Two-year Growth Response to Multi-nutrient Fertilizer Application on Boise Cascade Lands in Northeast Oregon

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In spring of 1995 two fertilizer trials were installed on Boise Cascade lands in northeast Oregon, one at Clear Creek in a young Ponderosa pine plantation, the other at Noregaard in a natural mixed conifer stand. Six growth monitoring plots were established at each site, three of which were treated with a multi-nutrient fertilizer; the other three plots remained untreated for use as experimental controls. Plot sizes of 0.05 and 0.1 acres were used at the Clear Creek and Noregaard installations, respectively. The elemental rates of the multi-nutrient fertilizer are shown in Table I.

Table I. Nutrient element rates for the multi-nutrient fertilizer.

Nutrient	Rate (lbs/a)	Source	Rate (lbs/a)
Nitrogen	200	Urea	387
		Ammonium Phosphate	193
Potassium	170	Potassium Sulfate	400
Phosphorus	100	Ammonium Phosphate	
Sulfur	90	Potassium Sulfate	
		Copper Sulfate	40
Boron	10	Borate FG	69
Copper	10	Copper Sulfate	
Zinc	10	Blu-Min-Zinc	55
Molybdenum	1	Sodium Molybdate	2.5

Foliage collections were made in fall of 1995 and again in fall of 1996. Analysis of the initial foliar chemistry data was presented by Terry Shaw (1996). The 1996 collections have not yet undergone chemical analysis.

At the time of establishment all growth plot trees were examined for condition and measured for diameter at breast height and total height. Measurements were taken on 71 and 132 trees and Clear Creek and Noregaard, respectively. Summaries of this information were presented by Shaw (1996). Average stand conditions at the start of the experiment for the two installations are shown in Table II.

In fall of 1996, two growing seasons after fertilizer application, all growth plot trees were measured for diameter at breast height. Tree condition was also recorded. From this data and information collected at the time of plot establishment, per acre values of stand size, density, and volume were calculated. Summaries of this information for the two installations are presented in Appendix A.

Table I. Average initial stand conditions for the two multi-nutrient fertilizer installations.

Characteristic	Clear Creek	Noregaard
Trees (stems/acre)	237	220
Basal Area (ft^2/a)	22.6	57.1
Total Volume (ft^3/a)	143	751
Crown Competition Factor	22.8	71.8
Quadratic Mean Diameter (in)	4.19	6.90
Relative Density (Curtis)	11.1	21.7
Species Composition (% of Basal Area)		
Ponderosa Pine	99.5	3.2
Grand Fir	0.0	31.3
Douglas-fir	0.0	29.0
Engelmann Spruce	0.3	19.7
Western Larch	0.1	15.7
Lodgepole Pine	0.1	1.0

Analysis Methods

Analysis of fertilizer effects on tree growth was made by comparing growth rates of control and treated plots using analysis of variance techniques. Two-year basal area growth and change in quadratic mean diameter were both examined. Basal area growth was calculated as the difference between initial and two-year total basal area on each plot; similar calculations were made for mean diameter change. As no mortality had yet occurred on any of the plots, there was no need to calculate separate values for gross and net growth.

Fertilizer effects on basal area growth were estimated using a randomized block analysis of covariance model. The particular model fit was (after Federer, 1955):

$$Y_{ijk} = \mu + I_i + F_j + \beta X_{ijk} + e_{ijk} \quad (1)$$

where Y_{ijk} is the two-year growth for the plot (ie. the k^{th} replicate of the j^{th} fertilizer treatment within the i^{th} installation), μ is the overall mean effect, I_i is a random effect due to the i^{th} installation, F_j is the effect due to the j^{th} fertilizer treatment, X_{ijk} is the basal area per acre at the start of the experiment for the plot, β is the coefficient for the regression of growth on initial basal area, and e_{ijk} is a random error effect. A similar model was used for change in mean diameter, using initial quadratic mean diameter as the covariate.

Results

Analysis of variance results for two-year basal area growth are shown in Table III. The overall model was highly significant ($p=0.0035$), accounted for 80% of the total variation in basal area

growth, and had a coefficient of variation of 9.6%. The initial basal area covariate was extremely useful in reducing variation. After adjusting plots to a common basal area of 39.9 ft^2/a, the multi-nutrient fertilizer was estimated to produce an increase of 2.4 ft_2/a over control plot growth rates; this response was highly significant (p=0.0063).

Table II. Analysis of covariance table with parameter estimates and least squares means for two-year basal area growth by treatment adjusting for differences in initial basal area.

Dependent Variable: BAGROW 2 year ba growth (sq.ft/a)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	38.87171404	12.95723801	10.82	0.0035
Error	8	9.58239860	1.19779983		
Corrected Total	11	48.45411264			

R-Square	C.V.	Root MSE	BAGROW Mean
0.802238	9.609135	1.09444042	11.38958275

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Installation	1	1.08824246	1.08824246	0.91	0.3684
Treatment	1	6.07152357	6.07152357	5.07	0.0544
Initial BA	1	31.71194801	31.71194801	26.48	0.0009

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Installation	1	32.72978295	32.72978295	27.32	0.0008
Treatment	1	16.09691309	16.09691309	13.44	0.0063
Initial BA	1	31.71194801	31.71194801	26.48	0.0009

