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CALCULATIONS CONCERNING THE PROFITABILITY OF FOREST FERTILIZATION

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Kari Keipi & Otto Kekkonen

CALCULATIONS CONCERNING THE PROFITABILITY OF FOREST FERTILIZATION

PREFACE

The present study has been made in the Finnish Forest Research Institute, Department of Forest Economics. It was initiated by OTTO KEKKONEN, M.F., who collected the material, and wrote the first draft of the manuscript. KARI KEIPI, M.F., completed the work, amending the calculations and revising the manuscript.

In the course of study the authors have received valuable assistance and advice from several people; it is appropriate that the Department of Forest Economics and the authors hereby formally express their appreciation to these people. The authors would also like to thank all those who gave assistance in preparing this paper for publication.

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1. INTRODUCTION

Fertilization is gaining ground in forest management. In Finland, where the shortage of roundwood is perhaps the greatest obstacle to the expansion of forest industry, forest fertilization is likely to be increased greatly in the next few years.

Forest fertilization can be viewed from several angles: the government's, the industrial company's or the private forest owner's. The decision-making authority in the government integrates the treatment of forests in the total national economy. Wood-using industry sees fertilization as a means of securing its supply of raw material. For the forest owner, fertilization is part of his management practice.

The present study will review forest fertilization from the point of view of a private forest owner. To start with, the factors to be taken into account in the economic planning of fertilization will be discussed. The factors affecting the profitability of fertilization will be analyzed and a few methods of calculating the profitability will be discussed. These calculation methods will be applied to the practical situation of determining the profits obtainable from a single fertilization of Scots pine and Norway spruce stands at final cutting age. They are based on increment increases recorded on the fertilization sample plots of the Finnish Forest Research Institute and on growth and yield tables worked out for pine and spruce stands treated with repeated thinnings.

The object of the present study is not so much to investigate the absolute financial profits accruing from fertilization as to observe the development of the advantages of fertilization in mature stands with increasing growing-stock d.b.h. The part played by the stumpage-price level in the profits obtainable from fertilization will also be analyzed.

The purpose of this preliminary study is to ascertain the economic advantages of fertilization in certain individual cases and above all to discover the overall possibilities of studies of this kind in Finnish conditions. It was deemed necessary to find out whether sufficient information existed on the development of the value of trees as a result of diameter increase. Another objective is to determine whether calculations of this type could be carried out within the framework of presently available growth and yield tables.

2. FACTORS AFFECTING THE PROFITABILITY OF FERTILIZATION

21. Costs and returns

Costs refer to the compensation the owners of the capital and production factors used by an enterprise must obtain in order to make the capital and production factors continuously available to that enterprise (DUE & CLOWER 1966, p. 116).

The costs can be divided into payable, *i.e.*, explicit, or non-payable, *i.e.*, implicit costs. Explicit costs arise when the production factors are owned by someone other than the enterprise or the entrepreneur. If the entrepreneur himself owns the production factors the cost arising from their use is implicit (DUE & CLOWER 1966, p. 117).

Forest fertilization usually involves both explicit and implicit costs. Payable costs arise from the purchase of fertilizer and usually also from transporting it to the fertilization site. If the forest owner himself spreads the fertilizer, the arising cost is implicit and its amount is determined by the profit obtained from the alternative use of hired manpower. In addition, fertilization entails the cost of interest on the capital, either explicit of implicit. In this context explicit and implicit costs are not separated.

The fertilization cost proper can usually be estimated with a fair degree of accuracy. The determination of interest on capital is more complicated and will be discussed separately later.

Only the differences between alternatives are of importance in investment calculations (DEAN 1960, p. 562; HONKO 1966, p. 42; VIRKKUNEN 1965, p. 67). Investment in fertilization is considered, in the present study, to affect the returns and costs of the stand which is fertilized, whereas it is not considered to affect the returns and costs of the other stands of the forest enterprise. Studies will, therefore, concern individual stands. However the financial situation of the forest enterprise affects the cost of financing, and when the financial plan is drafted the status of the whole forest enterprise must be taken into consideration (TANTTU 1941, pp. 259—261)

