THE RESPONSE OF INDIVIDUAL DOUGLAS-FIR TREES TO APPLICATIONS OF INORGANIC FERTILIZERS

by

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Introduction

The heavy removal of timber from European forests during and following World War II greatly reduced the growing stock available for future forest production. Faced with the economic consequences of total dependence upon the world markets, most of the countries of Europe embarked upon some form of forest fertilization work to increase wood production.

This work in forest fertilization met with moderate success in most of Europe. In Germany there have been some very striking results obtained by using nitrogen fertilizers (50) on young stands.

The successes observed in Germany and other parts of Europe encouraged foresters in this country to investigate the effects of fertilizers upon conifers native to the United States. Today there are numerous experiments in forest fertilization which are yielding valuable information about the responses that can be expected from fertilizer applications. Although many of these experiments are yielding valuable information equally as many are providing poor results because the experiment was set up without adequately determining what nutrients were needed and what consequences could result from improper fertilization.

Wilde (49 p. 346-348), in an article discussing this problem, points out that often "failures" are quite important in increasing our knowledge of the nutrient relations of forest trees but that they are beginning to have an adverse effect upon the acceptance of fertilization as a tool for increasing timber production. He states "the first reason, therefore, why the application of fertilizers in many previous trials has failed to increase the growth of trees rests in the fact that the treated soil had an entirely sufficient content of nutrients." He goes on to say that other causes of these "failures" have resulted from improper diagnostic techniques and also improper evaluation of the most critical limiting factors.

Another problem with forest fertilization research has been in attempting to extrapolate data from one year to apply to a complete rotation. Boards of directors of timber companies want to know what financial gains applications of fertilizers will return forty, fifty or one hundred years from now.

The agricultural worker can, through a few relatively simple soil examinations and laboratory analysis, determine what nutrients are needed to provide a desired yield. Observing this simple procedure, uninformed persons are prone to expect the researcher in forest nutrition to make similar rapid appraisals and fertility adjustments and be able to predict what the outcome will be. With a forty to one hundred year rotation this cannot be done. It will require several rotations before we know enough about the nutrition of forest trees to be able to predict the effects of fertilization upon the productive capacity of a stand. The seeming simplicity with which answers are obtained for field crops arises from the fact that many years ago workers in agriculture went through the same trial and error proceedures that foresters are going through today.

Fertilization of forest trees has been used in four general areas: nurseries, plantations, forest stands, and in seed production areas. For a number of years there has been considerable information published about the use of soil amendments in nurseries throughout the country. This was brought about by the demand for seedlings with higher vigor and more rapid growth rate.

At the same time workers were attempting to develope a better seedling, the British foresters (Leyton, 27) found that fertilization was quite effective in increasing growth and survival of seedlings in certain problem areas if the fertilizer was applied at the time of planting. Numerous experiments and field trials were established in an effort to determine the levels of nutrients needed to give the greatest return to the land owner.

As the results of the British plantation experiments became known, attempts were made to utilize fertilization on all forest stands no matter what the soil conditions. These attempts to fertilize older established stands have yielded both favorable and unfavorable results. Due to the disagreement arising from this conflicting evidence fertilization has found much disfavor. In many areas where it was used it proved to be only a waste of money because the soils were adequately supplied with nutrients. Furthermore the lack of moisture often prevented the tree from utilizing the added nutrients (Wilde, 49).

As the need for cheap sources of top quality seed became pressing, work was begun on developing seed production areas in young stands in the Pacific Northwest. It was found that fertilization of these trees with nitrogen and phosphorus would stimulate production of cones at an early age (Duffield _et al_. 4).

Literature Review

Forest trees like any plant have specific requirements for nutrients in order to develope enzyme systems, food supplies, tissues and photosynthetic pigments. Rennie (38 p. 64) makes comparisons between forest trees and agricultural crops. He concludes that the requirements of forest trees differ from farm crops only in the quantity of the element needed to supply the life processes.

Gessel (12 p. 365) working with phosphorus deficient soils from the lower Cascade Mountains in Washington found that Romaine lettuce (_Lactuca sativa_ L. var. _longifolia_ Lam.) grew poorly on these soils without additions of phosphate fertilizers but that Douglas-fir (_Pseudotsuga menziessi_ (Mirb) Franco), Western red cedar (_Thuja plicata_ Donn.), and Western hemlock (_Tsuga heterophyla_ Sarg.) grew satisfactorily without additions of this element. Laurie (23 p. 5-6) points out that "compared with agricultural crops, where in little over a century the ever increasing use of fertilizers has resulted in _enormously_ increased yields from the soil, forestry is, relatively speaking, about at the beginning." He quotes Sir John Maxwell as saying the following.

> "Most foresters are, or were, brought up to distrust the use of manures in the forest. They do not disdain their help --indirectly at least-- in the nursery where seedlings are made to grow at least three times as fast as those under natural conditions. But they feel, not without reason, that it is futile to offer a tablespoonful of manure to a plant which is intended to live 150 years, grow 100 feet high and weigh more than a ton."

Wood and Holmes (51 p. 40) also point out that many foresters in Europe still feel that the use of fertilizers in older stands will not be economical. The authors state, however, "it seems possible that increased volume increment can more than offset material and application costs under some conditions."

Gessel (9, 10, 11, 12), Heiberg (15, 16), Wittich (50) and Wilde (49) all suggest that fertilizers may not become a widespread silvicultural tool. However, on areas where definite deficiencies exist, soil amendments may be used to improve the site quality and thus obtain an economical increase in the volume.

Gessel and Shareef (9 p. 238) and Shareef (39) have proposed the use of fertilizers in stagnant stands, where the trees are too small to be commercially thinned, as a means of releasing trees that are beginning to express dominance. Their research has shown that the larger trees take up more of the applied nutrients. They feel that this is probably due to better developed root systems and more efficient photosynthetic systems in the larger trees. Thompson

(46 p. 19) found this same effect in loblolly pine (*Pinus taeda* L.) in the North Carolina Piedmont.

"What kind and how much fertilizer should be applied to increase the yields of forest stands?" In order to answer this question the research forester has been confronted with two main groups of problems. First, what method will adequately reveal the elements that are deficient and secondly what combination of fertilizers will correct this deficiency?

Lundegardh in Sweden has probably advanced the diagnostic phase of plant nutrition more than any one person. His work has led to the development of techniques of foliar analysis which have enabled forest scientists to make predictions about the nutrient status of forest soils.

In 1951 Mitchell (29) translated Lundegardh's book "LEAF ANALYSIS" into English. This translation has become a standard reference book for most workers in the area of plant nutrition. Chapman (2 p. 12), in California has developed a system similar to Lundegardh's which is used to keep an accurate record of the nutrient status of orange orchards. By combining soil and foliar analysis with knowledge of nutrient patterns in the orange tree, Chapman predicts the amounts of nutrients needed from fertilizers to maintain optimum growth in the orchard.

Gessel (12 p. 365) used this technique in Douglas-fir forests; White (47 p. 49), Wilde (49), and Heiberg (15, 16) used it in white pine and spruce forests; Tamm (44, 45) used it in birch and spruce forests; Leyton (24, 25, 26) used it in Japanese larch and Scots pine forests; and Wittich (50 p. 1-40) used it in Japanese larch and red oak forests.

Although the use of foliar analysis has worked effectively in many areas it has led to some false conclusions. As Leyton (24 p. 400) points out, there are many factors other than the nutrient status in the foliage of a forest tree which influences the level of an element in the foliage.

The position on the tree, the season, time of day, age of foliage and age of tree, the status of the nutrients in the soil and the climatic conditions during the growing season are the more common factors that have been found to influence the level of nutrient in the foliage. Lundegardh (29 p. 53) has found in work in Sweden that when one element is deficient or low, an increase in that element will increase the volume of the foliage to the extent that other elements will appear to be deficient when determined as a percentage of oven dry weight. Lundegardh cites the results of one experiment where he found that the phosphorus index of the foliage was depressed to a deficient level by ammonium nitrate. Lundegardh found, however, that this depression often lasted only for a short time.

Burr (1 p. 336), working with sugar cane, states that the level of one element in sugar cane tissue is often "strongly affected by the amounts of other elements present." He found that this depression was not uniform so no correction factor could be applied. Emmert (6 p. 234) found the same effect encountered by Burr (1) but found that in experiments conducted under his supervision, phosphorus depressed the nitrogen content of the foliage.

Prevot (37 p. 257-258) presents data which contradicts this trend. He found that the percentage of phosphorus in the foliage increased with increasing nitrogen. However, he does not clarify the conditions under which the data were derived since his conclusions were based primarily upon the results of a compilation of literature. Tamm (44 p. 29) found the same correlation between nitrogen and phosphorus in forest trees as was observed by Prevot (37) in farm crops.

Lundegardh (29 p. 40) suggests that foliar analysis is the best indicator of productivity and has ceased using soils analysis because of costs involved. However, Wilde (48 p. 138-140) in forest work and Chapman (2 p. 8) in orange work believe that soils analysis must be correlated with foliar analysis to get a true picture of the nutrient status of the area under observation.

Thompson (46 p. 37) concluded that although a correlation should exist between the soil test values and foliar test values, this correlation either does not exist or else cannot be determined due to the lack of a suitable technique which researchers can use to determine the levels of nutrients in the soil which are available for plant growth.

Kenworthy (21 p. 37) suggests using a nutrient balance index to determine the nutrient status of a plant or crop. This index is based upon a standard optimum level of the nutrient in the foliage. By comparing the results of foliar analysis with the standard

Kenworthy developed the index value. Using this value he made recommendations for fertilizer applications needed to bring a particular site into its highest production. Once the area is producing its maximum this index can be used to keep a continuous check upon the level of nutrients available for optimum growth. (See Appendix 5 for computation procedure.)

Leyton (26 p. 167-177) proposes the use of regression techniques to determine the need for fertilization. He states that when the yield is plotted against the nutrient concentration in the foliage, a steeply ascending curve indicates that fertilization will give a response. However, when the curve is flat or descending, fertilization with the element in question will not increase the yield enough to be economical. In fact, with the decreasing curve, leaching or the addition of other nutrients may be needed to lessen the apparent toxic effect.

Once the deficiency is determined what of the second question? "What combination of fertilizers will correct this deficiency?"

There have been numerous studies conducted throughout the United States and Canada in an effort to determine the levels of elements to apply and methods of application which will produce a particular desired effect. In the Northwest, Gessel (9, 10, 11), Duffield et al. (4 p. 105-110) and Erickson (7) have worked on solving this problem in the Douglas-fir type. The work reported so far has shown an increase in the volume of wood produced and the number of cones produced. Even though researchers have worked out levels of nutrients to apply on particular areas of Douglas-fir, only

Gessel (10 p. 18 and 22) suggests any basis for determining the amounts of fertilizers to apply over a wide range of sites.