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		-10.73421671 B	-2.43	0.0411	4.41349285
Install	1	14.51822413 B	5.23	0.0008	2.77737202
	2	0.00000000 B	.	.	.
Treatment	0	-2.42370341 B	-3.67	0.0063	0.66115045
	1	0.00000000 B	.	.	.
Initial BA		0.40322165	5.15	0.0009	0.07836543

Least Squares Means

Treatment	BAGROW LSMEAN	Std Err LSMEAN	Pr > |T| H0:LSMEAN=0	Pr > |T| H0: LSMEAN1=LSMEAN2
0	10.1777310	0.4572709	0.0001	0.0063
1	12.6014345	0.4572709	0.0001	

Because the two stands were so different in terms of species composition and initial size and density, additional analysis was conducted to see if relationships varied for the two sites. This was accomplished by including installation X treatment and installation X basal area terms in the analysis of covariance model. Results, shown in Table IV, indicate that basal area response did not vary significantly between the two sites; the installation X treatment term was non-significant (p=0.6030) and any differences by treatment in covariate adjustment were marginal (p=0.1463). These trends can be seen in the plot data shown in Figure 1. For both sites, two-year growth rises as initial basal area increases. The trend may be steeper for the Clear Creek installation, but not to a significant extent.

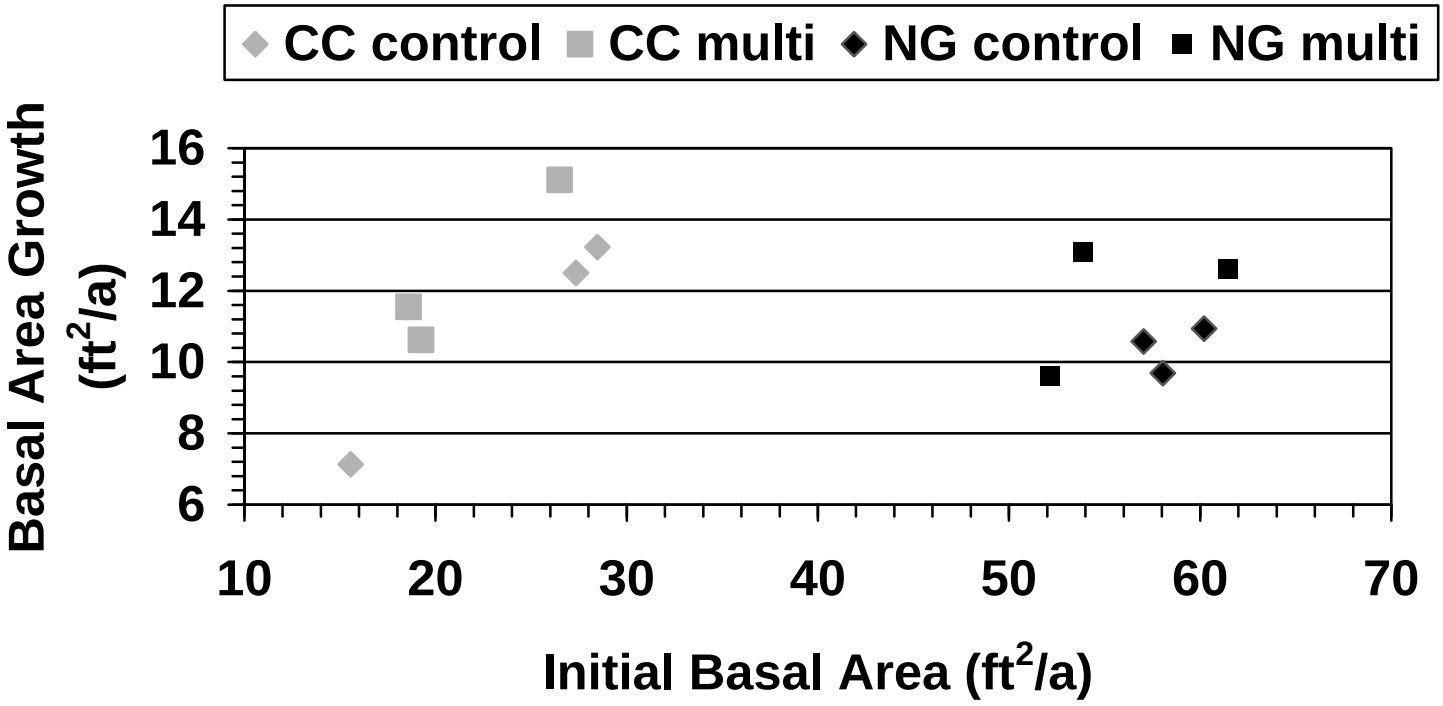

Figure 1. Two-year basal area growth versus initial basal area. Values on the left represent plots at Clear Creek (CC) while those on the right are from Noregaard (NG).

Two-year basal area growth and response are summarized in Figure 2. Using the parameter estimates given in Table IV, basal area growth was adjusted to a common initial basal area of 23 ft^2/a for Clear Creek and 57 ft^2/a for Noregaard. At those starting conditions, estimated average control two-year growth was quite similar for the two sites, 10.6 and 10.1 ft^2/a for Clear Creek and Noregaard, respectively (Figure 2a). The Clear Creek site showed better growth on the fertilized plots, averaging 13.2 ft^2/a versus 12 ft^2/a for the Noregaard site. Values for the average were obtained from parameter estimates given in Table III using an average initial basal area of 40 ft^2/a.

