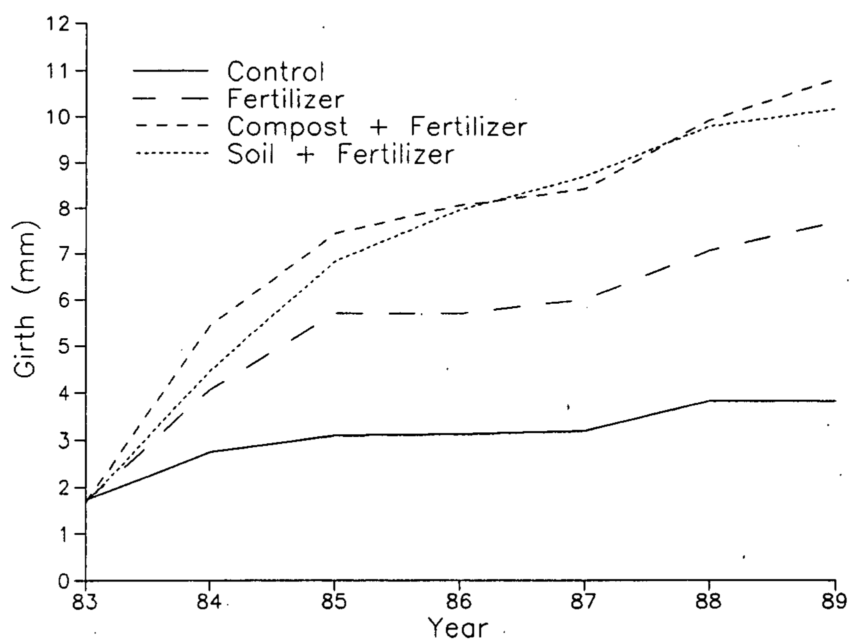

Figure 5. Redwood girth in Field Trial 1.

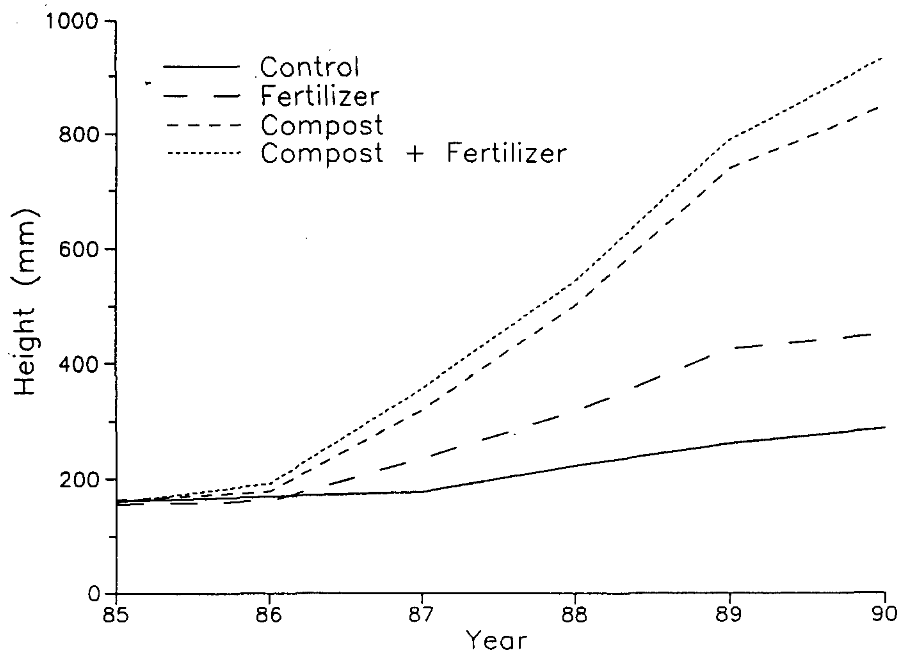

Figure 6. Redwood height in Field Trial 2.

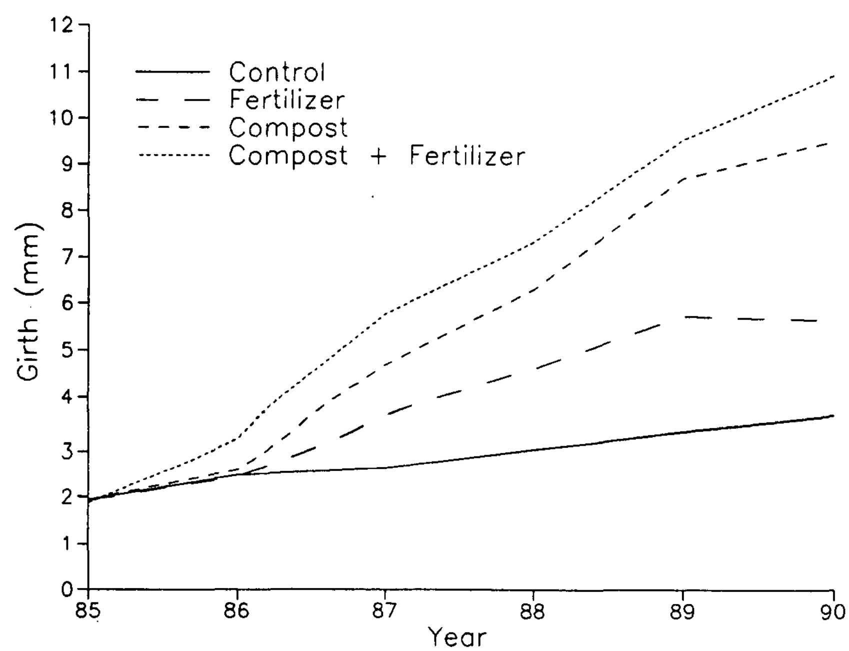

Figure 7. Redwood girth in Field Trial 2.

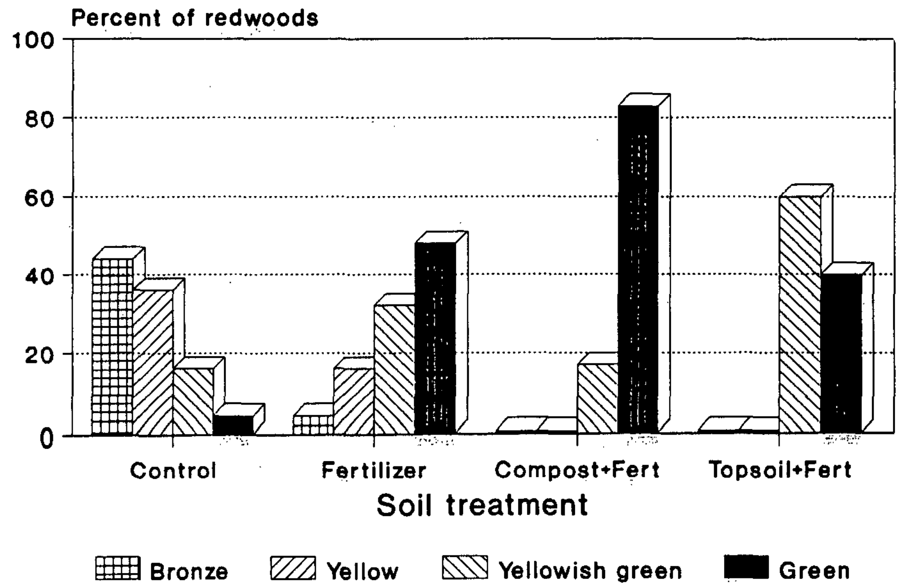

Figure 8. Redwood foliage color by treatment in Field Trial 1. Colors were recorded in August 1983, six months after planting.

Table 3. Significance of ANOVAs analyzing relative growth rates of redwoods among treatments in Field Trial 1.

Factor	Repeated-measures ANOVA for all years	Simple ANOVAs for individual years 1983	1984	1985	1986	1987	1988
Treatment	**	**	**	*	NS	NS	NS
Year	**						
Treatment x Year	**						

*,** Significant for all years at the 0.05/3 and 0.01/3 probability levels, respectively. Probability levels for individual years are 0.05/6 and 0.01/6, respectively.
NS Not significant.

Table 4. Significance of ANOVAs analyzing relative growth rates of redwoods in Field Trial 2.

Factor	Repeated-measures ANOVA for all years	Simple ANOVAs for individual years 1985	1986	1987	1988	1989
Compost	**	**	**	**	**	NS
Fertilizer	**	NS	*	NS	NS	NS
Comp. x Fert.	NS	NS	NS	NS	NS	NS
Year	**					
Comp. x Year	**					
Fert. x Year	NS					
Comp. x Fert. x Year	**					

*,** Significant for all years at the 0.05/7 and 0.01/7 probabilty levels, respectively. Probability levels for individual years are 0.05/15 and 0.01/15, respectively.
NS Not significant.

Table 5. Relative growth rates of redwoods in Field Trial 1, by treatment and year.[1]

Treatment	1983	1984	1985	1986	1987	1988
Control	1.03a	0.23a	0.07a	0.11a	0.37a	0.19a
Fertilizer	2.04b	0.90b	0.09a	0.22a	0.50a	0.40a
Comp. + Fert.	3.27c	0.88b	0.27ab	0.17a	0.48a	0.33a
Soil + Fert.	2.58bc	1.25b	0.50b	0.33a	0.38a	0.20a

[1] Means followed by the same letter are not significantly different at the 0.01 probability level, according to Duncan's multiple range test.

Table 6. Relative growth rates of redwoods in Field Trial 2, by treatment and year.[1]

Treatment	1985	1986	1987	1988	1989
Control	0.54a	0.07a	0.36a	0.32a	0.04a
Fertilizer	0.51a	1.00b	0.71ab	0.64b	0.01a
Compost	0.68a	1.64c	0.87b	0.98c	0.19a
Comp. + Fert.	1.23b	1.70c	1.05b	0.85bc	0.30a

[1] Means followed by the same letter are not significantly different at the 0.01 probability level, according to Duncan's multiple range test.

Naturally colonizing species

Daubenmire samples from compost-treated plots in Field Trial 2 averaged more species, higher cover values and taller individuals than samples from control plots. Figures 9, 10 and 11 compare cover distributions for grasses, forbs and coyote brush (*Baccharis pilularis* var. *consanguinea* (DC.) Kuntze), respectively, between compost and control treatments. Cover was greater in compost-treated plots for all categories of plants. Table 7 shows counts, by treatment and height class, of coyote brush, Douglas-fir and grand fir (*Abies grandis* Lindl.). There were more total seedlings in the control plots than the compost plots, but the counts of seedlings taller than 5 cm was greater in the compost plots. Table 8 lists frequencies of the species found, by treatment.

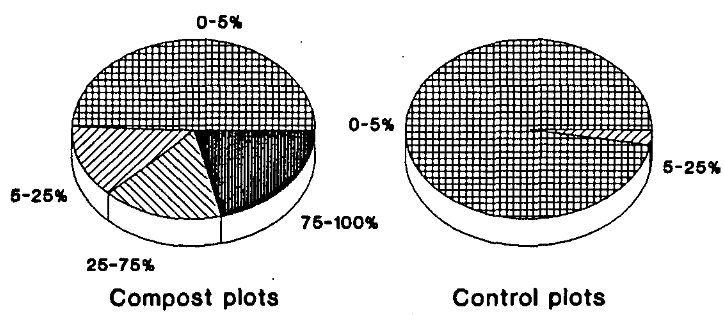

Figure 9. Colonization by grasses of compost and control plots, June 1988. Pie charts show percentage of cover classes for 75 samples from each treatment.

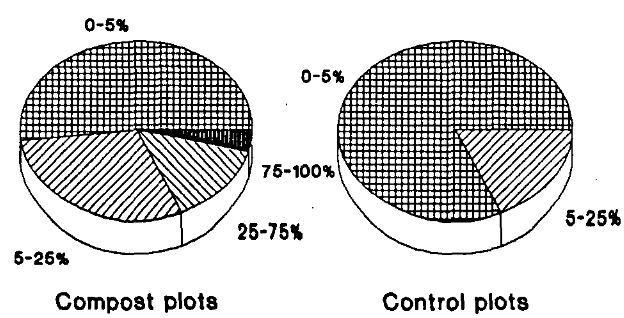

Figure 10. Colonization by forbs of compost and control plots, June 1988.

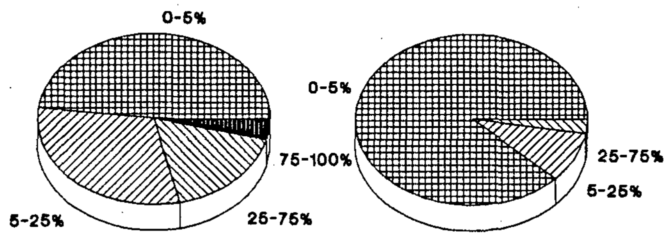

Figure 11. Colonization by coyote brush of compost and control plots, June 1988.

Table 7. Counts and height distributions of woody seedling colonizing compost and control plots. Counts are from 75 randomly placed Daubenmire samples each in control and compost plots. To calculate seeding densities, divide by area sampled, 75 samples x 0.1 m^2/sample = 7.5 m^2.

Treatment	Height class	Coyote brush Count	%	Douglas-fir Count	%	Grand fir Count	%
Control	>50 cm	3	(1)	0	(0)	0	(0)
	5-50 cm	61	(17)	0	(0)	0	(0)
	<5 cm	294	(82)	12	(100)	16	(100)
	Total	358	(100)	12	(100)	16	(100)
Compost	>50 cm	20	(7)	0	(0)	0	(0)
	5-50 cm	190	(63)	6	(67)	5	(56)
	>5 cm	90	(30)	3	(33)	4	(44)
	Total	300	(100)	9	(100)	9	(100)

Table 8. Frequencies of natural colonizers in plots, by treatment.