There are problems with fertilization which may not be corrected by "guess work" research. Lundegardh (29 p. 75-76) found that excesses of phosphorus on nitrogen deficient soils gave a "poisoning of the plant" by actually increasing the severity of the nitrogen deficiency. This same tendency was also reported by Kramer (22 p. 232) and Harada (14 p. 81).

This "poisoning of the plant" caused by phosphorus may be due to an increase in the osmotic pressure of the soil solution, ion antagonism, or it may be a secondary effect of change in the level of available phosphorus in the soil. Coleman (3 p. 1-7), Hemwall (17 p. 107-108), and Hou (18 p. 16-24) discuss at length the effect of phosphorus fertilization upon the nutrient cycle of a plant and also the mechanism whereby this added phosphorus can become fixed within the soil and thus not be readily available to the plant. Hemwall (17 p. 101-108) concluded that fixation is the breaking down of kaolinite and the formation of variscite, an insoluble phosphorus complex. This is brought about by an excess of phosphorus in the soil.

Description of Study Area

The Douglas-fir stand used for this study was located in the oldest high elevation cut-over area on Crown Zellerbach's Clackamas Tree Farm. The area is commonly referred to as HESPA, the abbreviation for "High Elevation Seed Production Area." The original stand of Douglas-fir, noble fir and hemlock was logged in 1936. At present there is a good stand of 25-year old second-growth Douglas-fir established on the area.

The tract is located southeast of Molalla, Oregon in the Cascade Mountains at an elevation of 2900 to 3000 feet. The soils were classified by Dr. Chester T. Youngberg of Oregon State University (53) as uncorrelated brown latosol developed on andesite residuum (see Appendix 2A and 2B). The stand is situated on a bench of southerly exposure with slopes from 15 to 20 percent. The Douglas-fir site class has been determined by Crown Zellerbach foresters as Site Class III although the present stand may be less than this due to the low nitrogen content in the soils (see Appendix 2B).

Strand (43) states that "the trees fertilized for seed production were selected because of their size, crown development, and growth rate as well as the absence of any frost damage, heavy limbs, forked stem, crooked limbs or boles and large number of limbs per whorl." After selection of the study trees, competing trees were cut in order to eliminate competition as a factor in the study.

Purpose of the Study

There has been considerable information published about the response of Douglas-fir applications of inorganic fertilizers. This information was primarily derived for areas in Washington by Gessel (9, 10, 11, 12). The primary purpose of this study was to evaluate the growth response of individual Douglas-fir trees to applications of nitrogen and phosphorus in hopes of determining if fertilization with these two elements would effect the growth patterns of trees growing at high elevations in the Oregon Cascades.

Although this study was confined to a limited area it is comparable to areas at similar elevations in the Central Oregon Cascades. It was assumed that this area would give an indication of responses that might be expected on areas similar to the experimental area.

Methods

Measurements:

The trees were first fertilized in 1957 with ammonium nitrate and treble super-phosphate at the rates shown in Table 1 (see also Appendix 3). At the outset and each year at the conclusion of the growing season, diameter measurements were taken with a diameter tape and records of this information were maintained.

Table 1. Fertilizer treatments applied to individual Douglas-fir trees in the study area.

Treatments applied only initially	Treatments applied annually
N0P0	N0P0
N2P2	N2P2
N2P4	N2P4
N4P2	N4P2
N4P4	N4P4
	N2P0
	N4P0
	N0P2
	N0P4

N = nitrogen, P = phosphorus, 0 = check, 2 = 200 pounds per acre of available nutrient, 4 = 400 pounds per acre of available nutrient.

The trees given a repeated application of fertilizer were treated each year prior to the beginning of the growing season.

Also each year at the time the diameter measurements were taken samples were collected from the current years foliage and from the previous years foliage. These samples were all taken from the fifth whorl from the top of the tree and from a branch on the north side of the tree. This was done in order to insure a consistent sample each year.

The diameter measurements and foliage samples were made available for this study by Crown Zellerbach Corporation.

Height measurements were made during the winter of 1961 utilizing a collapsible aluminum pole graduated in feet and tenths of feet. A record was made of the heights for the past ten years by measuring the tree to the upper edge of the whorl. It was found that a two man crew worked best on this operation. One man raised and lowered the pole and a second man aligned the tip of the pole with the whorl and recorded the height measurement read by the man operating the pole.

Combining the diameter and height measurements the cubic foot volume was computed from an alignment chart developed from Technical Bulletin 201 (30) of the U. S. Forest Service.

Foliar Analysis:

During the winter and spring of 1961 the foliage samples were analyzed for phosphorus and nitrogen.

<u>Phosphorus</u>: Phosphorus determinations were made by utilizing wet ashing procedures described by Jackson (20 p. 311) using nitric

acid as a pre-digestant and hot perchloric acid as the main oxidizing agent.

The samples obtained from the wet oxidation were then analyzed by the vanado-molybdophosphoric yellow color method for determining phosphorus as described by Jackson (20 p. 151). Even though this method is not as widely used as the molybdophosphoric blue color method it was chosen because of its simplicity. During the initial trial runs conducted on a lab sample used as a standard, this method was found to have negligible variation between duplicate samples. Since the variation was small it was decided that it was not necessary to duplicate every sample. As a check every fifth sample was duplicated. Also any sample which appeared out of line with the other replicates in the same treatment was duplicated. Estimation of parts per million of phosphorus was made with a Klett-Summerson Industrial Photoelectric Colorimeter by comparison with a standard curve. This value was entered into a conversion formula to yield percent phosphorus in the foliage. Values ranged from 0.0912 percent to 0.2413 percent with a standard deviation between replications of the same treatment of ± 0.1453.

Nitrogen: Total nitrogen was determined by standard micro-Kjeldahl techniques utilizing Jackson's book, SOIL CHEMICAL ANALYSIS, (20 p. 183) as a guide. The boric acid indicator and solution of unknown were titrated with 0.1 normal hydrochloric acid solution. Only every fifth sample was duplicated during this determination because the variation between duplicate samples was negligible. The value obtained from titration was converted to percent nitrogen on a dry weight basis. Percentages of nitrogen ranged from 1.08 percent to 2.24 percent with a standard deviation between replications of the same treatment of ± 0.2602 percent.

Statistical Analysis:

The original design of this experiment was set up to evaluate the influence of nitrogen and phosphorus fertilizers upon the production of seed by the study trees. Since the design was set up to test seed production and not growth of the trees, there were gaps in the design which created problems in interpreting the results of analysis of variance. In order to overcome these problems the author decided to use multiple regression analysis of the data. Also by using regression analysis variation due to factors other than fertilizers could be accounted for.

Normally in statistical analysis one should not wait until the data are collected before the model is set up to evaluate the experimental results. However, since the author was not involved with the establishment of the experiment, a model had to be chosen which would closely approximate the results expected in this type of study.

The second degree polynomial equation shown below was used to test the effect of fertilizers upon diameter, height, volume and percentage of nitrogen and phosphorus in the foliage.

$$y = b_o + b_1 \text{ 1958 effect} + b_2 \text{ 1959 effect} + b_3 \text{ 1960 effect} + b_4 N + b_5 N^2 + b_6 P + b_7 P^2 + b_8 \text{ Initial diameter} + b_9 \text{ Initial Height}$$

In the regression equation the year effects (i.e. 1958 effect, etc.) account for those factors (such as climatic variables and accumulative effect of the yearly applications of fertilizers) which change yearly and are not accounted for by regression equation. The factors indicated as N, N^2, P, and P^2 are to account for the total weight of nitrogen (N) and phosphorus (P) which had been applied up to the time of the observation (y value) used to solve the equation.

Preliminary analysis revealed that the interaction between nitrogen and phosphorus was not significant so this factor was left out of the model. Normally it is not advisable to ignore the interaction term no matter how small. However, in this case in order to tailor the model to the computing techniques the author decided to drop the interaction term from the model.

Development of the matrix for the multiple regression was done with a desk calculator but the inversion of the matrix and the computation of the constants for the regression equation was carried out on an IBM 1620 computer by the Statistics Department at Oregon State University.

Results and Discussion

Foliar Analysis:

Appendix 4 shows the percentage of nitrogen and phosphorus found in the foliage samples taken from the test trees. These data, though quite variable, reveal a definite increase in the percentage of nitrogen in the foliage from the plots treated with high rates of nitrogen fertilizer. There also appears to be some increase in foliar phosphorus, although the values are extremely variable. Regression analysis of the results of the chemical tests on the foliage revealed several things. First, as Appendix 6 shows, addition of the nitrogen fertilizer increased the percentage of the foliar nitrogen quite significantly (F = 36.7439) but the phosphorus fertilization decreased the percentage of nitrogen significantly (F = 46.2857).

At the end of four years the average amount of foliar nitrogen computed from the regression equation varied from 1.0331 percent for the zero level of nitrogen and the 400 pound level of phosphorus to 1.3429 percent for the zero level of phosphorus and 400 pound level of nitrogen (Table 2). By plotting the points obtained from the regression equation the response surface in Figure 1 was obtained.

Table 2. Average percentage of foliar nitrogen (by treatment) after applications of nitrogen and phosphorus fertilizers for the period 1957-1961.

	N0	N2	N4
P0	1.1099	1.2357	1.3429
P2	1.0727	1.1985	1.3057
P4	1.0331	1.1589	1.2661

The effect of fertilization upon foliar phosphorus was not found to be significant for ammonium nitrate fertilizer nor for treble superphosphate fertilizer. However, there is the possibility that vectors not accounted for in the regression equation may have produced

