FERTILIZING DOUGLAS-FIR FORESTS

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Abstract

This report supplements a slide-tape presentation of the same title. Part I of the report describes the current practice of nitrogen fertilization of Douglas-fir forests in western Washington and Oregon and the effects of this fertilization on tree growth and water quality. Part II discusses factors that affect costs and revenues from investments in forest fertilization. The appended tables, figures, and work sheet enable the user to prepare a break-even economic analysis for fertilization projects. This information should be useful in selecting stands for fertilization and in preparing Environmental Assessment Reports.

Metric Equivalents

1 acre = 0.40469 hectare

1 cubic foot = 0.0283 cubic meter

1 pound = 0.4536 kilogram

Contents

Preface

Fertilizing Douglas-fir Forests[1]

This report is in two parts. In Part I, we will discuss some of the biological bases of forest fertilization and describe the current practice of operational fertilization. We will then discuss both the reliability of fertilization for increasing tree growth and its environmental impacts. In Part II, we will show how to evaluate the economics of forest fertilization.

After reading and referring to this report, you should be able to:

1. Describe the current practice of fertilizing Douglas-fir forests, i.e, fertilizer prescription and stand selection.

2. Describe the effect of N fertilizer on Douglas-fir growth.

3. Cite evidence about some environmental impacts of N fertilization and use this information to prepare Environmental Assessment Reports.

4. Enumerate and discuss factors that affect the costs and revenues from investments in forest fertilization.

5. Use the accompanying worksheet to prepare a break-even analysis for your fertilization projects.

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[1] This General Technical Report supplements a slide-tape presentation titled, Fertilizing Douglas-fir Forests. This slide tape (772.1-.2 S-T) is available for rent or purchase from The Forestry Media Center, School of Forestry, Oregon State University, Corvallis, Oregon 97331.

PART I. Biological Bases and Effects of Nitrogen Fertilization

Yields From Douglas-fir Forests

UNMANAGED FORESTS

Douglas-fir is the predominant tree species in nearly one-half of the commercial forests in western Washington and Oregon. Yield from natural, unmanaged stands varies greatly and largely depends on the number of trees occupying a site and the inherent productivity or quality of the site. For example, harvesting of all live trees from a normal site quality V stand at 60 years would provide about 3,500 cubic feet per acre (McArdle et al. 1961) or enough wood to build one typical three-bedroom house (fig. 1).

In contrast, harvesting all live trees from a normal 60-year-old, site I stand would yield about 12,500 cubic feet per acre or enough wood to build nearly four typical houses:

The two solid lines in figure 1 represent trends in gross yield. Gross yield is the volume of live trees plus mortality, i.e., the cumulative volume of trees normally lost through competition, insects, and disease. This mortality volume averages about 20 percent of the total or gross growth of unmanaged, well-stocked stands of Douglas-fir. Reducing or salvaging this mortality volume can increase usable yields from our forests.
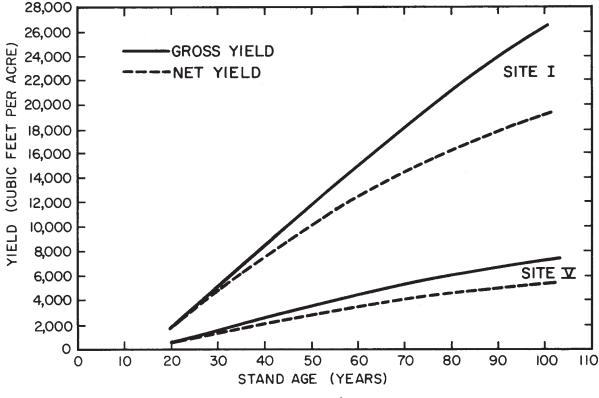

Figure 1.--Normal yields of Douglas-fir (derived from McArdle et al. 1961 and Staebler 1955).

MANAGED FORESTS

Most volume normally lost in unmanaged forests can be recovered in managed forests. By precommercially thinning young stands, foresters eliminate excess trees that will not reach merchantable size and thereby concentrate growth onto future crop trees. By commercially thinning older stands, dead trees of merchantable size are salvaged as part of the thinning operation.

In addition to controlling numbers and sizes of trees which share the site, foresters can increase site productivity by improving environmental conditions. Some environmental factors can be manipulated with relative ease, but others like temperature and precipitation are difficult to change. Moreover, correcting the initial growth-limiting factor will increase growth until some other factor becomes limiting. This principle is illustrated by the barrel analogy (fig. 2).
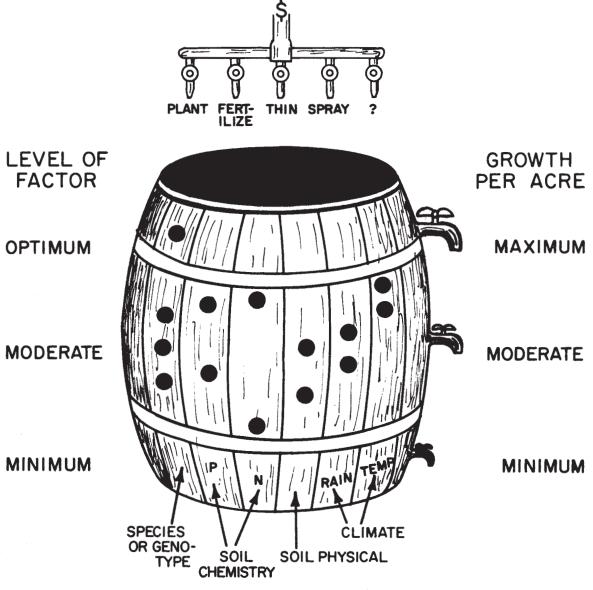

Figure 2.--Improving site quality.

Consider this barrel a forest site we want to improve. Each stave of the barrel represents a productivity factor. The level of production obtainable at this site is limited by the factor with the lowest opening in the barrel. In this example, the amount of available nitrogen is the first growth-limiting factor. If we remedy this by applying nitrogen fertilizer, we plug this weakness and increase production to the next factor in short supply. This next factor may be a physical property of the soil like compaction or stoniness. We can readily improve compaction in the surface soil by mechanical means, but correcting stoniness is usually too costly. Therefore, on this theoretical site--as in a practical field situation--we would add nitrogen until production was limited by some factor beyond our control.

Fertilization to Increase Yield

THE CURRENT PRACTICE

Forest fertilization is developing into a practical means for increasing yields of Douglas-fir forests of western Washington and Oregon. This commercial practice was preceded by numerous field trials where fertilizer was spread uniformly over the soil and trees were carefully measured for growth in diameter and height. These trials have provided direct evidence that nitrogen fertilizers can increase growth of established stands; direct evidence led to large-scale applications.

The first operational fertilization was in 1965 when 1,500 acres of Douglas-fir on Crown Zellerbach's holdings near Molalla, Oregon were treated with urea prills, small, white spheres of nitrogen fertilizer. For the l0-year period of 1965 through 1974, nitrogen fertilizer was applied to at least 825,000 acres in western Washington and Oregon.[2] About 90 percent of this

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[2] Personal communication with Robert T. Bergland, former Fertilization Forester, Washington State Department of Natural Resources, Olympia, Washington, on October 22, 1975.

acreage was industry-owned forests. Helicopters were used almost exclusively to fertilize these forests. Generally, the prescribed treatment was 150 or 200 pounds of elemental nitrogen per acre, applied as urea prill or larger forestry-grade granules.