Common name	Scientific name	Control[1]	Compost[1]
Grand fir	*Abies grandis* Lindl.	13	5
Colonial bentgrass	*Agrostis tenuis* Sibth.	3	0
Silver hairgrass	*Aira caryophyllea* L.	3	4
Pearly everlasting	*Anaphalis margaritacea* (L.) A. Gray	2	4
Coyote brush	*Baccharis pilularis* var. *consanguinea* (DC.) Kuntze	70	66
Bull thistle	*Cirsium vulgare* (Savi) Tenore.	1	2
Orchard grass	*Dactylis glomerata* L.	1	10
Fireweed	*Erechtites prenathoides* (A. Rich.) DC.	8	16
Purple cudweed	*Gnaphalium purpureum* L.	2	2
Hairy cat's ear	*Hypochoeris radicata* L.	69	65
Douglas' iris	*Iris douglasiana* Herbert	0	1
Trefoil	*Lotus micranthus* Benth.	14	5
Douglas-fir	*Pseudostuga menziesii* (Mirb.) Franco.	10	6
California blackberry	*Rubus vitafolius* Cham. and Sch.	1	1
Sheep sorrel	*Rumex acetosella* L.	0	4
Sow thistle	*Sonchus* sp.	2	7
Black huckleberry	*Vaccinium ovatum* Pursh.	5	1
Violet	*Viola* sp.	0	1
Six-weeks fescue	*Vulpia bromoides* (L.) S.F. Gray	54	61
Yerba de selva	*Whipplea modesta* Torr.	2	1

[1] Number of Daubenmire samples with species present. There were 75 samples each from the control and compost plots.

Soil tests

Results of the soil tests are summarized in Tables 9 to 11. OM and total N were significantly greater in compost-treated than control plots. Both total and mineralizable N increased significantly from 1985 to 1990. Table 11 gives the overall means and 95 percent confidence intervals for all the soil tests, by treatment.

Table 9. Significance of MANOVA analyzing annual soil tests for levels of organic matter (OM), total nitrogen (total N) and mineralizable nitrogen (mineralizable N).

Factor	Multivariate (all 3 tests)	Univariate (individual tests) OM	Total N	Mineralizable N
Compost	*	**	*	NS
Year	**	NS	*	**
Comp. x Year	NS	NS	NS	NS

*,** Multivariate F's are significant at the 0.05/3 and 0.01/3 probability levels, respectively. Probability levels for univariate F's are 0.05/9 and 0.01/9, respectively.
NS Not significant.

Table 10. Organic matter, total nitrogen and mineralizable nitrogen in compost and control plots, by year.

Treatment	Year	OM (percent)	Total N (percent)	Min. N (ppm)
Control (ppm)	1985	1.34	0.077	1.5
	1990	1.42	0.083	5.5
Compost (ppm)	1985	7.44	0.122	15.8
	1990	7.42	0.143	23.6

Table 11. Summary of soil test results from Field Trial 2.[1]

Soil Test	Compost Plots	Control Plots
pH (2:1 H_2O)	5.13 ± 0.20	5.42 ± 0.04
Extractable cations (meq/100g)		
Ca	2.60 ± 0.38	1.87 ± 0.09
Mg	2.02 ± 0.16	1.73 ± 0.05
Na	0.20 ± 0.03	0.12 ± 0.02
K	0.33 ± 0.01	0.21 ± 0.03
CEC (meq/100g)	12.43 ± 2.58	9.60 ± 0.69
Base saturation (%)	42.7 ± 8.9	41.2 ± 2.6
OM (%)	7.44 ± 0.80	1.34 ± 0.14
Total N (%)	0.122 ± 0.003	0.077 ± 0.002
C:N ratio	35:1	10:1
P (ppm, acid-fluoride)	37.2 ± 4.7	23.7 ± 1.1
NH4 + (ppm)	5.7 ± 2.0	3.7 ± 1.4
NO_3- (ppm)	0.63 ± 0.50	0.23 ± 0.05
Min. N (ppm)	15.8 ± 2.5	1.5 ± 0.4

[1] Data are presented as the mean ± the 95 percent confidence interval of 6 baseline samples from each treatment collected January 2, 1985.

According to the stepwise multiple regression, the five-year plot means for relative growth of redwoods were most closely correlated with OM. Fertilizer response was also most closely correlated with OM. Due to the high correlation among soil tests, adding total N or mineralizable N did not produce any further significant reduction in the residual sums of squares. Figure 12 shows that, when no fertilizer was used, growth was more-or-less proportional to OM. The growth response to fertilizer was large when OM was low but neglible when OM was high. Regression statistics are shown in Table 12.

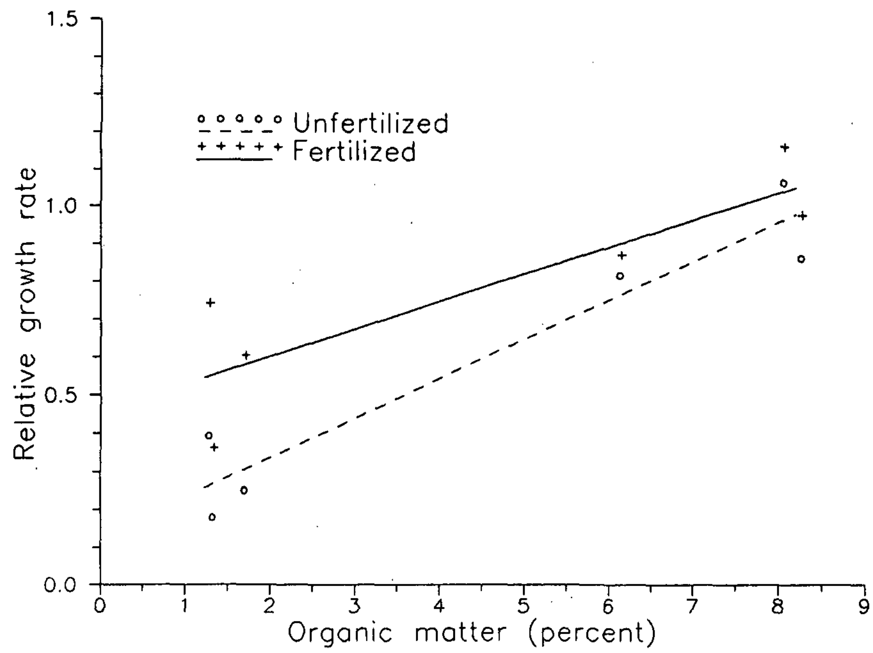

Figure 12. Relative growth rate of redwoods in relation to organic matter content and fertilization.

Table 12. Statistics for regression of mean relative growth rate on organic matter (OM) in plots.[1]

Group	Slope, **b**	Constant, **a**
Unfertilized	0.103 ± 0.043	0.131 ± 0.232
Fertilized	0.072 ± 0.056	0.457 ± 0.304

[1] Data are presented as the mean ± the 95 percent confidence interval. The regression equation is **R = a + b (OM)**, where **R** is the mean annual relative growth due to treatment and **a** and **b** are the regression coefficients.

DISCUSSION AND CONCLUSIONS

Benefits of fertilization

Fertilizer tablets improved first-year growth, foliage color and foliage density of redwoods in both field trials. Redwoods planted in compost-treated plots without fertilizer exhibited the same yellowish or bronzy foliage colors found in control plots. Although growth of unfertilized trees was greater in compost plots than control plots, the similarity of stress symptoms implies that there was still a marked deficiency of available nitrogen during the first year. Redwoods with fertilizer tablets had consistently dark green, dense foliage. Fertilizer apparently corrected the nutrient deficiency. The lack of a statistically significant growth response after the first year shows that these tablets are quickly expended. However, although relative growth rates actually increased only in the first year after fertilization, effects of this boost lasted throughout the period of monitoring in both field trials.

Benefits of compost

Compost was even more effective at accelerating growth of redwoods the first year than fertilizer tablets and compost continued to accelerate growth in subsequent years. The effect of compost with fertilizer in Field Trial 1 was not significantly different from the effect of topsoil with fertilizer. Growth was accelerated for three years in Field Trial 1, in which compost was mixed into 2.8 liter planting holes. Growth was accelerated for four years in Field Trial 2, in which compost was mixed into a large area. The redwoods in Field Trial 1 probably outgrew their planting holes after three years. Large-scale mixing of compost with a bulldozer is preferable to mixing in small planting holes because it does not confine root development.

Soil test interpretations

The purpose of using compost at the C-20 road was to restore soil organic matter. The laboratory analyses most indicative of soil organic matter properties were OM, total N, mineralizable N and cation exchange capacity (CEC). Higher levels were reported for all these tests in plots with compost added to the soil. However, the pattern of increase indicates that compost is not identical to native soil organic matter in every respect. Humus is most of what is measured as native soil OM. It consists of dark brown to black residues decomposed from roots of green plants and soil organisms. Humus has high CEC. Since the overall CEC of soil results from a combination of organic matter and clay minerals, CEC due to clay minerals must be subtracted out. Soil samples from old-growth redwood forests in Redwood National Park average CEC attributable to OM of 170 meq/100 g at a depth of 10 cm (4 in), using data in Popenoe (1987). Assuming that the compost and control plots on the C-20 have similar clay percentages and mineralogy, the CEC attributable to compost = $(CEC_{Compost} - CEC_{Control}) / (OM_{Compost} - OM_{Control}) = (12.43 - 9.60) / (0.0744 - 0.0134) = 46.4$ meq/100 g. This value is slightly less than a third of the value in forest soils, which indicates compost contained slightly less than a third as much humus in its organic fraction as forest soil organic matter. The remaining organic fraction must consist of larger, less thoroughly decomposed organic particles, most likely including a greater fraction of cellulose fibers.

The chemical test for OM actually measures only carbon. Organic carbon (OC) comprises about 58 percent of organic matter. Oxygen, hydrogen and nitrogen make up most of the remainder. Total soil nitrogen (total N) includes nitrogen compounds in several forms. Most total N exists as organic compounds in humus and living tissues. Green plants take up nitrogen only in the mineral forms, ammonium (NH_4^+) and nitrate (NO_3^-) ions, from the soil solution. As Table 11 shows, these ions comprise only about 0.6 percent of the total N in the soil. Green plants cannot directly access the much larger fraction of nitrogen that is in organic compounds. However, as nitrogen compounds are metabolized, nitrogen re-enters the available nitrogen pool. The term for this process is *mineralization*. The mineralizable nitrogen (mineralizable N) test measures the level of nitrogen in mineral forms from a soil sample, allowing for metabolism by the microbial population. This test comes closest to measuring nitrogen in the form that is actually used by forest trees (Powers 1980). Finally, if green plants or soil organisms take up mineral nitrogen to build tissues, this nitrogen is removed from the available pool. The term for this process is *immobilization*.

Incomplete decomposition and the wide ratio of carbon to nitrogen (C/N ratio) of park-generated compost may account for the low mineralizable N measured the first year in compost-treated plots (Table 8) and the stress symptoms observed in redwoods. The C/N ratio was 35:1 in compost-treated plots compared to 27:1 for native forest soils in the park. As a general rule, when organic materials with a C/N ratio greater than 30:1 are added to soil, available nitrogen becomes immobilized during initial decomposition (Tisdale and Nelson 1975). Nitrogen is immobiled by increases in populations of soil fungi and bacteria metabolizing fresh organic residues. Mushrooms were common in the compost-treated plots the first year. These and other saprophytes probably competed with the conifers for nitrogen as their biomass grew. Also contributing to the nitrogen shortage the first year was a loss of soluble nitrogen prior to application. The piles sat in storage uncovered on site all winter and were leached by the rain. Problems the first year with nitrogen deficiency could be lessened by covering the piles during storage. Nitrogen deficiency will not be a long-term problem where compost is used in conjunction with alders. Nitrogen fixation had measurably increased total N and narrowed the C/N ratio in compost-treated plots to 30:1 in 1990. Mineralizable N had increased by 50 percent. With the closed canopy of alders, soil conditions will continue to improve over time.

How long will the benefits of compost last? The 40- to 60-year total N recovery time for alders defines the period when compost treatments may be useful and relevant. During this time the compost will be starting to break down. Soil organic matter decomposes at a negative exponential rate. Soil disturbance accelerates decomposition for a time. Fresher organic residues are more unstable and have shorter half-lives than soil humus. For example, ryegrass residue has a half-life of approximately four years (Tisdale and Nelson 1975). A repeated-measures ANOVA was used to check for decomposition of park-generated compost after five years on the C-20 Road. Although this is a very sensitive statistical test, there was no measurable decomposition. Considering the confidence interval of the estimate, a three percent change was about the smallest that could have been detected. Within the five years of monitoring, compost did not decompose as much as three percent, so the half-life is at least $5 \times \ln(0.5) / \ln(1 - 0.03) = 115$ years (where ln is the natural logarithm). *No significant organic matter decomposition is predicted* within the 40-to-60-year lifespan of the red alders.

Differences in soil OM, total N and mineralizable N among treated plots confirmed the suspicion that pushing compost over loose earth causes dilution. Plot 5 had the farthest push and the lowest OM and N in treated plots. In addition to treatment variation, there was also considerable natural variation in OM, total N and mineralizable N among the control plots. This variation was a nuisance in terms of the factorial statistics (ANOVAs) but it provided a better opportunity for regression analyses between soil properties and plant growth. The correlation between OM and growth was strong. Organic matter levels accounted for 89 percent of the variation in growth of unfertilized redwoods among plots. To grow at normal rates, the redwoods needed fertility levels like those of native soils in the forest.

Comparison of tables 1 and 11 shows that levels of OM and total N in the control plots on the C-20 are similar to levels in deep roadcuts. The setting of the C-20 site on a through-cut ridge is particularly harsh, even for a rehabilitation site. Only one of the 48 soil samples collected from other watershed rehabilitation sites has been as low in total N as the samples from the C-20 control plots. Through-cuts on ridges are small, environmentally safe locations for compost which most need soil improvement.