Table III. Analysis of covariance table with parameter estimates and least squares means for two-year basal area growth by installation and treatment adjusting for differences in initial basal area.

Dependent Variable: BAGROW 2 year ba growth (sq.ft/a)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	41.90839998	8.38168000	7.68	0.0138
Error	6	6.54571266	1.09095211		
Corrected Total	11	48.45411264			

R-Square	C.V.	Root MSE	BAGROW Mean
0.864909	9.170543	1.04448653	11.38958275

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Installation	1	1.08824246	1.08824246	1.00	0.3565
Treatment	1	6.07152357	6.07152357	5.57	0.0564
Initial BA	1	31.71194801	31.71194801	29.07	0.0017
Install X Treatment	1	0.00002263	0.00002263	0.00	0.9965
Installation X BA	1	3.03666331	3.03666331	2.78	0.1463

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Installation	1	0.02615103	0.02615103	0.02	0.8820
Treatment	1	13.54701264	13.54701264	12.42	0.0125
Initial BA	1	18.29518137	18.29518137	16.77	0.0064
Install X Treatment	1	0.32851654	0.32851654	0.30	0.6030
Installation X BA	1	3.03666331	3.03666331	2.78	0.1463

Parameter		Estimate		T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.475003480	B	0.06	0.9542	7.93267983
Installation	1	1.644824014	B	0.20	0.8472	8.17652246
	2	0.000000000	B	.	.	.
Treatment	0	-1.901859879	B	-2.05	0.0868	0.92971159
	1	0.000000000	B	.	.	.
Initial BA		0.202435533	B	1.43	0.2030	0.14170100
Install*Treat	1 0	-0.701586393	B	-0.55	0.6030	1.27851369
	1 1	0.000000000	B	.	.	.
	2 0	0.000000000	B	.	.	.
	2 1	0.000000000	B	.	.	.
Install*BA	1	0.278349984	B	1.67	0.1463	0.16683829
	2	0.000000000	B	.	.	.

Least Squares Means

Inst	Trt	BAGROW LSMEAN	Std Err LSMEAN	Pr > |T| H0:LSMEAN=0	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	0	18.6854092	1.5391367	0.0001	1	.	0.0251	0.0082	0.0111
1	1	21.2888555	1.7316759	0.0001	2	0.0251	.	0.0038	0.0047
2	0	6.6442944	2.6985359	0.0490	3	0.0082	0.0038	.	0.0868
2	1	8.5461543	2.3391425	0.0107	4	0.0111	0.0047	0.0868	.

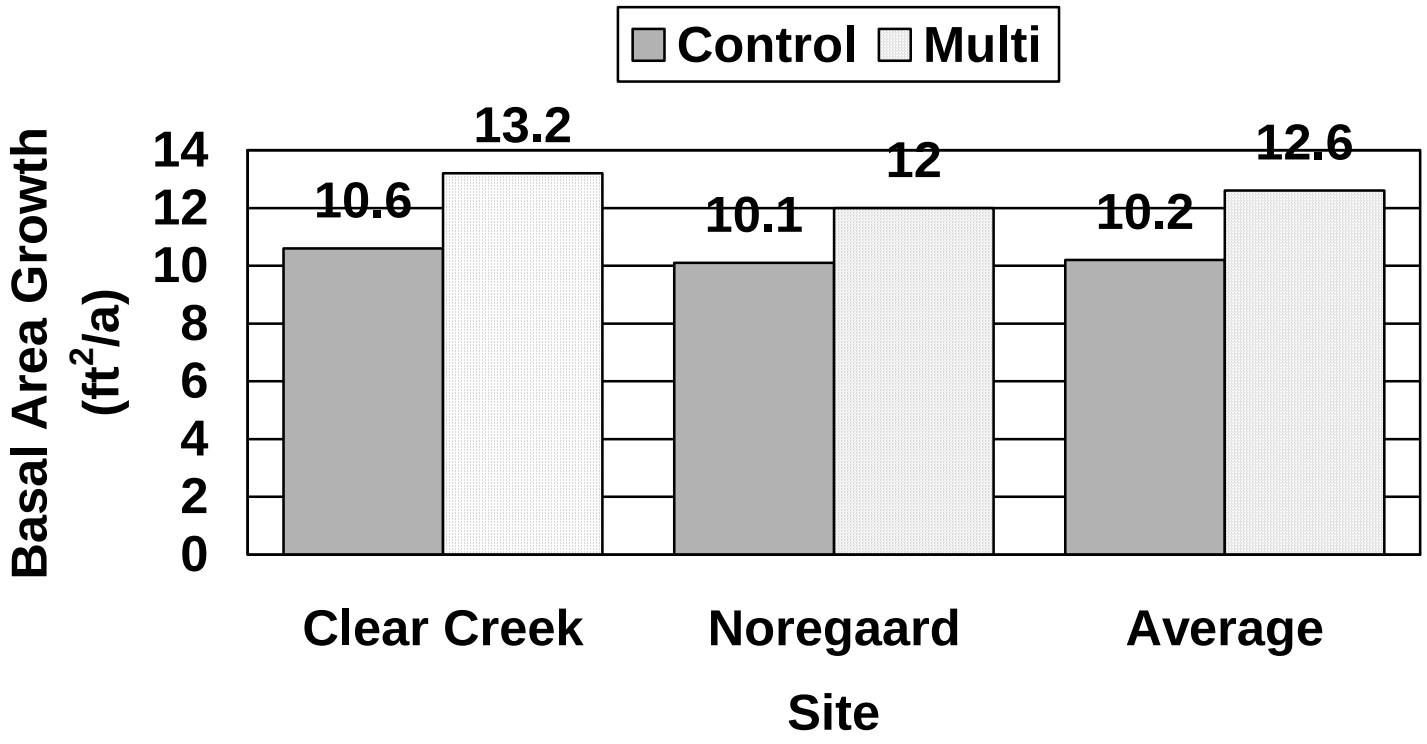

Figure 2a. Two-year basal area growth by site and fertilizer treatment (control, multi-nutrient) adjusted to the average initial basal area for each site.

