Effect of Nitrogen Fertilization on Allometric Relationships in Douglas-fir in Western Washington

by

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Master's Thesis

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INTRODUCTION

The practice and long range goals of forestry have changed dramatically over the last few decades. Originally foresters harvested old growth timber and left the sites to regenerate on their own. Now we recognize that forests are a limited but renewable resource and that, in addition to making sure that sites regenerate, we need to be able to predict the effects of different silvicultural treatments on the quality and quantity of our future wood supply.

Recently, much work has gone into developing regression equations based on associations between easily measured parameters such as diameter, and the desired unknown, such as leaf biomass. One of the most frequently used relationships is that between diameter at breast height (dbh) and aboveground tree component biomass. Many of these relationships have been developed for trees growing in naturally established forests on undisturbed sites. But there is no guarantee that these relationships remain the same for trees on sites that have undergone silvicultural treatments such as fertilization.

This study was undertaken with several objectives in mind. These were:

1. to determine the allometric relationship between dbh and sapwood basal area, and aboveground tree component biomass for

23 year old, thinned Douglas-fir trees on fertilized and control plots (site III).

2. to use these relationships to examine the effect of fertilization on tree component biomass.
3. to use these relationships to calculate a biomass estimate for a given plot.
4. to compare this calculated biomass estimate to an estimate made using previously published relationships for unfertilized Douglas-fir trees.

BACKGROUND INFORMATION

In 1788 Thomas Paine suggested that the mathematical relationship used to estimate the flow of water in a fountain could be used to estimate the wood in the stem and branches of a tree. He further hypothesized that total tree biomass could be predicted based on tree diameter and height (Fonar 1969).

Before Thomas Paine and in the two hundred years following his observations, foresters have been looking for better and easier ways to estimate forest biomass. Originally the interest was a practical one; the need to accurately determine wood volume for economic gain. More recently, as part of an attempt to improve quality and quantity of wood production, researchers have begun to study tree production as one major component of ecosystem analysis. Because accurate biomass estimates are such an essential part of any ecosystem model, much thought has gone into methods for improving these estimates (Cole and Dice 1969; Overton et. al. 1973; Grier and Logan 1977; Webber 1977; Grier et. al. 1978). Unfortunately, actual determination of total site biomass is a difficult, tedious process and relatively few complete studies have been done (Grier et. al.1981; Keyes and Grier 1981). More frequently researchers have limited themselves to looking at aboveground biomass or simply at aboveground tree biomass.

Most past attempts at above ground biomass estimation were based on the fact that any part of a tree must grow in proportion to the rest of that tree. Relationships like these are known as allometric relations (Webster 1981). And simple mathematical regression has provided the mathematical basis for determination of these relationships. Some of the relationships commonly used in the past included regression of dry component biomass against dbh or dbh^2 and live crown component biomass against sapwood basal area. Estimates made from these equations were based either on individual tree values or on mean tree values depending on the desired accuracy. Dice (1970) contains a good survey of past literature and methods for aboveground biomass estimation.

In 1965 Baskerville published results from a major study indicating that predictions based on mean tree diameters were not very accurate. Later, Baskerville (1972) and others (Kira and Shidei 1967; Whittaker and Woodwell 1971) began to use regression analysis as a basis for biomass predictions. The advantage of regression analysis, given that you had a good computer, was that it was easy to use and it related easily measured tree parameters (dbh, sapwood basal area etc.) to less readily obtainable tree data. Moreover, once derived, equations were, within limits, applicable to estimation of biomass of other similar trees.

Today most large scale biomass estimates are still calculated using allometric relationships. For this reason it is essential that one recognize the use and limitations of these equations. Xydias (1981) and others have shown that equations derived for a specific species on one site may give a rough estimate of biomass for that same species (of similar diameter) on another site, but the best estimates are derived from site-specific equations.

Another problem is caused by the exponential nature of much biological data. Exponential data must be transformed to their logarithms to equalize variance and obtain linear relations before the basic assumptions of linear regression are met (Baskerville 1972). This means that before a log/log relationship is used to predict biomass, a correction factor must be applied to account for bias introduced by logarithmic transformation (Baskerville 1972; Schlaegel 1981; Sprugel 1983).

Finally, it has become clear that reliablity of biomass estimates is limited by the accuracy of the equations they are based on. Therefore, it is imperative that one know the standard error, sample size, and diameter range of the data base used in creation of of any allometric relationship (McNab 1981; Cannell 1982). Unless these criteria are met, the researcher cannot asses reliability of estimates and also runs the substantial risk of error inherent in extrapolating outside the range of the original data base (Grier and Milne 1981).

The use of the regression technique for calculating forest biomass appears to provide the most accurate estimates (Baskerville 1965). However, a wide variety of independent variables have been used as the basis for estimates. Choice of parameters which best estimate various biomass components has narrowed over the years (Shinozaki 1964; Clark 1981; Conde 1981; Long 1981). A good example illustration of this point is the correlation between sapwood basal area and live crown biomass. Research by Grier and Waring (1974), Snell and Brown (1978) and numerous others has indicated that sapwood area measured at dbh is highly correlated with conifer foliage biomass. Other reliable estimates of foliage biomass include diameter outside bark and stem sapwood area below the last live branch. Since it is far easier to measure dbh than sapwood thickness, Waring et.al.(1982) looked to see if there was a predictable relationship between the two parameters. They found that on their sites sapwood area increased linearly an average of 36% from the bottom of the live crown to dbh.

Recently estimates of foliar biomass have been used to determine stand leaf areas (Whittaker and Woodwell 1967; Grier and Running 1977; Gholz et. al. (1978); Waring et. al. (1978); Waring 1980). These leaf area estimates are important because leaf area is directly related to photosynthetic capacity and therefore there should be a correlation between leaf area, net productivity and tree vigor (Waring et. al. 1980).

Work done by Kira and Shidei (1967) and Turner and Long (1975) among others, showed that during stand development leaf biomass reaches a maximum that is related to climate, soil nutrient status, species, and stand density. Grier and Running (1977) showed that in the Pacific Northwest, site water balance is often the factor limiting stand leaf area. They suggested that maximum stand leaf biomass in this area occurs at the point where maximum photosynthetic activity is balanced by maintainance of adequate internal water potential during the growing season.

This work on stand development is distinctly different from studies on individual trees which have shown that leaf biomass increased with fertilization (Brix 1981; Gholz 1982). And the interesting point is that these apparently conflicting sets of observations can readily be combined if one takes into account the mortality and growth patterns discussed by Drew and Flewelling (1979). In other words, silvicultural treatments such as thinning or fertilization may cause increased foliar biomass production and stem growth on vigorous (dominant and codominant) trees. But this increased competitiveness by the larger trees could lead to accelerated mortality of the smaller trees. And the net result would be the maintainance of maximum site leaf area.

This idea can not be accurately examined unless one knows the relationship between dry component biomass and a parameter such as dbh, on fertilized and control trees in similar stands. Once such relationships such are established, foliage biomass estimates of individual fertilized and control trees can be compared,. Futhermore, these estimates can be applied to stand data to examine the effect of fertilization on total and foliar stand biomass.

MATERIALS AND METHODS

Research site

This research was conducted on Weyerhaeuser land (within section 3, township 16N, range 3E, WM) located approximately equadistant between the towns of McKenna and Eatonville in Pierce County, Washington. All sample trees were removed from the harvest zones of the five control and five nitrogen (urea) fertilized plots established by John Blake in 1980 (1). The site elevation is about 250 m and the study area is virtually flat.

Climate of the study area is classified as mild marine, with cool dry summers and mild wet winters. Mean annual precipitation ranges from 91 cm to 114 cm, with most of the annual precipitation occuring as rain from November through March. The mean temperature for the area is 10.6 C with a mean January temperature of 3.9 C and a mean July temperature of 17.9 C (2). The growing season averages about 160 days. (Soil Survey Staff 1979).

As a result of thinning the research site is dominated by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco.). Other associated overstory species are western hemlock

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(1) John Blake, Research Forester, Burlington Northern, Cle Elum, Washington.

(2) Puyallup Experiment Station , NOAA, environmental data and information service.

(Tsuga heterophylla (Raf.) Sarg.) and red cedar (Thuja plicata Donn.). The sparse understory consists mainly of Polystichum munitum (Kaulf.) Presl, Gaultheria shallon Pursh, and associated mosses. There is virtually no herbaceous cover. The study area was thinned in 1969. Evidence of tree supression, competitive tree mortality and lack of understory vegetation suggest that canopy closure was re-established well before these study plots were established in November 1980. Dead trees present on the plots, prior to the commencement of this study, were not included as part of the stand measurements.

Destructive sampling was done between December 1981 and March 1982. At that time, average tree age, determined at the tree base, was 23 years; stand density was 997 trees per hectare.

Soils in this region were derived from glacial material and belong to the Kapowsin association. The soil on this site is known as a Kapowsin gravelly loam. It is a moderately drained gravelly loam above a strongly compacted basal till and it is classified as a Dystric Entic Durochrept - loamy - skeletal - mixed - mesic. According to the 1979 Soil Survey, major soil horizons include a dark brown, gravelly loam Ap, a dark brown and dark yellowish brown gravelly loam B2cn, a very compact mottled clay loam IIB2t, and a grayish brown compact clay loam IIC. Since it is doubtful that this soil was ever plowed it is more likely that what was described as a Ap horizon was actually an A1 layer about 6 cm thick.

In terms of tree growth this area is classified as Douglas fir site class III.

Plot Establishment and Treatment

In March 1980, ten 0.06 ha (20.1 m by 30.2 m) plots were established by Pacific Northwest Regional Forest Nutrition Research Project personnel. Each plot was surrounded by a 4.9 m harvest zone. All trees inside the plots were numbered and their diameter at breast height (dbh) measured. Before the 1980 growing season five of the plots and their harvest zones were fertilized with 224 kg of nitrogen as urea per hectare. The other five plots received no fertilization. All trees were remeasured in November 1980 and 1981.

Tree Measurements

During winter of 1981 - 1982, 13 trees from the harvest zone of the fertilized plots and 13 trees from the harvest zone of the control plots were choosen for destructive sampling. The probability of a tree being selected for sampling was proportional to diameter frequency distribution in the stands. All sample trees were taken from within the harvest zones so as not to interfere with other experiments in progress. To minimize dry weight losses due to carbohydrate respiration, each tree was sampled as soon after felling as possible. Tree height and length of the terminal leader were measured to the nearest cm. Stem diameter (to the nearest mm) measurements were obtained at 0.5 m, 1.0 m and 1.3 m above the soil surface and above that at two meter intervals to the top of the tree.

Stemwood and bark densities of one fertilized and one control tree were determined by water displacement (Forest Products Lab 1952). Total stem dry weight was then calculated from volume and dry densities of each section (Grier and Logan 1977). Volume of the butt log was determined using Bruce De-Mar's formula (Dilworth 1979). Smalian's formula was used for all other volume calculations (Husch 1963).

Wet stem biomass of all other trees was determined by weighing to the nearest 0.1 kg. A cross section (basal disk) was then removed from the base of each 2 m section and saved for further analysis. Sample discs were stored and transported in plastic bags to prevent water loss prior to weighing. In the laboratory wet weight of each basal disk was determined, to the nearest 0.1 g, within 24 hours of sampling. In addition, stem diameter, inside and outside bark, wood radial increment for the past seven years, and sapwood thickness were computed from the average of four right angle measurements on each disk. Sapwood was distinguished from heartwood visually with the aid of a standard pH indicator which marked the sapwood/heartwood boundary by color difference. Sapwood thickness was measured to the nearest whole millimeter. After all ring width measurements had been obtained, bark was removed from the stemwood and both were dried at 70 C. Total bark and wood dry weight were computed for each stem section based on wet weight of the stem section,the wet weight of each basal disk and the disk bark cross-section dry weight:stemwood cross-section dry weight ratio. (Appendix A).

In the field, length dead crown and live crown were measured. The live crown was then divided into three equal sections and all live and dead branches were removed from the stem. Total wet weight of all branches in the dead section of the crown was recorded and a subsample was removed for further analysis.

Each section of the live crown was treated separately. First, all dead branches and twigs were removed from the live branches. This was followed by removal of all foliage bearing twigs from the branches. Finally, the wet weights of dead branches, live branches, and foliage and twig were determined and recorded. A 500 to 1000 g sample of each tree component was removed.