WHAT WE KNOW

Although fertilization has joined traditional management tools like planting and thinning to increase wood production, researchers and land managers are continuing to improve gains from fertilization. We currently have general answers to questions concerning which nutrient elements, dosages, and fertilizers should be used, and when and how they should be applied. Refining these general answers will increase the gains from current practices.

Which nutrients?--Current applications of nitrogen are based on past observations that nitrogen fertilizers frequently increase growth of Douglas-fir at a wide range of locations. Other elements such as phosphorous, potassium, and sulphur have also been tested in combination with nitrogen; but these elements seldom improve the gain achieved from applying nitrogen alone in the Pacific Northwest (Gessel et al. 1965, Crossin et al. 1966, Steinbrenner 1968, Heilman 1971, Miller and Reukema 1974).

Douglas-fir, like other plants, requires relatively large quantities of nitrogen compared to most other elements. For example, productive stands annually require 40 to 100 pounds of nitrogen per acre. Most of this annual requirement is met by the roots which extract inorganic nitrogen from the soil and forest floor; however, some of this requirement is provided by internally recycling N extracted in previous years. Although soils of commercial Douglas-fir forests contain 2,000 to more than 20,000 pounds of nitrogen per acre (Gessel et al. 1972), most of this nitrogen is trapped in living organic matter or organic residues. Each year, only a small

fraction is mineralized into inorganic nitrogen and made available:to trees, other plants, and micro-organisms, all of which compete for this limited nutrient. Rates of N turnover in many stands are frequently inadequate to,meet tree requirements, as shown by the response that usually follows fertilization with 150 or more pounds of nitrogen per acre.

How much?--The biologically and economicaLLy optimum fertilizer dosage for established.stands of Douglas-fir probably lies between 150 and 300 pounds of nitrogen per acre. Lesser amounts may fail to provide measurable effectS. Larger amounts may provide slightly more volume and longer duration of response (fig. 3), but in some locations can lead to increased mortality (Lee 1974) or snow;or winter breakage brought on by sudden stimulation of foliar growth (Miller and Pienaar 1973).

Which source of N?--Most nitrogen fertilizer currently applied to Douglas-fir forests is urea. Urea is used primarily because of Its relatively low initial cost per pound of nitrogen and because its higher concentration of nitrogen (46 percent) provides a greater net payload than other nitrogen fertilizers like ammonium nitrate (34 percent) (table 1).

Table 1--Pounds of fertilizer to apply (per acre basis)

Desired nitrogen dosage	Fertilizer source	
	Urea (46-0-0)	Ammonium nitrate (34-0-0)
150	[1] 326	441
200	435	588

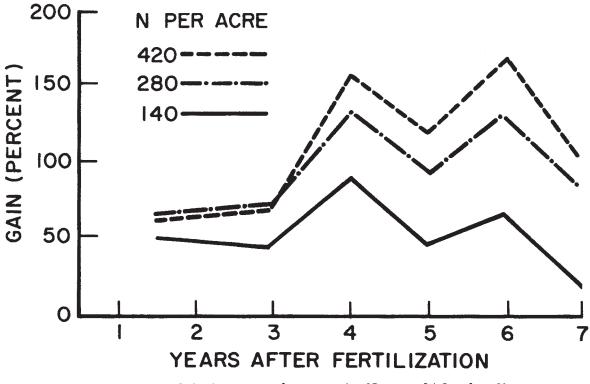[1] Calculation: $\dfrac{150}{0.46} = 326$

Figure 3.--Gain in gross volume growth, 35-year-old Douglas-fir (Miller and Pienaar 1973).

Application of urea during periods of dry, warm weather should be avoided because such climatic conditions could lead to gaseous losses of nitrogen and reductions in the amount available for growth (Watkins et al. 1972). The performance of urea and other sources of N is being compared under forest conditions; currently, however, we cannot specify circumstances where specific fertilizers will provide the greatest response per pound of nitrogen applied.

Stand age?--Biologic and economic considerations determine when to fertilize Douglas-fir stands. Fertilization at time of tree planting has seldom been beneficial (Austin and Strand 1960). Adding fertilizer pellets to the planting hole has not proved cost-effective,and broadcast applications of nitrogen to seedlings usually increase competition from other vegetation and reduce seedling survival.

Because nutrient demands are usually highest when annual rates of wood production and crown expansion are highest, it is biologically desirable to fertilize initially when the Douglas-fir stand is between 15 and 20 years old. Although this timing is likely to provide large gains in wood volume, it may not provide greater economic gains than fertilizing at a later period when the trees have reached a merchantable size. As we explain in Part II, the period of time between the fertilizer investment and the harvest of volume gained from this investment strongly influences economic benefits of fertilization.

IS FERTILIZATION A SUITABLE TOOL?

Land managers can use several criteria to judge the merits of fertilization. Specifically they want to know how reliable forest fertilization is, how environmentally safe it is in the forested watershed, and how much economic return it will provide. In the remainder of Part I, we'll see how well fertilization meets the criteria of reliability and environmental impact. In Part II, we'll examine the economics of forest fertilization.

How Reliable is Forest Fertilization?

Foresters want a tool that will enhance growth over a wide range of forest conditions, and they want a high probability of getting improved growth after using this tool.

PROBABILITY OF RESPONSE

some indication of the reliability of nitrogen fertilization is provided by results from the cooperative regional fertilization trials conducted at numerous locations in western Washington and Oregon by University of Washington researchers (Atkinson 1974). Of 87 unthinned stands of Douglas-fir tested, 72 percent responded with increased volume growth of at least 10 percent within 2 years of being fertilized with 200 pounds of nitrogen per acre applied as urea (Regional Forest Nutrition Research Project 1975b). Moreover, the percentage of stands that showed at least a 10-percent response to nitrogen was somewhat greater in lower than higher site qualities:

	Stands	
Site	Total	Responding
	Number	Percent
I	11	64
II	38	66
III	25	84
IV	10	80
V	3	67
All	87	72

This broadly based sample indicates a 72-percent chance of obtaining at least a 10-percent growth improvement if nitrogen is applied to well-stocked stands of Douglas-fir. These odds can be improved if land managers can identify the most and least profitable acres for fertilization. Then, fertilizer expenditures can be programmed selectively to increase reliability and profits. Several means to increase reliability will be discussed after describing some general effects of nitrogen fertilization on Douglas-fir.

EFFECTS OF NITROGEN FERTILIZER

ON DOUGLAS-FIR GROWTH

Fertilized Douglas-firs usually increase growth in diameter and volume during the first growing season after treatment. Foliage of trees with a severe nitrogen deficiency darkens, lengthens, and remains on the tree for 1 or more additional years. These changes in foliage and greater branch growth indicate a more rapid build-up of tree crown and a greater potential for future growth.

Response in volume growth generally peaks between the 3d and 5th year after fertilization. Although duration of response varies with location, stand, and nitrogen dosage, current data suggest that response gradually approaches zero within 10 to 15 years after treatment.

Field trials during the past 25 years have demonstrated that addition of nitrogen usually increases growth of Douglas-fir over the full range of site qualities, sites I through V. Initial results from the previously mentioned cooperative trials in western Washington and Oregon show that application of 200 pounds of nitrogen per acre to low quality sites can provide a greater cubic foot gain than the same application on higher quality sites (Turnbull and Peterson 1976). During a 4-year observation period, average yearly gains from fertilized Douglas-fir stands ranged from 27 cubic feet on site I, through 91 cubic feet on site IV (table 2). Thus far, an average of 108 to 364 cubic feet of extra wood was produced by treatment; and these gains will probably double during the future growth of most of these stands.