Returns refer to the gross income realized from increment increase produced by fertilization. The returns produced by a single fertilization of short-term effect can be assumed, in principle, to arise in two different ways. First, a stand with a given rotation may be considered. The returns in this case arise from the increased quantity of large-diameter wood obtained during the giver rotation than would have been obtained without fertilization. The value of returns is obtained by measuring the increase produced in the cutting value of the stand from the date of fertilization to the end of the period of rotation. Second, a given volume of wood to be grown may be considered. The returns arise in this case from the interest saved due to the shortened period of rotation. It is then assumed that the stand's maturity age is determined by the size of the trees and that after the fertilization is no longer effective the stand continues its development in the same way as an unfertilized stand of the same size. This method was proposed by CARBONNIER (1962).

In the event that the fertilization has a long-term effect or several consecutive fertilizations are carried out to the end of the rotation, neither of the above assumptions is sufficient alone. The returns from fertilization may be taken to arise from an artificial improvement of site quality. As a result, the site will yield more timber than before while at the same time the rotation is shortened. On the basis of the results of fertilization experiments to date we cannot yet discribe the influence of several consecutive fertilizations on the productive capacity of the soil. It is not known whether there is any sense in expecting a "permanent improvement of the site" as a result of fertilization. It is believed, for example. that fertilization with nitrogen alone may before long lead to a deficit of other nutrients (VIRO 1967, p. 122).

22. Period of investment

The period of investment equals the remaining length of the rotation of the fertilized stand. If a cutting of the increment increase produced by fertilization is made immediately after the direct action of fertilization ceases, the result may be a stand that contains less than the optimum density suggested by the growth and yield tables. Rather, it is often suggested that fertilization makes possible an increase in this optimum density (*e.g.*, EINOLA 1964, p. 61).

The basis for selecting an investment alternative is always the optimum period of investment (HONKO 1966, p. 62; EINOLA 1960, p. 81). In this case, therefore, the economic rotation will be used in calculations concerning the stand, as has been done previously in forest value calculations (*e.g.*, HEIKKILÄ 1930, p. 815).[1] Owing to the calculation methods used, however, this can be applied only to an unfertilized stand.

23. Calculative rate of interest

A characteristic of forest fertilization, and of investment in general, is the time dimension. Consequently, the expenditure required for and the income produced by an investment are not

1) See foot note 2 on page 7.

comparable, but must be either compounded or discounted to the same point in time with the aid of a given calculative rate of interest.

The lower limit of the rate of interest used in calculations may be set at the cost of financing the fertilization. This is usually the rate the capital would earn in an alternative use. According to HONKO (1966, p. 65), however, the rate of interest to be used in calculations ultimately equals the return expected from the investment. Hence the rate depends both on the cost of financing and on the forest owner's economic objectives and his subjective evaluations (HAHTOLA 1967, p. 33). The rate of interest used in calculations is therefore the link that connects an individual investment with the overall objectives of the enterprise and also with the world outside the enterprise.

Several factors must be taken into account when the rate of interest to be used in calculations is being determined: the cost of financing; the relative uncertainty of the investment; the liquidity of the investment; and possibly also the effect of taxation on the returns from different investments. The rate, therefore, ultimately depends on the forest owner's judgement, on the basis of which a target rate of return is defined in each case before an investment is made (JÖRGENSEN 1962; HONKO 1966; DUE & CLOWER 1966).

In young forests the uncertainty associated with the fertilization yield is also much greater than in old forests. Liquidity is poorer for the fertilization of young stands than for mature forests. Hence, the rate of interest expected by the forest owner is obviously higher the younger the forest to be fertilized. For example, in a stand approaching maturity the expected rate might be 5 %, in a middle-aged stand 7 %, and in a seedling stand 9 %. If a forest improvement loan, at a interest rate of only 3 % if young forests are being fertilized, can be obtained the expected rate may be somewhat lower. However, the loan is relatively short term and the fertilization investment must therefore be financed with the forest owner's own capital within a few years, it is hardly reasonable to make the expected interest rate lower for young stands than for old forests. Forest improvement loans granted for fertilization of old forests run at a rate of 5 %. In the following calculations, which deal with the profitability of fertilizing forests nearing the final cutting age, various rates of interest, 2, 4 and 6 per cent, have been applied.