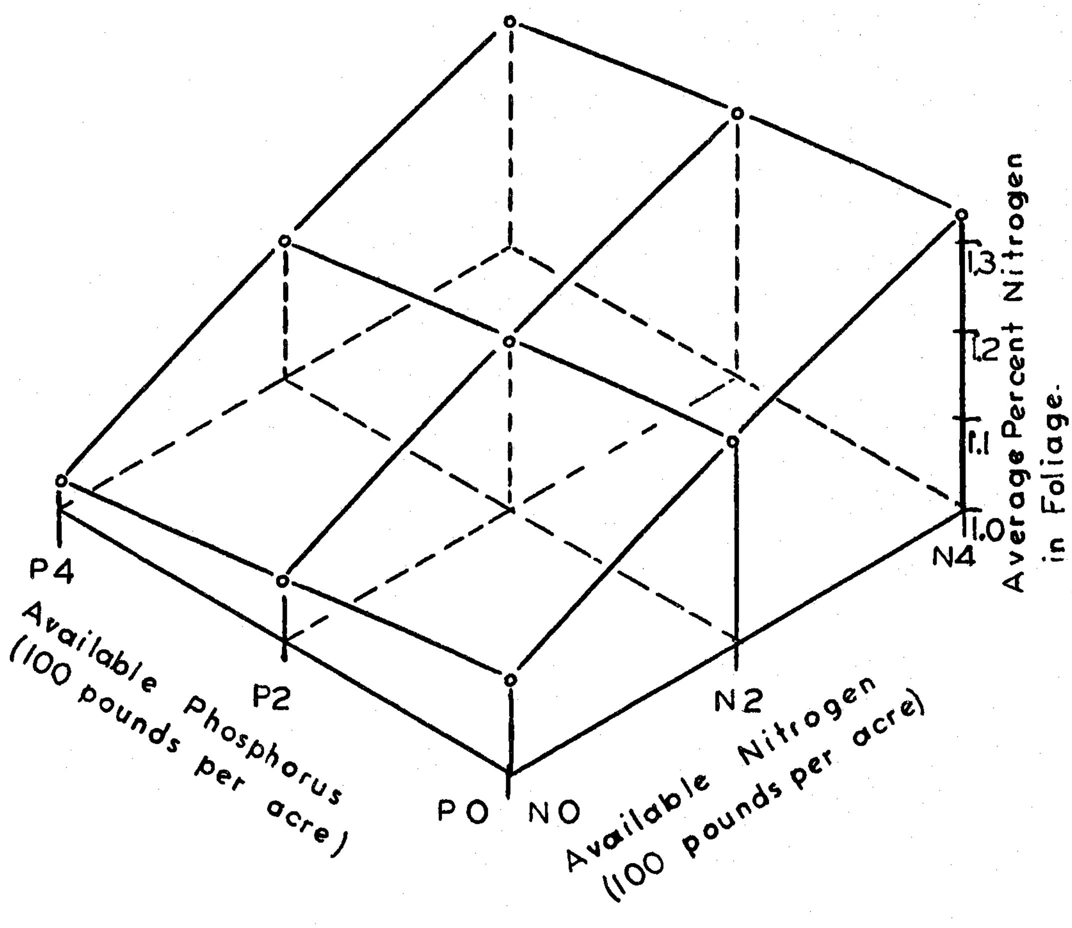

Figure 1. Effect of nitrogen and phosphorus fertilization on average nitrogen content of the foliage.

the wide variation encountered in the results of the phosphorus analysis. When dealing with percentages as small as 0.09 percent to 0.20 percent a variation of ±0.1453 percent phosphorus (Appendix 6) could well obscure any effect that fertilization may have had upon the level of foliar phosphorus. Figure 2 and Table 3 show that there was some influence of fertilization upon the percentage of foliar phosphorus.

Table 3. Average percentage of foliar phosphorus (by treatment) after applications of nitrogen and phosphorus fertilizers for the period 1957-1961.

	N0	N2	N4
P0	0.1752	0.1564	0.1374
P2	0.1808	0.1620	0.1430
P4	0.1868	0.1680	0.1490

Of interest is the fact that as the percentage of foliar nitrogen increased the percentage of foliar phosphorus decreased. Figure 3 shows that there was a pronounced reduction. Although these findings conflict with information presented by Prevot (37) and Harada (14) the findings of this study agree with those presented by Lundegardh (29), Gessel (11) and Burr (1). Portions of Harada's study (14 p. 69-82) conflict with the findings of this study but he suggested that with a soil deficient in one element, supplying this element will depress the level of the other essential elements in the foliage. Lundegardh (29 p. 1-9) shows a graph which is very similar to Figure 3 although in the case he presents, potassium was

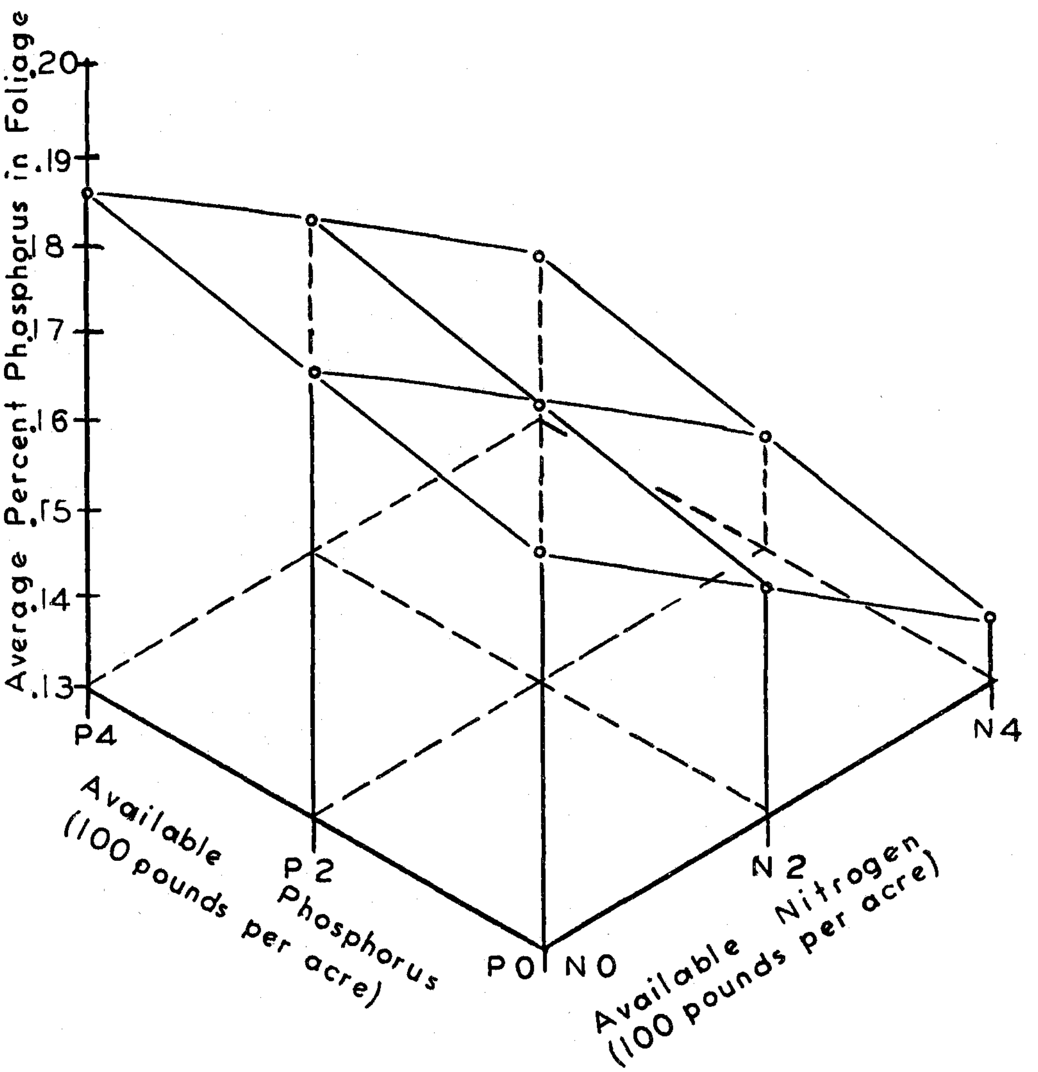

Figure 2. Effect of phosphorus and nitrogen fertilization on the average phosphorus content of the foliage.

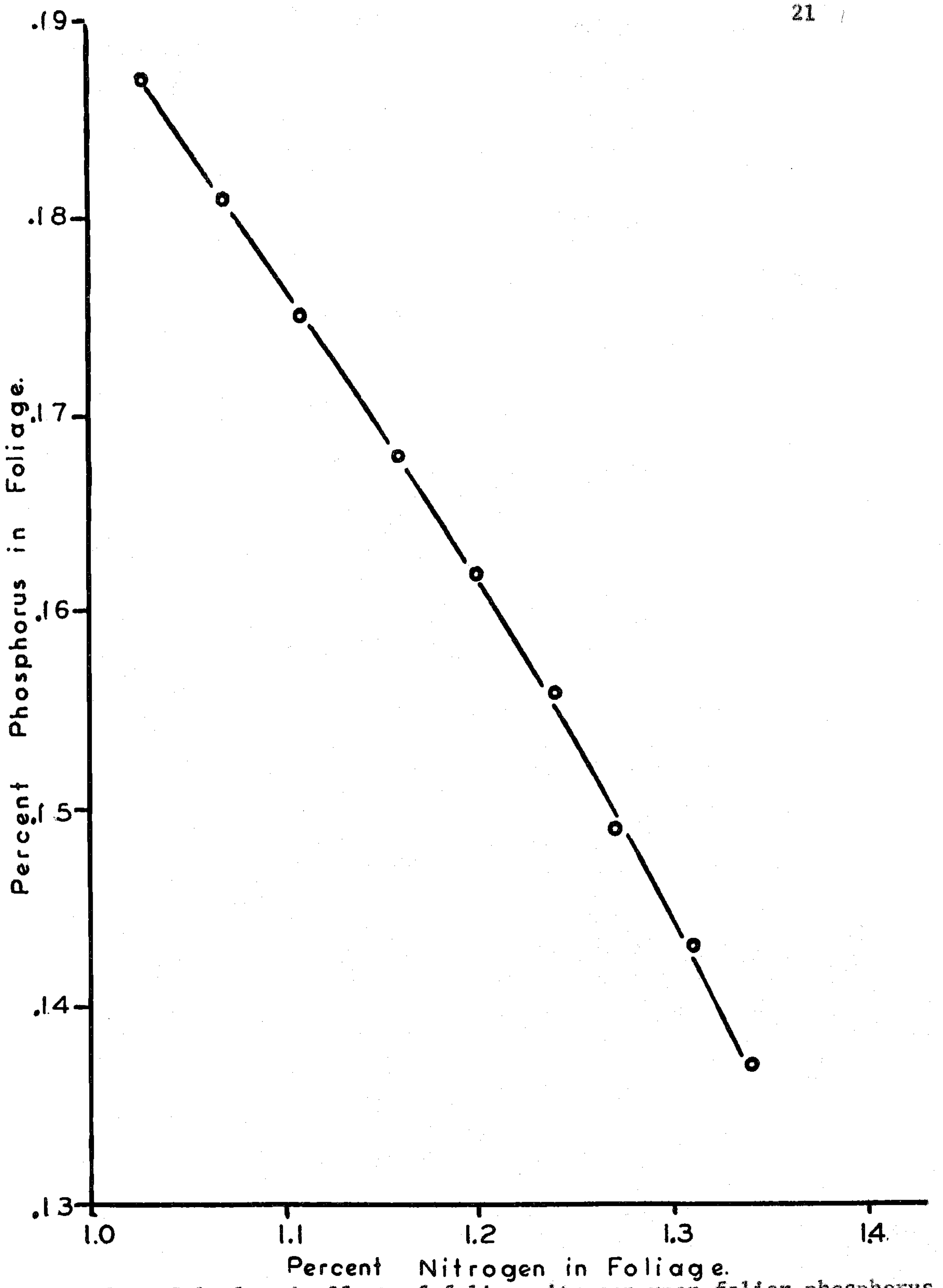

Figure 3. Calculated effect of foliar nitrogen upon foliar phosphorus.

the deficient element instead of nitrogen.