The finding that low quality sites provided a greater cubic-foot gain from 200 pounds of nitrogen per acre than higher quality sites to the same dosage fits the barrel analogy discussed earlier. The most limiting growth factor on these lower quality sites was evidently insufficient amounts of available nitrogen. Fertilizing with nitrogen temporarily removed

Table 2--Average gain from fertilizing Douglas-fir on sites I through IV[1]

Site	Gain	
	Yearly	4-year
	Cubic feet	Cubic feet
I	27	108
II	48	192
III	70	280
IV	91	364

[1] Fertilized with 200 pounds of nitrogen per acre as urea. Source: Adapted from Turnbull and Peterson (1976).

this limitation and, therefore, increased stand growth. Conversely, less response to fertilization occurred on the naturally more productive sites, probably because amounts of available nitrogen were not limiting growth as severely.

IMPROVING RELIABILITY

As suggested by results from the cooperative trials and earlier trials, site index of Douglas-fir stands in western Washington and Oregon is a basis for predicting response to nitrogen fertilizer. Response is greater and more likely on site IV land than on progressively higher site qualities. On site V and lower quality lands, however, the likelihood of response is less predictable for two reasons. First, from an empirical standpoint, fewer trials exist on such low sites to establish a reliable prediction. Second, from an intuitive standpoint and based on the barrel analogy, there is a greater likelihood that several factors besides available nitrogen will be at marginal levels and therefore will limit growth.

A second option is also available for predicting likelihood of fertilizer response. Chemical analysis of soil or foliage from proposed treatment areas has been used successfully in some agricultural crops and forest types to predict need for fertilizer. If close relationships exist between growth and the content of nitrogen in foliage or soil, then one can

reasonably predict that increasing the content of nitrogen by fertilization will enhance growth. Although such diagnostic techniques are being developed by several scientists for use in Douglas-fir (Lavender and Carmichael 1966 Shumway and Atkinson 1977),[3] they are not yet sufficiently developed for practical use.

Finally, the surest way to select responsive areas for operational fertilization is to match stand and soil characteristics of successful, experimental field trials (table 3).

p. 306), "There is no simple answer to the question whether a forest fertilization improves or decreases the environmental quality of a site. Pros and cons have to be evaluated and weighed at each site."

Beneficial effects of fertilizing Douglas-fir forests include temporary improvements in vegetative color and growth of trees and associated vegetation and faster rates of nutrient cycling between the soil and the Douglas-fir stand (Miller et al. 1976). Negative environmental impacts are also probable. For example,

Table 3--Stand response to nitrogen, an example of local experience to guide operational fertilization

Trial		Stand age	Soil number	Increased growth during period	
Number	Response period				
	Years	Years		Cubic feet	Percent
1	7	35	37	650	70
2	4	35	14	344	28
3	4	50	14	304	28
4	4	45	13	236	18

Having assembled experience data, a land manager can increase his certainty of achieving similar gains by fertilizing similar stands and soils. The closer the match, the more likely it is that similar gains will be obtained.

How Environmentally Safe?

The evaluation of probable effects of fertilization on the environment should precede the decision to fertilize. As stated by Tamm (1973,

temporary increases in road and air traffic and in audio and visual impacts are inherent to operational fertilization. The predominant concern, however, is excessive nitrogen in surface and ground waters. Specifically, increases in total nitrogen concentration can increase eutrophication, a natural but frequently nuisance growth of phytoplankton, algae, and aquatic weeds. Moreover, concentrations of nitrate-N exceeding 10 parts per million indicate the water is unfit for human consumption (NAS-NAE 1973).

RESULTS FROM STREAM MONITORING

Shortly after operational fertilization began in the Pacific Northwest, stream waters flowing from several forested watersheds in western Washington and Oregon were sampled before and after applications of 150 or 200

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[3] Ian George Morison. Foliar nitrogen range and variability in a second-growth Douglas-fir forest and its relationship to certain stand and tree characteristics. Doctorate Dissertation. University of Washington, Seattle. 268 p. 1970.

pounds of nitrogen per acre as urea fertilizer. Initial results from this monitoring were summarized in a 1972 report of the Environmental Protection Agency (Groman 1972, p. 3):

"A continual process of collecting and evaluating forest fertilization-water quality studies is required to supplement and refine current knowledge. The few studies conducted to date indicate no substantial or long-term detrimental effects on the environment associated with the practice...."

Water quality continued to be checked and results from 22 fertilized watersheds in Douglas-fir forests were reported by Moore (1974). He concluded that the maximum concentration of urea-, ammonia-, nitrite-, and nitrate-nitrogen in streams that were repeatedly sampled after forest fertilization easily met published standards for public water supplies.

The effects of increased nitrogen on stream habitat and esthetics are less definite. Thut and Hayden (1971) concluded that these increases in various forms of N found in streamwater after fertilization were well below toxic levels for aquatic life; they predicted that forest fertilization could increase aquatic productivity in nutrient-poor streams. Since most streams in forest watersheds of the Douglas-fir region are nutrient poor, this increase in nitrogen concentration and aquatic production could be considered environmentally desirable. Yet, fertilization could contribute to an undesirable condition outside the watershed, because increases in nitrogen concentration could increase eutrophication after mountain streams enter warmer, slower-moving streams or lakes at lower elevations. Clearly, the extent of fertilization in a watershed and the stream characteristics and land use downstream are key factors controlling the ultimate effect of forest fertilization on the aquatic environment.

Direct measurements of nitrogen in streams suggest that forest fertilization is compatible with accepted standards of water quality (NAS-NAE 1973). When reasonable precautions were taken to minimize direct application of fertilizer to major streams, increases in nitrogen content of the water were primarily from fertilizer that was inadvertently dropped into small streams. Moore (1974 and 1975) provided typical results from three studies in stand conditions ranging from old growth to a young plantation (table 4). Helicopters applied 200 pounds of nitrogen as urea. Repeated stream sampling during 29 and 52 weeks after fertilization showed the equivalent of less than one-half of 1 percent of the applied nitrogen was lost to streams.

Table 4--Loss of fertilizer nitrogen in streams after application of 200 pounds of nitrogen per acre as urea[1]

Area	Conditions	N-lost after designated period		
		Period	Per acre	Of application
		Weeks	Pounds	Percent
Coyote Creek	Old growth	52	0.34	0.17
Quilcene No. 1	Open and pole-sized plantation	29	.49	.25
Quilcene No. 2	40-year plantation	29	.67	.34

[1] Source: Moore 1974, 1975.

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Nitrogen losses from fertilizer landing on the soil or forest floor are of less concern. Leaching losses through soil to streams or ground water occur primarily when nitrogen is in the nitrate-ion form; therefore, leaching may occur where ammonium or urea fertilizers are converted to nitrate by soil bacteria or if nitrate-containing fertilizers are applied. Although a laboratory study showed that many forest soils of the Pacific Northwest convert fertilizer nitrogen and organic nitrogen to nitrate ions (Heilman 1974), field investigations have detected only small quantities of nitrate in stream water after fertilization with urea (McCall 1970, Burroughs and Froehlich 1972, Moore 1974 and 1975). Correspondingly low nitrate concentrations were measured at the one location where ammonium nitrate fertilizer was applied (Moore 1974). Presumably, applied or biologically converted nitrate is readily taken up by soil organisms and vegetation.