3. INVESTMENT CALCULATIONS. The present value, the internal rate of return and the pay-back period.

The primary methods used in investment calculations are the present value, or discount, method, the internal rate of return method and the pay-back period. Under the *present value* method, the future returns and costs are discounted to present values according to a given rate of interest. The investment is profitable if the present value of returns less the present value of costs is zero or greater than zero.

The *internal rate of return* method seeks to determine the rate of interest at which the returns and costs of investment discounted to a given point in time are equal. This method is usually preferred if the enterprise operates with its own limited capital and the highest possible relative return to this capital is desired. But if the capital available is relatively unlimited, the present value method may be better since its objective is to secure the highest possible net returns without too much consideration of the amount of capital.

Since the future is always uncertain, exact calculations are often omitted in practice and are replaced by various methods of approximation. Of them, the *pay-back period* is perhaps the best known; an investment must be able to pay for itself within a given period. The reason why this method is frequently used is, allegedly, that it gives an idea of the liquidity of the investment (HONKO 1966, p. 107). Some other method of determining the profitability proper is often used along with this method.

In theory, any of these methods can be applied to studies of the profitability of forest fertilization. Usually, however, the present value method has been used in calculations of forestry investment, and it will also be used in this study.

4. MEASURING THE RETURNS PRODUCED BY FERTILIZATION

41. Short-term fertilization

411. The felling value method

One way of determining the returns to forest fertilization is to calculate the differences in growing-stock felling values of similar fertilized and unfertilized stands immediatly after the fertilization effect has terminated. This has been done, for example, by VIRO (1966 and 1967). If the fertilized and unfertilized control stands are clear cut as soon as the fertilization has stopped producing an effect, such a calculation is relatively easy. Fig. 1 illustrates the theory which constitutes the basis for calculations made with this so-called felling value method.

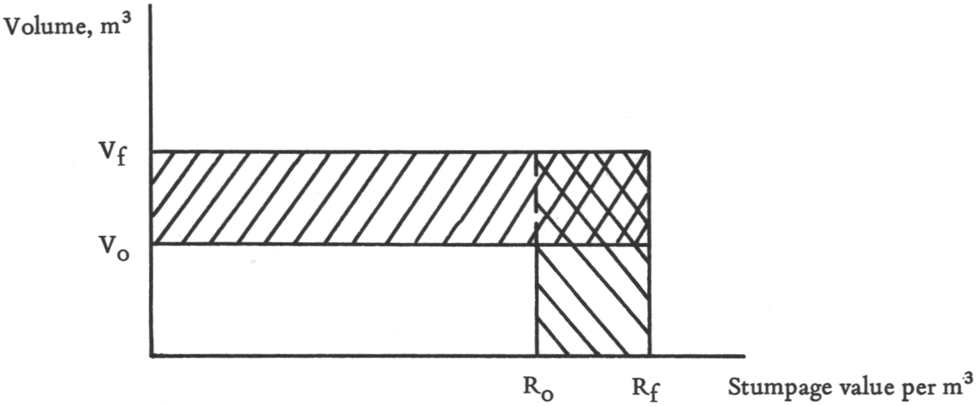

Fig. 1. Theoretical illustration of the calculation of returns produced by the fertilization of an individual stand. (ERKÉN 1969, p. 66).

The increase in the felling value due to fertilization (ΔF) is obtained by subtraction: the product of the increased volume[1] obtained as a result of fertilization (V_f) and the raised stumpage value of a cubic metre (R_f) minus the product of the volume of the corresponding unfertilized stand (V_o) and the stumpage value of a cubic metre (R_o).

$$\Delta F = V_f \cdot R_f - V_o \cdot R_o$$

If the increase in returns produced by fertilization, ΔF, exceeds the fertilization cost converted to the same point in time, the fertilization is a paying proposition.

The felling value method gives systematically erroneous results in certain cases. In mature stands it over-estimates profitability unless final cutting is planned to take place immediately after fertilization loses its effect, *i.e.*, unless the resulting increase in value is realized immediately. This seems to be particularly true if transition from pulpwood to saw timber is at its highest just when fertilization takes effect (see Fig. 6). In a young stand the situation is the reverse. The method based on shortened rotation then gives a higher though more uncertain result, which apparantly is more correct at least in a young stand with no felling value at all.