Comparisons among experiments

Results of growth measurements on alders planted in the field in 1985 were different than results of greenhouse experiments conducted in 1982 (Sacklin et al., 1984). In the greenhouse, alders grew faster with compost than without, and they responded more to compost than to fertilization with P, K, Ca, S or any combination. In the field on the C-20 road, there was no statistical difference between the compost treatments and the controls. Alders have nitrogen-fixing symbionts, so nitrogen is not limiting for them. Since the symbiotic actinomycetes which actually fix the nitrogen dwell within the tissue of alder roots, there is little likelihood that decomposers would compete successfully for the nitrogen against the alders. The difference between field and greenhouse growth must reflect different limiting factors. In the greenhouse, plants were watered regularly so that drought would not be limiting. Confinement within the pots and periods of saturation may have made oxygen limiting, and compost would certainly have improved aeration. In the field, there was little summer rain. There would never have been saturation of the soil during the growing season. Although permeability of the soil would have been increased by addition of compost, the permeability of even the unimproved subsoil was apparently more than adequate for growth of alder roots and actinomycetes. On the other hand, alders in the field began losing some of their leaves in the middle of summer, indicating that drought was a limiting factor in this environment.

Growth rates varied between field trials, reflecting both the growth curves of the redwoods and climatic variation over the periods of measurement. Comparison of the two field trials, started in 1983 and 1985, allows separation of some of the climate-related and age-related growth differences. The more rapid growth in all treatments of Field Trial 1 the first year is probably attributable mostly to an unusually wet "El Nino" summer. That is to say, drought was a greater limiting factor in the second and third years, with the third year being the driest. This trend in growth is not simply a reflection of the growth curve for redwood seedlings. In the first year after planting, growth of controls planted in 1985 was only about half the first-year growth of controls planted in 1983. The comparison shows clearly that first-year growth varies from year to year. On the other hand, in the 1985 growing year, the controls planted in 1985 grew faster than controls (in their third year) planted in 1983. This demonstrates that annual variation is not the only factor, that the age of the trees must also be taken into account. The youngest redwoods apparently have the greatest potential to grow rapidly in response to a favorable climatic year and to a favorable soil environment. The investment in careful site preparation begins to pay off immediately.

Compost supply and potential demand

The Wolf Creek facility can generate about 245 m^3 (320 yd^3) compost per year (Site Operator, Alan Shafer, personal communication). This will treat an area of 430 m^2 (4,600 ft^2) at the rate it was applied in experiments. Each year, earth-moving during watershed rehabilitation leaves about 20 to 25 ha (50 to 60 acres) of bare ground which is re-planted with trees. Of this area, about two percent is located on former through-cuts, rock pits, log decks and log landings without original soil. Often, fill has been end-hauled to these locations and they are re-shaped to mimic natural relief. Nevertheless, soil conditions remain very poor in comparison with the average for watershed rehabilitation sites. The total area of such sites varies from year to year with an average of about 0.4 ha (1 acre) treated each year. To treat an area this large with compost at the rate applied on the C-20 would take 2300 m^3 (3000 yd^3) of compost. Therefore, the potential demand for compost far exceeds the supply. There are nearly always one or more field locations where the available compost could be used. Locations can be selected to minimize operating costs. The main point is that analysis and planning can completely determine how the compost is used. Finding a location that could benefit from compost is rarely a constraint.

Cost analysis

The four principal costs associated with compost operations are 1) production, 2) transportation, 3) application and 4) water-quality monitoring. The cost of production is attributable mostly to the salary of the compost site operator. The use of manure and sawdust additives to promote higher temperatures adds only $150 to this cost. The current production limit is 320 yd^3/yr. Production of any amount, from 0 to 320 yd^3 would cost roughly the same.

Transportation involves using a dump truck to deliver the compost from Wolf Creek to the application site. This cost is mostly a function of travel time. Travel time is proportional to the amount of compost times the distance. Potential application sites exist east of Redwood Creek on two remaining spurs off the C-Line road to the Tall Trees trailhead. A round trip from Wolf Creek to a ridge on the C-10 or C-30 spur roads would take about three hours. One potential site west of Redwood Creek is a rock pit located on the old Y-Line. A round trip from Wolf Creek to the Y-Line rock pit would take about five hours. The park can reduce transportation costs by using compost on the closer sites and by selecting the most efficient type of dump truck. A 10-yd^3 rental dump truck cost about $44/hr and a 20-$yd^3$ rental dump truck cost about $55/hr in 1989 (Watershed Rehabilitation Supervisor, Terry Spreiter, personal communication). The park's 5-yd^3 dump truck cost about $25/hr to operate in 1989 (Road Engineer, John Wilson, personal communication). The largest dump truck provides the least expensive way to transport 320 yd^3 compost from Wolf Creek to the C-30 and this option appears in Table 13. This cost is $2,640. However, delivery is not time critical. Therefore, in certain cases, if the park's 5-yd^3 dump truck and personnel are idle, it may actually be less costly to use them, rather than pay for a rental.

Application involves mixing the compost into the ground with a bulldozer already on site for watershed rehabilitation. Compost was applied on the C-20 experimental site, the M-3 rock pit and the Redwood Creek overlook. It took about 80 hr/acre to mix in the compost at these sites and rental for the D-7 bulldozer was $80/hr. Table 13 shows the cost to incorporate 320 yd^3 is $683.

Water-quality monitoring requires collection of four samples per field site, as specified in the park's permit for compost operations (California Water Quality Control Board 1984). Tests are required for total N, fecal coliform bacteria and fecal streptococcus. Samples are to be collected twice per month during storms in the first rainy season from October 1 to May 1. The cost of water quality monitoring is minimized if all the compost is used at one site, as shown in Table 13. Assuming that runoff from five storms can be sampled and one site is treated, the cost is $3,500.

Table 13. Compost utilization cost calculations.

- **Transportation** (proportional to amount x travel distance) Dump truck (20yd^3 capacity, \$55/hr) Assume 3 hrs. round trip, 320 yd^3:	\$2,640
- **Application** D-7 bulldozer (\$80/hr, 80 hrs/acre) Assume 320 yd^3, 4600 ft^2 area:	\$ 683
- **Water Quality monitoring** (proportional to number of sites) Four sample points are required per site. Total (Kjeldahl) nitrogen, fecal coliforms and fecal streptococcus add up to \$664 per sample period. Need two samples per month during rains. Assume 1 site, 5 sample periods:	\$3,500
Total utilization cost:	\$6,823

Cost-benefit analysis

The purpose of a cost-benefit analysis is to weigh options and see which can do the most good, given the funding available. To do this objectively, there has to be a common measure of good. On rehabilitation sites, considering use of compost and alternatives, the area and degree to which pre-disturbance soil conditions are restored affects the regrowth of vegetation. Weaver and Sonnevil (1984) compared costs and benefits of various erosion-control techniques used in watershed rehabilitation. Their measure of benefit was sediment saved. Cost/benefit ratios were measured in dollars per unit volume of sediment saved. Cost/benefit ratios for compost treatments to promote revegetation can be measured in units of cost per unit area improved (dollars/m^2 or dollars/ft^2).

The decision to produce compost, rather than to pump chemical toilet waste into community sewage facilities, resulted from a judgement that it was better environmental practice. This was the *primary* justification for building a compost facility. The fact that, in the process, the park can convert a human waste product into something beneficial to soils and plants is a *secondary* benefit that adds little or no cost to operation of the facility.

Transportation and application are required for use of compost in the field. For rehabilitation sites, the most favorable estimate, given 320 yd^3 compost applied to an areas of 4600 ft^2 is \$2,640 for transportation and \$683 for application. The cost/benefit ratio is \$0.067/m^2 (\$0.72/ft^2). Unless other arrangements can be made, it will also be necessary to continue collection of water quality samples at each application site. Assuming there is one site, water sampling adds \$3,500 for a total cost of \$6,823. The cost/benefit ratio is \$0.138/m^2 (\$1.48/ft^2).

Excavation of a typical stream crossing 100 ft wide with 60 ft banks cost about $1,500 in 1989 (Terry Spreiter, personal communication). The *primary* justification for excavation is erosion control. The fact that, in the process, the excavation exposes surface soil for reestablishment of native plants is a *secondary* benefit that adds no further cost to the operation.

Suppose, instead of a stream crossing, that a dry swale of similar dimensions is excavated simply to promote revegetation. The cost would be about $1,500. The treatment exposes a buried topsoil with an area of 2 x 60 ft x 100 ft = 12,000 ft^2. The cost/benefit ratio is $0.012/m^2 ($0.125/ft^2). Other things being equal, physical excavation is at least six times more cost-effective at promoting revegetation on rehabilitation sites than compost. A *secondary* benefit of excavation is that the excavated fill can be pushed to a location where soil has been stripped off. This may not restore pre-disturbance fertility but it restores depth. Alders and other pioneers can then colonize the site and begin rebuilding the soil. At locations where excavation can uncover topsoil, using compost is not cost-effective. Considering its limited supply, compost should be reserved for sites with high priority which can be restored in no other way.

Balancing investments

An estimate of the typical annual cost of transportation, application and water-quality monitoring for compost was $6,823, assuming 320 yd^3 was applied on an area of 4600 ft^2. Standard 1-0 redwood nursery tube stock were the test plants used in the C-20 field trials. In January 1987, 17,000 of these trees were planted on rehabilitation sites. The average price was $0.17 per tree and labor for planting averaged $0.40 per tree. It is normal practice to plant trees of this size on 10-ft. centers. At this spacing, a 4600 ft^2 compost-treated area could be planted for ($0.17 + $0.40) x 4600 / 10^2 = $26.22. This small investment in plants is out of balance with the investment in compost for the same area. Larger plants are warranted if compost is to be used. The largest redwoods planted on rehabilitation sites in 1988 were "Plug 1" stock, averaging approximately 700 mm (28 in.) tall when planted. These cost $0.27 per tree and planting averaged $0.76 per tree. Planted on 10-ft. centers, the compost-treated area could be planted for ($0.27 + $0.76) x 4600 / 10^2 = $47.38. The 1-0 redwoods in compost-treated plots averaged 737 mm tall 4 years after planting. The four-year head start for "Plug 1" redwoods over 1-0 redwoods costs ($47.38 - $26.22) / 4 yr = $5.29/yr. Considering that the effectiveness of compost may decrease over time relative to controls, it seems prudent to start with the larger trees.

For landscaping projects, still larger trees should be used. In 1989, redwoods in five-gallon pots averaging 1700 mm (5.5 ft.) tall sold for $19 each. Fifteen-gallon trees, averaging 2100 mm (7 ft.) tall sold for $75 each. These trees would be planted on 15- or 20-ft. centers. Transportation and labor might run about 2.5 times the purchase price, if the same relationship exists between costs of purchase, transportation and planting as has been found for smaller trees. If so, five-gallon trees could be planted on 15-ft. centers for (2.5 x \$19) x 4600 / 15^2 = \$971.11. If height growth is projected linearly using the average growth rate from 1987 to 1990, the 1-0 redwoods in compost-treated plots will average 1700 mm tall in 1994, 8.6 years after outplanting. The head start for five-gallon trees over "Plug 1" trees costs \$971.11 - \$47.38) / (8.6 - 4) yr = \$200.81/yr. Fifteen-gallon trees on 20-ft. centers might cost (2.5 x \$75) x 4600 / 20^2 = \$2156.25. The 1-0 redwoods in compost-treated plots can be projected to reach 2100 mm tall in 1996, 10.5 years after outplanting. The head start for fifteen-gallon trees over five-gallon trees costs (\$2156.25 - \$971.11) / (10.5 - 8.9) = \$623.76/yr. Assuming that the beneficial lifespan of compost is 50 years, its annual cost is \$6823 / 50 yr = \$136.46/yr. By this reasoning, five-gallon redwoods give a better balance for the investment in landscaping costs than fifteen-gallon trees, although use of fifteen-gallon redwoods might be justified for other reasons. Other figures could be used for different spacings and sizes of plants. Better estimates for balancing these investments would be possible with a longer period in which to monitor plant growth. It is clear, however, that compost costs are more in keeping with landscaping projects than with what is being spent now to revegetate watershed rehabilitation sites.

As originally envisioned, compost was to be applied primarily on watershed rehabilitation sites (Sacklin 1982). However, in the future, landscaping projects may consume all the finished compost the park can produce. If so, this may be preferable from a cost-benefit perspective. Many roadside locations offer scenic vistas but lack the topsoil needed to support indigenous vegetation. Rebuilding the soil and landscaping with native plants creates an inviting and park-like foreground consistent with the value of a natural scene. Compost has been used successfully in park landscaping at Headquarters in Crescent City, Redwood Information Center on Orick Beach, South Operations Center and the Redwood Creek overlook along the Bald Hills Road. There will be increasing need for compost in landscaping as Redwood National Park matures and develops its visitor potential.

RECOMMENDATIONS

Redwood National Park's compost facility at Wolf Creek treats wastes generated in the park from chemical toilets and septic tanks. The compost can be either recycled or used to improve soil. Soil restoration is a costly process. Each case should be analyzed individually in terms of costs and alternatives. These recommendations are general guidelines for situations in which field application is elected or being considered.

Where to use compost:

1) Compost is valuable as a soil amendment where there is no topsoil and one must quickly establish native species.

2) Considering its low availability and high cost, the most cost-effective field application for compost is in landscaping projects.

3) If there is a surplus of compost after use in landscaping, it may be used in watershed rehabilitation on ridges with severely damaged soils. Landings, decks, rock pits and through-cut roads are examples.

Where not to use:

Compost is not necessary if native topsoil is available. The current practice of identifying, excavating and spreading buried topsoil is the most powerful physical method of promoting long-term natural revegetation on rehabilitation sites, and this procedure meshes well with other facets of physical site treatments.

How to use:

1) Most plants native to Redwood National Park are adapted to soils rich in organic matter and the larger species are quite deep-rooted. To correct an organic matter deficiency, compost should be incorporated to a depth and area sufficient to accommodate a mature root system. Power equipment is appropriate for projects of this scale. Equipment size may range from a rototiller to a backhoe or bulldozer, depending on the area and species. For native conifers, 30 centimeters (12 in) of compost should be applied over the surface of the treatment area. This should then be mixed into the soil to a depth of 60 cm (2 ft) with the equipment.