Crown component analysis followed the methods outlined by Grier and Logan (1977). Each foliage plus twig subsample was divided into old foliage plus twigs and current foliage plus twigs. Subsamples of all crown components were then dried at 70 C. After drying, all foliage and twig samples were further separated into dry foliage and dry twigs. Subsample dry weights of old foliage, current foliage, old twigs, current twigs, live branches and dead branches were recorded. Total crown dry weight was computed from the field weights and the fresh: dry weight ratios of each component (Grier and Logan 1977) (Appendix A).

Computations

Tree component dry weight was plotted against dbh and sapwood basal area to examine curve forms and their variances. For both fertilized and non fertilized trees, variance increased with the magnitude of dbh and was constant over sapwood basal area. These observations dictated the curve-fitting approach to be used. Regression equations were calculated by regressing tree component biomass against dbh or sapwood basal area at breast height. Although most work shows a linear relationship between live component biomass and sapwood basal area, ln/ln regressions were done so that the equations would be comparable to the ln/ln regressions done on dbh. The multiple regression equation $y = a + b1x + b2Dx$ (a=intercept, b=slope, D=dummy variable) was used to test for differences between slopes of regressions for fertilized and control tree data. If there was no significant difference ($p > .05$) between slopes of regressions for control and fertilized trees then all data were combined into a single line. All allometric equations derived in this study were corrected with the standard correction term $a = a + (s^2_{y \cdot x})/2$ where $(s^2_{y \cdot x})/2$ is the residual or error mean square. This term corrects the regression estimate for bias that occurs when an estimate obtained from an equation in ln/ln form is transformed to arithmetic units. (Baskerville 1972 and Sprugel 1983).

Total biomass and basal area of the experimental plots was computed using the dbh data collected by Weyerhaeuser and the allometric equations derived in this study. These plot biomass values were compared with the values derived using previously published equations based on non-fertilized trees in natural undisturbed stands (Gholz et. al. 1979).

Variation in crown needle weight was examined by taking the dry weight of 50 old and 50 new needles from the top, middle and bottom of six fertilized and six control trees.

RESULTS

Sample tree data

Mean linear dimensions, dry weights and basal areas of the control and fertilized trees are listed in Table 1.

Regression Equations

Dry component biomass of fertilized and control trees was regressed against dbh (Figures 1 to 11). Multiple regression analysis using a dummy variable (D=0) for control trees and D=1 for fertilized trees showed that the slopes of the regressions for current foliage and current twig biomass of fertilized trees were significantly greater ($p < .01$) than that of the unfertilized trees. Regressions of total foliage, total twigs, and all other components of biomass against dbh showed no significant difference between fertilized and control trees. Because there was no significant difference between slopes of fertilized and control regressions, other than for new foliage and twigs, all data for each component were combined to form one regression line for that component (Table 2). Allometric relationships between dry component biomass and sapwood basal area followed the same trends as the regressions against dbh (Figure 12 and 13). However, dry weight of each live crown component was more closely correlated with

Table 1. Some physical characteristics of the 26 Douglas-fir trees used in calculating allometric relations for the trees in this study.

	CONTROL	FERTILIZED
LINEAR DIMENSIONS		
No. of Trees	13	13
$\bar{x}$ dbh (cm)	19.8	19.7
Diam. range (cm)	9.3 - 32.8	9.3 - 29.1
$\bar{x}$ height (m)	16.5	16.4
Height range (m)	12.3 - 20.5	12.0 - 20.5
$\bar{x}$ terminal shoot elongation (cm)	0.96 (a)	0.86 (b)
$\bar{x}$ radial wood increment at breast height (mm)	0.45	0.49
$\bar{x}$ bark thickness at breast height (cm)	0.91	0.83
$\bar{x}$ sapwood thickness at breast height	4.13	4.07
MEAN DRY WEIGHTS (kg)		
Stemwood	98.2	87.8
Stembark	14.3	15.8
Living branches	21.6	18.1
Dead branches	10.6	10.6
Total Twig	5.5	6.4
Total Foliage	15.1	16.2
Current years twigs	0.8	1.3
Current years foliage	2.8	3.8
MEAN BASAL AREA (cm^2/TREE)		
1978	278.4	260.8
1981	336.7	320.0
2-year basal area increment (cm^2/tree)	58.3	59.3

a) 3 control tree leaders excluded due to damage
b) 4 fertilized tree leaders excluded due to damage

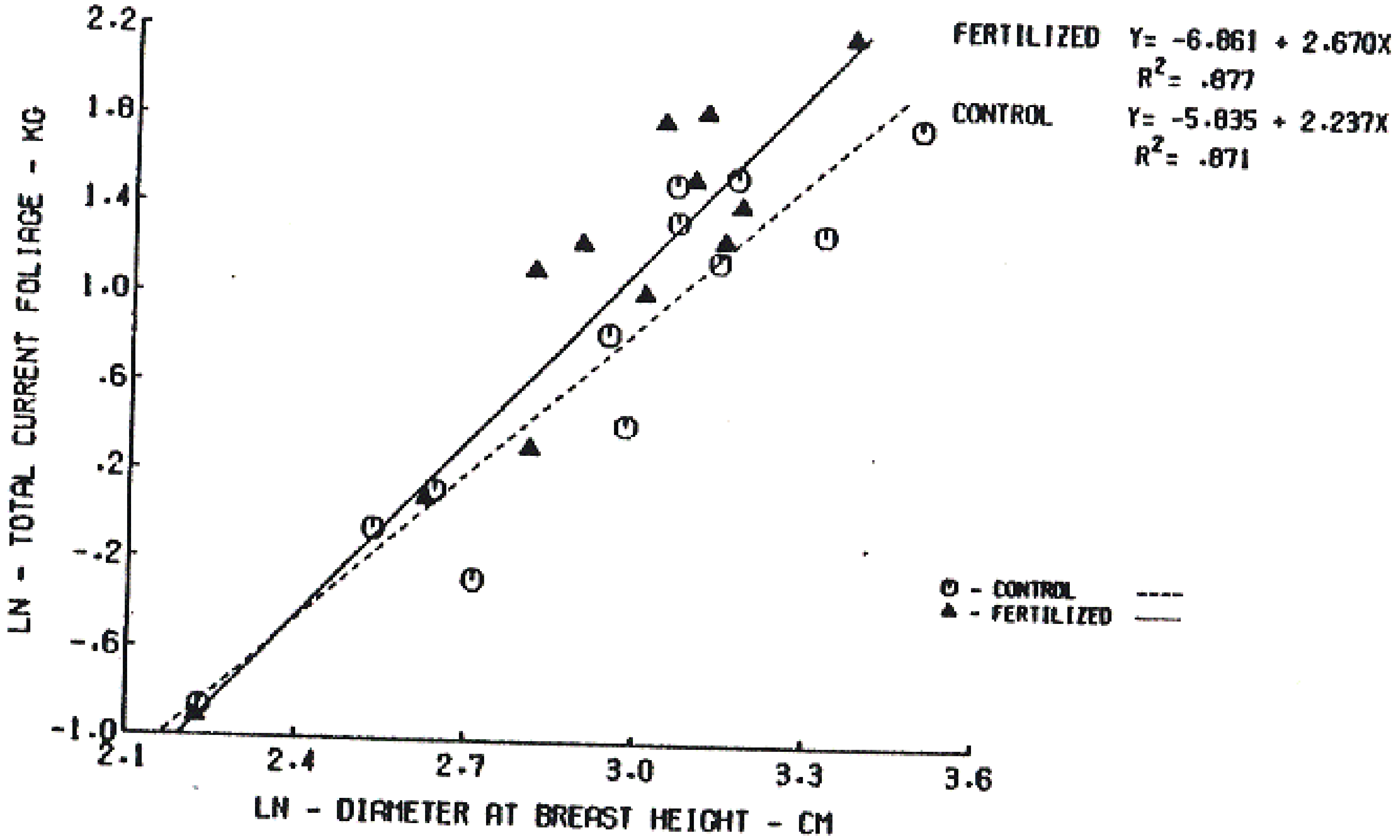

Figure 1. Regression of total current foliage biomass against diameter. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

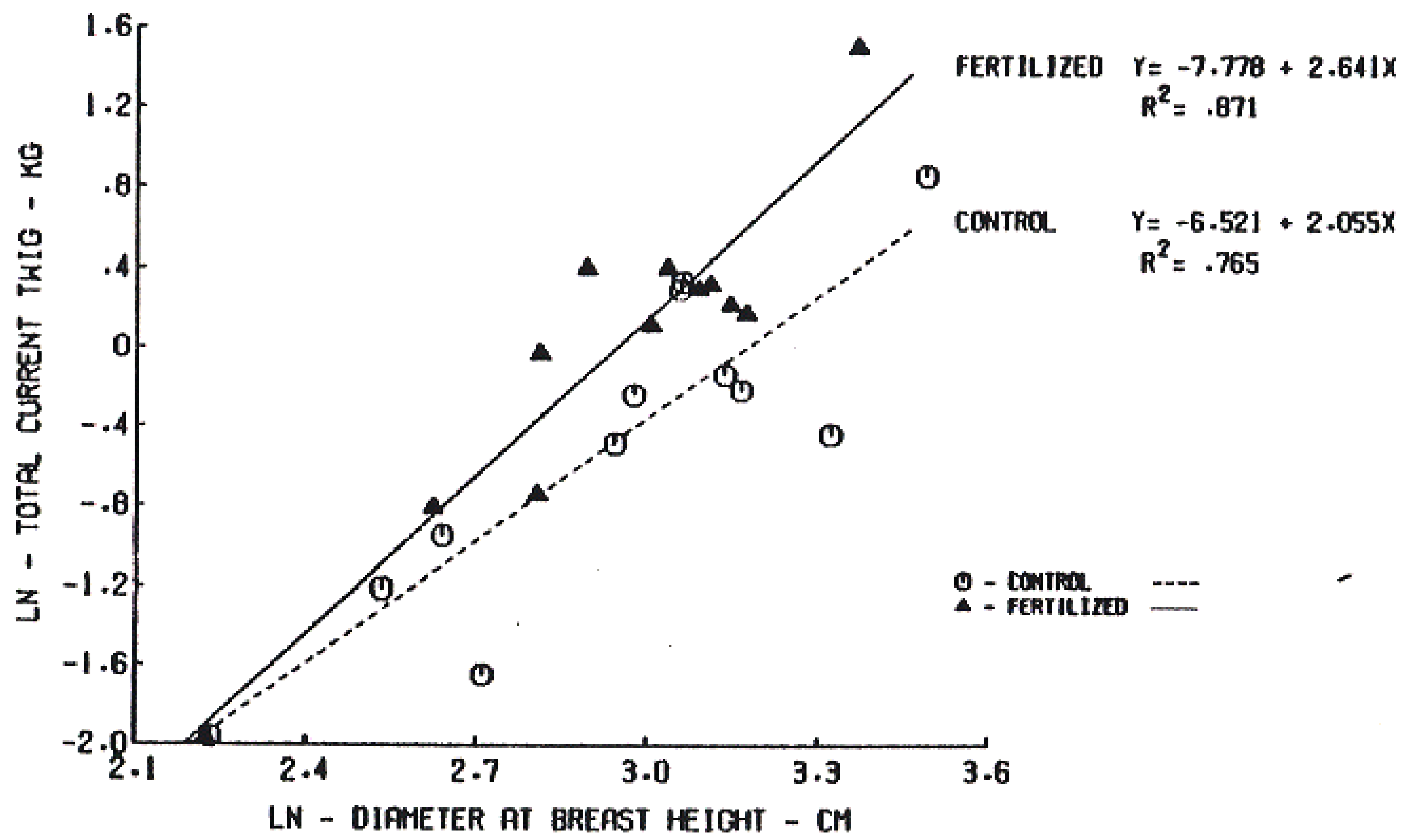

Figure 2. Regression of total current twig biomass against diameter. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