AVOIDING A POTENTIAL PROBLEM

Although additional information is needed about the effects of repeated fertilization to the same area and about using fertilizer solutions as foliar sprays (Norris and Moore 1976, Miller and Young 1976), available information suggests that little environmental damage is likely if nitrogen fertilizer is carefully broadcast at current dosages and intervals on forested land. When undertaking current operational practices, however, desirable precautions include: (1) maintaining untreated buffer areas along major streams; this buffer should be recognizable by the pilot and sufficiently wide to reduce accidental drift of small fertilizer particles, (2) avoiding applications when spring snow melt or heavy storms greatly expand small tributary streams, and (3) suspending operations whenever wind or reduced visibility could lead to significant losses of fertilizer from the target area (Norris and Moore 1971)

ENERGY TRADE-OFFS

When fertilizing forests with nitrogen, we expend nonrenewable energy (fossil fuels, especially petroleum and natural gas) to increase photosynthetic efficiency and thus wood production. For example, a conventional fertilization requires the equivalent of about 50 gallons of oil to produce, transport, and spread 200 pounds N per acre as urea by helicopter. Conversely, we can burn the additional wood gained from fertilization to produce energy or substitute this wood for metal or plastic products derived from nonrenewable resources. Several authors discuss these energy trade-offs and the means and economics of obtaining them (Grantham and Ellis 1974, Grantham et al. 1974, Evans 1974, Boyd et al. 1976)

Reifsnyder and Lull (1965) and Smith and Johnson (1977) maintained that growing wood, especially in conifer forests, is one of the most efficient ways to use energy to capture more energy. Assuming a return of 2 cubic feet of wood per pound of N applied as urea fertilizer, Smith and Johnson (1977) estimated a gross return of about 12 units of energy for each unit invested in fertilization of Douglas-fir forests. This gross return is converted to net return by subtracting the energy necessary to harvest (Dykstra 1976) and supply the final product (National Academy of Sciences 1976)

For example, assuming (1) 200 pounds of N/acre produces an additional 400 cubic feet/acre of Douglas-fir roundwood and (2) each 100 cubic feet of green roundwood is equivalent to 3.3 barrels or 139 gallons of fuel oil (Hartman et al., n.d.), then the gross energy return from fertilization is 556 gallons of oil. Further, assuming 5.16 gallons of oil to harvest 1 cord of roundwood (American Pulpwood Association 1975) at 85 cubic feet of solid roundwood per cord, then harvesting this extra 400 cubic feet would require 24 gallons of oil and thus reduce the net energy return to 532 gallons of oil-equivalent for expenditures of 50 gallons to produce, transport, and spread 200

pounds of N per acre by helicopter. Therefore, the net ratio of energy gain in this example is 10.6.

Summary

The four major points of Part I follow:

1. Fertilization with nitrogen is a reliable means for increasing wood production in most Douglas-fir forests.

2. Current operational fertilization is based on past research findings. From 1965 through 1974, at least 825,000 acres of established stands of Douglas-fir in western Washington and Oregon were fertilized. The usual treatment consisted of 150 to 200 pounds of elemental nitrogen per acre applied as urea by helicopter during late fall through early spring.

3. Experimental trials indicate that land managers can reasonably expect from 200 to 800 additional cubic feet of stem wood per acre from fertilizing commercial forests. Results from cooperative trials show that gains in cubic volume from fertilizing Douglas-fir stands are inversely related to site quality. Thus, application of 200 pounds of N per acre to site IV and III stands can provide a greater cubic-foot gain than the same application on higher quality sites. Continuing efforts by researchers and land managers can improve volume and financial gains from forest fertilization.

4. Environmental damage is unlikely if fertilizer is carefully broadcast to minimize direct application into major streams.

PART II. How Economic?

Forest managers want a financial gain or profit from their investments in fertilization. This goal is reached when revenue gained from fertilizing exceeds the total costs of fertilizing. In this section, we shall first show how various factors influence economic returns.

We will then present a break-even analysis to show how many cubic feet of extra growth are required and what stumpage prices are necessary to pay for assumed costs of fertilization. Finally, we'll discuss other financial considerations affecting fertilization decisions.

Treatment Costs

Costs of fertilizing clearly affect the profit from this silvicultural practice. The total cost has two components--the initial cost of fertilizing and the interest charges for carrying this investment.

INITIAL COSTS

The initial costs of fertilizing include the contract costs (supplying the fertilizer, transporting it into the forest, and applying it to specified areas by helicopter), and the costs of administering the contract, providing access roads and heliports, and in some instances, assessing water quality and tree response. Since the cost of fertilizer is usually 60-70 percent of the total treatment costs, the price of fertilizer strongly influences the initial cost of treatment.

Past costs of fertilization varied widely from year-to-year and from job-to-job. In 1970, the total cost of applying 200 pounds of nitrogen per acre averaged about $23. By 1974, when worldwide fertilizer and petroleum shortages developed, average costs more than doubled to about $57 per acre. On the income side of the financial ledger, however, stumpage prices increased by an even greater amount during the same period, so fertilization appeared to be a more attractive investment in 1974 than in 1970 (fig. 4)

One can minimize costs of a fertilization contract in at least two ways. As with most goods and services, the seasonal price for both fertilizer and application reflect supply and demand. Due to seasonal demands in agriculture, fertilizer prices are usually 3 to 5 percent lower in fall and winter. Application costs, however,
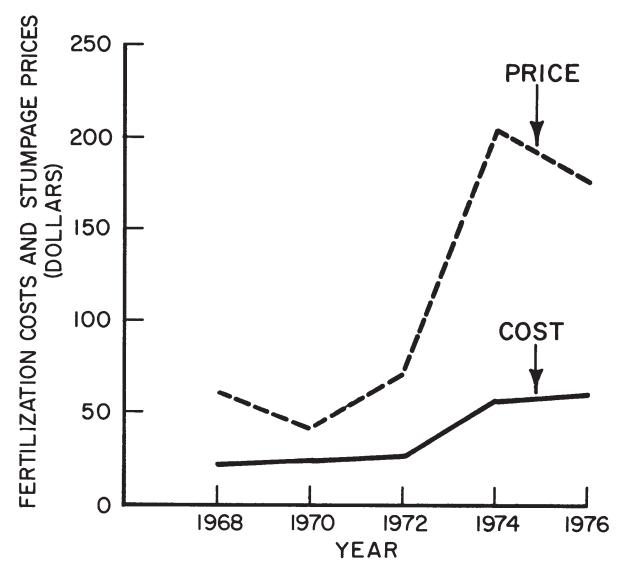
Figure 4.--Average fertilization costs and stumpage prices.

are generally much lower in spring, because many helicopters are contracted in fall for forest fire suppression. The net result is that fertilization contracts usually cost slightly less in spring.

second way to reduce costs is to include as many acres as possible in the contract. Costs of fertilization per acre generally decline as the size of the contract increases. One experienced Northwest contractor estimated that his bid per acre would be 20 percent less in a 2,000 ton contract involving 9,200 acres than in a 100-ton contract involving 460 acres.

In the economic analyses that follow, an average initial treatment cost of $60 per acre will be used. This approximates the cost of applying 200 pounds of nitrogen per acre in the form of 435 pounds of urea fertilizer on 7,400 acres of the

Willamette National Forest in 1976. To illustrate the effects of a lower initial cost, a $40 per acre treatment cost will also be used.