This tendency of one element to depress the concentration of another causes considerable difficulty in evaluating and interpreting the results of foliar analysis. Leyton (25 p. 210-218) used regression methods to show that the percentage of a nutrient in the foliage is correlated to height growth. If this technique were used in this case the influence of nitrogen upon phosphorus, or "dilution effect" as some workers call it, could well have led to misinterpretation of the effects of the fertilizers.

Figures 6 and 7 apparently show that phosphorus proved toxic to the trees. This may not be the case, however, because those trees, which were low in foliar nitrogen, were also high in foliar phosphorus thus appearing to grow less because of high phosphorus content when it was actually a low availability of nitrogen. Appendix 1 B shows that these soils were neither high nor deficient in phosphorus. If a research forester, using graphs similar to Figures 4, 5, 6, and 7, attempted to correct the apparent toxicity of phosphorus without examining the total picture carefully, he could well induce a true deficiency of phosphorus.

This points out a very definite need for research into methods for overcoming the "dilution effect" when dealing with foliage from large trees. If a method were developed which could make it possible to determine the actual weight per unit volume of the foliage in a tree and base the phosphorus determinations upon this then one might be able to show that rather than a reduction in phosphorus with

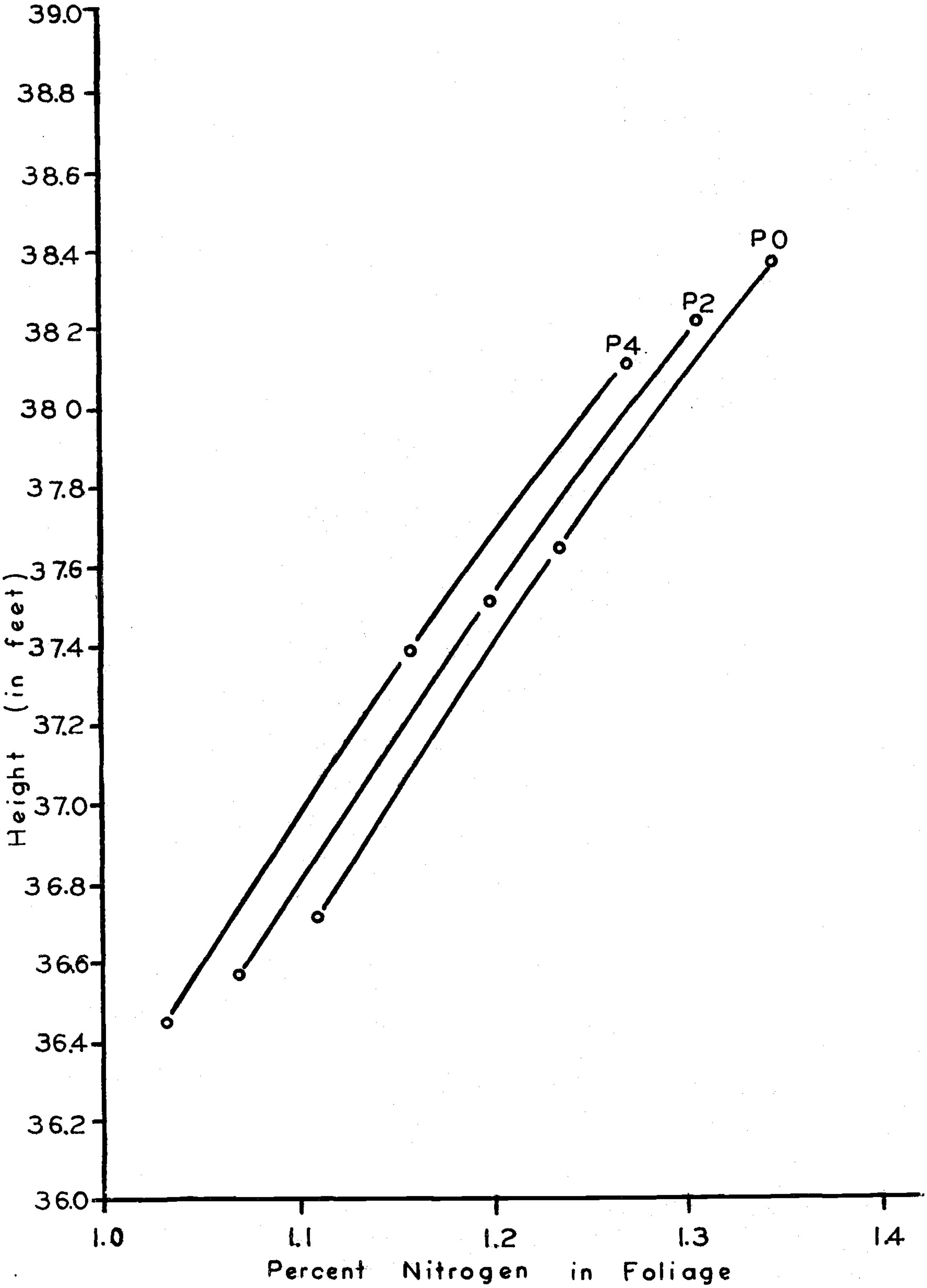

Figure 4. Influence of foliar nitrogen upon height growth at three levels of phosphorus fertilization.

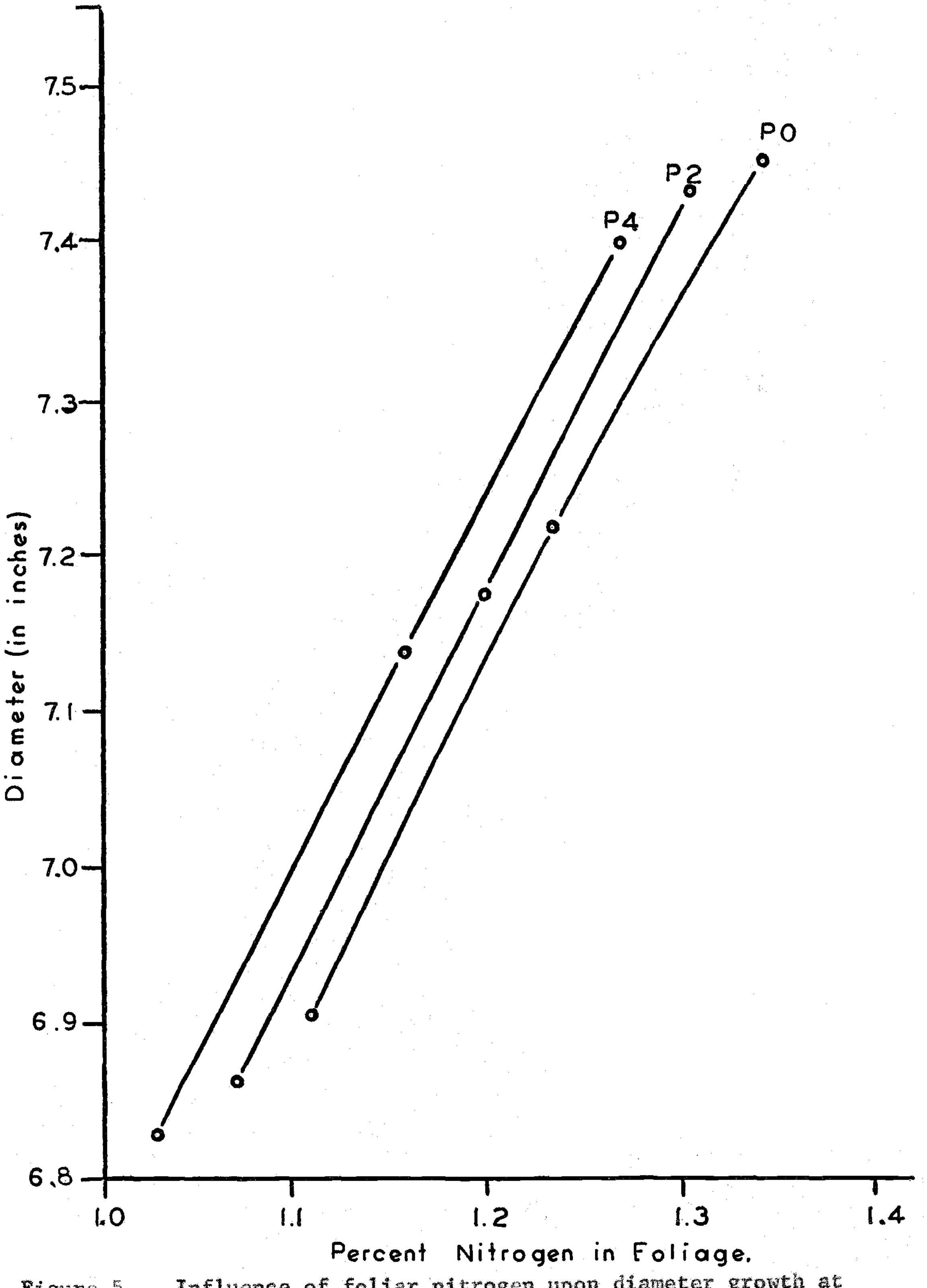

Figure 5. Influence of foliar nitrogen upon diameter growth at three levels of phosphorus fertilization.