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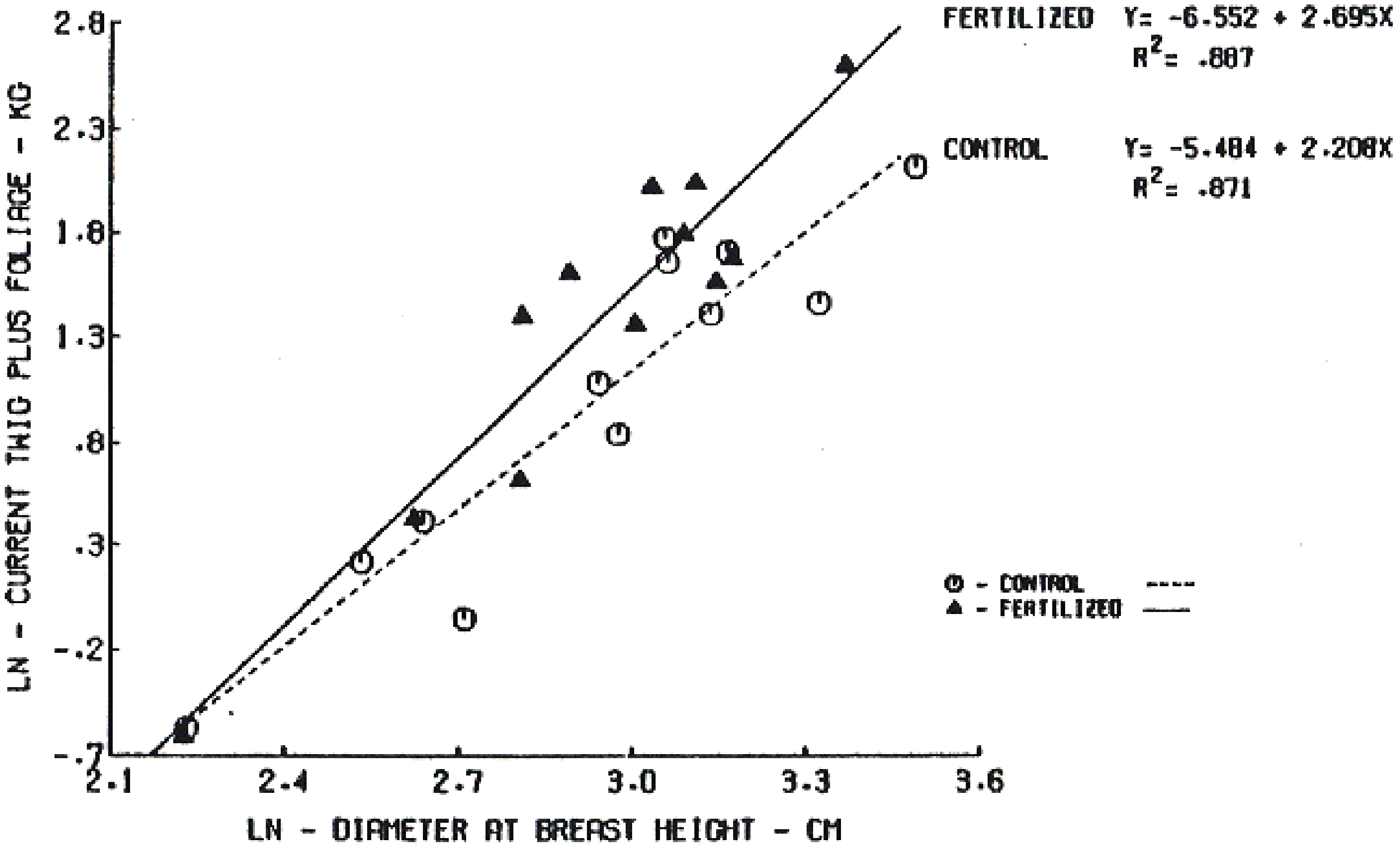

Figure 3. Regression of total current foliage plus current twig biomass against diameter. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

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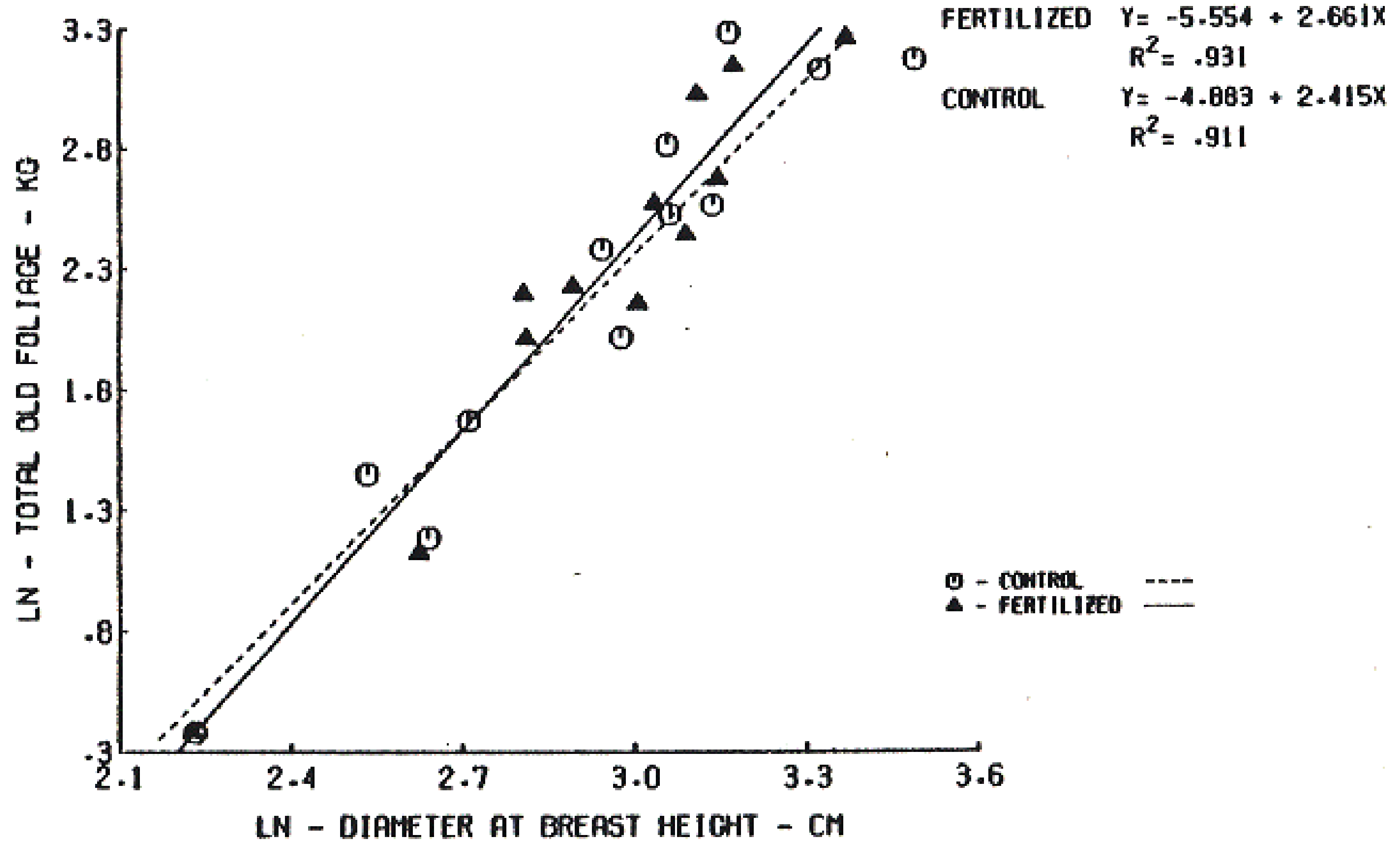

Figure 4. Regression of total old foliage biomass against diameter. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

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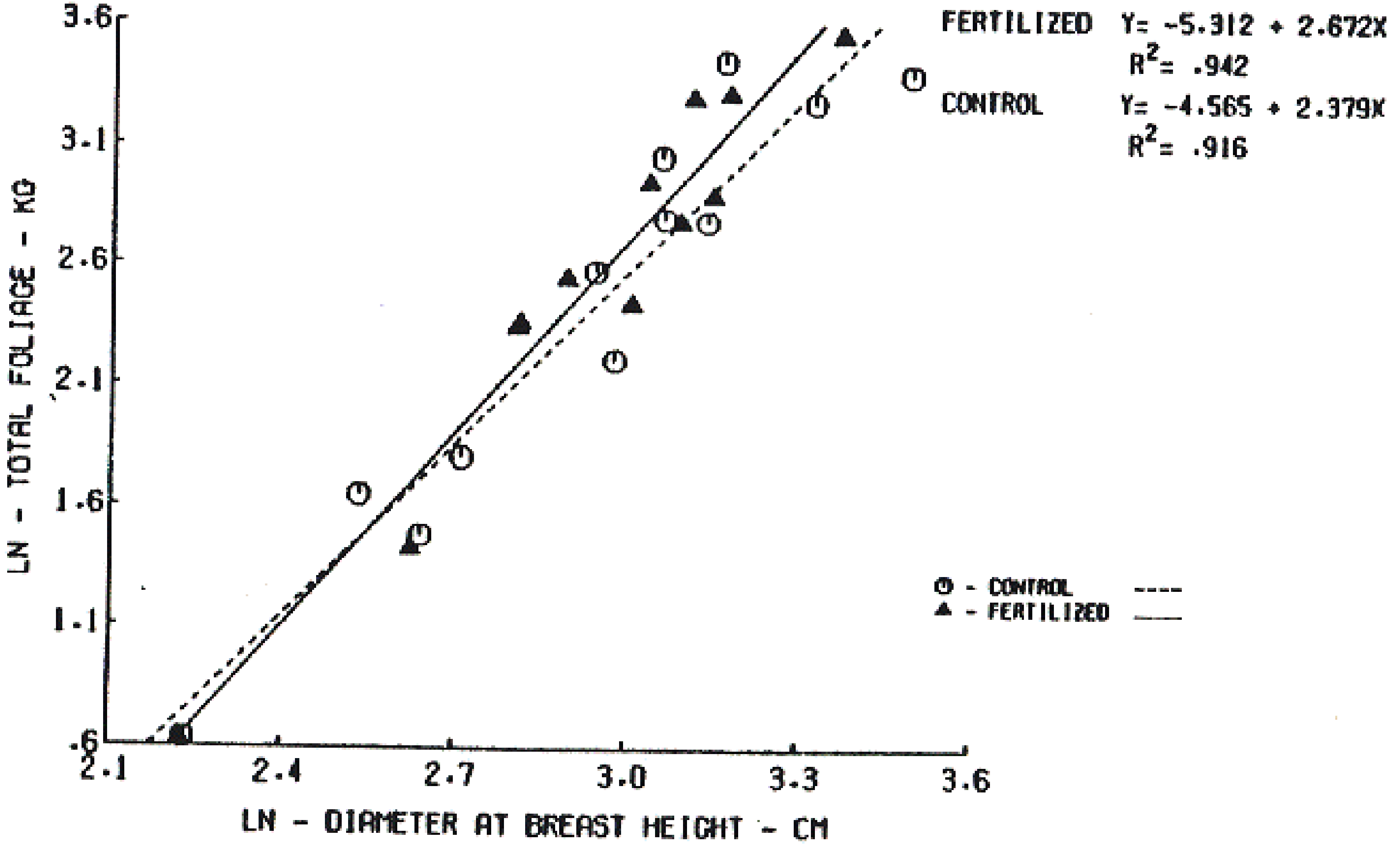

Figure 5. Regression of total foliage biomass against diameter. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