INTEREST CHARGES

The compound interest costs of carrying the initial investment strongly affect profits gained from fertilization and other intensive management practices. As consumers, we know that such carrying charges are based on interest rate and duration of the loan. Although the market rate of interest may be 12 percent, the real rate of interest is less because the rate of inflation must be subtracted from it. For example, if one borrows money at the market rate of 12 percent and the annual rate of inflation is 5 percent, then the real rate of interest is only 7 percent.

During a 10-year period, a fertilization cost of $60 borrowed at a real rate of 7 percent almost doubles to a cost of $118 (fig. 5). If carried 20 years, it doubles again to $232 or almost four times the initial cost. Therefore, to break even, the increase in value of wood harvested from the fertilized stand must equal $118 if harvested in 10 years and $232 if harvested in 20 years.

In the economic analyses that follow, we selected 10 and 20 years as investment periods. We assumed that most of the volume gained from fertilization would be accumulated in 10 years and that this extra volume could be cut and sold at that
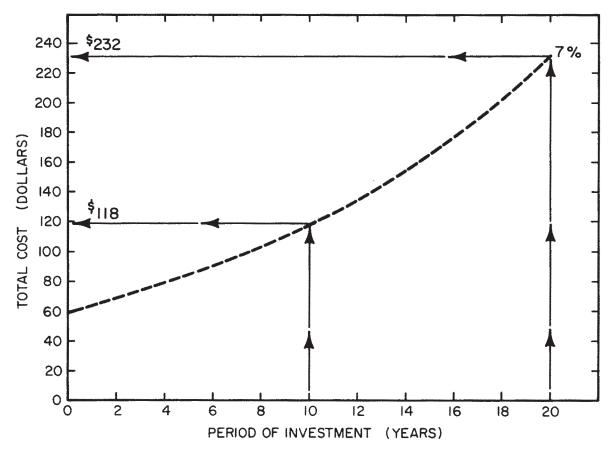

Figure 5.--Cumulative cost of fertilizing based on an initial cost of $60 per acre compounded at 7 percent interest.

time. But harvesting trees 10 years after treatment is only reasonable if fertilizer is applied to a stand that is merchantable or nearly merchantable. If smaller trees are fertilized, then a longer investment period is necessary until crop trees reach merchantable size.

Figure 6 shows the total cost of fertilization when initial costs of $60 and $40 per acre are compounded at 7-percent interest. Notice that the total or cumulative cost for a $60 initial cost is 1-1/2 times that for a $40 initial cost.

Revenue

The land manager who invests in forest fertilization anticipates increased growth and, therefore, increased revenue from his forest.

Investment is profitable when the increased revenue exceeds the attendant costs.

VOLUME GAINED

The extra wood attributable to fertilization increases revenue when it is harvested and sold. The additional revenue gained from fertilization depends on the amount of extra volume and its price per unit. For the landowner who sells only stumpage, this extra revenue is obtained from having more volume to sell. For landowners with manufacturing facilities, however, additional revenue can accrue because this extra volume may reduce a need to purchase higher-priced wood on the open market.

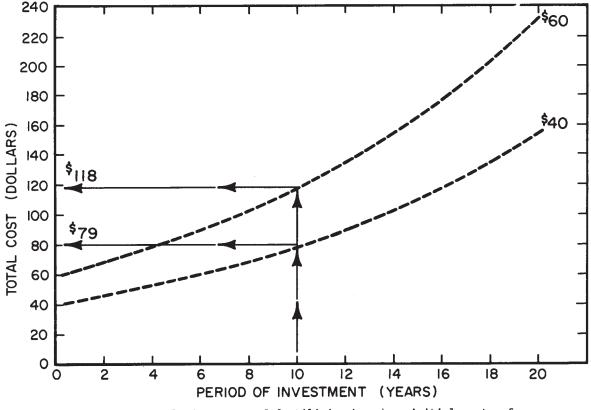The extra volume of wood gained from fertilization and how soon this

Figure 6.--Cumulative costs of fertilizing based on initial costs of $40 and $60 per acre compounded at 7-percent interest.

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wood can be harvested strongly affect the revenue gained from the invest-ment. Where natural productivity is restricted by nutrient deficien-cies, fertilizers not only increase usable yields, but also enable land managers to make earlier commercial thinnings and final harvests.

In Part I, we described the ef-fects of nitrogen fertilizer on growth of Douglas-fir. Experimental trials indicated that land managers can reasonably expect from 200 to 800 additional cubic feet of stem-wood per acre over a 10-year period after applying 150 to 200 pounds of nitrogen per acre. Moreover, the cubic foot gains in total stem volume were more on sites of low natural productivity than on sites of high natural productivity (table 2)

STUMPAGE PRICE

The stumpage price paid to the forest owner is the residual or net value after the costs of logging, loading, and hauling are subtracted from the price paid for logs at the mill, which is the usual delivery point. Large trees have more stump-age value because the price paid at the mill increases while the costs of harvesting decrease (Worthington and Staebler 1961, Adams 1965, Adams 1967, Worthington 1966). Therefore, the landowner receives a higher stumpage price for selling larger trees (table 5)

Although growth is more precisely measured in cubic feet, cubic-foot prices are seldom used. To estimate the stumpage value of extra cubic feet produced after fertilization, one must convert *conventional* stumpage prices per thousand board feet, Scribner scale, to a price per cubic foot (Fahey and Woodfin 1976).[4]

The number of board feet recover-able from a cubic foot of wood and the price per board foot are both strongly dependent upon tree size (table 6). Therefore, the price paid per cubic foot is higher for large diameter logs than for small logs. This difference in pricing means that a 300-cubic foot gain per acre from fertilization might return two times as much stumpage revenue to the landowner if he har-vested 16-inch trees instead of 8-inch trees.

The extra wood produced from fertilization will be harvested years after this treatment is applied. To compute financial gains from treat-ment, one can estimate the future price of this extra wood by select-ing an appropriate current stumpage price and projecting an annual rate of price increase. The average price for Douglas-fir stumpage on National

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[4] To convert stumpage values in board feet (BF) to cubic feet (CF):

$$\frac{\$}{CF} = \frac{\$}{BF} \times \frac{BF}{CF}$$

Table 5--Estimated prices and costs in 1976 by average tree diameter

Average d.b.h.	Mill price	Logging and hauling costs	Stumpage price
Inches	Dollars per thousand board feet, Scribner		
[1] 8	180	90	90
[1] 12	190	80	110
16	200	60	140
20	210	50	160
30	215	50	165

[1] Frequently bought and sold on a tonnage basis.

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Table 6--1976 stumpage prices in board feet and cubic feet

D.b.h. of harvested trees	Stumpage price per thousand board feet	Assumed conversion (board foot per cubic foot)	Stumpage price per cubic foot
Inches	Dollars		Dollars
8	90	2.8	0.25
12	110	3.8	.42
16	140	4.3	.60
20	160	5.0	.80
30	165	5.3	.87

Forests in western Washington and Oregon has increased substantially over the last decade. Even when prices are converted to constant dollars to remove general inflation, a substantial increase in real price is evident (table 7). Based on these regional prices and long-term lumber prices nationally, we assumed a 2-percent annual increase in the real value of stumpage. This is

Table 7--Average stumpage prices for old- and young-growth Douglas-fir by year

Year	Stumpage price	
	Actual[1]	1976 dollars[2]
	Dollars per thousand board feet	
1965	43	78
1966	50	88
1967	42	72
1968	61	100
1969	82	127
1970	42	62
1971	49	69
1972	72	98
1973	138	177
1974	202	233
1975	170	180
1976	176	176

[1] Prices paid to USDA Forest Service, Region 6. Source: Ruderman 1977.