1) In this study volume is solid measure and m^3 means solid cubic metre.

412. The method based on shortened rotation

Assuming, as suggested by CARBONNIER (1962), that the returns due to fertilization if the rotation is shortened accure in the form of saved interest costs, fertilization is an economic proposition if the increase in the discount value of the stand exceeds the cost of fertilization.

This method was proposed by EINOLA (1964, p. 61) and PEIPPO (1965, p. 20) for use in young forests.

If volume increment of the stand is used as a parameter, the shortening of the rotation is:

$$n = \frac{k}{i}$$

n = number of years by which the rotation is shortened

k = increase in volume increment as a result of fertilization (during the whole effective period)

i = annual volume increment of the stand after the fertilization loses its direct effect.

Since in practice the rotation can only be shortened by whole years, the problem is how to proceed if the rotation is shortened by some fraction of a year. As was obvious from the above, however, it makes little difference whether we assume that more timber is grown within the same period of rotation or the same quantity of timber is grown within a shorter period of rotation, since the effect of one-time fertilization on mineral soils is usually relatively small. Consequently, the calculations may assume that the rotation is shortened by a number of months although, in practice, a correspondingly larger quantity of timber is grown within the same unshortened rotation.

The formulas for calculating fertilization returns on the basis of shortened rotation are presented below. They are adapted from formulas derived by EINOLA (1964, p. 53) for determining the optimum regeneration time. Only returns and variable costs relating to a single stand are considered; fixed costs are not included because they are not affected by decisions concerning fertilization. The formulas estimate the contribution margin values of fertilized and unfertilized stands. The difference between the contribution margin values indicates the increase in discounted returns net of variable costs (but not including fertilization costs) produced by fertilization.[1]

$$T_o = \frac{(a\text{-}c) + \sum_{m}^{u} d_x \cdot 1.0\,p^{u-x} + \dfrac{(a\text{-}c) + \sum_{o}^{u} d_x \cdot 1.0\,p^{u-x}}{1.0\,p^{u} - 1}}{1.0\,p^{u-m}}$$

$$T_f = \frac{(a\text{-}c) + \sum_{m}^{u'} d_{x'} \cdot 1.0\,p^{u'-x'} + \dfrac{(a\text{-}c) + \sum_{o}^{u} d_x \cdot 1.0\,p^{u-x}}{1.0\,p^{u} - 1}}{1.0\,p^{u'-m}}$$

T_o = contribution margin value, unfertilized stand

T_f = contribution margin value, fertilized stand

a = revenue from final cutting

c = cost of regeneration

d_x = net revenue from thinning at age x

$d_{x'}$ = net revenue from thinning at age x', assuming that x' = x − n

u = rotation, unfertilized

u' = rotation in a fertilized stand, assuming that u' = u − n

m = age of stand in the year of fertilization

p = rate of interest used in calculations

n = shortening of the rotation as a result of fertilization

Only the returns and costs arising at or after the moment of fertilization are considered in calculating the contribution margin value. Fertilization is profitable if the increase in the contribution margin value ($T_f - T_o$) exceeds the cost of fertilization. As pointed out earlier, the basis to be used in the calculations is the economic rotation[2] of an unfertilized stand; that for which the contribution margin value at the beginning of the rotation is maximum.

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1) 1. op^u refers to the rate of interest factor $(1+i)^u$, in which $i = \frac{p}{100}$

2) Opinions differ widely whether or not to use this kind of "economic rotation" on "financial maturity" in the profitability calculations (e.g. HEIKKILÄ 1930; KELTIKANGAS 1962). Because in this study only the relative, not the absolute, profitability of forest fertilization will be scrutinized, the concept existing in the original manuscript has not been changed.

42. Long-term fertilization

If fertilization has a long-term effect, or if several consecutive fertilizations take place and the aggregate profitability of the various fertilizations is to be calculated, the situation is similar to that when the profitability of drainage is calculated; there is a long-term improvement in the site quality which must be taken into account.