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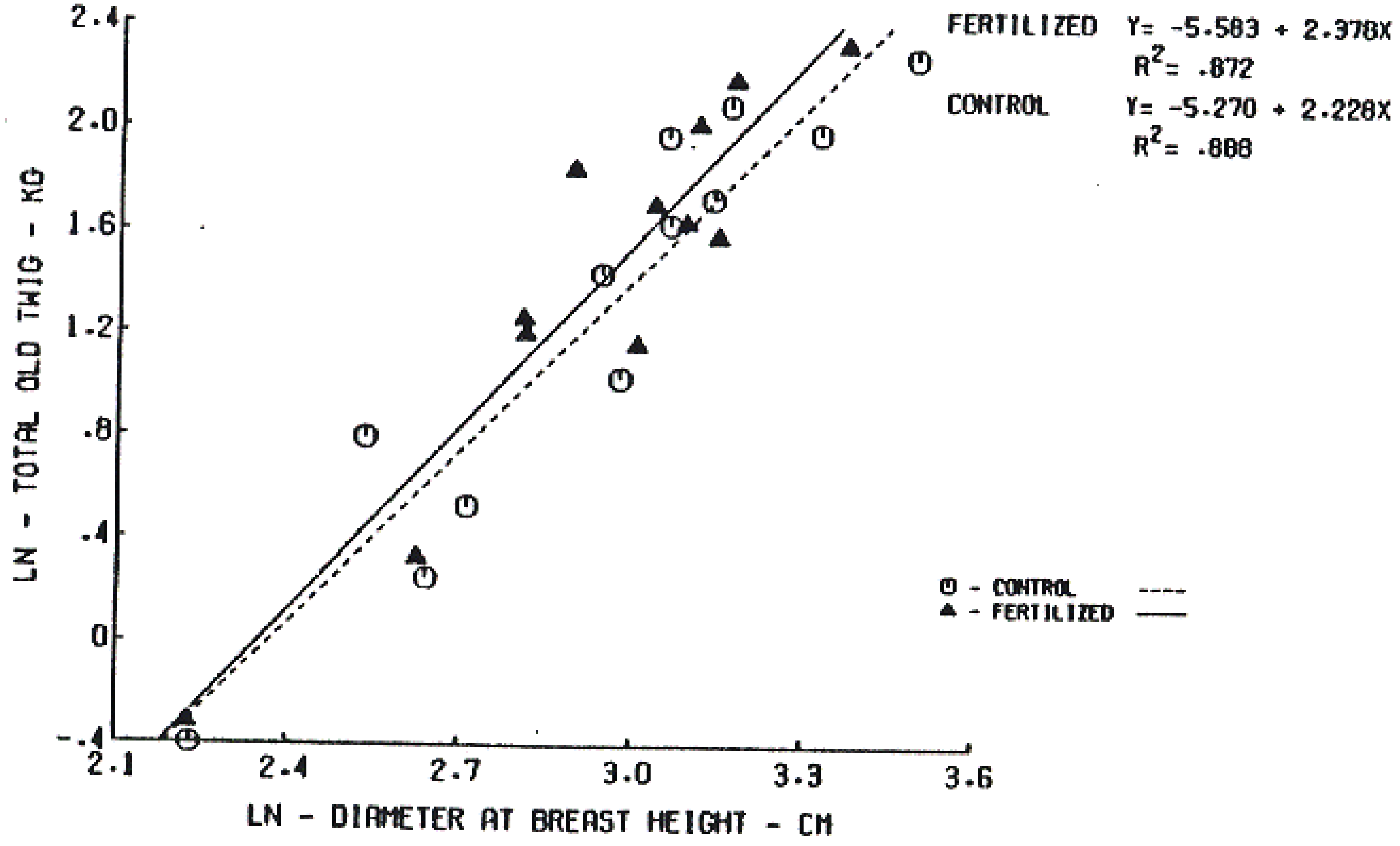

Figure 6. Regression of total old twig biomass against diameter. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

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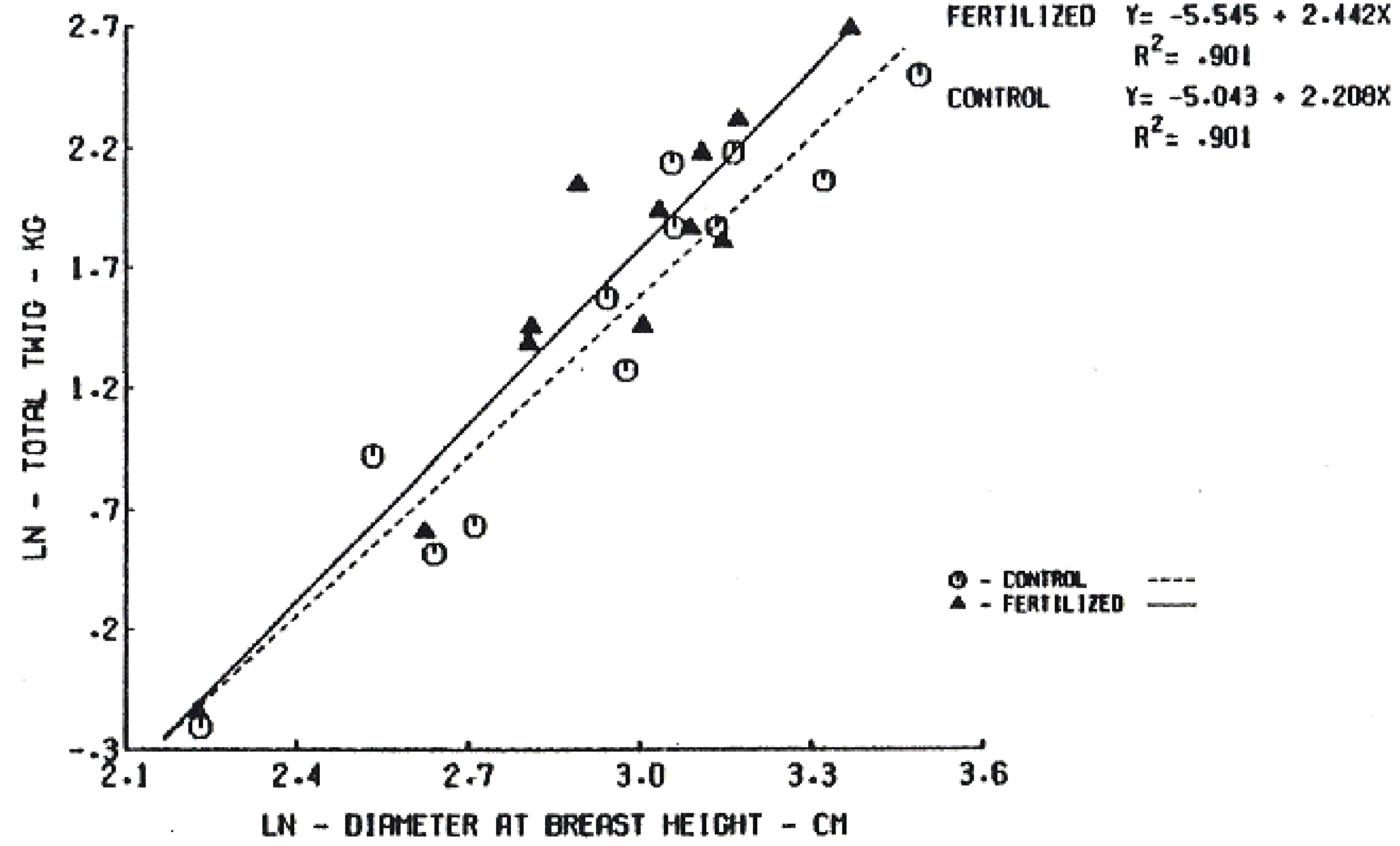

Figure 7. Regression of total twig biomass against diameter. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

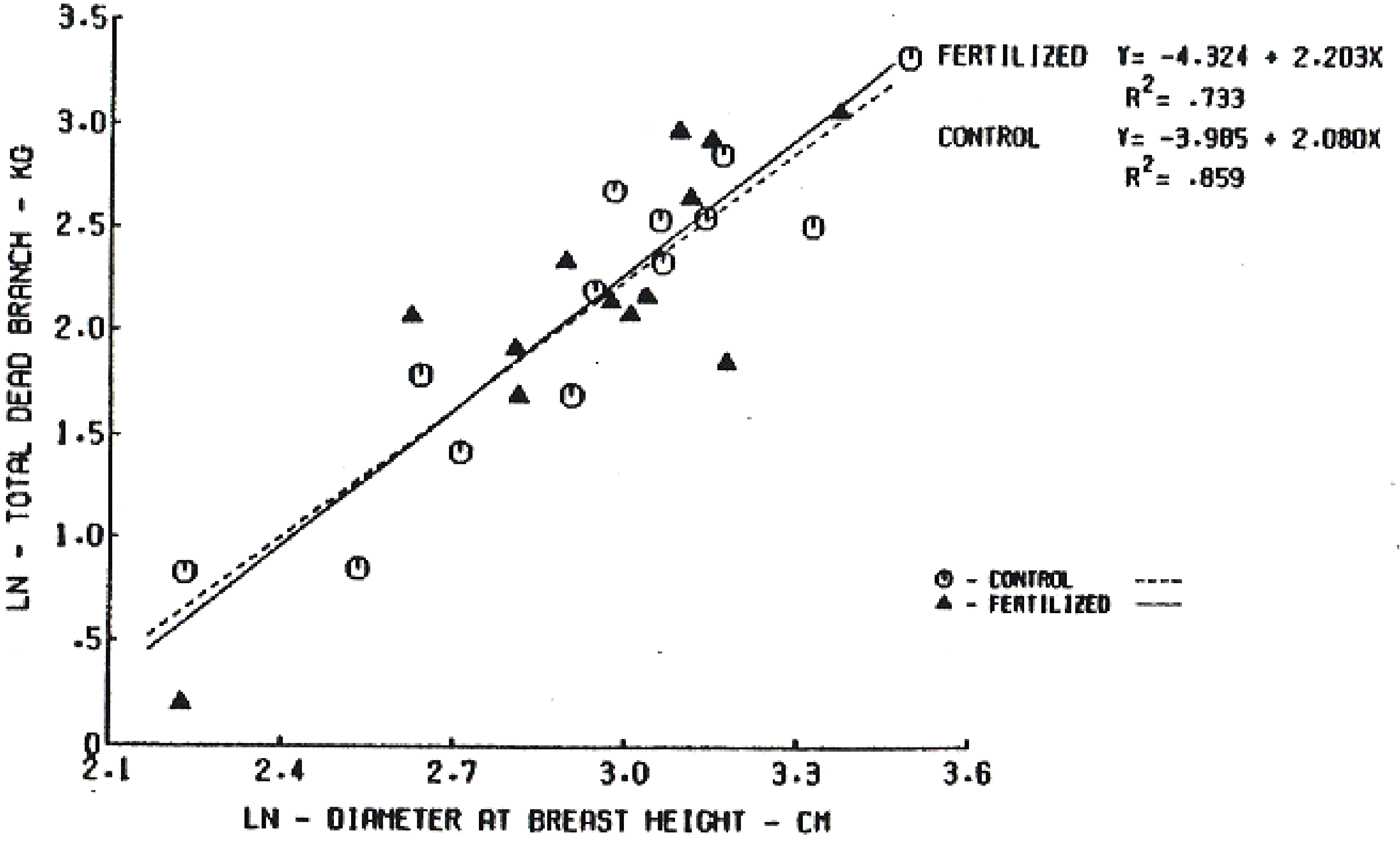

Figure 8. Regression of total dead branch biomass against diameter. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