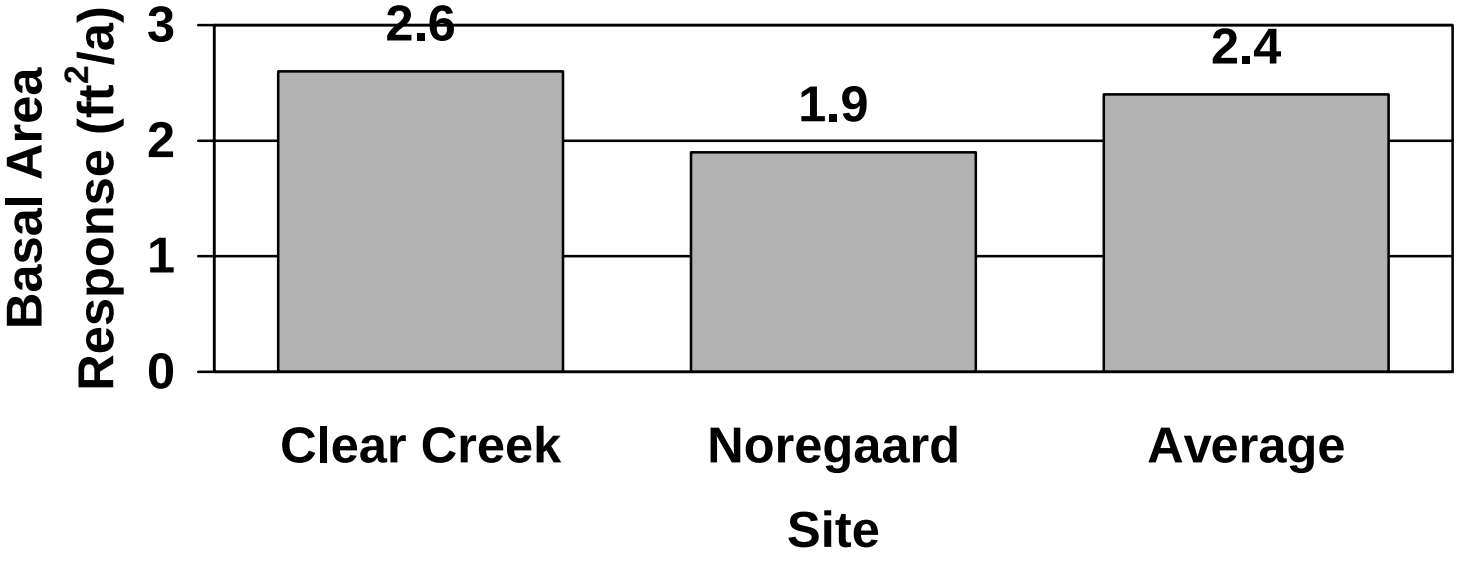

Figure 2b. Two-year basal area response by site. Response is the difference between treated and control.

Two-year basal area response, shown in Figure 2b, averaged 2.6 ft^2/a at Clear Creek, but only 1.9 ft^2/a at Noregaard, a 27 % reduction in treatment effect although statistically non-significant. Because the Noregaard site was growing at a slower rate, differences between relative responses to fertilization (Figure 2c) at the two sites were smaller: 24.5 % at Clear Creek versus 18.8 % at Noregaard. Averaged across the two sites, multi-nutrient fertilizers produced a 23.5 % increase in basal area growth.

Analysis of variance results for two-year mean diameter growth, given in Table V were similar, but stronger; the model was highly significant (p=0.0001), accounted for 98% of the variation in diameter growth, and had a low coefficient of variation of 3.4%. Note that a covariate was not included, as all tested showed lack of significance. The data plotted in Figure 3 clearly shows the lack of need for any covariate adjustment for initial diameter: the trend in growth versus initial diameter is flat for both sites.