If fertilization is begun in the year the stand is established and continued for not less than the first rotation, the present value of the returns to fertilization less the present value of fertilization expenses equals the increase in the contribution margin value produced by fertilization. If it is estimated, for example, that a *Vaccinium* site-type is converted by fertilization into a *Myrtillus* site-type, the present value of the returns to fertilization equals the difference between the contribution margin values of *Myrtillus* and *Vaccinium* sites. Any advantages of fertilization become evident when this increase in contribution margin value is compared with fertilization expenses.

If fertilization is initiated when the stand is older, the calculation is more complicated. If it is assumed as before that a *Vaccinium* site can be converted by fertilization into a *Myrtillus* site, fertilization starting when the stand is 50 years old (for example) and continuing for an unlimited period, then the present value of the returns to fertilization will equal the difference resulting when the contribution margin value of the *Vaccinium* stand with no fertilization is subtracted from that of the "new" *Myrtillus* stand. Yield tables show that a 50-year old *Vaccinium* pine stand approximately equals a 42-year old *Myrtillus* pine stand in height and volume. Consequently, the present value of the returns to fertilization would be the contribution margin value of the 42-year old *Myrtillus* pine stand minus that of the 50-year old *Vaccinium* pine stand.

If fertilization is to be continued only to the end of the rotation, the succeeding rotations should be calculated according to the unfertilized alternative, *i.e.*, the *Vaccinium* pine stand in both cases. This alternative, fertilization during only one rotation cycle, can be expressed by formulas as follows:

$$T_o = \frac{(a-c)_u + \sum_{m}^{u} d_x \cdot 1.0p^{u-x} + \dfrac{(a-c)_u + \sum_{o}^{u} d_x \cdot 1.0p^{u-x}}{1.0p^{u} - 1}}{1.0p^{u-m}}$$

$$T_f = \frac{(a-c)_y + \sum_{r}^{y} d_z \cdot 1.0p^{y-z} + \dfrac{(a-c)_u + \sum_{o}^{u} d_x \cdot 1.0p^{u-x}}{1.0p^{u-x} - 1}}{1.0p^{y-r}}$$

T_o = contribution margin value, unfertilized stand
T_f = contribution margin value, "new" stand on improved site
r = economic age of the "new" stand in the year of fertilization
a = final cutting revenue
c = cost of regeneration
y = rotation on the improved site
u = rotation unfertilized
d = thinning revenue at age x, or fertilized at age z
m = biological age of stand in the year of fertilization
p = rate of interest used in calculations

Fertilization, therefore, is profitable if $T_f - T_o$ exceeds the fertilization costs discounted to the date when the fertilization was first carried out.

This type of calculation, which presupposes several consecutive fertilizations within the remaining period of rotation, is probably not often required for a decision concerning fertilization. Each decision most often applies to a single fertilization, with a new decision being required in due course concerning refertilization.

5. CALCULATIONS CONCERNING THE PROFITABILITY OF A SINGLE FERTILIZATION IN STANDS OVER 60 YEARS OLD

51. Source materials and framework of the calculations

511. Growth and yield tables

The calculations concerning profitability of fertilization were carried out for forests nearing the final cutting age using the methods described above for calculating the profitability of fertilization: the felling value method and the method based on shortened rotation.

The primary yield of the stands was calculated according to the growth and yield tables worked out by NYYSSÖNEN (1954) for pine stands, treated with repeated thinnings, on *Vaccinium* sites and by VUOKILA (1956) for managed spruce stands on *Myrtillus* sites. The sample plots of both authors were mainly situated in southern Finland, south of the 62nd latitude. The tables were grouped together by KOIVISTO (1959), but are not fully comparable. For this reason, the tables of the above studies were not used as such in the following calculations: SIVONEN complemented and revised them, producing results which are yet to be published. These growth and yield tables concern stands which grow fully-stocked to final cutting and are treated with repeated low thinnings. Appendices 1 and 2 provide information on these tables.

512. Fertilization trial material and the increase in increment obtained

The Forest Research Institute in the Department of Soil Science has carried out extensive forest-fertilization trials since 1958. A number of sample plot systems established in *Vaccinium* pine stands and *Myrtillus* spruce stands aged over 60 years and situated in southern and central Finland were selected for use. Measurements to verify the effect of fertilization were carried out five years after the fertilization. Average growing-stock data concerning all the sample stands are given below.