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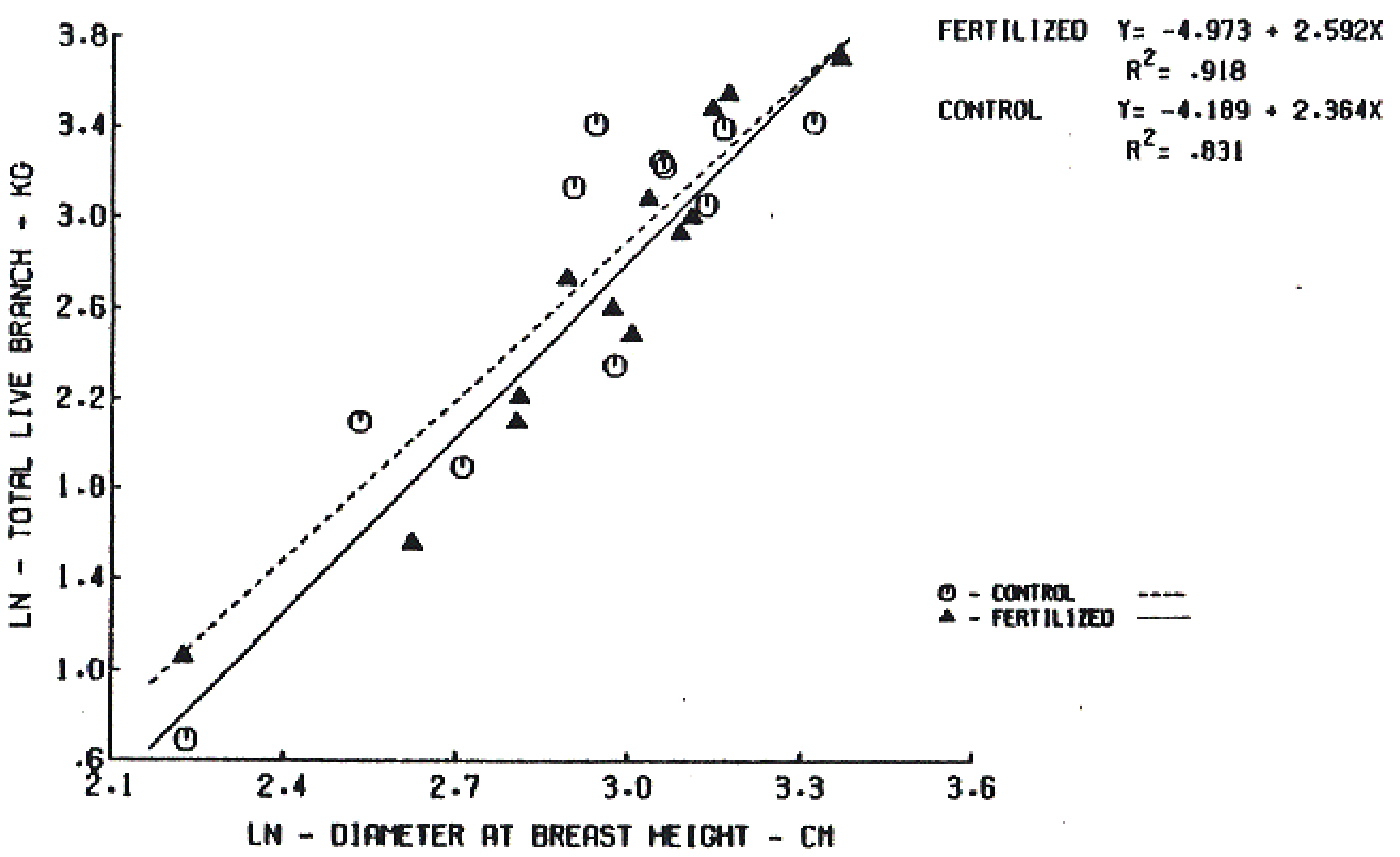

Figure 9. Regression of total live branch biomass against diameter. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

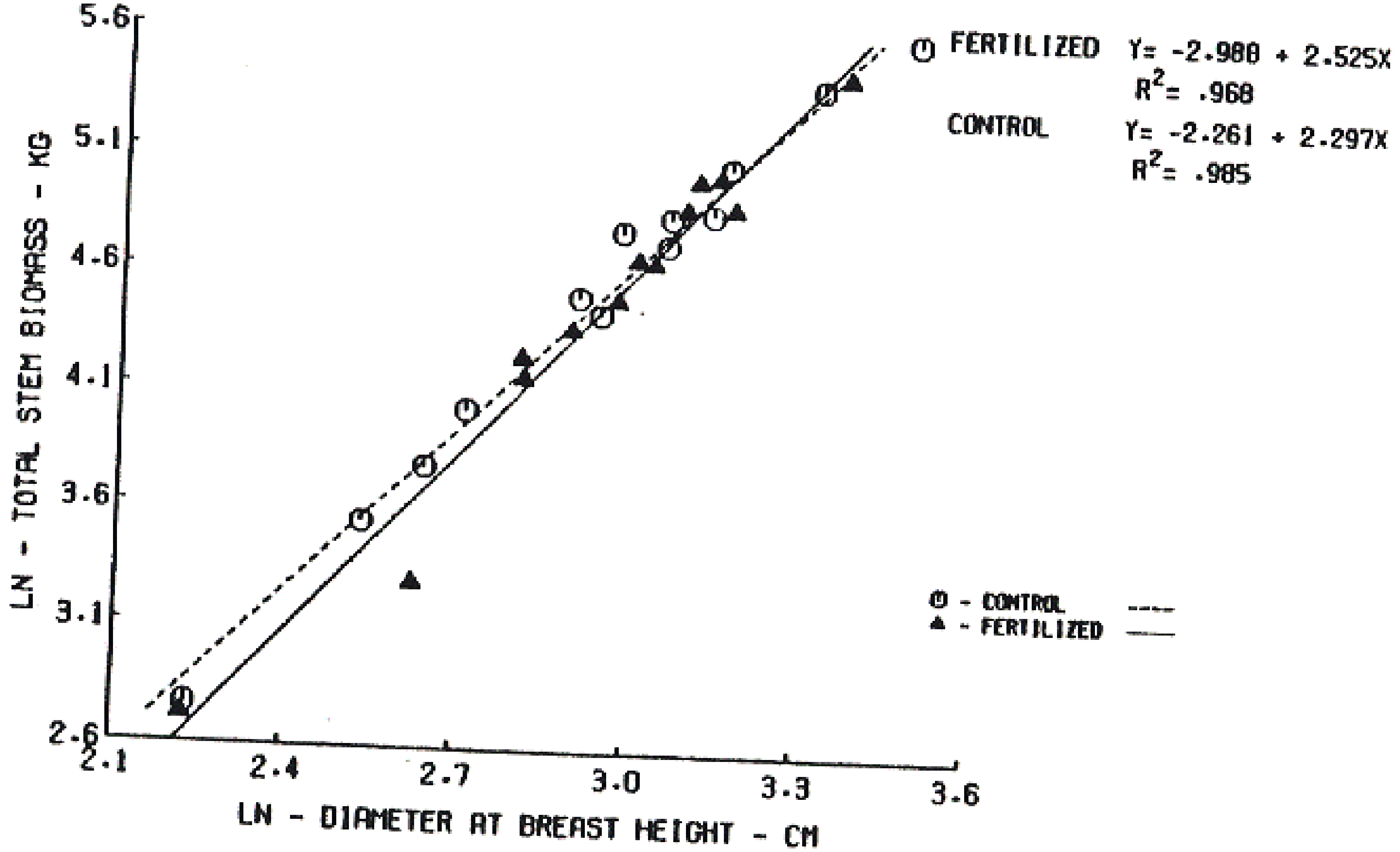

Figure 10. Regression of total stem biomass against diameter. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

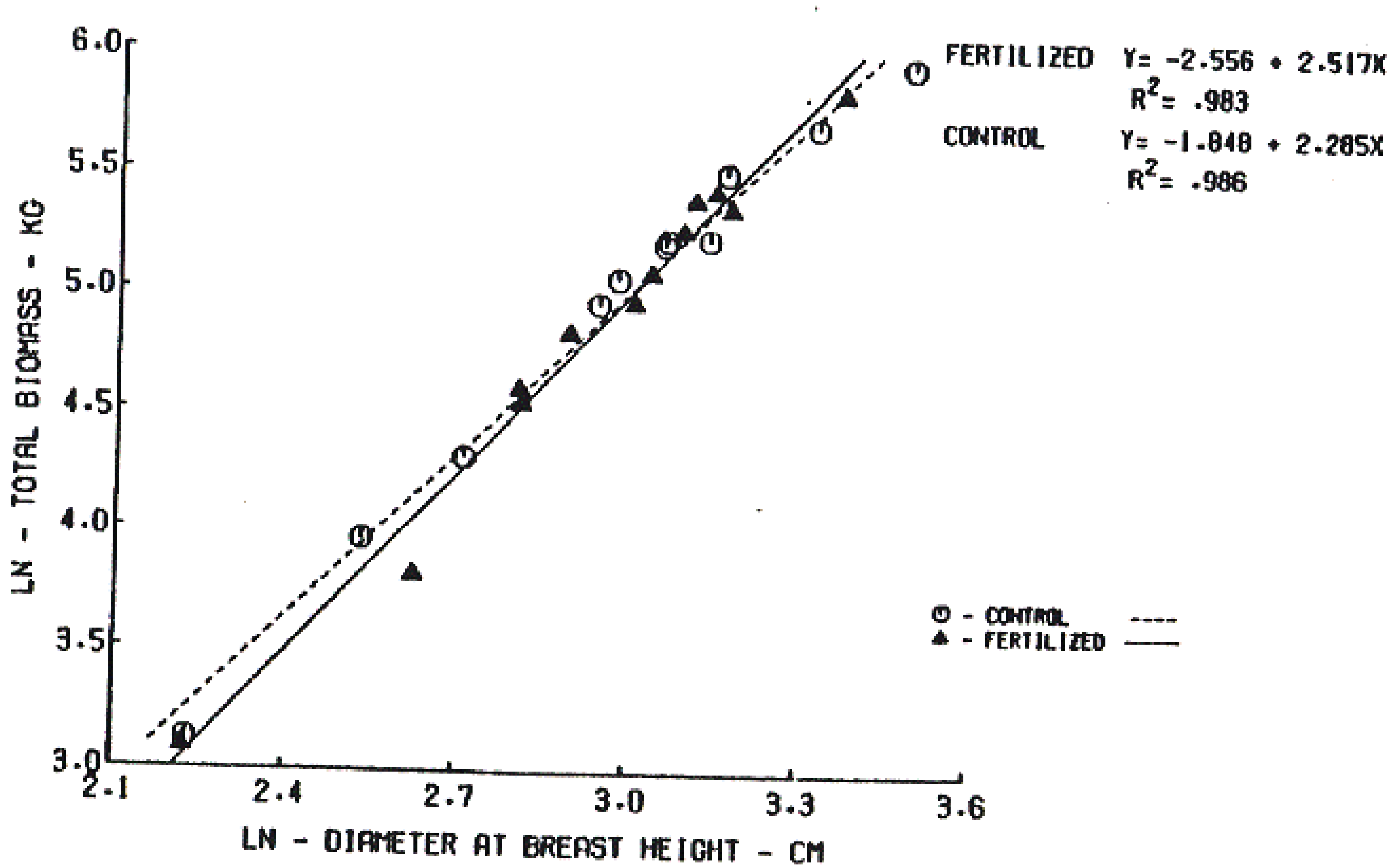

Figure 11. Regression of total biomass against diameter. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

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Table 2. Regressions of Douglas-fir component dry weight on stem diameter. Equations are of the form $\ln Y = a + b \ln X$ where X is stem diameter at dbh (cm) and Y is component dry weight (kg). Columns headed N, r^2 and $s^2_{y \cdot x}$ show number of individuals included in regression, correlation coefficient and mean square residual (Husch 1963), respectively. Control and fertilized tree data was combined to form one regression whenever the regression slope of fertilized data was not significantly different than the slope of the control data.

		a	b	N	r^2	$s^2_{y \cdot x}$
DEPENDENT VARIABLES (fertilized and control combined)						
Stem wood	(BST)	-2.603	2.367	26	.973	.081
Stem bark	(BBK)	-4.906	2.530	26	.943	.127
Stem wood + bark	(BWB)	-2.525	2.392	26	.973	.081
Living branches	(BLB)	-4.456	2.469	25	.865	.203
Dead branches	(BDB)	-4.016	2.132	26	.797	.220
Total Twigs	(BTT)	-5.152	2.306	24	.886	.176
Old Twigs	(BOT)	-5.299	2.291	24	.873	.186
Total Foliage	(BTF)	-4.791	2.502	26	.921	.156
Old Foliage	(BOF)	-5.079	2.518	25	.917	.162
BOT + BOF		-4.536	2.451	24	.911	.163
BTT + BTF		-4.297	2.446	24	.917	.157
BLB + BOT		-4.125	2.430	23	.898	.183
BLB + BTT		-4.075	2.427	23	.898	.179
Current foliage	(BCF)	-5.698	2.237	12	.870	.273
Current twigs	(BCT)	-6.341	2.055	12	.765	.360
Current twigs + Current foliage	(BCTF)	-5.349	2.208	12	.871	.269
DEPENDENT VARIABLES (fertilized trees)						
Current foliage		-6.702	2.699	12	.877	.319
Current twigs		-7.617	2.641	12	.871	.321
Current Twig + Current foliage		-6.400	2.695	12	.887	.304