2) Use of compost in remote locations for watershed rehabilitation requires advanced planning and logistics. The compost should be stockpiled on-site in an appropriate quantity prior to heavy equipment work. Once a deck or road has been ripped and outsloped, the loosened earth is easier to work. The compost should be mixed in at this time using the bulldozer on site.

3) The park's compost has a wide ratio of carbon to nitrogen and low cation retention capacity, compared to the organic fraction of native soils. In practical terms, this means there is a shortage of available nitrogen, especially during the first year. Slow-release fertilizer tablets should be used with woody plants. The tablets should be placed in the ground in late winter after planting so that they begin dissolving in time for spring growth. Alders should be planted on rehabilitation sites to begin restoring the carbon nitrogen balance.

How to store:

Compost is cured for at least six months to minimize survival of potentially pathogenic micro-organisms. To free space at the composting facility, it is a good idea to store finished compost at the application site. Experience at the C-20 site shows that very high weed populations can develop on compost curing in the field. When this weed-infested compost is used, weed seeds are introduced into the soil. Fall germinants compete with newly planted native species. To control weeds, compost piles should be covered with black plastic during spring and summer. Covered in this way, weeds will be unable to flower and set seed, and wind-born seed will not contaminate the piles. Covering may also help to reduce nitrogen losses, since rainwater leaches the piles.

How to minimize costs:

1) Determine if there is a real need and priority for soil improvement. If not, it is less expensive to recycle compost at the treatment facility than to use it in the field. On rehabilitation sites, consider whether alders would grow and whether they would suffice as a means of restoring soil fertility, allowing 40 to 60 years to complete the process.

2) List potential application sites in order of their distance to the composting facility. If there is no other priority scheme, select the closest site or sites to minimize transportation cost. On the average, high-use landscaping sites near highways are closer to a composting facility than back-country rehabilitation sites.

3) Other things being equal, use of the largest available dump truck minimizes transportation cost.

4) If possible, use all the compost on one site so that only one site requires water-quality monitoring.

5) If possible, route results of water quality tests through a staff bacteriologist, for a professional recommendation on need of continued monitoring. The California Water Quality Control Board has final authority but gives consideration to professional judgement on whether further monitoring is needed.

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GLOSSARY

Available. [Soil fertility] In reference to soil nutrients, available means readily take up by roots of green plants or by their mycorrhizal associates.

Cation exchange capacity (CEC). [Soil science] The sum total of exchangeable cations that can be adsorbed by the soil, expressed in milliequivalents per 100 grams of soil at neutrality (pH 7) or at some other stated pH value. Soil constituents most responsible for CEC are humus and clay. Topsoil has higher CEC than subsoil due to its high humus content.

Compost. Organic residues or a mixture of organic residues and soil that have been piled, moistened and allowed to undergo biological decomposition. The organic residues may originate from plants, manures and animal byproducts and may be supplemented with mineral fertilizers. Compost may be characterized in terms of the origin of organic material, its chemical and biological makeup and its stage of decomposition. Together, these properties determine the behavior and lifespan of compost as a soil amendment.

End-haul. [Watershed rehabilitation] Removal of earthen material from one location and deposit of the material at a second location. For example, earthen fill may be excavated from around a stream and end-hauled by dump truck to a ridge for erosion control and soil restoration.

Fertilizer. A material added to soil to supply one or more elements essential for plant growth.

Humus. [Soil science] The well decomposed, finely divided, more-or-less stable part of soil organic matter, usually dark in color.

Immobilization. [Soil fertility] Removal of nitrogen by plants and microbes from the available pool.

Leader. [Forestry, plant science] The top, usually vertical, stem (apical shoot) of a conifer, representing the current year's growth.

Mineralizable nitrogen. [Soil fertility] The nitrogen mineralized from organic compounds into inorganic form by micro-organisms during anaerobic incubation for a measured period at a measured temperature. Higher plants require nitrogen in inorganic form. A mineralizable nitrogen test provides an index of the rate of inorganic nitrogen production, hence nitrogen availability, for a given soil sample.

Mineralization. [Soil fertility] Release of nitrogen in organic compounds to available mineral forms during decomposition of organic matter.

Mulch. A material spread on the soil surface to protect the soil and plant roots from rainsplash, soil crusting, freezing and evaporation. Straw, wood chips, leaves, gravel, woven fabrics and plastic films may all be used as mulches.

Outboard slope. [Civil engineering, watershed rehabilitation] In hilly or mountainous terrain, the slope just below the edge of the road. If the slope gradient has been steepened by addition of earthen fill to the side of the road, this outboard slope extends downslope to the base of the fill where a natural slope gradient is encountered.

Outslope. [Civil engineering, watershed rehabilitation] In hilly or mountainous terrain:

1) to build or alter a road or trail crossing a slope so that water runs off toward the outboard slope, rather than concentrating in a ditch along the roadcut;

2) a road surface which slopes downhill toward the outboard slope, rather than toward a ditch along the roadcut.

Plug-1 Stock. [Forest nursery] Two-year-old bare-root conifers grown in tubes for one year, then transplanted outdoors to a nursery bed the second year. The plug-1 is a type of 1-1 stock (See tube stock).

Regolith. [Earth sciences] The mantle of unconsolidated material above solid rock. Regolith includes both soil and any underlying substratum, such as alluvial or colluvial deposits. Soil is more narrowly defined in that it is close enough to the earth's surface that it serves as a natural medium for growth of plants and its properties are subject to biological and surficial processes, such as development of structure, brightening of color and accumulation of clay and organic matter.

Ripping. [Watershed rehabilitation] The process of loosening compacted earthen material using a tractor with a toothed attachment behind it. Material is broken up with minimal mixing.

Roadcut. [Civil engineering] In hilly or mountainous terrain, the vertical or steepened cut from the edge of the road to the point above the road where the slope resumes its natural gradient. Depending on the width of road and steepness of slope, a roadcut may expose layers of subsoil, an underlying substratum or solid rock.

Soil amendment. Material added to an mixed into a soil in order to modify and enhance its properties as a medium for growing plants.

Soil fertility. The status of a soil with respect to its ability to supply the nutrients essential to growth of plants.

Soil horizon. A layer of soil, approximately parallel to the soil surface, recognizably uniform in its characteristics.

Soil organic matter (OM). [Soil science] Plants and animal residues in the soil in various stages of decomposition. Organic matter content is traditionally measured in the laboratory by digestion with an oxidizing agent. It is the carbon in the organic matter which is oxidized. Organic matter is then calculated, assuming organic matter is 58 percent carbon.

Soil profile. [Soil science] A vertical section of soil extending from the surface through all its horizons to the substratum or underlying rock. A typical soil profile includes a A horizon at the surface with topsoil highly modified by plants and plant roots, and a subsoil B horizon less affected by plants but often strongly affected by surface weathering and downward movement of clay.

Soil test. [Soil fertility] A chemical, physical or biological procedure which estimates a soil property pertinent to plant growth.

Stream crossing. [Watershed rehabilitation] A location along a road where the road crosses a stream.

Subsoil. [Soil science] A subsurface soil horizon (B horizon) between the surface A horizon and the substratum at greater depth. The subsoil contains less organic matter, and is less fertile than topsoil near the ground surface. Subsoil may have brighter reddish or brownish colors and more clay than surface topsoil layers.

Throughcut. In hilly or mountainous terrain, a road cut through a ridge or mountain. Throughcutting involves export of soil from the throughcut location. Therefore, soil restoration is more difficult and more costly during watershed rehabilitation than it is where the soil is merely moved to the outboard slope.

Topsoil. The upper part of the soil (A horizon) which is the most favorable material for plant growth. It is ordinarily rich in organic matter, relatively fertile and dark in color.

Total nitrogen. [Soil science] The total elemental nitrogen content in a sample of soil, including both that within organic compounds and residues and that in free mineral form. Total nitrogen is measured in the laboratory by digestion in hot sulfuric acid (Kjeldahl procedure) to free the nitrogen from organic matter. Most soil nitrogen is in organic form.

Tube stock. [Forestry, nursery science] General term for conifer seedlings grown in tubes in a nursery. Numbers refer to years that trees were in nursery containers and years they were in the ground when sold. For example, 1-0 tube stock is grown one year in a tube. 1-1 bare root stock is grown in a container for one year, planted in the ground and grown a second year before being sold.

Vexar tube. [Forestry] Plastic mesh tube, 915 mm (36 in) tall and 8.25 cm (3.25 in) in diameter. The tubes are placed over conifer seedlings and stapled to a wooden stake. The plastic mesh protects a seedling within from browsing by deer and elk.

APPENDICES

A. *SPSS procedures and data from Field Trial 1*

File PILOT.CMD Listing:

```
Title   'Statistical Analyses on Redwoods in'.
Sub     'the C-20 Road Compost Pilot Experiment'.

Set
      More=off/    Screen=off/    Length=59/    Eject=on/
      Listing='Pilot.out'.

Data List File='Pilot.dat' Free/
      Tree
      H0 G0
      H1 G1
      H2 G2
      H3 G3
      H4 G4
      H5 G5
      H6 G6.

If (Tree ge   1 and Tree le 325) Treat = 1.
If (Tree ge 326 and Tree le 350) Treat = 2.
If (Tree ge 351 and Tree le 368) Treat = 3.
If (Tree ge 369 and Tree le 378) Treat = 4.

If (H6 gt 0) RGR1 = Ln((G1*G1*H1) / (G0*G0*H0)).
If (H6 gt 0) RGR2 = Ln((G2*G2*H2) / (G1*G1*H1)).
If (H6 gt 0) RGR3 = Ln((G3*G3*H3) / (G2*G2*H2)).
If (H6 gt 0) RGR4 = Ln((G4*G4*H4) / (G3*G3*H3)).
If (H6 gt 0) RGR5 = Ln((G5*G5*H5) / (G4*G4*H4)).
If (H6 gt 0) RGR6 = Ln((G6*G6*H6) / (G5*G5*H5)).

Var Labels
      H0 'Initial Height  (mm)'/   G0 'Initial Girth  (mm)'/
      H1 '1st-year Height (mm)'/   G1 '1st-year Girth (mm)'/
      H2 '2nd-year Height (mm)'/   G2 '2nd-year Girth (mm)'/
      H3 '3rd-year Height (mm)'/   G3 '3rd-year Girth (mm)'/
      H4 '4th-year Height (mm)'/   G4 '4th-year Girth (mm)'/
      H5 '5th-year Height (mm)'/   G5 '5th-year Girth (mm)'/
      H6 '6th-year Height (mm)'/   G6 '6th-year Girth (mm)'/
      RGR1 '1st-year Relative Growth Rate'/
      RGR2 '2nd-year Relative Growth Rate'/
      RGR3 '3rd-year Relative Growth Rate'/
      RGR4 '4th-year Relative Growth Rate'/
      RGR5 '5th-year Relative Growth Rate'/
      RGR6 '6th-year Relative Growth Rate'.
```

```
Value Labels
      Treat  1 'Control'  2 'Fert'  3 'Comp+Fert' 4 'Soil+Fert'.

Select if (H6 gt 0).

Means  H0 to RGR6
       by Treat.

* Repeated-measures ANOVA for all growth years:

MANOVA RGR1 to RGR6
       by Treat (1,4)
       /WSFactors=Year(6)
       /Print=Signif(Hypoth AverF Univ).

* Years:  1983-4, 1984-5, 1985-6, 1986-7, 1987-8, 1988-9.

* Individual ANOVAs, by year:

MANOVA  RGR1  by Treat(1,4).
MANOVA  RGR2  by Treat(1,4).
MANOVA  RGR3  by Treat(1,4).
MANOVA  RGR4  by Treat(1,4).
MANOVA  RGR5  by Treat(1,4).
MANOVA  RGR6  by Treat(1,4).

* Duncan's Multiple Range Test:

ONEWAY RGR1 to RGR6 by Treat(1,4)
       /Ranges=Duncan(.01).

Finish.
```

<u>File PILOT.DAT Listing</u>:

Tree	H0	G0	H1	G1	H2	G2	H3	G3	H4	G4	H5	G5	H6	G6
301	157	1.7	163	3.0	165	2.6	172	2.5	168	3.0	65	3.0	187	3.5
302	154	1.9	158	2.7	165	3.0	165	2.7	175	4.0	183	3.3	199	3.0
303	162	2.6	172	3.3	174	3.3	198	3.6	190	3.7	181	4.7	205	4.1
304	172	1.2	175	2.3	174	2.3	183	2.1	176	2.0	175	2.5	207	2.1
305	135	1.7	140	2.7	141	3.2	156	2.8	158	2.2	164	2.8	204	3.2
306	155	1.8	168	2.8	168	3.4	171	2.8	198	4.2	195	3.4	244	3.2
307	201	2.0	208	3.0	212	3.5	232	4.1	227	3.0	258	4.6	305	3.7
308	182	2.5	187	3.2	182	3.5	197	3.3	205	3.7	242	5.7	278	5.8
309	183	1.5	198	2.7	205	2.7	205	3.8	230	4.1	264	5.1	249	5.2
310	178	2.3	190	3.3	218	4.0	230	3.7	300	4.3	456	5.7	521	5.6
311	210	1.3	220	2.0	243	3.0	260	2.4	288	2.7	446	5.1	691	5.5
312	150	1.1	156	2.2	161	2.5	155	2.1	164	2.8	180	3.5	213	3.1
313	189	1.7	193	3.2	196	3.4	195	2.7	215	2.3	202	2.9	235	3.0