Growing stock	*Vaccinium* pine stands	*Myrtillus* spruce stands
age	90 yrs	90 yrs
dominant height	19.9 m	20.0 m
volume including bark	132.6 m^3/ha	136.7 m^3/ha
current annual volume increment excluding bark	3.2 m^3/ha	3.6 m^3/ha

The trials were 2^3 or 2^4 factor trials. The total number of sample plots was 152. The nutrients used were nitrogen, phosphorus and lime in the 2^3 trials and in the 2^4 trials, also potassium. Appendix 3 illustrates the arrangement of a 2^3 trial.

Table 1 specifies the fertilizers used in the trials, their nutrient content and the quantities of fertilizer spread over the sample plots.

Before determining the increase in increment produced by the different fertilizers, the homogenity of the material was analyzed. The blocks fertilized with ammonium sulphate and urea, on the one hand, and those fertilized with "Kotka" phosphate and "fine" phosphate, on the other, were grouped into groups of 2–4 blocks according to age, dominant height and volume increment at the time of fertilization. One-way analysis of variance was used to study whether any significant differences existed in the average growth of the groups before the trial. No such differences were recorded either in these small groups or in larger ones. Nor were significant differences recorded for average

Table 1. Fertilizers used in the trials, their nutrient content, and the quantities spread over sample plots, kg/ha.

Fertilizer	Nutrient content	Quantity used, kg/ha
Nitrogen fertilizers		400
ammonium sulphate	20.5 % N	400
urea	46.3 % N	200 (313)[1]
Phosphorus fertilizers		
"Kotka" phosphate	23.5 % P_2O_5	400
"fine" phosphate	33.0 % "	200
Potassium fertilizer		
potassium salt	50.0 % K_2O	400
Limestone powder	. .	2000

1) 313 kg/ha of urea was spread over one 2^3 block.

growth of the unfertilized sample plots before and during the trial. This showed that measured results could be used in later calculations without correction for increment fluctuations.

The effect of the different fertilizers was verified by the usual method used for calculating the results of factor tests (see, for example, COCHRAN & COX 1964, pp. 155–161). The degrees of the principal and aggregate effects of the fertilizers were tested with the *F* test. The calculations showed that in the five-year trial period the nitrogen fertilization in all cases caused a highly significant increment increase (at the risk of 0.1 per cent). The principal effects of the other fertilizers were not significant (at the risk of 5 per cent). Nor did the fertilizers show an aggregate increasing effect on growing-stock increment. On the contrary, in some of the 2^4 trials, the aggregate fertilizer effect on the sample plots treated with all four nutrients was negative.

The following figures show the average increment increase due to nitrogen fertilization during the five-year trial period. Ammonium sulphate fertilization was used both in the *Myrtillus* spruce stands and *Vaccinium* pine stands. Urea was used only to fertilize *Myrtillus* spruce blocks.

Fertilizer	*Vaccinium* pine stands	*Myrtillus* spruce stands
	m^3 excluding bark/ha/year	
urea	–	1.14
ammonium sulphate	1.06	1.50

The total increment increase in five years in the pine stands averaged 5.3 m^3/ha, in spruce stands fertilized with urea, 5.7 m^3/ha, and in spruce stands fertilized with ammonium sulphate, 7.5 m^3/ha.

On the basis of the results of fertilization trials, the correlation between the fertilization effect produced by nitrogen and some stand characteristics was analyzed. In this case the age of the stand showed no correlation. The stand volume proved to be a poor explaining variable and the pre-fertilization increment did not adequately explain the increment increase due to fertilization.

The insertion of increment and stand volume in a regression model with two independent variables showed that even together they only slightly explained the increment increase due to fertilization. The linear model

$$E = A + B \cdot I + C \cdot V$$

E=increment increase due to fertilization
I= growing stock increment prior to fertilization
V=growing stock volume
A, B, C=constants

proved to be the most serviceable of six linear and three non-linear models. The degree of determination, on application of the equation, averaged 0.194 and the common correlation coefficient was 0.44.