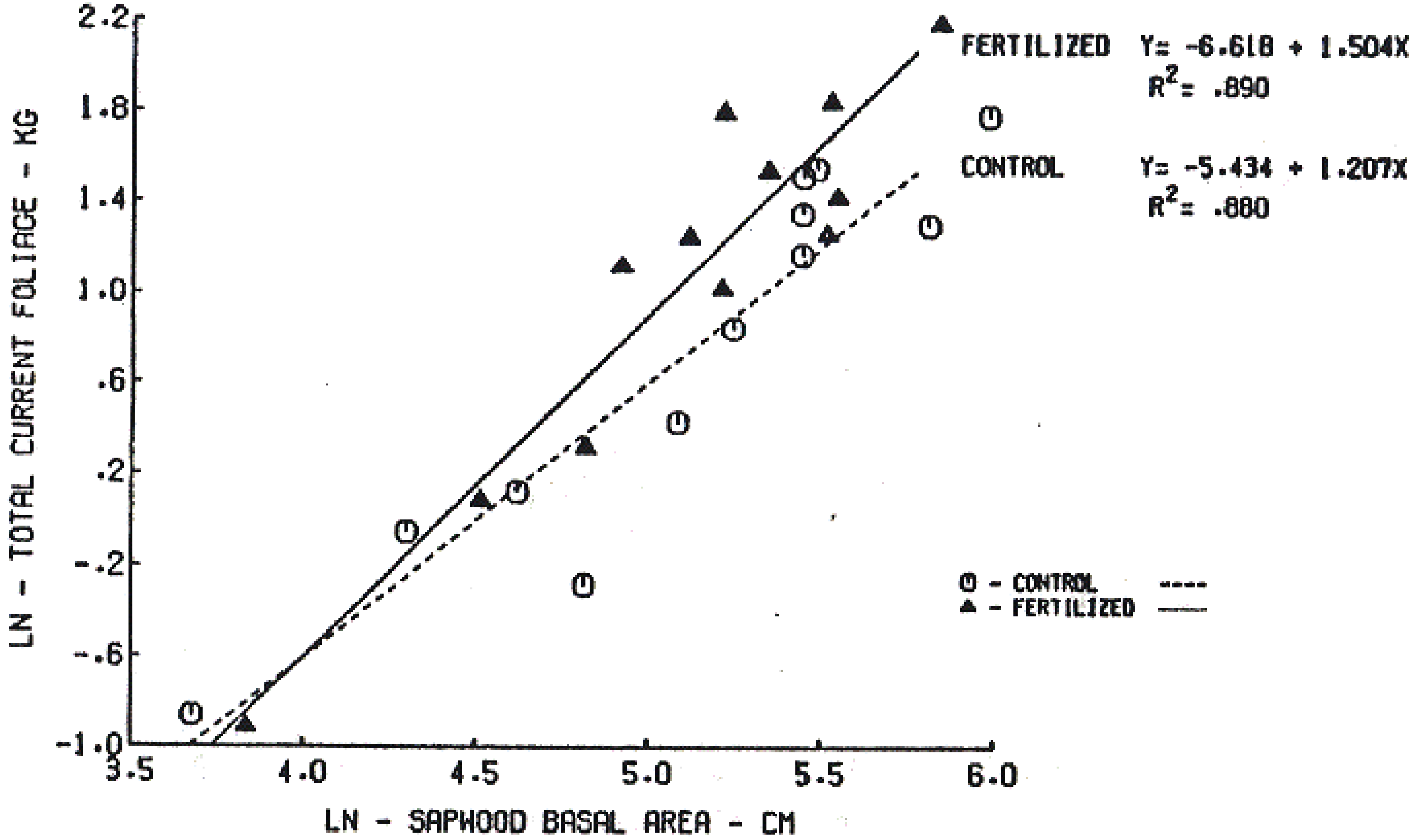

Figure 12. Regression of total current foliage biomass against sapwood basal area. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

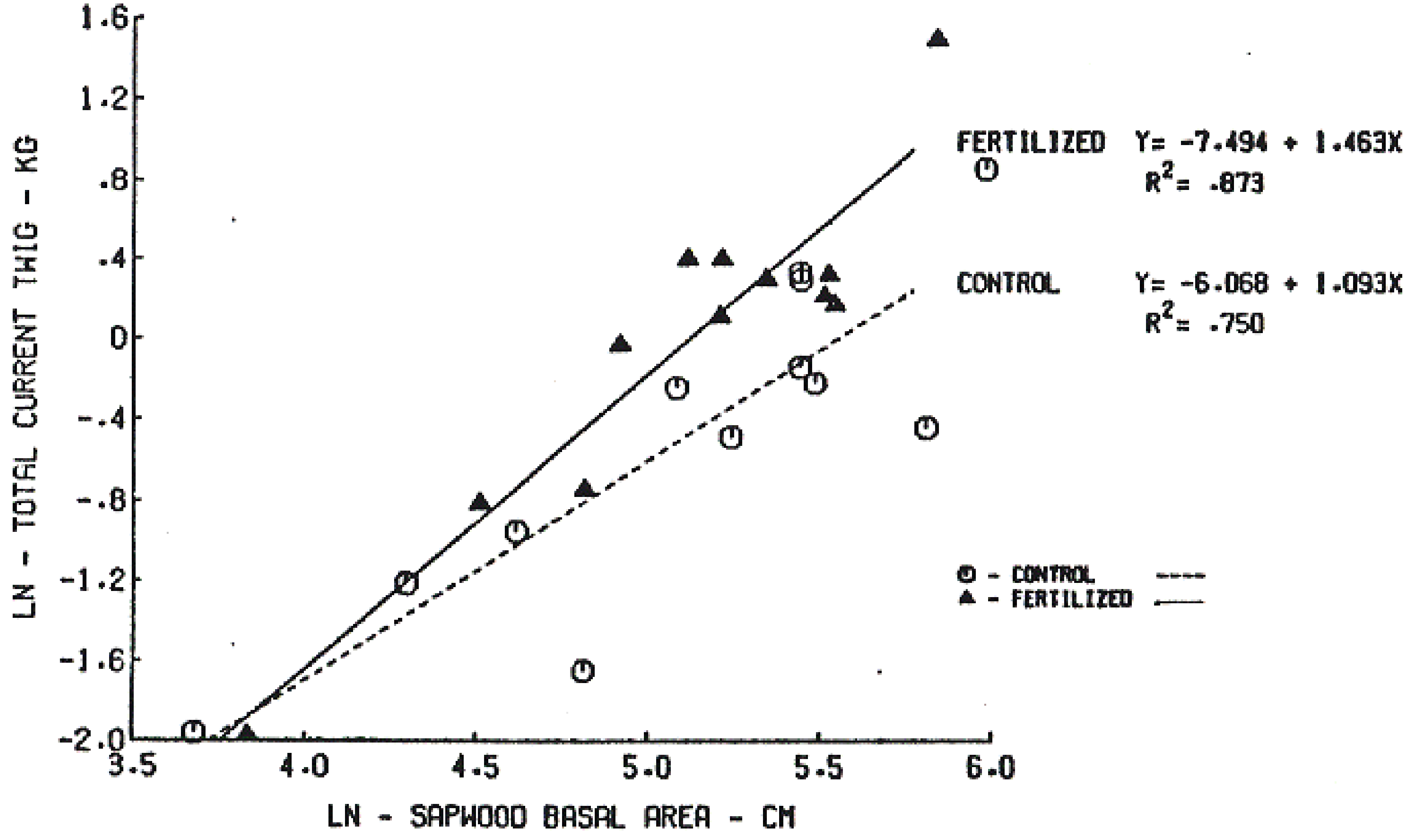

Figure 13. Regression of total current twig biomass against sapwood basal area. Data obtained by destructive analysis of 23-year old control and fertilized Douglas-fir trees in Western Washington.

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Table 3. Regressions of Douglas-fir component dry weight on sapwood basal area. Equations are of the form $\ln Y = a + b \ln X$ where X is sapwood basal area at dbh (cm) and Y is component dry weight (kg). Columns headed N, r^2 and $s^2_{y \cdot x}$ show number of individuals included in regression, correlation coefficient and mean square residual (Husch 1963), respectively. Control and fertilized tree data was combined to form one regression whenever the regression slope of fertilized data was not significantly different than the slope of the control data.

		a	b	N	r^2	$s^2_{y \cdot x}$
DEPENDENT VARIABLES (fertilized and control combined)						
Stem wood	(BST)	-2.208	1.280	26	.963	.052
Stem bark	(BBK)	-4.517	1.372	26	.938	.072
Living branches	(BLB)	-4.210	1.361	25	.895	.097
Dead branches	(BDB)	-3.624	1.394	26	.770	.127
Total Twigs	(BTT)	-4.842	1.257	24	.891	.094
Old Twigs	(BOT)	-5.009	1.251	24	.882	.097
Total Foliage	(BTF)	-4.463	1.366	24	.930	.080
Old Foliage	(BOF)	-4.749	1.375	24	.926	.083
BOT + BOF		-4.219	1.339	24	.920	.084
BTT + BTF		-3.974	1.336	24	.925	.081
Current foliage	(BCF)	-5.363	1.207	12	.880	.141
Current twigs	(BCT)	-5.969	1.093	12	.750	.199
Current twigs + Current foliage	(BCTF)	-4.992	1.187	12	.873	.143
DEPENDENT VARIABLES (fertilized trees)						
Current foliage		-6.534	1.504	12	.890	.167
Current twigs		-7.405	1.463	12	.873	.177
Current Twig + Current foliage		-6.219	1.499	12	.897	.160

sapwood than with dbh (Table 3).

Plot Biomass and Basal Area

Total pre-fertilized (1979) basal area of the fertilized plots was 0.6% greater than that of the control plots (Table 4). Two years after fertilization, basal area of fertilized plots was 2.5% greater than that of control plots. In 1981, two year basal area increment was 11.5% greater in fertilized plots than in the control plots.

Two estimates of plot dry component biomass were obtained. The first was made by applying site specific allometric relations obtained in this study to diameter data supplied by Weyerhaeuser Company Personnel (Table 5). Published equations (Gholz et. al. 1979) and the same diameter data were used to make the second estimate (Table 6). Based on site specific allometric relationships, total pre-fertilized (1979) above ground tree biomass was 0.3% greater in the fertilized than control plots (Table 7). Two years after fertilization, aboveground biomass of the fertilized plots was 2.8% greater than that of the control plots (Table 8). Therefore, during the two year period following treatment, the fertilized plots accumulated 11.8% more biomass per year than the control plots (Table 9). Total biomass estimates made using the published equations were 6.8% higher than estimates made from the site specific

__Table 4.__ Basal area of the experimental plots in m^2 /ha. Based on dbh data from 300 control and 305 fertilized Douglas-fir trees. BAI = Basal Area Increment.

	CONTROL	FERTILIZED	% Difference
1979	24.28	24.42	0.6
1980	27.00	27.30	1.1
1981	29.88	30.64	2.5
average BAI (m^2 ha^{-1} yr^{-1})	2.79	3.11	5.8

Table 5. Component biomass estimates (kg/ha) in the experimental plots. (Based on data from 300 control and 305 fertilized Douglas-fir trees). All estimates are based on the regressions developed in this study. (Stemwood (BST), Stembark (BBK), Live branch (BLB), Total twig (BTT), Total foliage (BFT), Current twig (BCT), Current foliage (BCF), Dead branch (BDB), Total biomass (BT))

CONTROL

	BST	BBK	BLB	BTT	BFT	BCT	BCF	BDB	BT
1979	67,445	10,880	14,273	4402	11,241	640	2078	8212	116,453
1980	76,490	12,449	16,276	4976	12,842	713	2340	9194	132,228
1981	86,244	14,152	18,447	5593	14,579	792	2621	10243	149,259
average one year increment (kg ha^{-1} yr^{-1})	9,400	1,636	2,088	596	1,669	76	272	1016	16,403

FERTILIZED

	BST	BBK	BLB	BTT	BFT	BCT	BCF	BDB	BT
1979	67,625	10,901	14,304	4415	11,264	1009	2986	8243	116,752
1980	77,278	12,575	16,442	5028	12,973	1171	3479	9292	133,587
1981	88,640	14,566	18,976	5746	15,002	1366	4072	10508	153,437
average one year increment (kg ha^{-1} yr^{-1})	10,507	1,833	2,337	665	1,869	179	543	1133	18,343

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Table 6. Component biomass estimates (kg/ha) in the experimental plots. (Based on data from 300 control and 305 fertilized Douglas-fir trees). All estimates are based on the regressions reported in Gholz et. al. 1979. (Stemwood (BST), Stembark (BBK), Live branch (BLB), Total foliage (BFT), Current foliage (BCF), Dead branch (BDB), Total biomass (BT))

CONTROL

	BST	BBK	BLB	BFT	BCF	BDB	BT
1979	85,393	14,710	11,536	7,491	1130	4371	123,501
1980	98,053	16,740	12,921	8,194	1259	4794	140,701
1981	111,841	18,935	14,400	8,931	1395	5238	159,344
average one year increment (kg ha^{-1} yr^{-1})	13,225	2,113	1,432	720	133	434	17,922

FERTILIZED

	BST	BBK	BLB	BFT	BCF	BDB	BT
1979	85,525	14,745	11,580	7,537	1135	4396	123,784
1980	99,040	16,911	13,058	8,286	1272	4847	142,143
1981	115,178	19,471	14,772	9,132	1430	5358	163,912
average one year increment (kg ha^{-1} yr^{-1})	14,867	2,363	1,596	798	148	481	20,064

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Table 7. Comparison of the total 1979 biomass estimates (kg/ha) on the experimental plots. (Study equations are based on the regressions developed in this study. Published equations are based on the regressions reported in Gholz et. al. 1979.)