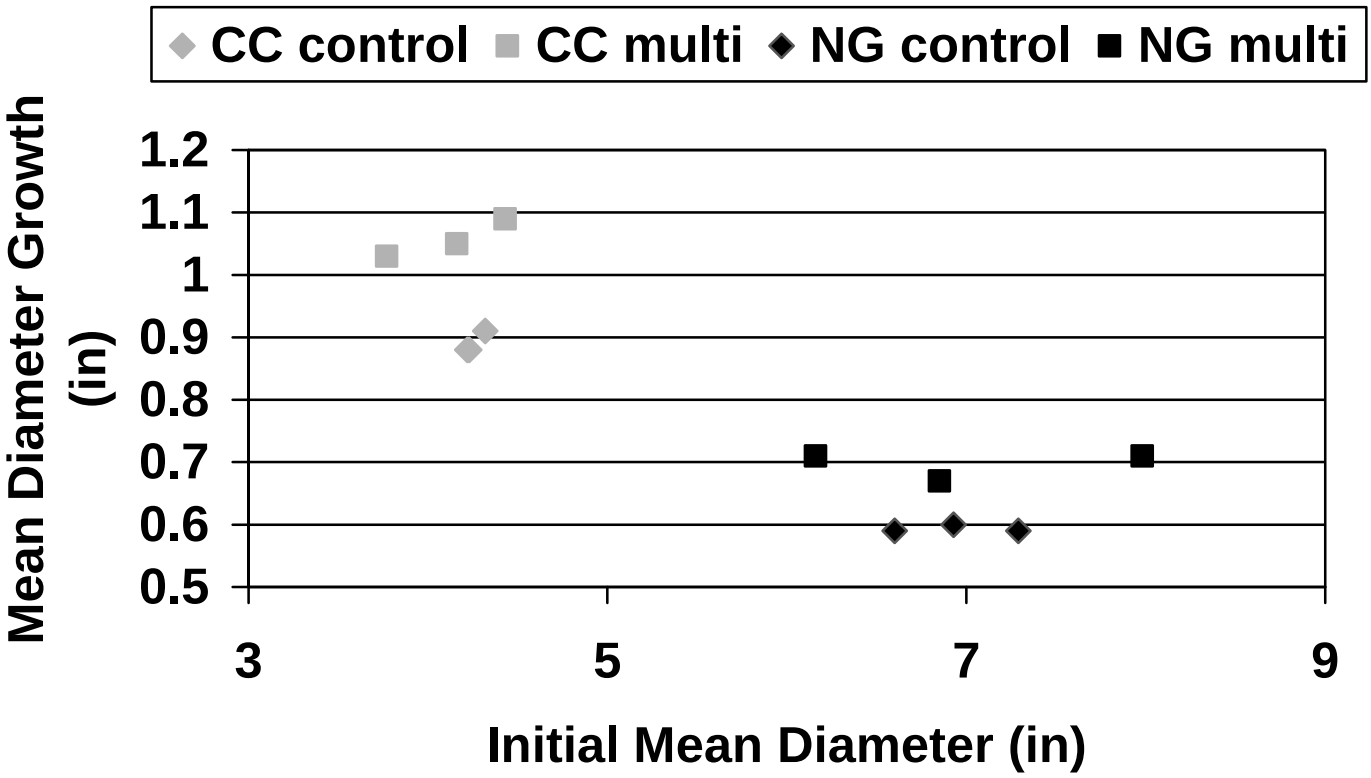

Figure 3. Two-year mean diameter growth versus initial mean diameter. Values on the left come from plots at Clear Creek (CC) while those on the right are from Noregaard (NG).

Table IV. Analysis of variance table with parameter estimates and least squares means for two-year mean diameter growth by treatment.

Dependent Variable: DBHGROW 2 year change in mean dbh (in)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.38121563	0.19060782	252.25	0.0001
Error	9	0.00680072	0.00075564		
Corrected Total	11	0.38801635			

R-Square	C.V.	Root MSE	DBHGROW Mean
0.982473	3.403479	0.02748883	0.80766841

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Installation	1	0.32502193	0.32502193	430.13	0.0001
Treatment	1	0.05619371	0.05619371	74.37	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Installation	1	0.32502193	0.32502193	430.13	0.0001
Treatment	1	0.05619371	0.05619371	74.37	0.0001

Parameter		Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT		0.7115237670 B	51.77	0.0001	0.01374441
Install	1	0.3291513980 B	20.74	0.0001	0.01587068
	2	0.0000000000 B	.	.	.
Treatment	0	-.1368621024 B	-8.62	0.0001	0.01587068
	1	0.0000000000 B	.	.	.

Least Squares Means

Treatment	DBHGROW LSMEAN	Std Err LSMEAN	Pr > |T| H0:LSMEAN=0	Pr > |T| H0: LSMEAN1=LSMEAN2
0	0.73923736	0.01122227	0.0001	0.0001
1	0.87609947	0.01122227	0.0001	

Possibilities of between-site variation in relationships of growth to treatment were again tested by examining a model including an installation X treatment effect: results, shown in Table VI, indicate a difference in response between the two sites ($p=0.0223$).

Table V. Analysis of variance table with parameter estimates and least squares means for two-year mean diameter growth by installation and treatment.

Dependent Variable: DBHGROW 2 year change in mean dbh (in)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.38461305	0.12820435	301.36	0.0001
Error	8	0.00340330	0.00042541		
Corrected Total	11	0.38801635			

R-Square	C.V.	Root MSE	DBHGROW Mean
0.991229	2.553713	0.02062553	0.80766841

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Installation	1	0.32502193	0.32502193	764.02	0.0001
Treatment	1	0.05619371	0.05619371	132.09	0.0001
Install*Treatment	1	0.00339742	0.00339742	7.99	0.0223

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Installation	1	0.32502193	0.32502193	764.02	0.0001
Treatment	1	0.05619371	0.05619371	132.09	0.0001
Install*Treatment	1	0.00339742	0.00339742	7.99	0.0223

Parameter			Estimate	T for H0: Parameter=0	Pr > |T|	Std Error of Estimate
INTERCEPT			0.6946976448 B	58.34	0.0001	0.01190816
Installation	1		0.3628036426 B	21.54	0.0001	0.01684067
	2		0.0000000000 B	.	.	.
Treatment	0		-.1032098578 B	-6.13	0.0003	0.01684067
	1		0.0000000000 B	.	.	.
Install*Treat	1	0	-.0673044891 B	-2.83	0.0223	0.02381631
	1	1	0.0000000000 B	.	.	.
	2	0	0.0000000000 B	.	.	.
	2	1	0.0000000000 B	.	.	.