513. Cost of fertilization

In the following profitability calculations the fertilizer quantities are the same as in the fertilization trials described in **Table 1**. Fertilizer prices as of December, 1969 have been used. The retail price of urea was 33.00 mk/100 kg and ammonium sulphate, 27.80 mk/100 kg. The cost of freight, distribution and spreading of each fertilizer was estimated at 7.00 mk/100 kg. The total cost of fertilization with urea was thus 91.20 mk/ha and with ammonium sulphate 132.90 mk/ha.

514. Stumpage prices and regeneration costs

The effect of the stumpage-price level on the profitability of fertilization was studied on the basis of the results of the fertilization trials described above. The calculations were carried out using the mean stumpage prices paid in felling years 1963/64–1967/68 in the forestry board district of Satakunta and, for comparison, that of North Karelia.[1] The prices are presented in the following table:[2]

Table 2. Stumpage prices used in calculations.

Timber assortment	Satakunta	North Karelia
Coniferous saw logs	1.52 mk/cu,ft.	1.31 mk/cu.ft.
2-metre spruce pulpwood including bark	15.0 mk/piled m^3	11.1 mk/piled m^3
2-metre pine pulpwood including bark	11.1 –"–	7.8 –"–
1-metre small sized wood, including bark	3.7 –"–	1.8 –"–

The stumpage prices of spruce and pine pulpwood were converted from stumpage prices of partly barked 2-metre long pulpwood into those of 2-metre long pulpwood including bark by multiplying the values in VÄÄNÄNEN (1965) and those in Metsätilastoa . . . by 0.900 according to the instructions in **Tapion taskukirja.**

The prices of coniferous saw logs were stepped with the aid of coefficients proposed by HARVE (1940, p. 68) according to the mean volume of the stem. The mean price was multiplied by 1.02 to obtain the price of pine logs and by 0.95 to obtain the price of spruce logs (KALLIO 1957, p. 93). The stepped prices are given in **Table 3.**

When the profitability of forest fertilization is calculated by the method based on shortened rotation, the regeneration cost must be known. The regeneration of both the *Vaccinium* pine stands and the *Myrtillus* spruce stands is assumed to take place artificially On the basis of calculations carried out by the Committee on Forest Regeneration Costs, the following costs of planting and management of a seedling stand (converted to the 1969 cost level) were arrived at:[3]

	Pine on *Vaccinium* site	Spruce on *Myrtillus* site
Satakunta	650 mk/ha	710 mk/ha
North Karelia	510 mk/ha	660 mk/ha

1) For location of the districts, see map in Appendix 4.

2) Sources: Metsätilastoa... p. 68; Tapion taskukirja, pp. 81, 83; VÄÄNÄNEN 1965, p. 2. Stumpage prices for 1967/68 were advance estimates.

3) The amounts cover planting with the necessary preparatory work (clearing, scarification, brodcast burning, etc.), complementary planting and seedling-stand improvement.

Table 3. Price stepping of coniferous saw logs according to log volume.

Volume cu.ft.	Satakunta		North Karelia	
	Pine	Spruce	Pine	Spruce
4.0– 4.9	1.22	1.14	1.06	0.98
5.0– 5.9	1.29	1.20	1.11	1.03
6.0– 6.9	1.25	1.25	1.17	1.08
7.0– 7.9	1.41	1.31	1.22	1.13
8.0– 8.9	1.46	1.25	1.26	1.17
9.0– 9.9	1.50	1.40	1.30	1.20
10.0– 10.9	1.55	1.44	1.34	1.24
11.0– 11.9	1.60	1.48	1.38	1.28
12.0– 12.9	1.68	1.53	1.42	1.31
13.0– 13.9	1.69	1.57	1.56	1.35
14.0– 14.9	1.72	1.60	1.49	1.38
15.0– 15.9	1.75	1.63	1.51	1.40
16.0– 16.9	1.80	1.67	1.55	1.44
17.0– 17.9	1.84	1.71	1.59	1.48
18.0– 18.9	1.88	1.74	1.62	1.50

52. Results based on the felling value method

Using the felling value method the additional returns due to fertilization are determined by calculating the difference in money terms between the growing stocks of similar fertilized and unfertilized stands immediately as fertilization becomes ineffective.

The volume increase due to fertilization, required in the calculations, was obtained from the figures quoted above under section 512.