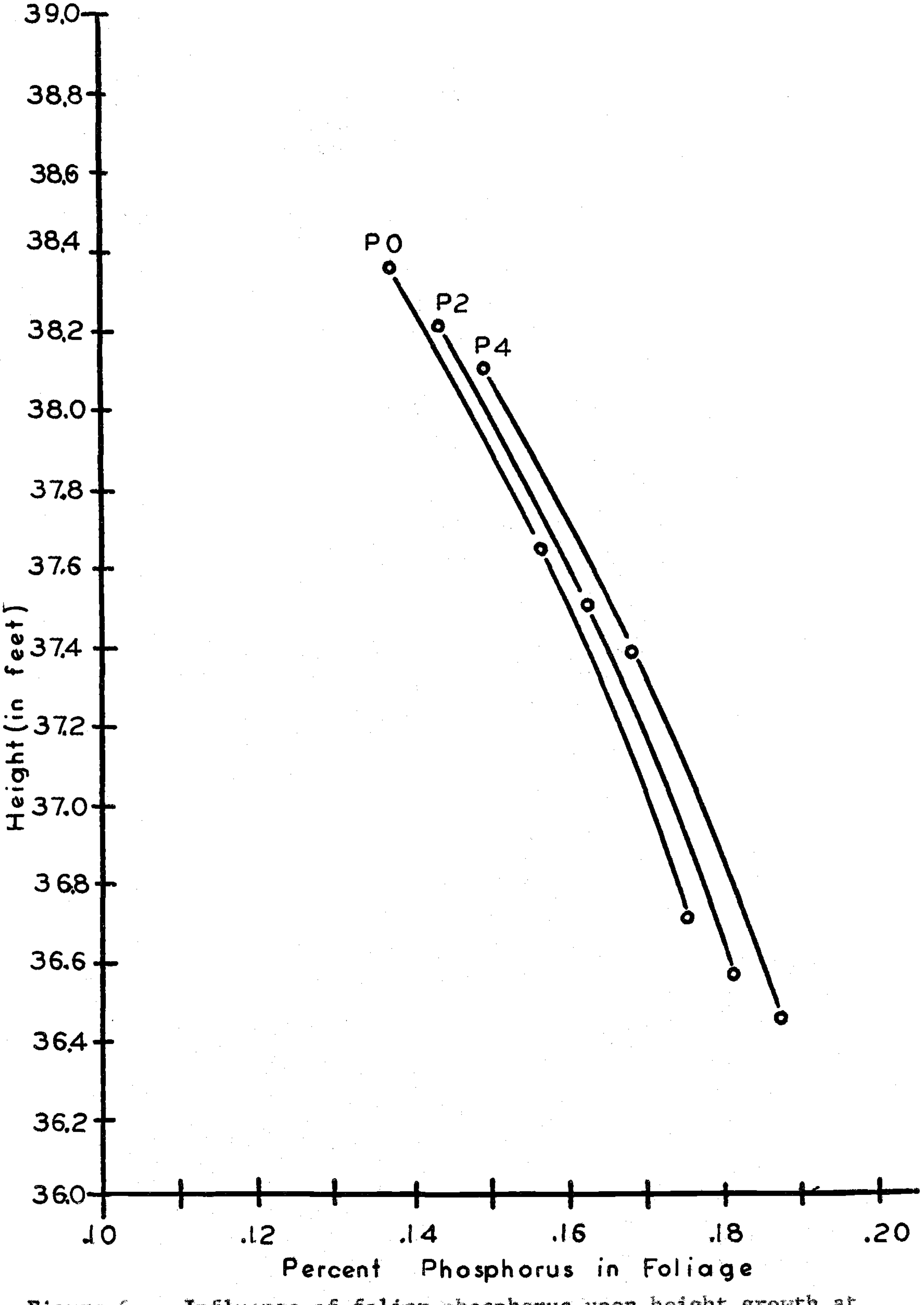

Figure 6. Influence of foliar phosphorus upon height growth at three levels of phosphorus fertilization.

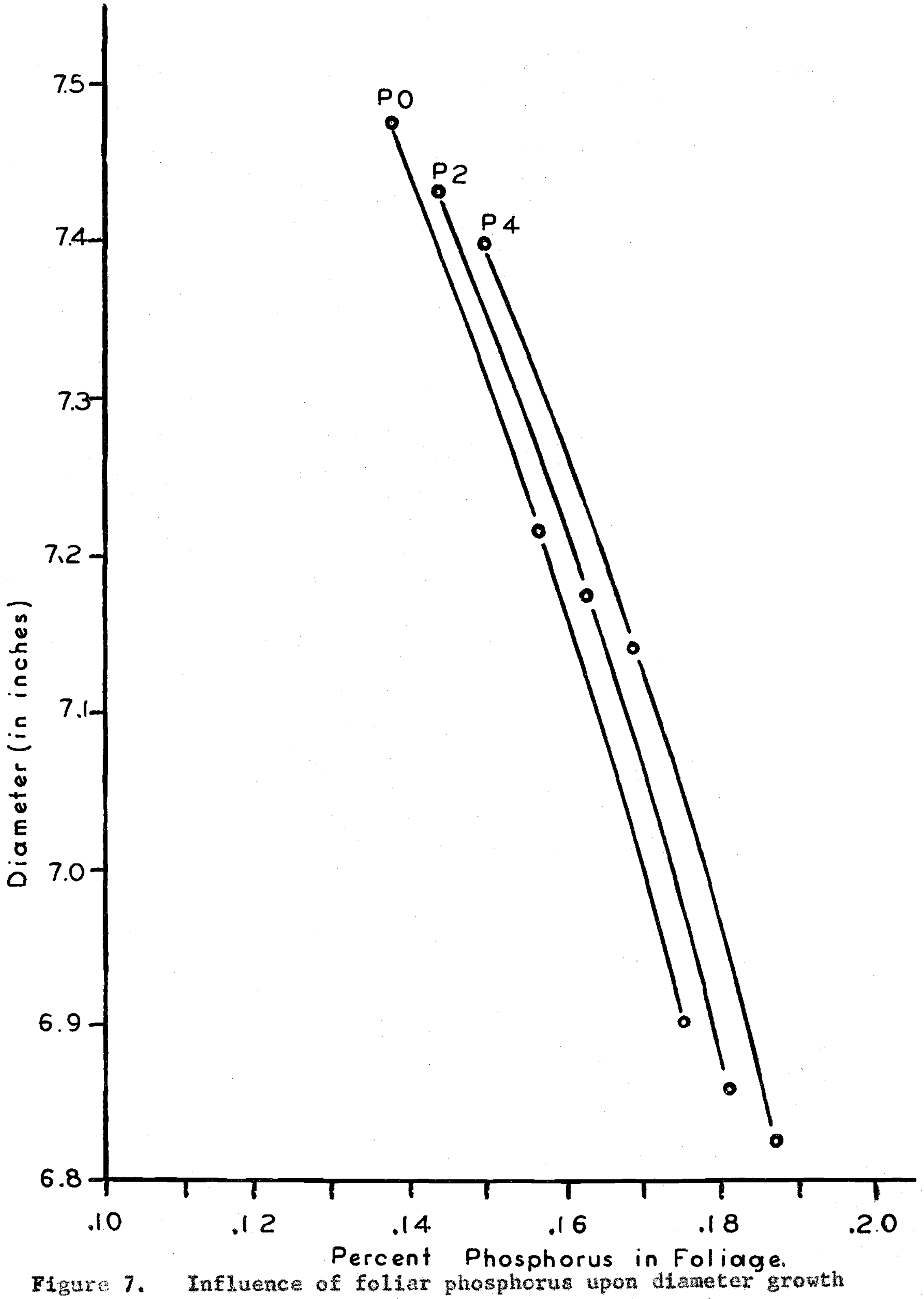

Figure 7. Influence of foliar phosphorus upon diameter growth at three levels of phosphorus fertilization.

increasing nitrogen, there was a slight increase as was shown by Prevot (37).

Appendix 5 compares the various treatments with a standard taken from Gessel (10 p. 22). This index, suggested by Kenworthy (21 p. 37), gives an indication of how close a particular treatment comes to meeting the optimum demands of a plant for a particular element. According to this index, yearly applications of four hundred pounds of available nitrogen per acre and two hundred pounds of available phosphorus per acre gave the optimum nitrogen level in the foliage. The treatment annually supplying no nitrogen but four hundred pounds of phosphorus yielded the best level of phosphorus in the foliage. The single application of four hundred pounds of nitrogen and four hundred pounds of phosphorus gave the best balance between the two elements but this does not provide the optimum growth. It is not known if this index will be of any real value in Douglas-fir stands where the level of nitrogen is usually exceedingly deficient.

Growth Response to Fertilizers:

The influence of the fertilizers upon the growth of the trees was quite striking. Nitrogen applied in the form of ammonium nitrate greatly aided in correcting the deficiency of nitrogen found in the test stand. Appendix 6 shows that nitrogen produced significant increases in diameter ($F = 21.3069$), height ($F = 8.9633$), and volume ($F = 6.7087$). In contrast to this phosphorus produced a significant decrease in volume ($F = 8.7097$) but had no effect upon diameter or height at the 1% significance level (at the 5% significance level there was also a significant decrease in diameter). There is no obvious explanation for volume response being significant and diameter and height response being non-significant unless it is the fact that diameter response was almost enough to be classed as significant.

The influence of the fertilizers can be seen better by comparing the response to the different rates of application shown in Tables 4, 5, and 6. The data in these tables, obtained from the solution of the regression equations, were plotted isometrically to give the response surfaces shown in Figures 8, 9, and 10.

Table 4. Calculated average diameters (by treatment) after applications of nitrogen and phosphorus fertilizers for the period 1957-1961 (values in inches).

	N0	N2	N4
P0	6.90	7.22	7.47
P2	6.86	7.18	7.43
P4	6.83	7.14	7.40

Table 5. Calculated average heights (by treatment) after applications of nitrogen and phosphorus fertilizers for the period 1957-1961 (measurements in feet).

	N0	N2	N4
P0	36.72	37.65	38.37
P2	36.58	37.55	38.22
P4	36.46	37.39	38.11

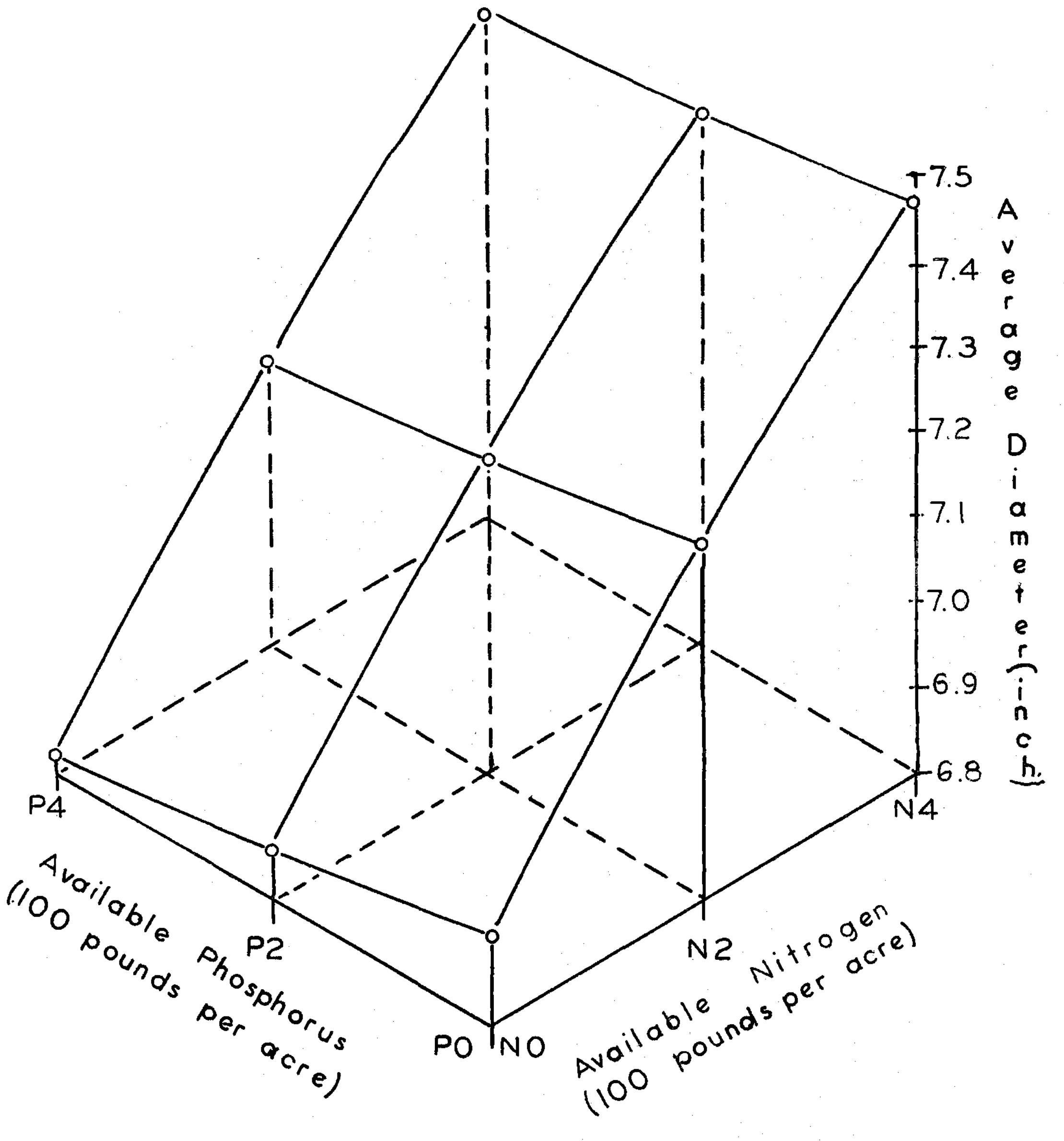

Figure 8. Calculated average diameter of trees fertilized during the period 1957 - 1961 (includes only 3 levels of nitrogen and 3 levels of phosphorus fertilizer.).