Least Squares Means

Inst	Trt	DBHGROW LSMEAN	Std Err LSMEAN	Pr > |T| H0:LSMEAN=0	Pr > |T| H0: LSMEAN(i)=LSMEAN(j) i/j	1	2	3	4
1	0	0.88698694	0.01190816	0.0001	1	.	0.0001	0.0001	0.0001
1	1	1.05750129	0.01190816	0.0001	2	0.0001	.	0.0001	0.0001
2	0	0.59148779	0.01190816	0.0001	3	0.0001	0.0001	.	0.0003
2	1	0.69469764	0.01190816	0.0001	4	0.0001	0.0001	0.0003	.

Two-year change in mean diameter (Figure 4a) on untreated plots averaged 0.89 inches at Clear Creek but only 0.59 inches at Noregaard, a 33% reduction. With application of multi-nutrient fertilizer these changes increased to 1.06 at Clear Creek and 0.69 at Noregaard. Average change in mean diameter across the two sites, obtained from the model in Table V, was 0.74 inches on

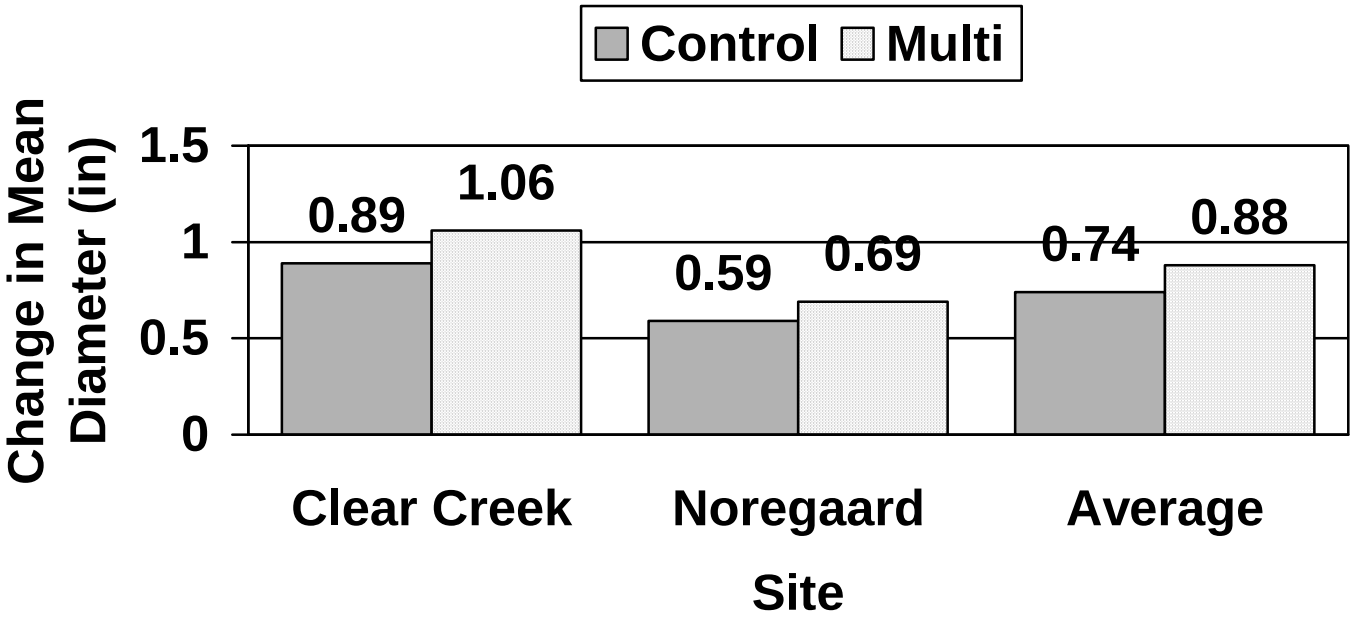

Figure 4a. Two-year change in mean diameter by site and fertilizer treatment (control, multi-nutrient).