314	179	1.2	171	2.0	170	1.9	178	2.5	200	2.5	207	3.1	202	2.8
315	196	1.8	205	3.1	209	3.0	230	3.1	250	3.0	291	2.8	410	3.0
316	182	1.4	208	2.4	194	2.6	220	3.7	240	3.2	300	5.0	359	5.0
317	188	2.0	199	2.8	197	3.5	214	3.4	240	3.6	266	4.0	342	4.1
318	140	1.0	152	2.3	170	3.0	200	2.9	310	4.6	374	4.6	429	5.2
319	223	1.6	268	2.9	245	3.3	257	4.3	257	3.0	267	5.0	272	4.5
320	161	1.7	154	2.9	155	3.0	167	3.2	170	3.0	169	3.0	191	3.5
321	131	1.5	145	2.5	140	2.8	165	3.4	188	3.5	228	3.5	437	4.2
322	164	1.9	252	4.1	245	5.0	250	4.8	260	3.8	270	4.6	285	5.1
323	201	1.8	216	2.6	190	3.3	188	3.1	200	2.5	192	2.4	114	1.4
324	145	1.9	130	2.2	130	3.1	149	2.5	145	2.8	152	3.2	202	3.0
325	189	1.8	199	2.4	191	2.8	211	3.1	200	2.4	231	3.1	276	3.2
326	196	2.0	196	3.2	331	5.7	342	6.6	370	7.9	391	7.9	443	6.7
327	126	1.7	155	3.2	215	6.2	238	5.2	218	4.1	225	5.2	217	4.4
328	156	1.6	379	5.1	511	8.8	526	6.7	595	7.0	653	8.6	717	8.2
329	125	1.5	200	4.2	318	6.3	310	6.5	416	6.0	464	7.2	592	8.3
330	155	1.9	258	3.9	360	6.8	350	5.6	392	5.4	430	5.4	578	5.8
331	198	1.9	335	5.9	418	7.0	480	8.2	584	7.9	769	9.3	1002	10.0
332	172	1.6	333	4.8	388	6.7	470	6.2	781	8.1	1207	10.9	1540	12.5
333	153	1.7	284	5.5	332	6.9	377	7.5	572	7.8	538	8.6	858	14.9
334	122	1.3	145	2.4	144	3.4	168	3.4	175	2.8	219	2.7	356	5.4
335	244	2.2	345	6.5	288	9.7	382	7.3	497	9.9	613	12.7	1041	12.7
336	200	1.6	286	5.7	418	6.6	470	7.5	602	8.9	877	10.9	869	13.0
337	152	1.5	164	3.2	184	4.6	186	4.6	200	3.1	289	5.4	354	5.5
338	163	1.5	195	2.9	298	4.1	356	5.0	380	4.6	402	5.2	500	4.8
339	139	1.4	190	3.3	273	6.4	280	6.3	320	6.0	464	7.7	597	7.9
340	142	1.9	165	3.0	155	3.0	159	3.2	210	3.9	305	4.3	514	6.8
341	195	2.0	196	3.2	241	4.4	290	6.0	330	6.0	392	5.8	545	6.2
342	175	1.9	205	3.1	210	4.6	245	4.1	270	5.2	237	5.6	332	5.1
343	221	1.7	252	3.5	305	4.5	323	3.9	460	5.3	637	8.5	940	7.7
344	140	2.0	293	5.3	372	6.4	366	6.9	370	7.0	448	6.7	581	7.0
345	72	1.4	224	4.6	334	5.3	362	5.7	340	5.4	441	5.7	546	4.5
346	203	1.2	206	2.0	219	2.3	225	2.3	-0	-0	-0	-0	-0	-0
347	147	1.5	147	3.1	152	2.8	-0	-0	-0	-0	-0	-0	-0	-0
348	171	1.3	185	3.1	176	3.6	185	3.0	190	3.2	204	4.3	220	5.6
349	140	1.7	198	1.4	147	3.6	160	3.8	160	3.9	167	4.1	182	4.3
350	155	1.6	335	6.7	461	6.3	475	7.7	488	8.8	634	10.2	738	9.7
351	119	1.9	199	3.8	316	6.7	447	8.3	488	9.1	505	10.3	546	9.9
352	165	1.9	254	5.0	480	10.0	520	11.6	543	15.4	598	15.3	728	16.0
353	208	1.7	330	4.3	400	5.6	406	5.6	461	6.6	478	7.8	531	9.0
354	107	1.5	414	7.0	487	8.6	400	9.0	535	6.0	526	10.5	762	13.7
355	138	1.4	232	6.0	440	9.0	440	9.3	440	10.2	529	11.5	532	9.1
356	182	1.7	721	6.1	833	8.4	950	10.5	965	11.3	1082	11.0	1127	11.5
357	131	2.1	312	6.2	455	7.3	458	7.8	710	8.0	1099	11.4	1371	15.9
358	151	1.3	345	5.3	426	7.0	548	8.2	649	6.5	773	8.2	995	10.4
359	198	2.5	217	4.0	340	6.0	360	6.3	405	7.0	470	8.0	561	6.8
360	154	1.4	327	5.0	456	5.3	488	7.6	530	9.0	558	9.6	605	9.1
361	109	1.9	317	4.9	339	8.2	348	7.5	375	7.7	430	8.5	520	7.5
362	114	1.5	456	6.6	553	7.9	662	8.2	705	5.0	789	9.7	939	10.9
363	152	1.5	425	5.0	522	6.4	604	6.5	629	7.0	626	7.8	668	11.4
364	170	1.6	612	6.2	753	7.9	786	7.8	793	9.1	942	9.1	1021	8.4

365	118	1.4	310	5.1	364	6.1	397	6.9	524	7.8	437	8.5	728	8.7
366	152	2.0	370	5.4	408	7.9	535	7.9	555	8.4	774	10.3	1036	10.6
367	86	1.4	1025	8.0	761	10.3	838	10.2	860	11.5	1056	14.0	1559	18.5
368	169	1.6	286	4.0	410	5.4	547	6.1	641	6.4	707	7.4	816	7.9
369	175	1.4	191	2.7	331	5.0	501	5.9	788	6.8	1046	8.0	1201	10.1
370	151	1.3	319	3.1	287	5.3	385	6.2	340	7.5	452	8.0	464	9.0
371	143	2.0	214	3.4	363	5.2	452	7.3	558	7.5	612	8.8	703	8.7
372	157	1.8	372	5.6	586	9.0	648	9.2	718	10.0	775	10.4	792	11.3
373	170	1.8	395	5.0	487	6.5	513	7.6	555	8.6	472	7.9	665	8.5
374	160	1.4	251	4.2	248	7.2	270	7.3	308	9.2	444	11.0	736	5.4
375	161	1.8	310	5.9	605	8.2	812	9.6	830	12.3	1123	15.0	1239	16.5
376	121	2.0	330	4.6	538	7.0	572	9.0	745	9.1	904	8.9	1091	10.8
377	142	1.5	326	5.7	582	8.2	657	9.6	810	7.5	820	10.2	838	11.4
378	145	1.4	350	5.2	484	7.2	556	8.9	560	8.4	612	9.3	720	10.2

B. SPSS procedures and data from Field Trial 2

File ALDER.CMD Listing:

```
Title   'Statistical Analyses on Alders'.
Sub     'at the C-20 Road Compost Test Site'.

Set
      More=off/   Screen=off/
      Length=59/  Eject=on/
      Listing='Alder.out'.
Data List File='Alder.dat' Fixed/
      Plot     2
      H0       8-11       G0 12-16
      H1      17-20       G1 21-25
      H2      26-31       G2 32-36
      H3      37-42       G3 43-47
      H4      48-53       G4 54-58.

Compute Block   = Trunc((Plot + 1) / 2).
Compute Compost = 2 * Block - Plot.
If (H4 gt 0) RGR1 = Ln((G1*G1*H1) / (G0*G0*H0)).
If (H4 gt 0) RGR2 = Ln((G2*G2*H2) / (G1*G1*H1)).
If (H4 gt 0) RGR3 = Ln((G3*G3*H3) / (G2*G2*H2)).
If (H4 gt 0) RGR4 = Ln((G4*G4*H4) / (G3*G3*H3)).

Var Labels
      H0 'Initial Height  (mm)'/   G0 'Initial Girth   (mm)'/
      H1 '1st-year Height (mm)'/   G1 '1st-year Girth (mm)'/
      H2 '2nd-year Height (mm)'/   G2 '2nd-year Girth (mm)'/
      H3 '3rd-year Height (mm)'/   G3 '3rd-year Girth (mm)'/
      H4 '4th-year Height (mm)'/   G4 '4th-year Girth (mm)'/
      RGR1 '1st-year Relative Growth Rate'/
      RGR2 '2nd-year Relative Growth Rate'/
      RGR3 '3rd-year Relative Growth Rate'/
      RGR4 '4th-year Relative Growth Rate'/
Value Labels
      Compost 0 'No Compost' 1 'With Compost'.

Select if (H4 gt 0).

Means  H0 to RGR4 by Compost.

MANOVA RGR1 to RGR4
       by Compost(0,1)
       /WSFactors=Year(4)
       /Print=Signif(Hypoth AverF Univ).

* Years:  1985-6, 1986-7, 1987-8, 1988-9.

Finish.
```

File ALDER.DAT Listing:

Plot	Row	Column Position	H0	G0	H1	G1	H2	G2	H3	G3	H4	G4
P1	R2	1A	181	2.4	-0	-0	-0	-0	-0	-0	-0	-0
1	2	1B	163	2.1	593	7.8	1938	21.8	3426	37.6	4316	71.1
1	2	2A	202	3.0	490	8.6	839	14.4	1475	18.2	2505	28.6
1	2	2B	146	1.8	138	4.6	-0	-0	-0	-0	-0	-0
1	2	3A	185	2.5	608	10.4	2192	35.6	3322	49.8	3176	58.7
1	2	3B	130	2.4	677	10.6	2155	37.4	3463	48.3	4359	57.8
1	2	4A	145	1.9	55	2.8	1190	15.3	2859	27.3	3975	64.2
1	2	4B	149	1.9	364	7.1	877	12.4	1999	16.4	2018	46.5
1	2	5A	122	2.1	574	9.1	1712	27.9	2579	34.4	3286	46.1
1	2	5B	163	2.9	734	10.0	2014	29.3	3487	41.5	4414	73.2
1	2	6A	160	2.4	887	10.0	2306	36.2	4188	61.0	5084	57.5
1	2	6B	150	2.8	798	10.4	2044	29.9	3353	48.7	4554	66.9
1	R3	1A	113	2.1	646	9.6	1872	28.0	3066	36.7	3810	49.5
1	3	1B	175	2.0	780	10.4	1873	31.0	3139	43.5	4078	62.6
1	3	2A	155	2.1	396	6.5	1620	24.6	2694	31.4	-0	-0
1	3	2B	124	1.7	434	8.3	1555	27.1	2890	40.5	3658	56.0
1	3	3A	232	2.4	922	11.0	2344	34.5	3536	43.3	3694	51.2
1	3	3B	172	2.4	464	7.8	1571	26.4	2871	31.9	3834	52.9
1	3	4A	188	1.5	450	6.5	1030	13.1	2633	30.5	3475	62.5
1	3	4B	201	3.1	-0	-0	-0	-0	-0	-0	-0	-0
1	3	5A	194	2.3	640	7.2	1646	22.8	3341	34.1	4542	67.4
1	3	5B	222	2.1	560	8.2	2079	39.0	3767	49.5	4712	60.0
1	3	6A	168	2.0	614	8.2	2172	30.0	3609	42.3	4560	46.1
1	3	6B	205	2.1	625	9.0	2422	41.4	4145	57.9	4796	57.7
P2	R2	1A	180	2.1	695	12.5	1679	24.2	2573	33.6	3176	63.8
2	2	1B	175	2.2	515	10.0	1630	20.8	2554	28.5	3048	38.1
2	2	2A	120	2.0	589	9.0	1878	24.1	3097	34.6	3895	48.2
2	2	2B	236	2.9	592	8.8	1492	18.2	2585	27.8	3432	42.4
2	2	3A	204	2.4	747	10.2	1906	20.1	2883	29.4	3792	45.6
2	2	3B	167	2.5	641	10.3	1931	24.0	2969	37.3	3706	53.9
2	2	4A	183	2.2	1018	15.9	2710	38.5	4139	45.4	5127	61.1
2	2	4B	189	2.1	1019	14.6	2982	40.5	4493	53.7	4682	54.3
2	2	5A	199	2.7	-0	-0	-0	-0	-0	-0	-0	-0
2	2	5B	133	2.1	993	13.9	2486	43.2	3737	58.9	4913	74.8
2	2	6A	164	1.6	882	13.5	2242	39.3	3682	45.6	4340	64.2
2	2	6B	142	1.8	844	11.7	2274	37.8	3999	58.6	4993	71.7
2	R3	1A	114	1.2	285	7.7	1235	16.3	2573	24.5	3548	48.7
2	3	1B	87	1.9	336	7.0	1568	21.7	2841	33.3	3450	43.1
2	3	2A	170	1.9	439	7.3	1432	18.0	2652	30.4	3560	46.0
2	3	2B	150	2.0	581	11.5	1667	23.8	2554	31.6	3292	45.5
2	3	3A	115	2.0	797	10.5	2119	28.7	3280	39.6	4231	57.5
2	3	3B	145	2.6	858	12.2	2169	30.0	3420	40.5	4011	51.5
2	3	4A	126	2.0	998	12.0	2362	28.4	3359	38.5	3950	46.4
2	3	4B	137	1.7	884	16.5	1725	32.1	2225	35.7	3066	56.4
2	3	5A	185	2.7	851	12.7	2828	34.8	4371	47.1	5218	60.5