[2] Converted to 1976 dollars using consumers price index.

probably a conservative estimate of the long-term trend.

For our analysis, we want to ignore general inflation because it reduces the purchasing power of the dollar by an amount that offsets the increases in revenue. One can readily see, however, that a long-term increase in the price of wood which exceeds general inflation will increase the attractiveness of investments that produce more wood. Therefore, these increases in the real price of wood must be included in an economic analysis.

We consider two ways to accommodate increases in real price. If we included them by projecting current prices at a 2-percent rate of increase, we would have stumpage prices that differed every year. To avoid this inconvenience, we lowered the interest rate on the fertilization investment to adjust for the expected 2-percent increase in the real price of wood. Consequently, we could use today's prices in our analyses. Notice that "today's prices" means current stumpage prices at the time you are performing an economic analysis.

Our procedure is simply a second reduction in interest rates. Recall that we first adjusted market rates of interest to real rates of interest to remove the general effects of inflation. We now calculate an effective rate of interest to incorporate the rate of increase in the real price

of wood. By simple subtraction, we reduce the real rate of interest by the rate of increase in the real price of wood.[5] In our example, the real rate of interest is 7 percent and the rate of real price increase is 2 percent; therefore, the effective rate of interest is 5 percent. Cumulative costs based on other effective rates of interest are provided (Appendix A)

Using an effective rate of interest will make it easier to compare fertilizer investments. Notice, however, that this effective rate of interest does not show the full return on the investment. The full return from the fertilizer investment has two components: the in-

creased volume of wood and the increase in the real price of that extra wood. Therefore, the full return on investment for our break-even analysis is 5 percent plus 2 percent, or 7 percent.

To compare this full rate of return from a fertilization investment with other investments such as stocks and bonds, one must subtract the expected rate of inflation from the market rate of return of stocks and bonds. For example, with inflation estimated at 6 percent, a bond yielding a 10-percent market rate has a net rate of 4 percent compared to the 7 percent of our break-even analysis.

We get a lower cumulative cost when we use an effective rate of interest to project treatment costs. This is an adjusted cost (fig. 7)

_____
[5] Although this is not precisely correct (Flick 1976), the bias is negligible in the range of interest rates relevant to this kind of analysis.
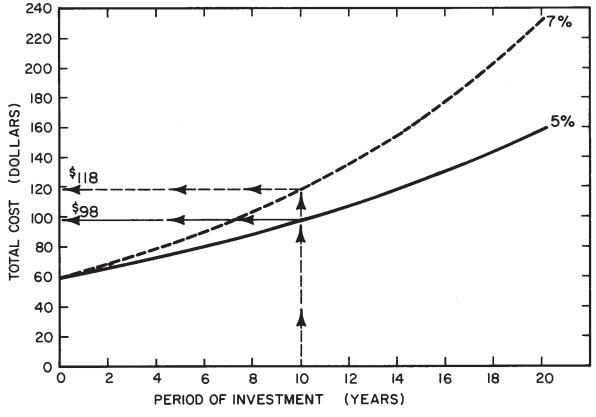

Figure 7.--Cumulative costs of fertilizing based on an initial cost of $60 per acre compounded at 5- and 7-percent interest.

The broken line shows a $60 treatment cost that became a cost of 818 after 10 years. The solid line shows that a $60 treatment cost expands to an adjusted cost of $98. When we use the effective rate of interest, we have automatically incorporated our assumed 2-percent annual increase in the real price of wood. In effect, we have offset part of the cumulative cost of fertilization by the anticipated increase in the real price of wood.

Revenue Required to Break Even

Now we will put these economic definitions and principles into practice by answering some practical questions about the economics of forest fertilization. Appendix B includes a sample worksheet supporting some of these examples and a blank form that can be used for other analyses. You will see what combinations of stumpage prices and extra yields will provide a break-even return from a specified investment in forest fertilization. We have a break-even situation if we specify in our analysis that the revenue should equal the total costs. A profit, however, is indicated if anticipated revenue exceeds the break-even revenue. One can estimate this profit by using more complex methods of economic analysis (Regional Forest Nutrition Project 1975a, 1977)

WHAT BREAK-EVEN VOLUME?

What extra volume from fertilization is necessary to break even? The curving line in figure 8 shows the various combinations of stumpage prices and volumes that will produce a $98 revenue. Recall from figure 7 that a $60 initial cost compounded at 5-percent effective interest rate for 10 years equaled $98.

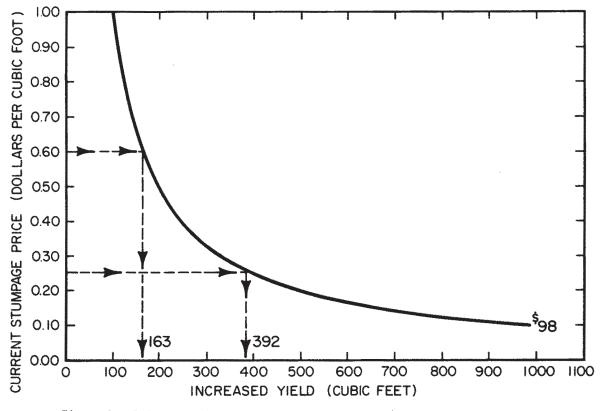

Figure 8.--Price-quantity combinations to offset a $98 per acre cumulative cost of fertilizing.

Notice that the amount of extra volume needed to break even depends on the stumpage price; lesser volumes are needed when stumpage prices are high.

For example, stumpage price for trees averaging 8-inch d.b.h. at harvest was estimated at 25 cents per cubic foot and for trees averaging 16-inch d.b.h. was 60 cents (table 6). Using these stumpage prices, we see that the break-even volume from 8-inch trees is 392 cubic feet and 163 cubic feet if harvested from 16-inch trees (fig. 8). This clearly illustrates the economic advantage of increasing growth of larger trees and harvesting gains from larger trees.

Lower initial costs of treatment reduce the break-even volume. As discussed previously, several factors can lower initial cost of treatment. These include fertilizing large contiguous acreages, applying lesser amounts of fertilizer, or negotiating a contract when the demand for fertilizer or applicators is low. Assume that initial cost can be reduced from $60 per acre to $40. Whereas the $60 cost increases to $98 after 10 years, the $40 cost increases to only $65, as shown by the broken line (fig. 9). Therefore, a lesser volume will cover these reduced cumulative costs. For example, assuming a current stumpage price of 60 cents per cubic foot, 108 additional cubic feet would be necessary to offset a $40 treatment cost, compared to 163 cubic feet to offset a $60 initial cost.