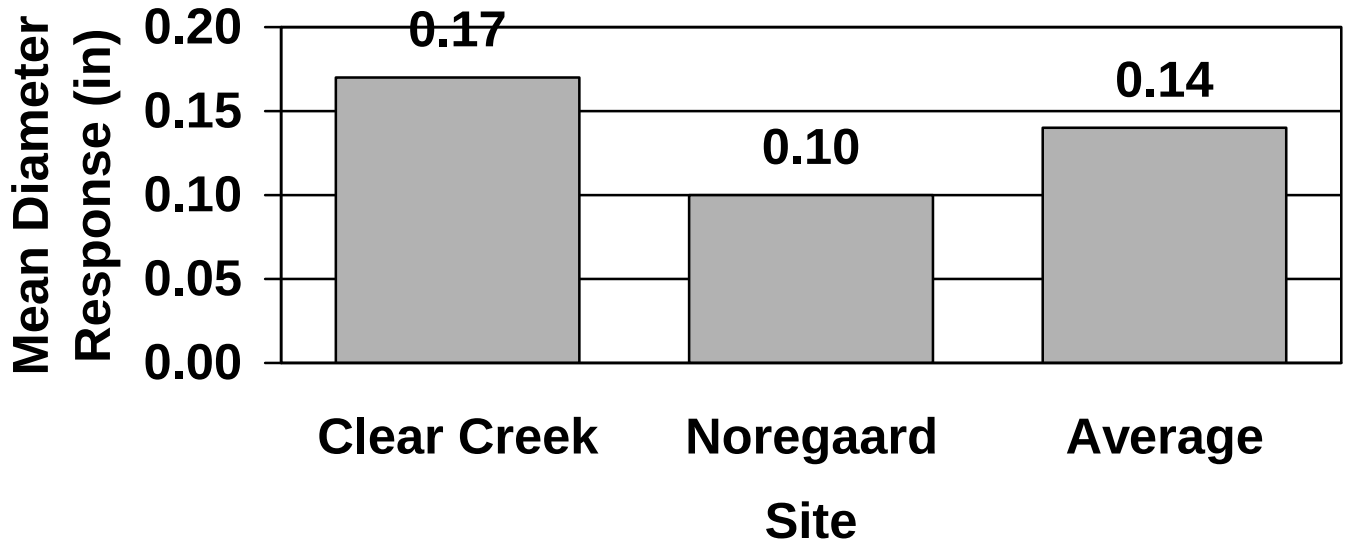

Figure 4b. Two-year mean diameter response by site. Response is the difference between treated and control.

controls and 0.88 inches on treated plots. While response to the multi-nutrient fertilizer was significant at both sites, the average response (Figure 4b) at Clear Creek of 0.17 inches in two

years was significantly greater than the 0.1 inch response at Noregaard; this corresponds to a 41% reduction in absolute response. When expressed as percentages of control change in mean diameter, the difference in response between the sites is greatly reduced (Figure 4c): Clear Creek showed a 19.1 % response in mean diameter while Noregaard showed a 16.9 % response, a reduction of only 2.2 %.

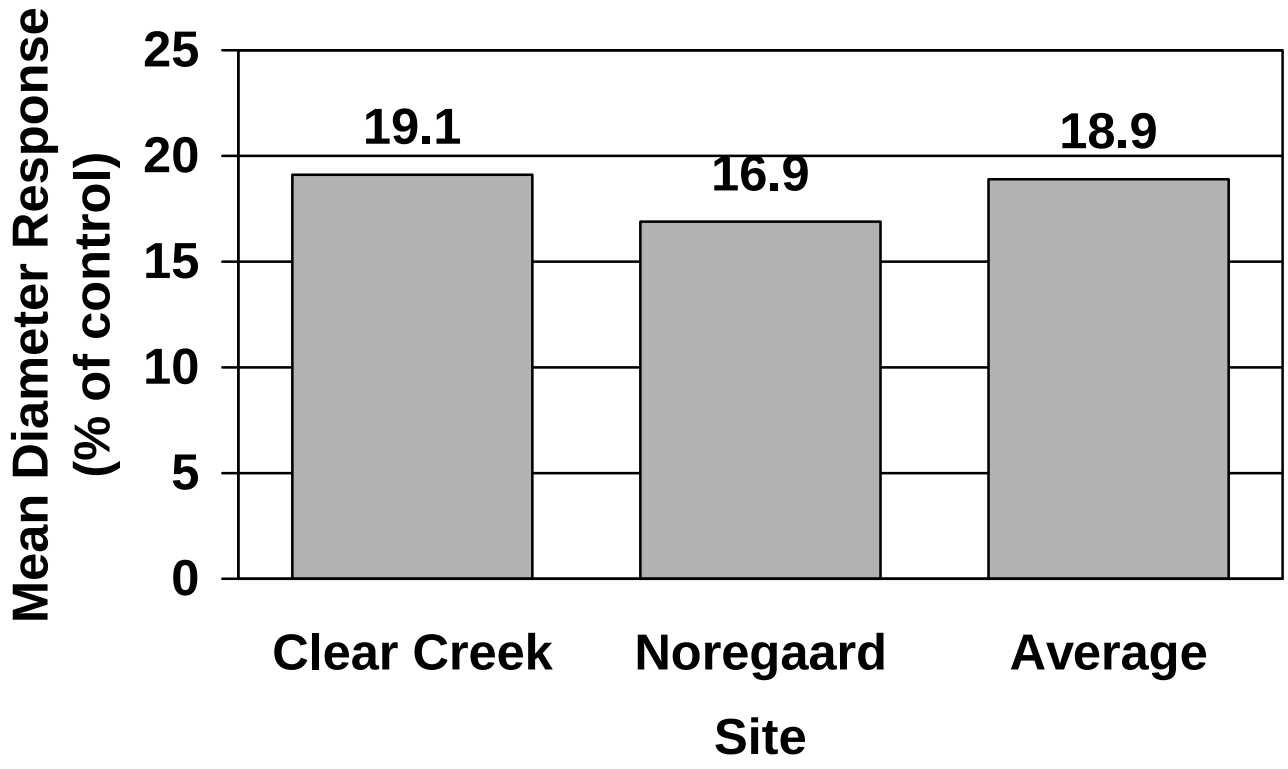

Figure 4c. Two-year mean diameter % response by site. Response is the difference between treated and control expressed as a percentage of control change in mean diameter.