2	3	5B	193	2.6	1065	12.4	2818	37.1	4157	51.2	5066	69.8
2	3	6A	168	2.6	972	11.9	2592	34.5	3645	47.1	4414	57.8
2	3	6B	149	2.5	619	12.1	2405	37.6	3450	50.1	4292	60.9
P3R2		1A	160	2.1	495	9.2	1638	30.4	2694	47.7	3304	47.3
3	2	1B	165	2.5	510	10.0	1766	27.8	2810	33.9	3523	63.0
3	2	2A	145	2.1	502	7.0	1325	22.3	2591	33.1	3414	52.1
3	2	2B	190	2.3	155	5.5	857	18.2	2371	30.6	2670	32.8
3	2	3A	195	2.5	736	8.7	1674	23.3	2536	30.1	3286	46.4
3	2	3B	152	2.0	495	7.6	1644	23.0	3030	36.1	3810	44.8
3	2	4A	145	1.8	605	9.2	1563	22.6	3097	39.9	4060	57.6
3	2	4B	178	2.8	736	10.7	1990	31.5	3389	45.7	4103	55.5
3	2	5A	161	1.9	358	8.4	1399	22.2	2743	30.5	3798	44.5
3	2	5B	138	1.7	765	9.2	2080	27.4	3310	38.2	3975	48.1
3	2	6A	203	3.0	748	10.0	2408	36.2	4133	51.4	5054	65.1
3	2	6B	168	2.0	821	9.7	2258	28.2	3804	44.6	4596	56.0
3R3		1A	126	2.3	848	10.2	1865	26.4	2963	40.0	3792	54.1
3	3	1B	133	2.0	748	11.4	1927	31.2	2981	39.7	3633	50.8
3	3	2A	179	2.7	586	9.0	1306	21.8	2469	30.0	3414	47.3
3	3	2B	150	1.6	456	6.3	1973	28.0	3158	34.0	4036	54.6
3	3	3A	191	2.6	830	9.2	1924	25.9	3213	36.3	3804	47.0
3	3	3B	160	1.8	266	7.6	1047	20.4	1890	22.7	2505	38.3
3	3	4A	193	2.8	810	11.5	1826	34.3	3353	37.9	4432	71.7
3	3	4B	123	1.6	694	8.9	2099	28.4	3182	40.8	3133	38.4
3	3	5A	164	1.8	57	4.0	1019	18.5	2079	26.5	3152	42.5
3	3	5B	136	1.6	432	8.5	1105	21.4	2384	48.2	3188	51.5
3	3	6A	205	2.7	1063	13.3	2277	33.5	3359	34.8	4152	51.1
3	3	6B	136	1.8	885	11.0	2178	32.9	3938	51.9	5182	74.6
P4R2		1A	164	2.1	604	10.0	852	16.6	1042	17.7	1695	27.8
4	2	1B	160	2.2	577	11.9	1580	21.6	2621	42.8	3402	53.0
4	2	2A	149	2.4	471	10.2	1829	28.0	3054	37.6	3950	52.1
4	2	2B	187	3.0	1192	13.7	2826	42.8	3993	50.9	4773	71.4
4	2	3A	172	2.2	517	9.0	1682	25.9	3072	41.9	3828	58.8
4	2	3B	142	1.5	497	7.3	1281	15.4	2060	24.0	2597	31.4
4	2	4A	185	2.3	189	8.5	756	13.1	1774	19.7	3060	48.2
4	2	4B	144	2.2	450	7.5	1050	10.1	1615	16.1	2469	26.6
4	2	5A	160	2.0	671	10.0	1889	22.3	3231	36.6	4438	50.7
4	2	5B	113	1.7	385	8.7	978	13.6	1548	19.9	-0	-0
4	2	6A	150	2.0	662	10.6	2000	25.5	3152	31.3	3604	44.5
4	2	6B	152	2.1	795	10.8	2378	33.6	3840	50.5	4773	63.2
4R3		1A	160	2.0	488	8.2	1552	20.1	2573	28.5	3347	42.9
4	3	1B	153	1.9	668	10.0	1916	25.3	2999	38.5	3481	48.2
4	3	2A	126	1.6	462	8.6	1657	23.1	2707	33.5	3566	48.0
4	3	2B	121	1.9	519	9.5	1747	27.7	2743	37.3	3280	46.6
4	3	3A	114	2.5	658	10.8	2000	28.1	3170	41.8	3798	52.5
4	3	3B	112	1.7	446	7.6	1238	15.8	2402	24.0	3402	36.9
4	3	4A	125	2.3	739	12.4	2282	29.5	3633	54.3	4365	72.4
4	3	4B	138	2.2	535	9.3	1607	22.8	2658	32.0	3432	42.6
4	3	5A	149	2.0	587	9.7	1607	23.4	2487	30.6	3438	42.2
4	3	5B	158	2.1	595	9.6	1642	24.9	2640	37.1	3505	49.8
4	3	6A	177	3.1	429	7.2	1445	22.0	2414	27.8	3475	44.4
4	3	6B	144	2.1	360	7.3	1555	23.5	2871	29.4	3615	44.7

P5R2		1A	118	1.9	765	10.8	2079	27.1	3481	45.7	4304	55.8
5	2	1B	149	2.0	607	8.3	1685	22.0	3011	32.4	3773	42.8
5	2	2A	202	2.8	775	9.2	2073	21.2	3469	33.4	4645	53.3
5	2	2B	163	2.4	645	8.7	1739	19.1	2853	30.6	3828	46.1
5	2	3A	144	2.3	547	9.8	1715	22.8	3249	36.4	4444	51.5
5	2	3B	90	1.4	488	10.0	1695	28.4	2993	34.4	4011	53.7
5	2	4A	178	2.5	330	6.1	1141	13.2	2073	21.1	3420	49.1
5	2	4B	150	2.0	382	8.2	1373	19.9	2585	33.1	3597	51.6
5	2	5A	158	1.4	375	8.1	1271	17.8	2146	24.7	3249	40.5
5	2	5B	146	1.8	536	9.8	1308	24.5	2749	38.3	4054	59.5
5	2	6A	152	2.1	438	9.2	1415	19.3	2353	26.0	2890	32.5
5	2	6B	163	2.2	688	8.7	1609	21.4	3109	34.6	4292	53.3
5R3		1A	154	1.5	504	8.9	1410	18.7	2274	25.8	3371	46.0
5	3	1B	148	2.0	729	9.7	1656	17.6	1957	18.8	1939	25.7
5	3	2A	117	2.1	728	8.7	2099	30.5	3450	38.1	4170	48.9
5	3	2B	188	3.0	931	9.4	2077	23.2	3280	32.3	4090	45.8
5	3	3A	188	3.0	705	10.4	742	15.1	1542	18.4	2426	29.3
5	3	3B	169	2.6	372	9.9	1128	21.2	2298	28.4	3530	46.9
5	3	4A	233	2.8	695	10.0	2012	24.5	3255	37.7	4158	52.0
5	3	4B	71	1.7	228	4.8	732	7.4	1231	11.9	1670	17.1
5	3	5A	150	1.9	410	7.4	1202	16.0	1902	20.3	2670	27.0
5	3	5B	174	2.5	437	7.5	1218	11.5	2048	20.1	2573	24.1
5	3	6A	178	2.4	463	9.2	1827	25.6	3237	42.2	4176	59.2
5	3	6B	120	1.4	571	8.7	1769	21.4	3127	32.7	4292	43.6
P6R2		1A	240	2.1	205	3.8	534	17.5	2286	40.5	4029	67.9
6	2	1B	232	2.5	499	8.0	1670	23.6	2548	36.3	3347	50.7
6	2	2A	202	1.8	169	6.8	763	15.8	2012	25.9	3024	42.2
6	2	2B	149	1.6	147	4.2	693	13.6	1634	26.1	2743	46.5
6	2	3A	106	1.4	102	2.8	521	9.5	1311	17.6	2195	31.4
6	2	3B	186	1.8	166	4.6	588	17.9	1817	31.0	2097	46.6
6	2	4A	266	2.7	541	8.7	1651	22.5	3109	33.6	4011	52.2
6	2	4B	331	2.7	-0	-0	-0	-0	-0	-0	-0	-0
6	2	5A	180	2.3	474	6.7	1028	15.3	-0	-0	-0	-0
6	2	5B	243	3.0	414	6.5	970	12.0	-0	-0	-0	-0
6	2	6A	227	2.0	-0	-0	-0	-0	-0	-0	-0	-0
6	2	6B	189	1.7	-0	-0	-0	-0	-0	-0	-0	-0
6R3		1A	130	1.5	-0	-0	-0	-0	-0	-0	-0	-0
6	3	1B	221	2.0	220	6.0	1338	26.9	2512	39.8	3078	61.2
6	3	2A	190	2.6	199	7.8	1140	22.5	2536	31.4	3450	53.2
6	3	2B	346	3.0	852	11.6	2095	30.2	2987	37.0	3341	47.2
6	3	3A	272	2.4	543	8.7	1955	25.0	3292	39.2	3968	55.0
6	3	3B	230	2.1	70	5.5	828	11.4	2560	28.2	3700	46.3
6	3	4A	306	2.5	606	7.8	1972	27.4	3463	45.9	4243	59.5
6	3	4B	318	2.6	667	10.8	1887	30.1	2597	35.3	2975	48.5
6	3	5A	344	4.0	806	10.2	2007	41.6	3591	64.5	4048	87.6
6	3	5B	276	1.9	-0	-0	-0	-0	-0	-0	-0	-0
6	3	6A	298	2.6	578	6.4	1145	12.6	1201	21.4	2079	30.9
6	3	6B	172	1.5	-0	-0	-0	-0	-0	-0	-0	-0

File REDWOOD.CMD Listing:

```
Title   'Statistical Analyses on Redwoods'.
Sub     'at the C-20 Road Compost Test Site'.

Set
More=off/   Screen=off/
Length=59/  Eject=on/
Listing='Redwood.out'.

Data List File='Redwood.dat' Fixed/
Plot     2
Row      5
Position 7
H0        8-12  G0 13-16
H1       17-21  G1 22-25
H2       26-30  G2 31-34
H3       35-39  G3 40-44
H4       45-49  G4 50-54
H5       55-59  G5 60-64
BROWSE   67.

Compute Block   = Trunc((Plot + 1) / 2).
Compute Compost = 2 * Block - Plot.
Compute Fert    = Row - 2 * Trunc(Row / 2).
Compute Cell    = 2 * Compost + Fert + 1.

If (H5 gt 0) RGR1 = Ln((G1*G1*H1) / (G0*G0*H0)).
If (H5 gt 0) RGR2 = Ln((G2*G2*H2) / (G1*G1*H1)).
If (H5 gt 0) RGR3 = Ln((G3*G3*H3) / (G2*G2*H2)).
If (H5 gt 0) RGR4 = Ln((G4*G4*H4) / (G3*G3*H3)).
If (H5 gt 0) RGR5 = Ln((G5*G5*H5) / (G4*G4*H4)).

Compute RGR11 = RGR1.
Compute RGR12 = RGR1.
Compute RGR13 = RGR1.
Compute RGR14 = RGR1.

Var Labels
   H0 'Initial Height  (mm)'/  G0 'Initial Girth  (mm)'/
   H1 '1st-year Height (mm)'/  H1 '1st-year Girth (mm)'/
   H2 '2nd-year Height (mm)'/  H2 '2nd-year Girth (mm)'/
   H3 '3rd-year Height (mm)'/  H3 '3rd-year Girth (mm)'/
   H4 '4th-year Height (mm)'/  H4 '4th-year Girth (mm)'/
   H5 '5th-year Height (mm)'/  H5 '5th-year Girth (mm)'/
   RGR1 '1st-year Relative Growth Rate'/
   RGR2 '2nd-year Relative Growth Rate'/
   RGR3 '3rd-year Relative Growth Rate'/
   RGR4 '4th-year Relative Growth Rate'/
   RGR5 '5th-year Relative Growth Rate'/
   Browse 'Browse condition, January 1990'.
```

```
Value Labels
   Compost0 'No Compost'     1 'With Compost'/
   Fert  0 'Unfertilized'  1 'Fertilized'/
   Browse 0 'Unbrowsed'     1 'Browsed'.

Select if (H5 gt 0).

Means    H0 to RGR5
         by Compost by Fert.

* Repeated-measures ANOVA for all growth years:

MANOVA   RGR1 to RGR5
         by Compost(0,1) Fert(0,1)
         /WSFactors=Year(5)
         /Print=Signif(Hypoth AverF Univ).

* Years:  1985-6, 1986-7, 1987-8, 1988-9, 1989-90.

* Repeated-measures ANCOVA for last four years:

MANOVA   RGR2 to RGR5
         by Compost(0,1) Fert(0,1)
         with RGR11 RGR12 RGR13 RGR14
         /WSFactors=Year(4)
         /Print=Signif(Hypoth AverF Univ).

* Individual ANOVAs, by year:

MANOVA   RGR1  by Compost(0,1) Fert(0,1).
MANOVA   RGR2  by Compost(0,1) Fert(0,1).
MANOVA   RGR3  by Compost(0,1) Fert(0,1).
MANOVA   RGR4  by Compost(0,1) Fert(0,1).
MANOVA   RGR5  by Compost(0,1) Fert(0,1).

* Duncan's Multiple Range Test:

ONEWAY   RGR1 to RGR5 by CELL(1,4)
         /Ranges=Duncan(.01).

* Cells:  1 Control   2 Fert   3 Comp   4 Comp + Fert

Finish.
```

File REDWOOD.DAT Listing:

Plot	Row	Column	H0	G0	H1	G1	H2	G2	H3	G3	H4	G4	H5	G5	Browse Status
P1	R1	1	162	2.2	170	2.5	255	4.4	330	5.4	569	6.1	406	7.2	1
1	1	2	150	2.0	150	2.0	198	3.7	319	5.6	422	6.3	437	7.9	1
1	1	3	90	2.0	130	2.4	466	6.4	799	9.1	949	12.5	1307	18.9	0
1	1	4	92	1.8	178	3.1	335	4.6	647	6.4	1173	10.9	1396	15.0	0
1	1	5	130	2.0	165	3.0	364	7.3	710	7.8	1194	12.5	1472	15.9	0
1	1	6	187	2.4	252	3.2	544	7.5	437	6.1	822	8.6	1040	11.0	0
1	R2	1	228	2.5	239	2.7	510	8.7	475	8.7	765	10.7	857	15.0	0
1	2	2	200	1.9	192	2.8	336	4.6	630	5.8	1113	9.1	1406	12.2	0
1	2	3	150	1.6	162	2.7	224	3.0	462	6.0	890	9.5	1195	12.8	0
1	2	4	135	2.0	139	1.8	384	4.4	871	6.5	1153	11.8	1423	14.0	0
1	2	5	138	1.9	165	2.2	352	5.4	665	7.5	615	8.9	1105	10.1	0
1	2	6	108	1.7	135	2.6	392	5.2	769	7.8	1084	17.4	1628	27.1	0
1	R3	1	133	1.1	152	2.1	152	2.3	183	3.4	284	3.6	189	3.5	1
1	3	2	204	2.0	221	2.3	498	6.2	734	10.0	847	13.6	1255	20.0	0
1	3	3	175	1.5	188	3.2	482	7.8	548	10.0	1132	16.6	1259	17.9	0
1	3	4	190	1.9	202	2.4	741	7.2	1165	12.1	1517	16.9	1999	21.5	0
1	3	5	206	1.7	201	2.0	-0	-0	-0	-0	-0	-0	-0	-0	0
1	3	6	161	1.7	175	3.3	376	8.9	780	12.3	1119	17.8	1743	22.0	0
1	R4	1	230	2.2	236	2.5	259	2.8	268	3.2	364	3.8	262	3.4	1
1	4	2	106	1.5	112	3.1	176	3.2	373	3.9	662	6.0	712	7.1	0
1	4	3	190	1.8	195	2.2	395	4.1	480	5.5	777	10.4	1093	10.3	1
1	4	4	160	2.0	172	2.7	510	6.5	820	7.0	968	8.9	1030	9.1	0
1	4	5	205	2.2	243	2.7	497	6.1	770	8.0	1240	10.0	1466	7.9	0
1	4	6	120	1.9	138	3.4	455	5.9	839	6.4	1198	10.5	1465	10.5	0
P2	R1	1	121	2.0	150	1.7	135	3.5	142	2.2	135	2.7	167	3.1	0
2	1	2	165	2.0	188	2.2	180	2.6	294	3.3	448	4.3	361	3.9	1
2	1	3	127	2.1	132	2.0	224	4.6	268	5.5	325	5.4	413	5.9	0
2	1	4	168	2.2	172	2.5	221	3.2	311	4.4	452	6.4	472	5.9	1
2	1	5	215	1.7	227	2.2	131	2.4	273	2.7	386	2.9	370	2.6	0
2	1	6	128	2.0	112	1.8	118	1.7	143	1.5	118	2.4	185	2.0	0
2	R2	1	88	1.4	104	2.6	95	2.0	105	2.3	112	2.3	152	2.6	0
2	2	2	185	1.8	179	1.8	35	1.5	90	1.8	28	1.9	41	2.4	0
2	2	3	95	1.8	107	2.0	100	2.5	100	2.4	129	2.2	198	1.5	0
2	2	4	75	1.7	110	2.1	97	2.5	101	2.2	250	2.7	194	3.4	1
2	2	5	200	2.2	200	2.5	198	2.3	210	2.0	238	2.7	202	1.9	1
2	2	6	127	2.3	127	3.3	120	1.9	128	2.8	127	2.3	162	2.9	0
2	R3	1	105	1.8	146	2.7	134	2.6	190	2.0	178	2.3	232	2.8	0
2	3	2	135	2.0	147	3.0	132	1.9	155	2.3	192	2.8	201	1.9	1
2	3	3	65	1.4	73	1.6	170	3.7	194	4.3	272	6.7	267	3.5	1
2	3	4	83	2.0	92	2.2	76	2.0	108	2.5	108	2.2	184	2.3	0
2	3	5	133	1.9	145	2.1	25	2.6	30	2.0	-0	-0	-0	-0	0
2	3	6	140	1.4	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	0
2	R4	1	121	1.8	140	2.6	170	2.2	131	2.5	168	2.3	175	2.1	0
2	4	2	147	2.1	160	2.6	170	3.3	180	2.8	182	3.5	196	4.0	0
2	4	3	145	2.0	125	2.2	145	2.1	165	2.2	221	2.0	125	1.9	1
2	4	4	125	1.7	147	1.9	128	2.1	135	2.1	156	2.7	225	3.0	0

2	4	5	170	2.2	147	3.0	164	2.3	173	3.0	242	2.7	148	2.0	1
2	4	6	128	1.8	129	2.0	145	2.5	208	3.2	238	3.9	430	4.1	0
3	R1	1	213	2.3	214	3.2	366	5.2	509	6.0	648	8.7	697	6.9	1
3	1	2	178	2.0	201	2.9	333	5.3	379	7.1	581	8.8	670	9.0	1
3	1	3	128	1.4	128	2.3	230	4.8	435	6.4	841	8.9	790	8.5	1
3	1	4	122	1.5	198	3.7	440	7.3	878	9.7	1110	13.1	1804	19.0	0
3	1	5	230	2.0	245	2.0	285	4.6	527	6.6	784	5.5	812	7.0	0
3	1	6	175	2.4	183	3.6	250	5.7	518	6.0	798	8.4	999	8.0	1
3	R2	1	195	2.0	204	2.8	299	4.1	449	5.9	764	7.6	866	7.1	1
3	2	2	262	2.3	262	2.6	311	4.2	394	5.4	702	7.0	769	6.5	1
3	2	3	215	2.0	215	2.6	250	3.3	527	6.1	784	10.5	956	8.2	0
3	2	4	180	1.5	160	2.0	-0	-0	-0	-0	-0	-0	-0	-0	0
3	2	5	190	1.8	199	2.3	252	2.5	305	4.3	684	8.7	577	8.0	1
3	2	6	284	2.2	259	2.5	298	3.3	383	5.5	655	8.2	546	11.4	1
3	R3	1	145	2.0	220	6.2	600	9.3	802	11.8	1243	13.7	1512	19.9	0
3	3	2	192	1.0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	0
3	3	3	146	1.8	165	2.1	186	4.0	232	3.7	400	4.8	651	6.2	0
3	3	4	205	1.6	200	2.1	295	3.0	429	5.1	668	8.1	599	6.0	1
3	3	5	222	2.0	216	2.5	235	3.8	574	10.8	1054	12.4	1129	10.0	1
3	3	6	225	2.1	224	1.5	-0	-0	-0	-0	-0	-0	-0	-0	0
3	R4	1	182	2.0	180	2.0	249	3.0	589	5.0	819	7.5	891	5.7	1
3	4	2	190	2.2	212	2.6	392	5.9	724	7.2	1368	12.7	1394	13.0	1
3	4	3	143	2.2	140	2.7	290	6.1	515	7.7	633	10.1	885	11.9	0
3	4	4	238	2.0	239	3.2	265	3.8	358	6.8	588	8.2	545	4.3	1
3	4	5	177	1.3	194	1.1	290	4.6	377	6.3	755	7.9	698	9.5	1
3	4	6	155	1.7	162	2.1	205	5.2	426	6.8	744	6.5	975	9.7	0
P4	R1	1	167	2.0	152	2.3	292	4.4	495	6.7	670	7.3	616	5.5	1
4	1	2	172	1.7	163	2.6	242	3.3	310	4.7	378	5.3	367	5.0	1
4	1	3	155	2.2	175	3.0	210	4.6	501	6.0	887	9.1	946	11.1	1
4	1	4	168	1.6	168	2.6	180	3.2	280	3.7	385	5.6	364	5.0	1
4	1	5	162	2.0	181	2.8	320	5.7	373	5.8	504	7.3	430	7.2	1
4	1	6	83	1.6	100	1.3	110	1.7	125	2.6	128	2.3	177	2.4	0
4	R2	1	180	1.8	190	2.8	201	2.3	217	2.3	212	3.2	252	3.9	0
4	2	2	175	2.1	174	3.3	154	3.0	156	2.7	172	3.0	200	3.8	0
4	2	3	135	1.2	97	2.0	92	1.5	98	1.4	135	1.8	170	1.9	0
4	2	4	204	2.1	204	2.5	199	1.9	215	1.9	212	1.8	204	1.4	0
4	2	5	218	1.8	223	1.7	225	2.3	230	2.2	268	2.5	310	2.5	0
4	2	6	214	2.2	218	2.7	236	3.4	237	2.9	239	3.9	247	3.5	0
4	R3	1	240	2.1	243	2.1	264	2.2	304	3.7	370	7.3	231	4.0	1
4	3	2	175	2.1	174	2.2	185	2.7	200	3.2	218	3.8	193	3.0	1
4	3	3	163	1.7	164	3.3	431	4.7	463	5.3	641	6.9	590	6.9	1
4	3	4	187	1.5	190	2.4	442	5.2	516	6.5	734	6.9	716	6.6	1
4	3	5	165	2.1	161	2.7	355	5.1	409	6.5	608	7.2	555	5.8	1
4	3	6	138	2.1	152	2.3	160	3.1	188	3.6	200	5.8	214	5.8	0
4	R4	1	131	2.0	139	2.3	137	2.4	140	2.6	173	2.9	193	3.0	0
4	4	2	161	1.6	143	2.5	150	2.5	163	2.6	154	2.8	197	3.4	0
4	4	3	155	2.4	169	2.3	165	2.4	178	2.6	220	3.4	29	1.5	1
4	4	4	140	1.7	265	2.3	341	4.9	586	5.3	788	7.5	842	7.4	0
4	4	5	165	2.0	167	2.4	180	3.6	318	5.2	452	5.4	357	5.5	1
4	4	6	208	1.8	215	2.3	218	3.5	233	2.7	301	3.1	265	2.8	1
P5	R1	1	138	2.0	152	2.9	408	4.6	585	4.9	671	5.6	829	6.2	1

5	1	2	173	2.1	232	5.4	558	8.3	820	9.4	1162	11.4	1295	12.5	0
5	1	3	164	1.8	155	2.6	164	3.0	205	3.3	304	3.9	242	3.9	1
5	1	4	152	1.3	252	3.7	305	4.8	534	5.8	826	8.2	995	8.0	1
5	1	5	145	1.7	214	4.0	360	6.2	531	6.6	824	9.6	995	11.8	1
5	1	6	258	1.9	325	4.1	471	6.3	695	7.6	715	11.1	645	9.3	1
5	R2	1	122	2.0	155	3.0	200	4.4	292	6.0	404	6.4	445	7.4	0
5	2	2	128	1.6	130	3.0	154	3.1	236	3.5	364	4.1	334	4.4	1
5	2	3	135	1.8	145	2.4	278	4.4	199	4.4	335	7.2	324	5.0	1
5	2	4	202	1.4	202	3.2	254	3.0	342	5.0	265	5.3	465	6.2	0
5	2	5	100	2.0	100	3.1	113	4.2	203	5.1	252	5.4	343	6.0	0
5	2	6	140	2.0	172	2.8	205	4.4	316	5.1	502	8.0	374	6.4	1
5	R3	1	121	1.9	124	3.1	229	5.0	310	5.3	382	4.8	285	5.0	1
5	3	2	144	1.8	206	4.6	320	7.0	436	7.8	486	8.2	599	8.7	1
5	3	3	125	2.0	162	4.2	315	6.8	419	8.5	463	10.0	667	11.0	0
5	3	4	124	1.8	130	3.2	275	4.5	303	4.7	446	4.5	425	4.0	1
5	3	5	165	2.0	225	5.5	340	8.1	580	9.4	770	11.7	785	8.4	1
5	3	6	134	1.9	231	4.2	397	6.4	557	6.7	834	7.3	769	9.6	1
5	R4	1	112	2.4	111	2.1	118	2.3	147	4.3	206	3.0	135	3.0	1
5	4	2	157	2.7	170	3.0	298	6.6	552	7.7	738	8.9	757	9.6	1
5	4	3	98	2.1	98	2.2	258	4.6	408	5.4	518	5.9	517	7.1	1
5	4	4	200	1.6	191	1.9	483	5.9	634	7.5	788	7.1	819	7.2	0
5	4	5	92	1.8	274	4.4	730	7.5	974	11.8	1222	14.5	1284	15.5	0
5	4	6	58	1.7	116	2.7	520	7.6	726	11.2	893	16.4	1140	19.8	0
P6	R1	1	190	2.3	175	3.4	233	3.7	330	4.1	492	5.9	458	5.4	1
6	1	2	214	2.6	220	3.0	255	4.0	281	4.8	312	5.2	336	5.7	1
6	1	3	105	1.6	122	1.5	238	2.7	419	4.4	575	4.9	530	4.6	1
6	1	4	148	1.6	165	2.4	202	3.1	402	4.4	594	4.9	729	6.0	1
6	1	5	227	2.6	231	2.8	460	5.1	697	7.3	783	8.4	1080	11.0	0
6	1	6	162	2.0	165	2.2	508	6.1	703	12.5	855	16.8	910	18.0	1
6	R2	1	188	2.1	213	4.0	198	3.1	208	3.1	247	2.9	309	3.4	0
6	2	2	110	1.8	128	2.1	117	2.5	133	1.9	118	2.7	207	2.0	0
6	2	3	165	2.0	140	2.2	171	2.5	323	4.7	339	5.3	445	6.3	0
6	2	4	105	1.5	122	2.8	116	2.3	144	2.5	167	2.4	150	2.6	0
6	2	5	158	2.1	170	2.3	166	2.3	303	3.9	270	4.9	293	4.0	1
6	2	6	164	2.4	178	3.1	478	6.4	889	12.1	1140	11.4	1640	20.0	0
6	R3	1	205	2.1	225	3.7	220	3.0	265	3.4	438	6.9	549	7.6	0
6	3	2	110	1.2	98	1.9	99	2.9	119	3.3	163	2.8	246	3.0	0
6	3	3	160	2.4	160	2.8	154	2.6	260	4.9	286	4.1	361	4.0	1
6	3	4	160	1.6	166	2.4	265	4.0	372	4.5	562	4.9	552	5.5	1
6	3	5	143	1.9	144	2.8	203	6.2	265	6.0	293	7.2	373	7.7	0
6	3	6	200	1.7	196	3.3	450	6.6	459	8.0	751	9.7	944	11.0	0
6	R4	1	242	2.1	255	2.2	260	2.4	253	2.4	245	2.7	260	2.8	0
6	4	2	180	2.0	200	2.6	185	2.8	204	2.8	192	2.7	177	2.6	1
6	4	3	172	1.9	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	0
6	4	4	195	2.1	174	3.0	177	2.6	200	2.5	206	2.5	240	2.8	0
6	4	5	204	2.1	218	2.8	223	2.4	268	3.3	309	4.1	323	3.6	1
6	4	6	285	2.3	288	2.6	290	2.9	394	4.0	490	4.5	536	5.2	0