Finally, by lowering the carrying charges, one can reduce the break-even volume. Fertilizing mature trees is one way to do this, because commercial thinning or final harvests
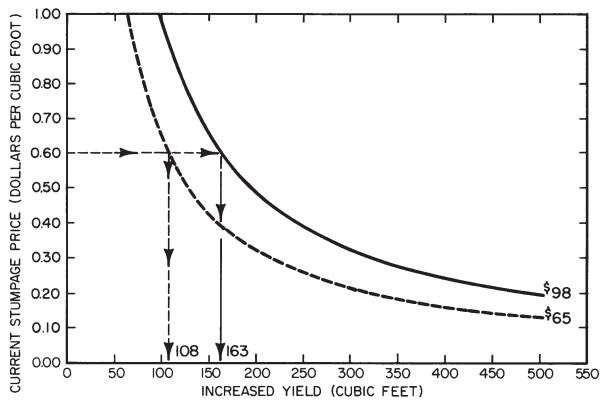

Figure 9.--Volume necessary to offset $65 and $98 cumulative costs at specified stumpage price, per acre basis.

can remove extra volume within 5 to 10 years after fertilization. In figure 10, the solid, curving line again indicates the $98 revenue necessary to cover a $60 treatment cost when carried for 10 years at 5-percent compound interest. If harvest is delayed for 20 years after fertilization, however, this initial cost expands to $159. Therefore, more volume is necessary to break even.

For example, if we fertilize a stand averaging 6-inch d.b.h. and waited 10 years until crop trees averaged 8 inches with an estimated stumpage value of 25 cents per cubic foot, we would need 392 cubic feet to break even (fig. 10). Now compare this volume to the 636 cubic feet necessary for another land manager who fertilizes 3-inch trees and must wait 20 years for the increase to be harvested from 8-inch trees. Doubling the investment period increases the total cost from $98 to g59 per acre. Therefore, 636 cubic feet instead of 392 would be necessary to break even.

WHAT BREAK-EVEN PRICE?

Now, let us use these same curves in a different way. Based on existing data from fertilized stands (table 3), some managers can estimate the amount of extra volume they expect from fertilizing a specific stand. Therefore, they can judge the economic feasibility of fertilization by determining the current stumpage price needed to break even.

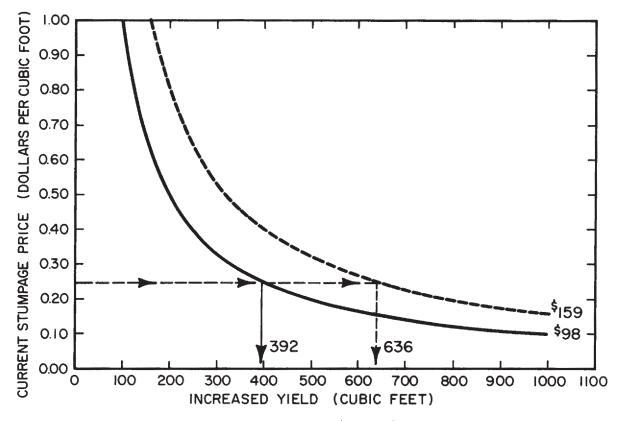The same procedure used to estimate break-even *volume* can also be used to find the break-even *price*. First,

Figure 10.--Volume necessary to offset $98 and $159 cumulative costs at specified stumpage price, per acre basis.

estimate the gain in salable volume from fertilization and the years between fertilization and harvest, i.e, the period of investment. Second, determine the total cost of fertilization for a specified initial cost and the estimated period of investment. Third, use the graph of price-quantity combinations to estimate the current stumpage price necessary to offset this cumulative cost. If this estimated stumpage price is less than would be anticipated for the current market, then the break-even price is exceeded and a profit is indicated. An example will clarify this.

Assume a harvest of 500 cubic feet per acre 10 years after fertilization. An initial treatment cost of $60 per acre will expand to a total cost of $98 in 10 years. Therefore, a stumpage price of 20

cents per cubic foot would be necessary to offset thiS cumulative cost (fig 11). A profit is indicated if current stumpage price exceeds 20 cents per cubic foot (the break-even price).

The preceding examples can be verified using the worksheet (Appendix B), the table of multipliers (Appendix A), and the graph of price-quantity combinations (Appendix C). Reworking these examples will check your understanding of the procedure before solving other problems of your choosing. A worksheet with data inserted from some of the sample problems is included as well as a blank form for solving other problems.
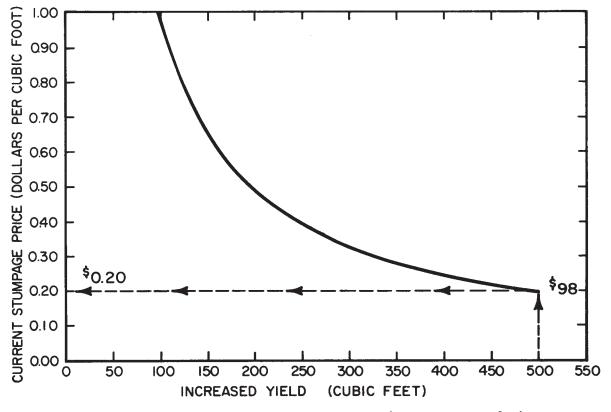

Figure 11.--Stumpage price necessary to offset a $98 per acre cumulative cost of fertilizing when expected gain in volume is 500 cubic feet per acre.

Other Financial Considerations

The effect of income taxes, the timing of cash flow, and other factors to be included in investment decisions are discussed below.

EFFECT OF INCOME TAXES

Our previous discussion and examples were directed toward obtaining a break-even analysis on a before-tax basis. Forestry and nonforestry investments should, however, be compared on a before- and after-tax basis. Net income from the timber sale will ordinarily be taxed as a capital gain rather than as ordinary income. This reduces the tax effect, because part of the income is tax exempt. Thus, the effect of taxation on forestry investments is often less than it is on most other investments.

Costs and revenues could be entered on the accompanying worksheet on an after-tax basis by adjusting them for tax effects. The result would be a break-even analysis on an after-tax basis that could be compared to other investments on an after-tax basis. More detailed procedures for doing that, however, are beyond the scope of this report.

CASH FLOW MANAGEMENT

As anyone with a checking account and financial obligations knows, cash flow management requires some attention. Negative balances are not tolerated for long and penalty costs are associated with them. Cash flow management by forest landowners poses similar problems. Some landowners have ready access to outside sources of investment capital while others do not. Those without ready access to capital must pay particular attention to cash flow management. Even those with ready access to capital must manage cash flows carefully, because the cost of borrowing capital is usually higher when it comes from outside sources. For most landowners, financing new investments out of accumulated savings or current income is probably the least costly method of financing. Therefore, forest landowners should consider timing receipts from timber harvest to provide cash needed for investments like fertilization. In some circumstances, altering the timing of commercial thinning or final harvest to coincide with needs for cash may be the most attractive method of financing.

CASH FLOW EFFECTS

Our economic analysis relates to fertilizing a specific stand of trees. Costs are incurred when a stand is fertilized. Subsequently, interest charges accrue on this investment. Revenue is received when the fertilized stand is thinned or harvested. This sequence of activities closely approximates the cash flow that results from fertilization investments for many private and some public forest managers. The effect of fertilization on the cash flow from some forests, however, may be very different.

On most public lands, the policy is to provide a non-declining flow of wood from the forest. This policy makes current harvests sensitive to current and future growth rates.

Mature or overmature stands in the forest inventory provide flexibility to harvest immediately extra growth gained from treating immature stands. For example, when growth is increased by fertilizing young stands, the harvest and resulting cash flow from mature stands may increase immediately. The increase in current harvest that occurs before any treated stands are actually harvested is called the "allowable cut effect" (Schweitzer et al. 1972).

It is widely recognized that the allowable cut effect occurs. It is also widely recognized that the immediate increase in current harvest and cash flow is the result of increasing the growth on future stands. Clearly, this immediate increase in cash flow does not come directly from the sale of wood that is produced by the fertilizer. Yet, through the allowable cut effect,

fertilization can increase harvest level and cash flow.