The two sites differed greatly in species composition which could explain some of the differences in response to fertilization. As Ponderosa pine made up 99 % of the Clear Creek stand but was generally absent from the Noregaard site, a direct comparison of species-specific response between the sites was not possible. However, possible differences in species response could be checked at Noregaard. Analysis of covariance indicated that basal area growth rates did differ significantly ($p=0.0074$) among species, with western larch showing slower growth, but there was no evidence that responses to fertilizer were different ($p=0.4736$). Results for mean diameter growth were similar.

References

Federer, W. T. 1955. Experimental Design: Theory and Application. The Macmillan Co., New York, USA

Shaw, Terry M. 1996. Foliar nutrient characteristics after mixed fertilizer application on Boise Cascade lands in northeast Oregon. Unpublished report, Intermountain Forest Tree Nutrition Cooperative, Univ. of Idaho, Moscow

Appendix A

Plot Mensurational Characteristics

Boise Cascade Multi-nutrient Trials
Plot Summary Report

Installation 1 Clear Creek
Region: Northeast Oregon Ownership: Boise Cascade
Legal Description: T03N R41E Section 4 Meridian: Willamette

Plot Number	1	2	3	4	5	6
Treatment (1994)	Cont	Cont	Cont	Multi	Multi	Multi
Mensurational Characteristics:						
At Time of Treatment (Spring, 1995) Stand Age = NA						
Live Trees per Acre	280	280	160	280	180	240
Live Basal Area (sq.ft/a)	28.5	27.3	15.6	26.5	19.2	18.6
Live Total Volume (cu.ft/a)	189	176	98	164	122	109
Crown Competition Factor	29	27	16	27	19	19
Relative Density Index	13.7	13.3	7.6	13.0	9.1	9.6
Mean Diameter (in)	4.3	4.2	4.2	4.2	4.4	3.8
Site Height (feet)	17.7	16.9	17.5	16.8	15.8	15.5
Species Composition (% of BA)						
Grand Fir	0.0	0.0	0.0	0.0	0.0	0.0
Western Larch	0.0	0.0	0.0	0.0	0.0	0.9
Lodgepole Pine	0.6	0.0	0.0	0.0	0.0	0.0
Ponderosa Pine	99.4	100.0	100.0	100.0	98.0	99.1
Engelmann Spruce	0.0	0.0	0.0	0.0	2.0	0.0
2 Years After Treatment (Fall, 1996)						
Live Trees per Acre	280	280	160	280	180	240
Live Basal Area (sq.ft/a)	41.7	39.9	22.7	41.6	29.9	30.1
Crown Competition Factor	40	39	22	40	28	30
Relative Density Index	18.2	17.6	10.0	18.2	12.7	13.8
Mean Diameter (in)	5.2	5.1	5.1	5.2	5.5	4.8
Dead Trees per Acre	0	0	0	0	0	0
Dead Basal Area (sq.ft/a)	0.0	0.0	0.0	0.0	0.0	0.0
Dead Total Volume (cu.ft/a)	0	0	0	0	0	0

Boise Cascade Multi-nutrient Trials
Plot Summary Report

Installation 2 Noregaard
Region: Northeast Oregon Ownership: Boise Cascade
Legal Description: T03N R41E Section 2&11 Meridian: Willamette

Plot Number	1	2	3	4	5	6
Treatment (1994)	Cont	Cont	Cont	Multi	Multi	Multi
Mensurational Characteristics:						
At Time of Treatment (Spring, 1995) Stand Age = NA						
Live Trees per Acre	200	230	240	150	260	240
Live Basal Area (sq.ft/a)	58.1	60.2	57.0	52.2	53.8	61.5
Live Total Volume (cu.ft/a)	773	790	668	826	666	781
Crown Competition Factor	65	76	71	64	80	75
Relative Density Index	21.5	22.9	22.2	18.5	21.7	23.5
Mean Diameter (in)	7.3	6.9	6.6	8.0	6.2	6.9
Site Height (feet)	41.5	35.2	35.3	45.7	38.7	38.9
Species Composition (% of BA)						
Douglas-fir	42.8	15.3	14.6	11.2	18.3	67.3
Grand Fir	8.9	40.3	33.6	45.4	58.9	5.6
Western Larch	18.5	2.6	20.8	23.6	21.7	9.4
Lodgepole Pine	0.0	5.8	0.0	0.0	0.0	0.0
Ponderosa Pine	0.0	0.0	19.2	0.0	0.0	0.0
Engelmann Spruce	29.9	35.9	11.9	19.7	1.1	17.7
2 Years After Treatment (Fall, 1996)						
Live Trees per Acre	200	230	240	150	260	240
Live Basal Area (sq.ft/a)	67.7	71.1	67.6	61.8	66.9	74.1
Crown Competition Factor	76	88	83	74	97	88
Relative Density Index	24.1	25.9	25.2	21.0	25.5	27.0
Mean Diameter (in)	7.9	7.5	7.2	8.7	6.9	7.5
Dead Trees per Acre	0	0	0	0	0	0
Dead Basal Area (sq.ft/a)	0.0	0.0	0.0	0.0	0.0	0.0
Dead Total Volume (cu.ft/a)	0	0	0	0	0	0