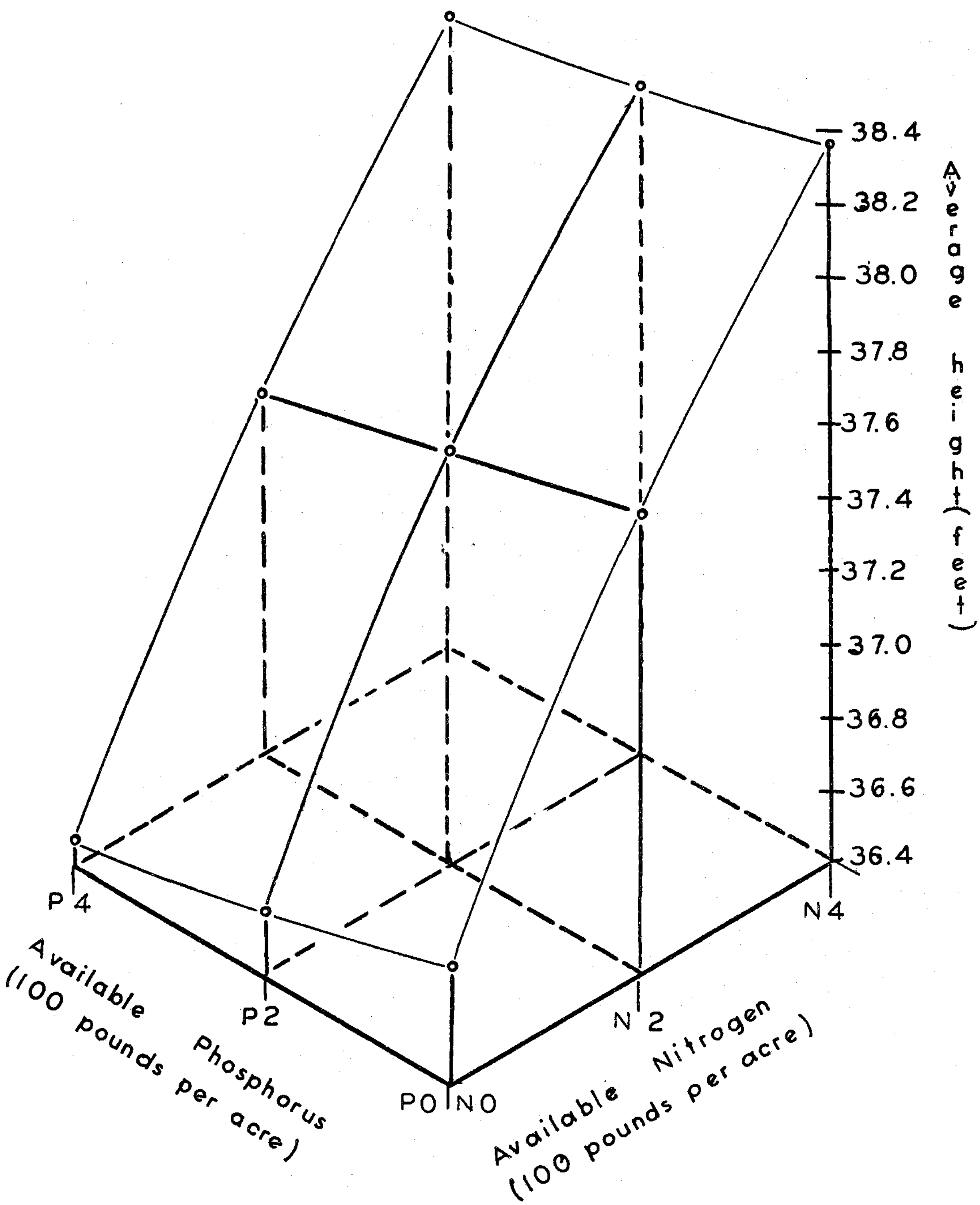

Figure 9. Calculated average height response to fertilization with nitrogen and phosphorus during the period 1957 - 1961.

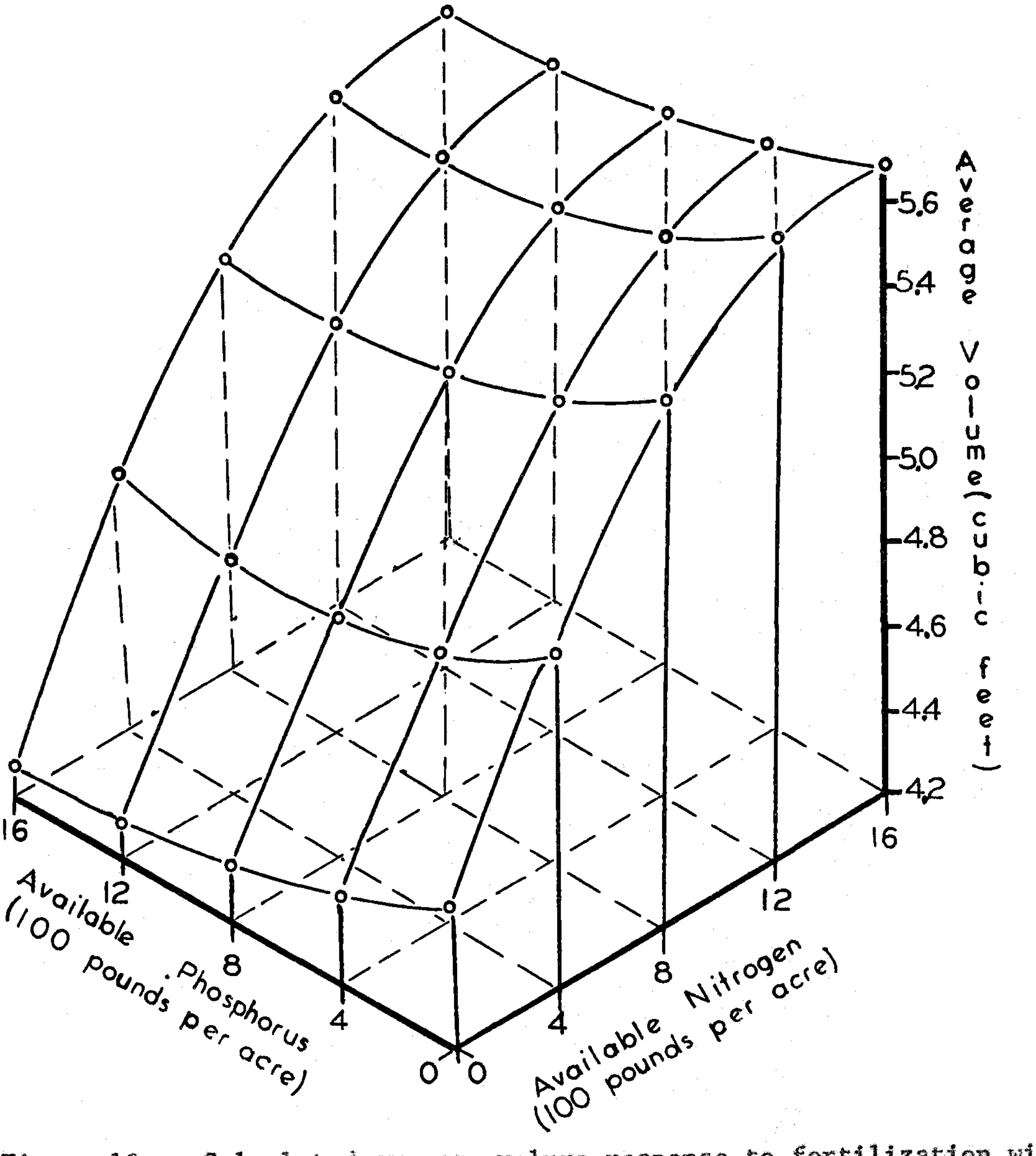

Figure 10. Calculated average volume response to fertilization with nitrogen and phosphorus during the period 1957 - 1961.

Table 6. Calculated average volumes (by treatment) after applications of nitrogen and phosphorus fertilizers for the period 1957-1961 (values in cubic feet).

	N0	N2	N4	N16*
P0	4.52	4.76	4.97	5.70
P2	4.46	4.69	4.90	5.64
P4	4.40	4.64	4.84	5.78
P16*	4.25	4.49	4.71	5.29

* Included to show the effect upon volume of repeated yearly applications of fertilizer for the period of the experiment.

The observed decreases from phosphorus application were difficult to interpret upon first evaluation of the data because the soils, though adequate in phosphorus for growth of Douglas-fir, are not considered high enough for additional applications of phosphorus fertilizer to give rise to a toxic effect. Lundegardh (29 p. 75-76) and Harada (14 p. 69-82) clear this up for as they point out an application of a non-deficient element (in this case phosphorus) to a soil deficient in another element (in this case nitrogen) will accentuate the deficiency. By applying treble superphosphate to this area nitrogen was made more deficient.

Several fertilizers which are recommended by manufacturers as a slowly available form of nitrogen contain high percentages of phosphorus. One in particular[1], an 8-40-0 mixture which also contains

1. 8-40-0, Magnesium Ammonium Phosphate. Ammonium nitrogen 8%, available phosphoric acid 40%, total magnesium oxide 24%. Produced by Davidson Chemical Division of W. R. Grace and Company, Baltimore, Md.

24 percent total magnesium oxide, shows promise of releasing the nitrogen slowly but may well produce an increased deficiency because the phosphorus would be applied at a higher rate than the nitrogen. In light of the observed depression effect of the phosphorus fertilizer used in this experiment it may well prove to be non-economical to use the slowly available forms of nitrogen without modifying the ratio of nitrogen to phosphorus.