	CONTROL	FERTILIZED	% Difference
Study equations	116,453	116,752	0.26
Published equations	123,501	123,784	0.23

Table 8. Comparison of the total 1981 biomass estimates (kg/ha) on the experimental plots. (Study equations are based on the regressions developed in this study. Published equations are based on the regressions reported in Gholz et. al. 1979.)

	CONTROL	FERTILIZED	% Difference
Study equations	149,259	153,437	2.80
Published equations	159,344	163,912	2.86

Table 9. Comparison of the average one year (post-fertilization) biomass increment (kg/ha^{-1} yr^{-1}) on the experimental plots. (Study equations are based on the regressions developed in this study. Published equations are based on the regressions reported in Gholz et. al. 1979.)

	CONTROL	FERTILIZED	% Difference
Study equations	16,403	18,343	11.8
Published equations	17,922	20,064	12.0

allometric equations (Tables 7 and 8).

During the two year period 1979-1981 the site specific live crown biomass estimate was 26.4% of the total biomass (Table 10). The live crown biomass estimate based on the published equations was only 12.0% of total biomass. Relationships developed in this study always allocate a greater % of total biomass to the live crown. (Table 11).

Distribution of Crown Biomass

The biomass of each third of the crown of each study tree was subdivided into its component parts - old twigs, old foliage, current twigs, current foliage, live branches and dead branches. A nested analysis of variance using natural log transformed data showed no significant differences ($p > .05$) between the fertilized and control components of biomass (Keppel 1973). However, examination of the mean biomass values (Table 12) showed that fertilized trees had less live branch biomass and more current twig and current foliage biomass than control trees. Moreover, the increase in current twig and current foliage biomass occured primarily in the middle of the crown. Total foliage and twig biomass did not increase with fertilization because the increase in current twig and current foliage occured in conjunction with a decrease in old twig and old foliage biomass.

Table 10. Percent distribution of the two year (post-fertilization) biomass increment. (Study equations are based on the regressions developed in this study. Published equations are based on the regressions reported in Gholz et. al. 1979.)

	Study Eq.	Published Eq.
Stemwood	57.3	73.9
Stembark	10.0	11.8
Live branch and twigs	16.4	8.0
Total foliage	10.2	4.0
Dead branch	6.2	2.4
New foliage (control)	1.7	0.7
New foliage (fertilized)	3.0	---

Table 11. Percent distribution of total 1981 biomass. (Study equations are based on the regressions developed in this study. Published equations are based on the regressions reported in Gholz et. al. 1979.)

	Study Eq.	Published Eq.
Stemwood	57.8	70.2
Stembark	9.5	11.9
Live branch and twigs	16.1	9.0
Total foliage	9.8	5.6
Dead branch	6.9	3.3
New foliage (control)	1.8	0.9
New foliage (fertilized)	2.7	---

Table 12. Mean biomass values (kg) for live crown components of 13 fertilized and 13 control Douglas-fir trees in Western Washington.

			CONTROL	FERTILIZED
Foliage				
	old	top	0.577	0.764
	old	mid	7.029	5.923
	old	bot	4.702	5.653
	current	top	0.930	1.057
	current	mid	1.613	2.280
	current	bot	0.269	0.447
Twigs				
	old	top	0.361	0.488
	old	mid	2.504	2.469
	old	bot	1.757	2.093
	current	top	0.424	0.464
	current	mid	0.375	0.752
	current	bot	0.053	0.087
Branches				
		top	1.400	1.534
		mid	9.807	6.948
		bot	9.921	9.577

Data in Table 13 shows the relative proportions of current and old foliage biomass in fertilized and and control trees. As in Table 12, fertilized trees showed an increased percentage of current foliage to total foliage; primarily in the middle of the crown. While the percentage of old foliage to total foliage in fertilized trees increased slightly in the top and bottom of the crown and decreased in the mid crown.

The data for current and old twigs follows the same patterns as the foliage data (Table 14).

Needle Weight

No significant differences in needle weight between fertilized and control trees were measured at either the top, middle or bottom of the crown. However, mean weight of needles from fertilized trees was always greater than the mean weight of needles from control trees (Table 15). In both fertilized and control trees, mean needle weight of old foliage was always significantly greater ($p < .05$) than mean weight of new foliage. In general, top foliage weight was always significantly greater than middle foliage and middle foliage weight was significantly greater than bottom foliage (Table 16).

Table 13. The percentage distribution of current and old foliage biomass in 13 fertilized and 13 control Douglas-fir trees in Western Washington. (current foliage top (CFT), current foliage mid (CFM), current foliage bot (CFB), old foliage top (OFT), old foliage mid (OFM), old foliage bot (OFB), total current foliage (TCF), total old foliage (TOF), total foliage (TOTF)).

	Control	Fert.		Control	Fert.
FOLIAGE					
CFT/TCF	37.57	35.03	OFT/TOF	5.33	7.10
CFM/TCF	52.81	53.06	OFM/TOF	54.66	49.54
CFB/TCF	9.01	11.01	OFB/TOF	37.40	40.45
CFT/TOTF	7.07	8.09	OFT/TOTF	4.27	5.34
CFM/TOTF	9.91	12.89	OFM/TOTF	44.56	37.83
CFB/TOTF	1.81	2.58	OFB/TOTF	30.26	30.96
TCF/TOTF	18.90	23.75	TOF/TOTF	81.11	76.25

Table 14. The percentage distribution of current and old twig biomass in 13 fertilized and 13 control Douglas-fir trees in Western Washington. (current twig top (CFT), current twig mid (CFM), current twig bot (CFB), old twig top (OFT), old twig mid (OFM), old twig bot (OFB), total current twig (TCF), total old twig (TOF), total twig (TOTF)).

	Control	Fert.		Control	Fert.
TWIGS					
CTT/TCTB	53.20	47.67	OTT/TOTB	8.18	10.86
CTM/TCTB	40.37	45.28	OTM/TOTB	51.69	47.99
CTB/TCTB	5.94	6.52	OTB/TOTB	37.19	38.16
CTT/TOTF	8.34	9.18	OTT/TOTF	6.86	8.62
CTM/TOTF	6.08	9.50	OTM/TOTF	43.89	38.44
CTB/TOTF	0.91	1.26	OTB/TOTF	31.40	30.55
TCT/TOTF	15.39	20.03	TOT/TOTF	84.61	79.97

Table 15. Needle weights for fertilized and control trees. (grams per 100 needles)

		Top Third		Middle third		Bottom third		All
		new	old	new	old	new	old	foliage
Control trees n=6	$\bar{x}$	0.509	0.655	0.351	0.461	0.288	0.414	0.446
	s.e.$\bar{x}$	0.055	0.069	0.040	0.060	0.034	0.027	0.046
Fertilized trees n=6	$\bar{x}$	0.571	0.680	0.452	0.553	0.292	0.438	0.498
	s.e.$\bar{x}$	0.053	0.077	0.046	0.053	0.032	0.031	0.043

Table 16. Results of t-tests comparing needle weights (grams/50 needles) of six fertilized and six control trees. (> means that there was a significant difference p < .05.)

WEIGHT OF ALL FOLIAGE	control	- old > new
	fertilized	- old > new
WEIGHT OF NEW FOLIAGE	control	- top > middle > bottom
	fertilized	- top > middle > bottom
WEIGHT OF OLD FOLIAGE	control	- top > middle = bottom
	fertilized	- top > middle > bottom

DISCUSSION

Composite regression equations published by Gholz et. al. (1979) were derived from pooled data, covering a wide range of diameter classes, tree ages, and site classes on silviculturally undisturbed sites (Table 17). This type of pooled data generally produces regressions with lower slopes than those developed on single-stand data sets (Grier and Milne 1981). Therefore, it is not surprising that higher slopes were obtained using regressions developed during this study than when composite regressions were used (Table 17). Low stemwood and generally elevated foliage regression slopes suggest that the 1969 thinning caused an increase in the crown to stem biomass ratio.

Graphs of the major dry components of biomass against dbh showed no significant difference between fertilized and control trees (Figures 4 to 11). Even though significant differences could not be detected, there are apparent trends that should be examined in future research. For instance, the major components of biomass, stemwood and live branches, and total foliage showed that total biomass in the largest fertilized trees was greater than in the same diameter control trees. The reverse situation was true for smaller diameter trees. This implies that, in the stand, accelerated biomass accumulation on larger fertilized trees

Table 17. Regressions of Douglas-fir component dry weight on stem diameter (from Gholz et. al. 1979).

	a	b	N	r^2	$s^2_{y \cdot x}$
Stemwood	-3.0396	2.595	99	.99	.096
Stembark	-4.3103	2.430	99	.99	.104
Live Branch	-3.6941	2.138	123	.92	.399
Dead Branch	-3.5290	1.750	85	.84	.530
Total Foliage	-2.8460	1.701	123	.86	.483

occured in conjunction with decreased accumulation on, and accelerated mortality in smaller trees. This effect was most noticeable in the regressions of total current foliage and total current twigs against dbh (Figures 1 and 2). Both these components showed significant differences between control and fertilized trees and both showed increased biomass production in all but the smallest fertilized trees.

This effect is also important because it implies first, that leaf area on the fertilized plot is not significantly greater than in the control plot and second, that increased aboveground biomass production on fertilized plots may be, in part, caused by increased photosynthetic efficiency.

When tree component biomass was regressed against sapwood basal area rather than dbh (Figures 12 and 13), the error mean square of all components was reduced. However, the fit of the equation (r^2) improved only for the living crown components. This supports findings of Grier and Waring (1974); Waring et. al. (1978); Rogers and Hinckely (1979); Kaufmann and Troendle (1981) and many others that living crown biomass is more directly related to sapwood basal area than to dbh.

The slopes of regressions of total foliage (Figure 5) and total twig biomass (Figure 7) against dbh showed no significant difference between fertilized and control trees. However the slope of the regression of combined total current twig and total current foliage biomass of fertilized trees against dbh is significantly greater ($p < .01$) than the slope for control trees. In other words, in fertilized trees the increase in total current twig and total current foliage biomass must be counteracted by a decrease in total old foliage and old twig biomass. Examination of the crown component data shows that this redistribution is occuring predominantly in the middle of the live crown. This supports the work done by Brix (1981) showing that retention of older foliage is decreased by fertilization.

According to the regression analysis, fertilized and control trees of the same diameter have approximately the same total biomass. This does not mean that fertilization had no effect on the biomass of fertilized trees. Following fertilization, the two year basal area increment on the fertilized tree plots was 11.5% greater than on the control trees plots (Table 4). Since our biomass estimates are based on dbh, this suggested that biomass on the fertilized plots had to be greater than biomass on the control plots. The actual biomass estimates, made from the site specific regressions showed that the two year biomass increment in the fertilized plots was 11.8% larger than that on the control plots (Table 8).

Percentages of current foliage to total foliage biomass in control and fertilized trees were 18.90% and 23.75% respectively. These values were considerably lower than the 28% estimate obtained by Silver (1962). But it is difficult to compare these figures since Silver based his estimates on 80-year old trees and no soil fertility or climatic data were included in his study.