Understandably, there is disagreement and controversy over the consideration that should be given to this immediate cash flow increase in ranking alternative investments in forest management (Lundgren 1973, Teeguarden 1973). Furthermore, the magnitude of the allowable cut effect does not have a predictable relationship to the increases in future growth (Bell 1976). The allowable cut effect can be reliably estimated only by making a series of allowable harvest calculations and then comparing them. Because of these limitations, it is probably unsafe to consider the allowable cut effect in investment decisions without t~e counsel of someone knowledgeable in the economic theory that supports benefit-cost analysis. The immediate increase in cash flow, however, that would accompany a fertilization program is a consequence that decisionmakers should recognize.

Summary

The seven major points of Part II follow:

1. The total costs of fertilization include the initial costs of fertilizing and the interest charges on this investment.

2. Because of the nature of compound interest charges, fertilizing stands that will be harvested in 10 years will generally be more profitable than fertilizing stands that will be harvested after a longer investment period.

3. Because larger trees bring a higher price than smaller trees, fertilizing larger trees will generally be more profitable than treating smaller trees on sites of equal productivity.

4. Because of the greater growth increases reported for low-quality sites after fertilization, fertilizing trees on these poorer sites will generally be more profitable than treating trees of the same size on sites of higher natural productivity.

More precise statements about setting priorities among stands for fertilization require more detailed information and analysis.

5. A projected long-term increase in the price of wood which exceeds general inflation will increase the attractiveness of fertilization and other investments that produce more wood.

6. Timing of receipts from timber harvests to coincide with cash needs for fertilization will often be the least costly method of financing.

7. Fertilization can be an economically attractive way to increase wood production of Douglas-fir forests.

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Appendix A

Multiplier to convert initial cost to total cost[1]

Years	Effective rates of interest — percent						
	3	4	5	6	7	8	9
5	1.16	1.22	1.28	1.34	1.40	1.47	1.54
6	1.19	1.27	1.34	1.42	1.50	1.59	1.68
7	1.23	1.32	1.41	1.50	1.61	1.71	1.83
8	1.27	1.37	1.48	1.59	1.72	1.85	1.99
9	1.30	1.42	1.55	1.69	1.84	2.00	2.17
10	1.34	1.48	1.63	1.79	1.97	2.16	2.37
11	1.38	1.54	1.71	1.90	2.10	2.33	2.58
12	1.43	1.60	1.80	2.01	2.25	2.52	2.81
13	1.47	1.67	1.89	2.13	2.41	2.72	3.03
14	1.51	1.73	1.98	2.26	2.58	2.94	3.34
15	1.56	1.80	2.08	2.40	2.76	3.17	3.64
16	1.60	1.87	2.18	2.54	2.95	3.43	3.97
17	1.65	1.95	2.29	2.69	3.16	3.70	4.33
18	1.70	2.03	2.41	2.85	3.38	4.00	4.72
19	1.75	2.11	2.53	3.03	3.62	4.32	5.14
20	1.81	2.19	2.65	3.21	3.87	4.66	5.60

[1] Example: Assuming (1) initial cost of fertilizer = $60, (2) an investment period = 10 years, (3) an effective rate of interest = 5 percent, then total cost = $60 X 1.63 = $97.80.

Appendix B

Worksheet for determining break-even volume or stumpage price

<u>Known or assumed</u>

1. Initial cost of fertilizing $ **60** per acre

2. Years to next commercial cut   **10** years

3. Average d.b.h. of trees to be harvested   **8** inches

4. Market rate of interest   **12** percent

5. Rate of inflation   **5** percent

6. Rate of increase in real price of stumpage   **2** percent

<u>Compute or determine</u>

7. Effective rate of interest   **5** percent
    (Item 4 - Item 5 - Item 6)

8. Cumulative cost of fertilizing $ **98** per acre
    (Item 1 X multiplier from Appendix A)

9. Break-even volume

    A. Assumed stumpage price $ **.25** per cubic foot
        (Table 6 or supply your own)

    B. Volume needed to break even   **392** cubic feet per
        (Read from Appendix C or   acre
        item 8 ÷ item 9A)

10. Break-even price

    A. Assumed volume gain   **500** cubic feet per
        (Tables 2 and 3 or supply your own)   acre

    B. Stumpage price needed to break even $ **.20** per cubic foot
        (Read from Appendix C or
        item 8 ÷ item 10A)

Worksheet for determining break-even volume or stumpage price

<u>Known or assumed</u>

1.   Initial cost of fertilizing $_____ per acre

2.   Years to next commercial cut   _____ years

3.   Average d.b.h. of trees to be harvested   _____ inches

4.   Market rate of interest   _____ percent

5.   Rate of inflation   _____ percent

6.   Rate of increase in real price of stumpage _____ percent

<u>Compute or determine</u>

7.   Effective rate of interest   _____ percent
     (Item 4 - Item 5 - Item 6)

8.   Cumulative cost of fertilizing $_____ per acre
     (Item 1 X multiplier from Appendix A)

9.   Break-even volume

     A.   Assumed stumpage price $_____ per cubic foot
          (Table 6 or supply your own)

     B.   Volume needed to break even   _____ cubic feet per
          (Read from Appendix C or   acre
          item 8 ÷ item 9A)

10. Break-even price

     A.   Assumed volume gain   _____ cubic feet per
          (Tables 2 and 3 or supply your own)   acre

     B.   Stumpage price needed to break even $_____ per cubic foot
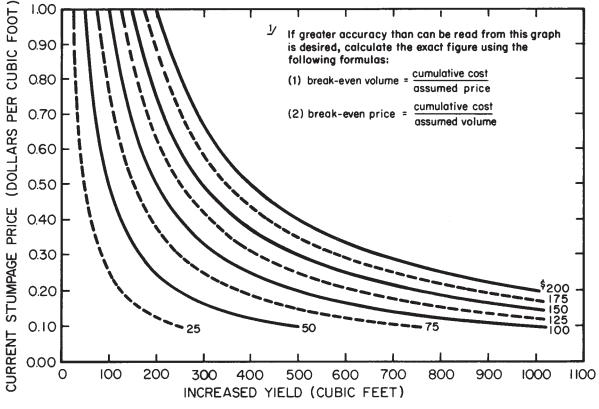   (Read from Appendix C or
          item 8 ÷ item 10A)

Figure 12.--Price-quantity combinations to offset specified cumulative costs of fertilizing, per acre basis.

The graph axes and labels:
- Y-axis: CURRENT STUMPAGE PRICE (DOLLARS PER CUBIC FOOT), from 0.00 to 1.00
- X-axis: INCREASED YIELD (CUBIC FEET), from 0 to 1100

Note on graph:
[1] If greater accuracy than can be read from this graph is desired, calculate the exact figure using the following formulas:

(1) break-even volume $= \dfrac{\text{cumulative cost}}{\text{assumed price}}$

(2) break-even price $= \dfrac{\text{cumulative cost}}{\text{assumed volume}}$

Curve labels: 25, 50, 75, 100, 125, 150, 175, $200

The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range. and related environments.

Within this overall mission the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.

2. Developing and evaluating alternative methods and levels of resource management.

3. Achieving optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington. Alaska, and, in some cases, California, Hawaii. the Western States, and the Nation. Results of the research are made available promptly. Project headquarters are at:

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