At the beginning of this study the author observed that there appeared to be some correlation between the initial diameter of the tree and the response of the trees to fertilization. Since work done by Gessel (9 p. 38) suggested that trees with larger initial diameters responded better to fertilization, this was made a factor in the regression analysis. In all cases initial diameter was found to be highly significant. (Lowest F value was 133.33.) According to the regression equations the increase in diameter attributed to the initial diameter for a 2 inch tree (the smallest studied) was 0.02 inches growth for the period of the study and for a 6 inch tree 0.05 inches growth. A similar response was considered by Gessel (9) to be the result of a better root system, more fully developed crown and generally a more vigorous tree.

In addition to initial diameter, initial height was included in the regression equation. This was also found to be highly significant. (Lowest F value was 10.00.) Although the author knows of no data supporting the observed dependence of growth response upon initial height, Thompson (46) reported initial volume of the tree as being correlated with the response to fertilization. This would suggest that the growth response to fertilization could be correlated to factors which produce a response in both height and diameter.

The forester usually refers to the largest trees as "dominant trees." The reasons for the ability of one tree to respond to the nutrients made available to it and another quite similar tree fail to respond to these nutrients is not clearly understood. Undoubtedly this results in part from genetic factors, however, there may be biological factors within the environment influencing the ability of one tree to express dominance over another. Apparently those factors which enable the dominant tree to grow faster than its neighbors are also enabling the dominant tree to better utilize the nutrients made available through fertilization. In order to determine what factors are manifesting themselves in an expression of dominance there needs to be a detailed study made which would reveal these factors to the forester.

Conclusions

Frequently evidence appears in the literature suggesting that applications of nitrogen fertilizers will increase the yield of Douglas-fir. This study provides evidence of a response to fertilization for Douglas-fir in the Oregon Cascades and shows that nitrogen may well be able to increase yields sufficiently to insure its use in the management of future Douglas-fir stands. However, before any definite conclusions can be drawn from data as shown in Table 7 and Figure 11 a detailed economic study must be conducted before any large scale program of fertilization is undertaken. As Gessel (9 p.238) suggests, fertilizers may well become a silvicultural tool for releasing young stagnant stands not yet of commercial size since the larger, more vigorous trees seem to be able to utilize the nutrients better than the small trees. This study, though not conducted in a stagnant stand, shows the same trend as was observed by Gessel (9).

Table 7. Summary table comparing percentage response of each treatment with the control (control = 100%).

Treatment	Diameter	Height	Volume	% Foliar N	% Foliar P	Average
N0P0	100.0	100.0	100.0	100.0	100.0	100.0
N0P2	99.3	99.6	98.7	96.6	103.2	99.5
N0P4	98.9	99.3	97.4	93.1	106.6	99.1
N2P0	104.5	102.5	105.3	111.3	89.3	102.6
N2P2	103.9	102.1	103.8	108.0	92.5	102.1
N2P4	103.4	101.8	102.6	104.4	95.9	101.6
N4P0	108.3	104.5	109.9	121.0	78.4	104.4
N4P2	107.7	104.1	108.5	117.6	81.6	103.9
N4P4	107.2	103.8	107.1	114.1	85.0	103.4

Before any combination of fertilizers is applied to an area, foliar analysis and soils analysis should be conducted in order to reveal the true status of the available nutrients in the soil. Chapman (2 p. 8) states that in some areas foliar samples are adequate but when starting on a new area complete analysis of foliage and soil should be conducted. If this is done there would be less chance of faulty conclusions based upon the influence of fertilizers upon concentration of nutrients in the foliage. This could have happened if only Figures 4, 5, 6, and 7 were studied.

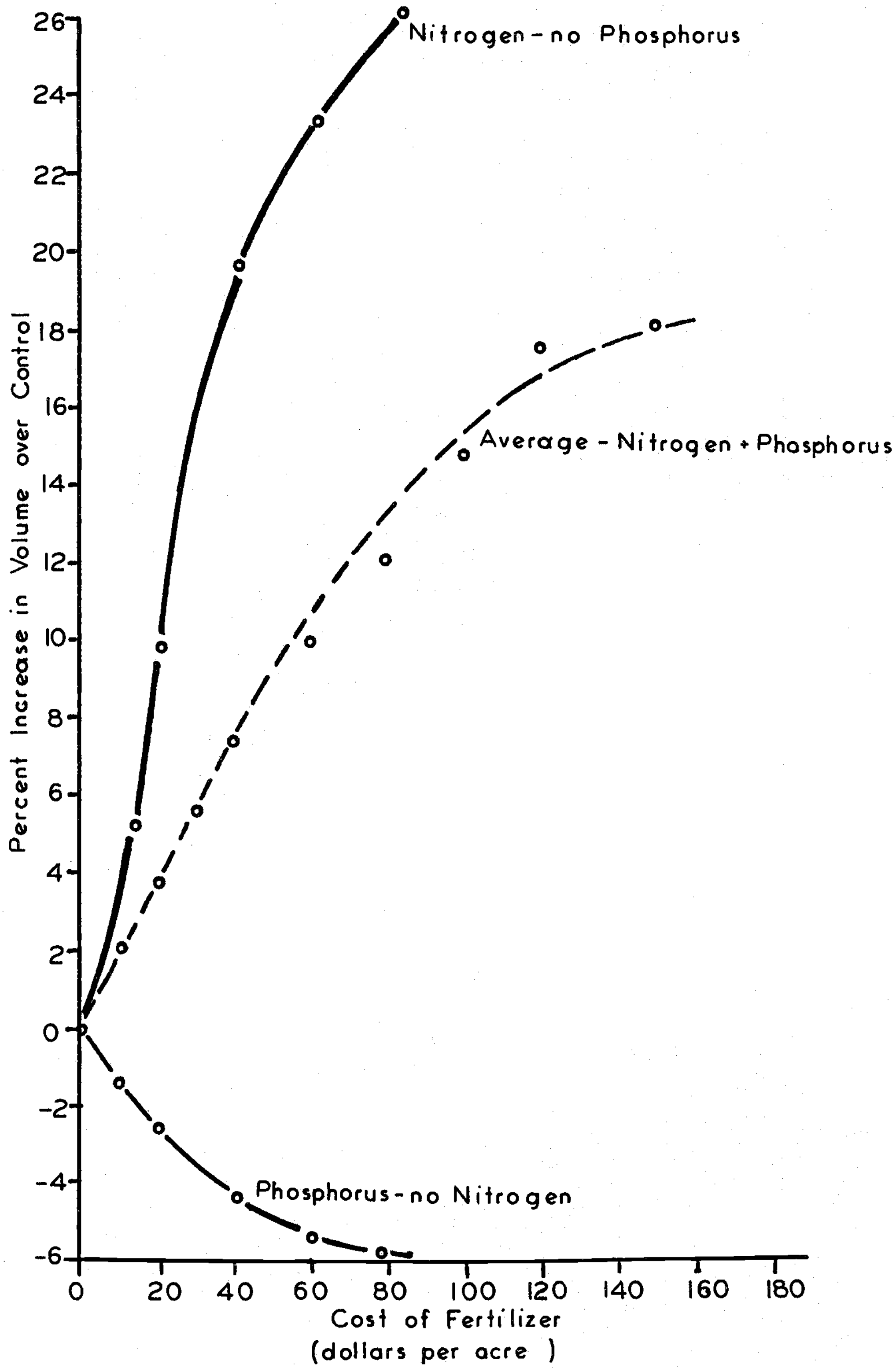

Figure 11. Relationship between volume and fertilization investment for three combinations of nitrogen and phosphorus fertilizers.

Phosphorus fertilizer applied to the nitrogen deficient soil of the test area produced a marked reduction in volume growth of the study trees.

This study points up the need for additional basic research in the area of forest fertilization for as Wilde (48 p. 348) states:

> ....the effective use of fertilizers in forestry can be reached via the classroom, laboratory, and greenhouse, rather than through empirical trials. In fact on the basis of the theory of probability, there are enormous odds that an indiscriminant application of fertilizers will produce harmful rather than beneficial results. On the other hand, definite success achieved with tree fertilization in different parts of the world indicates that the time is at hand when fertilizers will become an important auxiliary tool in the production of forest crops.

Summary

In 1957 a study was established on Crown Zellerbach's Clackamas Tree Farm near Molalla, Oregon to study the influence of fertilization upon the production of Douglas-fir seed at high elevations. This area, referred to as the "High Elevation Seed Production Area," was fertilized with varying rates of ammonium nitrate and treble super-phosphate. Each year at the end of the growing season diameter measurements were made and foliage samples were taken.

The data, made available by Crown Zellerbach, was analyzed statistically and revealed that the growth of trees with nitrogen showed significant increases in diameter, height, volume and percentage of foliar nitrogen. Phosphorus produced a significant decrease in volume and percentage of nitrogen in the foliage.

Examination of the literature and these results showed that indiscriminate use of fertilizers containing non-deficient elements when applied to an area deficient in another element can result in decreased yield. In this case the application of phosphorus, essential for seed production, reduced the yield by about one and a half percent with each two hundred pound increment added to the soil.

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APPENDIXES

Appendix 1

Initial tree measurements by treatment and number for trees used in the development of the regression equation.

Number	Treatment	Initial Diameter	Initial Height
1	N4P2-R	4.4	19.8
3	N4P2	4.7	26.1
4	NoPo	5.8	31.3
5	N2P2-R	5.8	32.0
8	N2P4-R	3.8	19.4
13	NoPo	4.7	31.4
14	N2P2	4.0	27.1
17	N2P2-R	3.8	25.1
19	N2P4	5.1	29.8
22	N2P4-R	4.9	25.0
23	N2P2	5.5	28.6
24	NoPo	4.3	22.8
25	N4P4	5.0	29.5
29	N2P4	3.5	21.5
31	NoPo	4.9	29.3
32	N4P4-R	4.0	25.0
38	NoPo	5.0	27.0
39	N4P4-R	4.4	25.7
40	N4P4	5.3	24.8
41	N2P2-R	4.3	26.4
42	N4P2-R	4.3	24.0
45	N4P4-R	3.7	24.6
47	N2P2	3.5	20.5
49	N4P4	5.9	30.8
50	N4P2	5.1	24.1
51	N2P4	3.5	22.2
52	N4P4-R	4.4	26.6
53	N2P2-R	4.1	24.8
57	NoPo	5.3	26.7
60	N4P2-R	3.9	23.8
61	N4P4	5.8	29.9
64	N4P2-R	5.8	33.4
65	N2P4-R	3.7	23.8
67	N2P2	3.9	25.9
68	N4P4-R	4.2	26.3
71	N2P4	6.1	29.8
75	N2P2-R	4.9	27.3
76	N4P2	4.0	29.7
77	N2P2	5.3	28.4
78	N4P2-R	4.8	30.8
80	N2P4-R	4.8	28.9
81	N2P2-R	5.1	22.7

Appendix 1 (cont)

Number	Treatment	Initial Diameter	Initial Height
83	N4P2	4.5	30.8
84	N4P2-R	5.8	35.7
88	N2P2	4.4	31.0
95	N2P4	4.1	25.6
98	N2P4-R	4.0	24.1
101	N2P4	4.7	27.5
102	N4P2	5.0	28.8
104	N4P4-R	4.8	26.2
105	N4P4-R	4.1	24.2
106	NoP2-R	3.6	24.3
107	N4Po-R	3.6	21.3
108	NoP4-R	3.7	26.3
109	N2P0-R	3.7	25.3
110	N2P0-R	3.9	24.0
111	NoP2-R	2.2	16.8
112	NoP2-R	4.3	23.1
113	N4P0-R	3.3	18.2
114	NoP2-R	3.5	22.6
115	N2P0-R	3.6	23.5
116	N2Po-R	4.1	23.5
117	NoP2-R	4.6	26.5
118	NoP4-R	3.9	24.1
121	N2Po-R	4.2	27.5
122	N2Po-R	4.6	27.0
123	NoP4-R	3.9	28.2
124	N4P0-R	4.1	23.8
126	NoP4-R	4.3	21.5
127	N4P0-R	3.7	22.4
128	N4P0-R	4.5	22.5
129	NoP4-R	4.2	27.5
130	N2P4-R	2.7	22.0
131	N4P0-R	4.8	31.0
134	NoP2-R	3.6	27.0

Tree numbers are those assigned by Crown Zellerbach personnel for their seed production study.