Comparison of fertilized and control tree needle weights showed the same trends as noted by Mitchell (1974). First, needles on fertilized trees were always heavier than the comparable needles on control trees. Second, old needles were heavier than comparable new needles. Third, needle weights decreased from top to bottom of the crown. Since needles on fertilized trees were always heavier than those on control trees and since regression analysis showed no significant difference between total foliage biomass of fertilized and control trees, this implies that fertilized trees actually have fewer but larger and heavier needles than control trees. Needle area was not measured in this study but observations made during weighing suggest that needles on fertilized trees are indeed slightly heavier than needles on control trees.

CONCLUSIONS

1. Fertilized trees had significantly greater current foliage and current twig biomass than control trees. Regressions of all other components of dry weight against dbh showed no significant differences between fertilized and control trees.

2. Regression of each live crown component against sapwood basal area showed improved fit (higher r^2) and lower mean square error ($s^2_{y \cdot x}$) than when regressed against diameter.

3. Total plot biomass estimates made with the equations from this study were slightly lower than the estimates made using previously published equations (Gholz et. al. 1979). Also the equations from this study allocate a greater percentage of biomass to the living crown.

4. Over a two year period, fertilized trees put on 11.5% more basal area and 11.8% more total biomass than the control trees.

5. Increase in current twig and current foliage biomass in fertilized trees occured in conjunction with increased loss of old foliage and old twig biomass.

6. Foliage on fertilized trees was heavier than foliage on control trees. Old foliage was heavier than new foliage. Foliage located on the top oof the tree was heavier than middle foliage which was heavier than bottom foliage.

7. Fertilization lead to accelerated biomass production in the larger trees and decreased biomass production and accelerated mortality in smaller trees.

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APPENDIX A

RAW DATA

Key to Abbreviations

(unless specified all values are measured in kg)

TR - tree number
DIA4 - diameter at breast height (dbh) (cm)
IBR1 - inside bark radius at dbh (mm)
BRK1 - average bark thickness at dbh (mm)
SPWD1 - average sapwood thickness at dbh (mm)
RNGT1 - aver. 7-year ring growth (1975-1981) (mm)
LDLEN - total tree height (m)
LDR - leader length (m)
LDR + LCRN - length of live crown (m)
BST - total stem wood
BBK - total stem bark
TLB - total live branches
LBWNT - live branches top of crown
LBWNM - live branches middle of crown
LBWNB - live branches bottom of crown
DBBW - dead branches below live crown
DBLM - dead branches within live crown
TOTB - total old twigs
OTT - old twig top
OTM - old twig middle
OTB - old twig bottom
TCTB - total current twigs
CTT - current twigs top
CTM - current twigs middle
CTB - current twigs bottom
TOF - total old foliage
OFT - old foliage top
OFM - old foliage middle
OFB - old foliage bottom
TCF - total current foliage
CFT - current foliage top
CFM - current foliage middle
CFB - current foliage bottom
----- - missing value

Table A.1 Stem and biomass data for 23-year old, untreated Douglas-fir trees in Western Washington. (Stem measurements taken 1.3m above the ground.)

TR	DIA4	IBR1	BRK1	SPWD1	RNGT1	LDLEN	LDR	LDR+ LCRN
2	23.034	103.460	11.710	45.760	39.280	18.130	.930	11.730
5	27.772	128.980	9.880	51.580	43.050	20.380	1.080	14.880
6	32.836	152.580	11.600	49.540	44.180	20.490	.990	12.990
7	18.980	85.160	9.740	50.320	33.340	14.750	.850	10.250
8	21.280	99.920	6.480	49.040	42.040	17.040	.840	12.340
15	21.382	97.360	9.550	51.490	42.250	17.400	1.100	12.100
16	18.250	84.350	6.900	42.900	38.720	15.700	1.000	10.500
17	15.042	70.040	5.170	38.690	28.280	15.700	1.000	10.200
18	9.312	43.410	3.150	18.440	14.230	12.260	.860	7.160
19	14.014	63.790	6.280	34.820	24.130	14.100	.900	7.900
20	12.588	57.740	5.200	26.260	25.290	14.020	1.020	10.120
23	19.624	91.500	6.620	34.720	31.090	17.600	1.000	9.200
26	23.706	110.010	8.530	43.680	41.500	16.930	.930	12.530

Table A.1 (continued)

TR	BST	BBK	TLB	LBWNT	LBWNM	LBWNB	DBBW	DBLM
2	111.756	17.213	21.322	1.167	8.586	11.569	10.760	2.110
5	198.466	23.378	30.758	1.975	16.100	12.683	10.980	1.360
6	239.514	30.863	44.974	3.334	23.711	17.929	24.740	3.270
7	70.388	13.413	30.479	2.098	12.518	15.863	7.110	1.930
8	100.020	13.133	25.810	1.585	11.906	12.319	9.980	2.740
15	109.334	17.531	25.183	1.370	8.391	15.422	9.440	.920
16	78.301	11.740	23.042	.697	8.250	14.085	4.340	1.140
17	49.362	6.561	2.557	.265	2.639	3.753	3.900	2.520
18	13.844	1.969	1.994	.272	.593	1.129	2.120	.160
19	37.930	5.352	------	2.219	------	3.301	5.630	.350
20	30.204	4.174	8.147	.454	3.293	4.400	1.830	.510
25	103.076	15.730	10.534	1.255	4.837	4.442	13.720	.930
26	135.200	24.540	29.890	1.512	16.855	11.523	16.190	1.300

Table A.1 (continued)

TR	TOTB	OTT	OTM	OTB	TCTB	CTT	CTM	CTB
2	5.648	.249	3.216	2.183	.873	.404	.377	.092
5	7.283	.700	4.638	1.945	.646	.237	.393	.016
6	9.797	.823	5.944	3.030	2.374	1.463	.794	.117
7	4.221	.660	1.249	2.312	.616	.359	.177	.080
8	7.178	.450	3.977	2.751	1.350	.633	.700	.017
15	5.102	.218	2.073	2.811	1.401	.552	.718	.131
16	------	-----	1.854	1.678	------	-----	.702	.079
17	1.692	.050	.908	.734	.193	.136	.057	0.000
18	.671	.071	.304	.296	.141	.094	.044	.003
19	1.290	.202	.502	.586	.387	.192	.169	.026
20	2.213	.105	1.145	.963	.298	.187	.061	.050
25	2.797	.241	1.730	.826	.787	.550	.211	.026
26	8.091	.562	5.008	2.521	.807	.295	.458	.054

Table A.1 (continued)

TR	TOF	OFT	OFM	OFB	TCF	CFT	CFM	CFB
2	13.015	.479	7.556	4.980	3.233	.963	1.932	.338
5	22.958	1.607	15.125	6.226	3.665	1.089	2.482	.094
6	23.899	.113	15.978	7.808	5.963	2.552	2.813	.598
7	10.830	1.003	4.092	5.735	2.327	1.185	.725	.417
8	16.730	.566	6.838	7.326	4.549	1.135	3.322	.092
15	12.560	.602	5.314	6.644	3.861	.786	2.398	.675
16	-------	-----	4.686	6.128	------	------	2.051	.448
17	5.322	.128	3.128	2.066	.758	.345	.413	.010
18	1.467	.086	.815	.566	.422	.215	.189	.018
19	3.272	.462	1.274	1.536	1.131	.499	.486	.146
20	4.265	.132	2.104	2.029	.948	.346	.373	.229
25	7.570	.348	4.818	2.404	1.535	.728	.705	.102
26	26.737	1.404	17.649	7.684	4.714	1.310	3.076	.328

Table A.2 Stem and biomass data for 23-year old, fertilized Douglas-fir trees in Western Washington. (Stem measurements taken 1.3m above the ground.)

TR	DIA4	IBR1	BRK1	SPWD1	RNGT1	LDLEN	LDR	LDR+ LCRN
1	16.624	76.180	6.940	38.250	28.630	15.550	.650	10.150
3	18.042	83.150	7.060	43.170	33.390	15.580	1.080	12.880
4	23.252	105.180	11.080	49.120	29.170	17.850	.950	11.950
9	20.796	96.380	7.600	37.970	44.170	17.500	.900	11.700
10	9.258	42.150	4.140	24.750	14.990	12.000	.700	7.400
11	13.784	63.850	5.070	29.550	16.200	14.250	.650	7.050
12	22.426	103.060	9.070	51.930	43.890	18.850	1.250	10.850
13	21.978	99.540	10.350	42.740	29.850	16.650	.750	8.750
14	19.520	91.290	6.310	37.090	37.090	15.900	.800	8.900
21	23.906	108.400	11.130	48.510	47.850	15.400	.900	11.900
22	20.202	92.050	8.960	40.770	29.900	17.260	.560	9.760
23	16.554	75.260	7.510	33.710	32.860	16.400	1.000	9.800
24	29.076	132.410	12.970	51.470	46.330	20.500	1.000	15.100

Table A.2 (continued)

TR.	BST	BBK	TLB	LBWNT	LBWNM	LBWNB	DBBW	DBLM
1	54.462	9.252	9.122	1.199	4.060	3.863	4.930	.510
3	67.846	10.455	15.379	1.509	6.820	7.050	6.600	3.770
4	127.336	23.223	32.520	3.630	9.790	19.100	15.430	3.330
9	89.000	15.478	21.864	2.148	7.448	12.268	6.770	2.000
10	13.311	1.868	2.882	.522	.799	1.561	1.130	.090
11	23.639	3.015	4.740	.430	1.100	3.210	7.280	.640
12	125.279	23.086	20.132	1.211	7.182	11.739	11.670	2.440
13	112.399	18.629	18.735	1.713	7.062	9.960	18.440	1.160
14	77.669	11.497	13.473	1.380	4.335	7.756	8.120	.420
21	109.494	22.519	34.838	2.202	12.833	19.803	4.460	1.890
22	88.298	17.642	12.076	1.265	4.132	6.679	7.340	.680
23	60.997	8.330	8.142	.760	2.238	5.144	6.250	.530
24	191.519	40.079	40.863	1.976	22.527	16.360	14.470	7.060

Table A.2 (continued)

TR	TOTB	QTT	QTM	QTB	TCTB	CTT	CTM	CTB
1	3.318	.396	1.645	1.277	.971	.523	.364	.084
3	6.296	.921	3.707	1.668	1.498	.639	.758	.101
4	4.876	.752	2.171	1.955	1.242	.760	.413	.049
9	5.484	.576	2.750	2.158	1.497	.573	.837	.087
10	.727	.114	.331	.262	.139	.107	.026	.006
11	1.391	.124	.545	.722	.445	.301	.109	.035
12	7.496	.227	3.399	3.870	1.383	.465	.836	.082
13	5.135	.653	2.484	1.998	1.348	.458	.846	.044
14	------	.371	-----	2.199	------	.359	-----	.038
21	8.926	.746	4.071	4.109	1.190	.411	.516	.263
22	3.185	.529	1.325	1.331	1.121	.479	.538	.104
23	3.524	.181	1.983	1.360	.476	.341	.128	.007
24	10.246	.752	5.215	4.281	4.489	.596	3.056	.237

Table A.2 (continued)

TR	TOF	OFT	OFM	OFB	TCF	CFT	CFM	CFB
1	7.533	.761	3.678	3.094	3.067	1.276	1.411	.380
3	9.278	.764	6.108	2.406	3.477	1.008	2.106	.363
4	14.516	.739	7.235	6.542	3.530	1.540	1.697	.293
9	13.109	1.053	6.241	5.815	6.033	1.722	3.748	.563
10	1.471	.188	.773	.510	.401	.251	.124	.026
11	3.073	.176	1.353	1.544	1.088	.501	.429	.158
12	20.656	.385	7.456	12.815	6.314	1.120	4.564	.630
13	11.527	1.035	5.604	4.888	4.647	1.262	3.145	.240
14	------	.701	------	5.521	------	.947	------	.191
21	23.291	1.322	10.425	11.544	4.140	1.079	1.887	1.174
22	8.682	.736	4.067	3.879	2.779	.811	1.353	.615
23	9.021	.312	5.516	3.193	1.375	.714	.619	.042
24	26.123	1.757	12.623	11.743	8.915	1.504	6.272	1.139