File LOGSOIL.CMD Listing:

```
Title   'MANOVAs on Log-transformed Soil Data from'.
Sub     'Plots at the C-20 Road Compost Test Site'.

Set
      More=off/   Screen=off/
      Length=59/  Eject=on/
      Listing='LogSoil.out'.

Data List File='Soilplot.dat' Free/
      Plot      Compost
      MinN85    MinN90
      TKN85     TKN90
      OM85      OM90.

Compute   MinN85 = ln(MinN85 + 1.4).
Compute   MinN90 = ln(MinN90 + 1.4).
Compute   TKN85  = ln(TKN85).
Compute   TKN90  = ln(TKN90).
Compute   OM85   = ln(OM85).
Compute   OM90   = ln(OM90).

Var Labels
      Plot     'Plot number'/              Compost 'Compost level'/
      MinN85   '1985 Mineralizable N'/    MinN90  '1990 Mineralizable N'/
      TKN85    '1985 Total Kjeldahl N'/   TKN90   '1990 Total Kjeldahl N'/
      OM85     '1985 Organic matter'/     OM90    '1990 Organic matter'.

Value Labels
      Compost  0 'No Compost'   1 'With Compost'.

MANOVA  MinN85 to MinN90
        by Compost(0,1)
        /WSFactors=Year(2)
        /Measure=MinN.

MANOVA  TKN85 to TKN90
        by Compost(0,1)
        /WSFactors=Year(2)
        /Measure=TKN.

MANOVA  OM85 to OM90
        by Compost(0,1)
        /WSFactors=Year(2)
        /Measure=OM.

Finish.
```

File SOIL.DAT Listing:

Sample	Compost	Rep.	MinN ppm	TotN ppm	OM percent
85RNP-1A	1	1	23.8	1290	8.67
85RNP-1B	1	2	19.6	1400	9.15
85RNP-1C	0	1	1.4	806	1.27
85RNP-1D	0	2	1.4	818	1.13
85RNP-1E	1	1	25.2	1270	8.74
85RNP-1F	1	2	18.2	1340	7.98
85RNP-1G	0	1	1.4	655	1.68
85RNP-1H	0	2	1.4	728	1.69
85RNP-1I	1	1	4.2	1050	5.90
85RNP-1J	1	2	2.8	1040	7.15
85RNP-1K	0	1	1.4	762	1.14
85RNP-1L	0	2	0.0	767	0.94
90RNP-1A	1	1	28.0	1620	8.14
90RNP-1B	1	2	32.2	1340	7.90
90RNP-2A	0	1	5.6	812	1.34
90RNP-2B	0	2	5.6	879	1.25
90RNP-3A	1	1	35.0	1600	7.10
90RNP-3B	1	2	35.0	1510	8.45
90RNP-4A	0	1	2.8	795	2.08
90RNP-4B	0	2	4.2	823	1.70
90RNP-5A	1	1	5.6	1140	4.45
90RNP-5B	1	2	9.8	1200	6.30
90RNP-6A	0	1	4.2	812	1.00
90RNP-6B	0	2	4.2	846	1.25
85RNP-1A Dup	1	1	21.0	1290	9.93
85RNP-1B Dup	1	2	25.2	1340	2.80
85RNP-1C Dup	0	1	2.8	801	1.30
85RNP-1D Dup	0	2	1.4	806	1.27
85RNP-1E Dup	1	1	22.4	1280	8.36
85RNP-1F Dup	1	2	18.2	1300	8.15
85RNP-1G Dup	0	1	2.8	728	1.71
85RNP-1H Dup	0	2	1.4	767	1.54
85RNP-1I Dup	1	1	5.6	1040	6.95
85RNP-1J Dup	1	2	2.8	1060	5.56
85RNP-1K Dup	0	1	1.4	795	1.24
85RNP-1L Dup	0	2	1.4	778	1.19
90RNP-1A Dup	1	1	26.6	1620	8.74
90RNP-1B Dup	1	2	26.6	1600	8.70
90RNP-2A Dup	0	1	5.6	762	1.29
90RNP-2B Dup	0	2	5.6	874	1.30
90RNP-3A Dup	1	1	33.6	1610	8.29
90RNP-3B Dup	1	2	30.8	1580	8.60
90RNP-4B Dup	0	2	4.2	862	1.60
90RNP-4A Dup	0	1	16.8	840	1.19
90RNP-5A Dup	1	1	8.4	1150	5.60
90RNP-5B Dup	1	2	11.2	1220	6.80
90RNP-6A Dup	0	1	2.8	795	1.25
90RNP-6B Dup	0	2	4.2	840	1.80

File SOILPLOT.DAT Listing:

Plot	Compost	Min. N (ppm) 1985	Min. N (ppm) 1990	Total N (ppm) 1985	Total N (ppm) 1990	Organic matter (%) 1985	Organic matter (%) 1990
1	1	22.40	28.35	1330.00	1545.00	7.6375	8.3700
2	0	1.75	5.60	807.75	831.75	1.2425	1.2950
3	1	21.00	33.60	1297.50	1575.00	8.3075	8.1100
4	0	1.75	7.00	719.50	830.00	1.6550	1.6425
5	1	3.85	8.75	1047.50	1177.50	6.3900	5.7875
6	0	1.05	3.85	775.50	823.25	1.1275	1.3250

Results of nested analyses of variance on soil properties:

Nested, Repeated-Measures Analysis of Variance on Mineralizable N

Source	SS	df	MS	F	Signif.
Among Plots					
Compost	783.275	1	783.275	5.77	.07417
Residual	542.838	4	135.710		
Total	1326.114	5			
Years within Plots					
Year	104.135	1	104.135	21.98	.00939
Comp x Yr	11.117	1	11.117	2.35	.20030
Residual	18.947	4	4.737		
Total	134.199	6			
Samples within Design (sampling error)					
Total	52.675	12	4.390		
Replicates within Samples (lab error)					
Total	140.140	24	5.839		

Nested, Repeated-Measures Analysis of Variance on Total N

Source	SS	df	MS	F	Signif.
Among Plots					
Compost	845219	1	845219	23.75	.00820
Residual	142325	4	35581		
Total	987544	5			
Years within Plots					
Year	53969	1	53969	28.87	.00580
Comp x Yr	16152	1	16152	8.64	.04243
Residual	7479	4	1870		
Total	77599	6			
Samples within Design (sampling error)					
Total	25799	12	2150		
Replicates within Samples (lab error)					
Total	47379	24	1974		

Nested, Repeated-Measures Analysis of Variance on Organic Matter

Source	SS	df	MS	F	Signif.
Among Plots					
Compost	109.8983	1	109.8983	77.32	.00092
Residual	5.6856	4	1.4214		
Total	788.9608	5			
Years within Plots					
Year	0.0024	1	0.0024	0.02	.89452
Comp x Yr	0.0078	1	0.0078	0.06	.81211
Residual	0.4801	4	0.1200		
Total	0.4902	6			
Samples within Design (sampling error)					
Total	7.3384	12	0.6115		
Replicates within Samples (lab error)					
Total	25.3510	24	1.0563		

C. *Analysis of browsing effects in Field Trial 2*

Summary

In January 1985, 144 one-year-old redwoods were planted, half in compost plots and half in control plots. The redwoods were protected against browsing by vexar mesh tubes 915 mm (36 in) tall. The tubes were removed in January 1989. Of the original redwoods, 137 were still alive in January 1990. Of these survivors, 66 had browsed leaders. As a group, trees with browsed leaders decreased in height from January 1989 to January 1990, while the unbrowsed group increased in height. Trees that were from 250 to 800 mm tall in 1989 were more likely to have browsed leaders than taller or shorter trees. Compost had no effect on browse frequency or tree growth from January 1989 to January 1990. Vexar mesh tubes protected most trees from having their leaders browsed until they emerged from the tops of tubes. Once trees reached this height, most browsing was concentrated on lateral shoots and the probability of a browsed leader was small. From the standpoint of general knowledge concerning the effects of browsing on conifers planted in the park, the C-20 field trial is simply one observation. Browsing intensity should be expected to vary widely from site to site depending on the number of deer and elk frequenting the site. A study designed specifically to document or predict wildlife impacts on conifer regeneration in an area would be sampled at many sites within the area of concern.

Tables

Numbers of redwoods with leaders browsed in 1989, by height and treatment

Height class (mm)	Counts in Control Plots			Counts in Compost Plots			Grand Total
	Browsed	Unbrowsed	Total	Browsed	Unbrowsed	Total	
1-250	8	27	35	1	0	1	36
251-500	13	7	20	9	5	14	34
501-800	8	3	11	18	8	26	37
> 800	2	1	3	7	20	27	30
All	31	38	69	35	33	68	137

Percent of redwoods with leaders browsed in 1989, by height and treatment

Height class (mm)	Control	Compost	Total
	-----------	percent browsed	----------
1-250	22.9	100.0	25.0
251-500	65.0	64.3	64.7
501-800	72.7	69.2	70.3
> 800	66.7	25.9	30.0
All	44.9	51.5	48.2

Contingency table analyses

4 x 2 table

df = (r-1)(c-1) = 3 x 1 = 3.

Critical Chi^2 = 7.81473 for α = 0.05,

Critical Chi^2 = 11.3449 for α = 0.01.

Ho: The proportion of trees browsed was the same for all height classes when compost treatment was taken into account.

Chi^2 = 13.71659 Reject Ho.

Ho: The proportion of trees browsed was the same with or without compost when height class was taken into account.

Chi^2 = 3.82221 Accept Ho.

Relative growth rates of redwoods during the 1989-1990 season

Height class (mm)	RGR in Control Plots Browsed	Unbrowsed	Total	RGR in Compost Plots Browsed	Unbrowsed	Total
1-250	-1.027	+0.299	-0.074	-0.371	--	-0.371
251-500	-0.257	+0.359	-0.005	-0.252	+0.594	-0.021
501-800	-0.108	+0.399	+0.005	-0.122	+0.655	+0.008
> 800	+0.331	+0.717	+0.588	+0.092	+0.626	+0.493
All	-0.409	+0.362	+0.016	-0.118	+0.626	+0.243

<u>File BROWSE.CMD Listing</u>:

```
Title   'Browsing Analyses on Redwoods'.
Sub     'at the C-20 Road Compost Test Site'.

Set
   More=off/    Screen=off/    Length=59/    Eject=on/
   Listing='browsing.out'.

Data List File='Redwood.dat' Fixed/
   Plot        2
   Row         5
   Position    7
   H0       8-12       G0 13-16
   H1      17-21       G1 22-25
   H2      26-30       G2 31-34
   H3      35-39       G3 40-44
   H4      45-49       G4 50-54
   H5      55-59       G5 60-64
   Browse     67.
```

```
Compute Block   = Trunc((Plot + 1) / 2).
Compute Compost = 2 * Block - Plot.
Compute Fert    = Row - 2 * Trunc(Row / 2).

If (H5 gt 0) LnH4 = Ln(H4).
If (H5 gt 0) RGR1 = Ln((G1*G1*H1) / (G0*G0*H0)).
If (H5 gt 0) RGR2 = Ln((G2*G2*H2) / (G1*G1*H1)).
If (H5 gt 0) RGR3 = Ln((G3*G3*H3) / (G2*G2*H2)).
If (H5 gt 0) RGR4 = Ln((G4*G4*H4) / (G3*G3*H3)).
If (H5 gt 0) RGR5 = Ln((G5*G5*H5) / (G4*G4*H4)).

Var Labels
   H0 'Initial Height  (mm)'/  G0 'Initial Girth  (mm)'/
   H1 '1st-year Height (mm)'/  G1 '1st-year Girth (mm)'/
   H2 '2nd-year Height (mm)'/  G2 '2nd-year Girth (mm)'/
   H3 '3rd-year Height (mm)'/  G3 '3rd-year Girth (mm)'/
   H4 '4th-year Height (mm)'/  G4 '4th-year Girth (mm)'/
   H5 '5th-year Height (mm)'/  G5 '5th-year Girth (mm)'/
   RGR1 '1st-year Relative Growth Rate'/
   RGR2 '2nd-year Relative Growth Rate'/
   RGR3 '3rd-year Relative Growth Rate'/
   RGR4 '4th-year Relative Growth Rate'/
   RGR5 '5th-year Relative Growth Rate'.

Value Labels
   Compost        0 'No Compost'   1 'With Compost'/
   Fert           0 'Unfertilized' 1 'Fertilized'/
   Browse         0 'Unbrowsed'    1 'Browsed'.

Select if (H5 gt 0).

MANOVA  RGR5
   by Compost(0,1) Browse(0,1)
   with LnH4.

* Years:  1985-6, 1986-7, 1987-8, 1988-9, 1989-90.

Finish.
```

Analysis of variance on relative growth rates of redwoods.
Critical alpha = .05/5 for five F statistics.

Ho_1: Relative growth was the same for trees of all heights during the 1989-1990 season.

F = 5.33. *P* = .0225. Accept Ho.

Ho_2: Compost did not affect relative growth during the 1989-1990 season.

F = 0.72. *P* = .3978. Accept Ho.

Ho_3: Browsing did not affect relative growth during 1989-1990 season.

F = 78.05. *P* = .0000. Reject Ho.

Ho_4: The effect of browsing was the same with or without compost.

F = 1.18. *P* = .2794. Accept Ho.

Ho_5: The effect of height was the same with or without compost.

F = 0.61. *P* = .4363. Accept Ho.

Tests of Significance for RGR5 using UNIQUE sums of squares

Ho	Source of Variation	SS	df	MS	F	Signif
1	Regression (LnH4)	1.40	1	1.40	5.33	.0225
2	Compost	.19	1	.19	.72	.3978
3	Browse	20.49	1	20.49	78.05	.0000
4	Compost by Browse	.31	1	.31	1.18	.2794
5	Compost by Regression	.16	1	.16	.61	.4363
	Within Cells	34.39	131	.26		

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