-R indicates yearly replication of fertilizer application.

Appendix 2 A

Soil description -- Crown Zellerbach High Elevation Seed Production Area. (53)

This soil is an uncorrelated brown latosol developed on andesite residuum at an elevation of 3100 feet under cover of Douglas-fir, western hemlock and noble fir and a rainfall of 65-70 inches a year. It is situated on a gentle mountain slope (bench) on a south east exposure and a 20% slope. The understory vegetation consists of bracken fern, fire weed, trailing blackberry, violet, star flower, huckleberry, elderberry and scattered rhododendron. Oregon grape and salal were also observed on the seed production area. The soil is a well drained soil with moderate permeability and is stony throughout the profile. Roots were abundant in the A1 and A3, few in B1 and B2 and sparse below. The A1 and A3 horizons were dry when observed and the horizons below were moist.

Aoo	3/4 - 0"	Scattered leaf litter.
A1	0 - 5"	Brown (10YR 4/3 dry) and dark brown (10YR 3/3 moist) shot loam; moderate fine granular; loose when dry, very friable when moist; slightly sticky and slightly plastic when wet; pH 5.2; boundary is abrupt and smooth.
A3	5 - 20"	Yellowish brown (10YR 5/4 dry) and dark yellowish brown (10YR 3/4 moist) shot loam; moderate medium granular and fine subangular blocky; soft when dry, friable when moist; slightly sticky and slightly plastic when wet; pH 5.2; boundary clear and wavy.
B1	20 - 32"	Dark brown (10YR 4/3 moist) silty clay loam; weak fine subangular blocky; friable when moist; sticky and plastic when wet; pH 5.0; boundary gradual wavy.

B2	32 - 38"	Dark yellowish brown (10YR 5/4 moist) silty clay loam on light clay; weak fine subangular blocky; firm when moist, sticky and plastic when wet; pH 4.8; boundary clear and wavy.
B3C	38" +	Dark yellowish brown (10YR moist) gritty clay loam; massive; firm when moist, sticky and plastic when wet; pH 4.8.

The organic matter content in the A1 appeared to be lower than normal for a brown latosol with the rainfall associated with the elevation. It is possible that this is a result of fire since charcoal was observed in the soil profile.

Appendix 2 B

Results of soil tests conducted on soils from the experimental area prior to fertilization.

Soil Depth (inches)	Na	K	Ca	Total Cations (me/100 g)	Exchange Capacity (me/100 g)	P (lbs/acre)
	(me/100 g soil)*					
0 - 5	0.357	.785	2.65	3.79	31.4	10.5
5 - 20	.275	.262	.790	1.33	24.5	4.4
20 - 32	.451	.199	.778	1.43	18.3	2.8
32 - 38	.329	.289	.784	1.39	21.5	2.6
over 38	.275	.357	.790	1.42	24.6	2.4

* Values in milliequivalents per 100 grams oven dry soil.

Appendix 3

Rates of Fertilizer Applied to Plots on the Experimental Area.*

Treatment	Pounds Element Applied		Pounds Fertilizer Applied	
	N	P	Ammonium Nitrate 33.5 % N	Treble Super. 42 % P
N2P2	200	200	597	444
N4P2	400	200	1194	444
N2P4	200	400	597	888
N4P4	400	400	1194	888
NoP2	---	200	----	444
NOP4	---	400	----	888
N2P0	200	---	597	---
N4P0	400	---	1194	---

* On treatments where fertilization was repeated each year these levels were applied yearly.

Appendix 4

Results of Foliar Analysis conducted on foliage from test trees on the experimental area.

Percent of phosphorus in foliage:

Treatment	1958	1959	1960
N0P0	.1400	.1756	.1422
N2P2	.1572	.1900	.2092
N4P2	.1333	.1570	.1739
N2P4	.1580	.2424	.1749
N4P4	.1490	.2330	.1999
N0P2-R*	-----**	.2411	.2410
N2P0-R	-----	.1410	.1249
N0P4-R	-----	.2080	.2336
N4P0-R	-----	.1167	.0831
N2P2-R	.1331	.1745	.1748
N2P4-R	.1493	.1750	.1915
N4P2-R	.1164	.1164	.0996
N4P4-R	.1996	.1910	.2079

Percentage of nitrogen in the foliage:

N0P0	1.18	1.41	1.31
N2P2	1.13	1.08	1.18
N4P2	1.60	1.27	1.10
N2P4	1.27	1.11	1.18
N4P4	1.40	1.23	1.17
N0P2-R*	----**	1.19	1.23
N0P4-R	----	1.14	1.17
N2P0-R	----	1.67	1.19
N4P0-R	----	1.77	1.34
N2P2-R	1.35	1.19	1.12
N2P4-R	1.16	1.37	1.16
N4P2-R	1.51	1.81	1.36
N4P4-R	1.66	1.53	1.23

* -R indicates treatments repeated each year during experimental period.

** indicates that no samples were taken during this year.

Appendix 5

Nutrient balance index (by treatment) of nitrogen and phosphorus
Kenworthy (20)

Treatment	Nitrogen Index	Phosphorus Index	P/N Ratio
N0P0	73.0	68.9	0.9438
NoP2-R	60.5	97.5	1.6116
N0P4-R	53.4	98.3	1.8408
N2P0-R	78.6	46.1	0.5865
N2P2	50.0	90.5	1.8100
N2P2-R	63.2	77.9	1.2326
N2P4-R	58.8	88.7	1.5985
N2P4-R	62.8	86.0	1.3694
N4P0-R	52.5	7.7	0.1467
N4P2	72.7	71.0	0.9766
N4P2-R	94.1	20.8	0.2210
N4P4	79.7	87.2	1.0941
N4P4-R	87.7	-1.7	0.011

Method of computing the index of a particular nutrient.

1. (X ÷ S) X 100 = P
2. (100 - P) X (V + 100) = I (if X is less than S)
   (P - 100) X (V + 100) = I (if X is greater than S)
3. P - I = B

X = sample value
S = standard value
P = percent of standard
V = co-efficient of variation
I = influence of variation
B = balance index

Appendix 6

Statistical Data

A. Values computed for inverse matrix.

	General mean	0.028366
c_{11}	1958 effect	0.319566
c_{22}	1959 effect	0.331428
c_{33}	1960 effect	0.368751
c_{44}	N	0.001829
c_{55}	N^2	0.000009
c_{66}	P	0.000109
c_{77}	P^2	0.000001
c_{88}	Initial diameter	0.00000004
c_{99}	Initial height	0.000000002

B. Table of "Beta" values for vectors used in regression analysis.

Vector	Diameter	Height	Volume	% N	% P
Mean	4.7912	27.98908	1.762704	1.2867	-0.01698
1958	0.1182	0.744942	0.217851	0.0624	0.03633
1959	0.7258	2.835114	0.880853	-0.0464	0.07387
1960	1.2447	5.041189	1.590287	-0.1932	0.06702
N	0.1709	0.517708	0.123214	0.0675	-0.00940
N^2	-0.0070	-0.026441	-0.003123	-0.0023	-0.00001
P	-0.0229	-0.008132	-0.034290	-0.0180	0.00269
P^2	0.0010	0.004258	0.001075	-0.0003	0.00005
In. Dia.	0.0019	0.012204	0.002910	0.0002	0.00333
In. Ht.	0.0006	0.002141	0.000692	-0.00002	0.00002

C. Table of "F" values for vectors used in regression analysis.

Vector	Diameter	Height	Volume	% N	% P
1958	0.5857	1.0621	1.2004	1.8009	1.9583
1959	21.2937*	14.8339*	18.9226*	0.9599	78.0655*
1960	56.2862*	42.1530*	55.4341*	14.9604*	5.7733#
N	21.3969*	8.9633*	6.7087*	36.7439*	2.2656
N^2	7.0000*	4.7560#	0.8866	5.2900#	0.0001
P	6.4742#	3.7113	8.7097	46.2857*	3.6181
P^2	1.0000	1.1332	1.1556	0.9000	0.1250
In. Dia.	1203.3333*	212.7680*	169.3620*	133.3333*	11088.9000
In. Ht.	3600.0000*	152.7960*	239.4320*	40.0000*	10.0000*

* = 1% significance level (F = 6.6349 @ 1 and 274 df)

\# = 5% significance level (F = 3.8415 @ 1 and 274 df)

Appendix 6 (continued)

D. Standard deviations between replications for vectors considered in regression analysis.

Diameter	± 0.8639 inches
Height	± 4.0435 feet
Volume	± 1.1316 cubic feet
Percent Nitrogen	± 0.2602 percent
Percent Phosphorus	± 0.1453 percent

Appendix 7

Comparison between volume increment of treated trees and volume increment of control trees.

Treatment	Percent Increase
N0P0	0.00
N0P2	-1.3
N0P4	-2.6
N0P8	-4.5
N0P12	-5.5
N0P16	-5.8
N2P0	5.3
N2P2	3.8
N2P8-N2P16	Not computed
N4P0	9.9
N4P2	8.5
N4P4	7.1
N4P8	5.4
N4P12	4.4
N4P16	4.1
N8P0	19.6
N8P4	17.0
N8P8	15.1
N8P12	14.0
N8P16	13.7
N12P0	22.8
N12P4	19.2
N12P12	17.2
N12P16	16.9
N16P0	26.1
N16P4	23.4
N16P8	21.5
N16P12	20.4
N16P16	17.0