As became apparent above, stand age showed no effect on, and pre-fertilization increment and stand volume were not particularly good variables for explaining, the increment increase due to fertilization. For this reason, the same absolute fertilization effect has been used in the following calculations at all ages of the growing stock from 60 years upwards.

The stumpage price increase due to larger average d.b.h. and increased age was obtained, with the aid of the tables compiled by KOIVISTO (1959) as revised by SIVONEN, by calculating the development of the average monetary value per cubic metre of growing stock as a function of age for an unfertilized stand. The corresponding money value for a fertilized stand was determined by taking into account the increased growing-stock volume resulting from fertilization. This can be done with the aid of the formula of section 412 indicating the shortening of rotation due to fertilization, or by the method shown in Fig. 2.

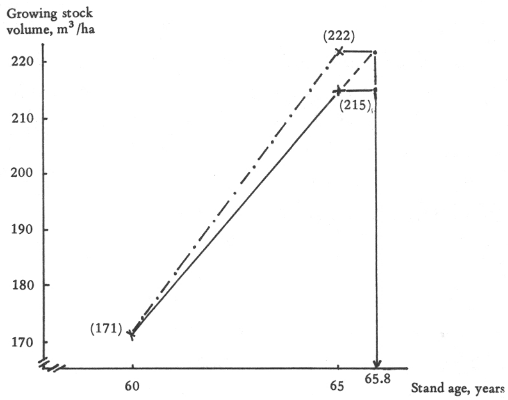

Fig. 2. Determining the "time saved" by fertilization with the aid of curves showing the development of growing stock volume for an unfertilized stand (solid line) and a fertilized stand (broken line).

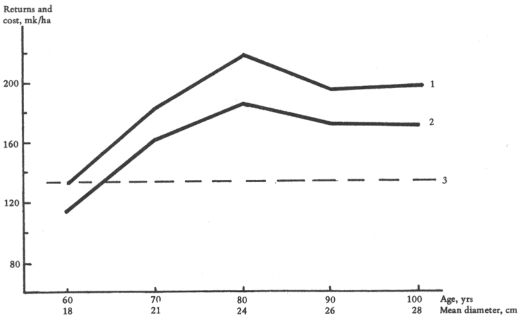

Fig. 3. Cost of ammonium sulphate fertilization and the returns, *Vaccinium* pine stand. Curve 1 is the additional returns calculated at the stumpage prices of Satakunta and curve 2 is returns at prices in North Katelia. Line 3 indicates the cost of fertilization. The calculative rate of interest is 6 per cent.

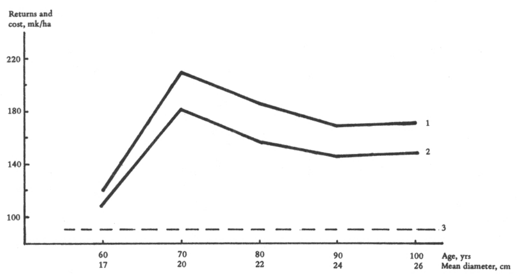

Fig. 4. Cost of urea fertilization and the returns, *Myrtillus* spruce stand. For definition of the curves, see Fig. 3. Calculative rate of interest, 6 per cent.

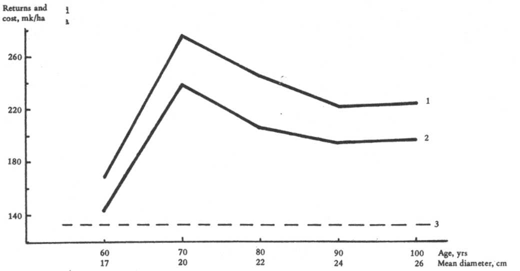

Fig. 5. Cost of ammonium sulphate fertilization and the returns, *Myrtillus* spruce stand. For definition of the curves, see Fig. 3. Calculative rate of interest, 6 per cent.

In Fig. 2 fertilization is assumed to take place when the stand is 60 years old. The effect of fertilization is supposed to last five years during which time the fertilization produces an increment increase of 7 m^3/ha. By extrapolating the curve showing the volume development of an unfertilized stand, the age corresponding to the increased volume is found to be 65.8 years. From this age the stumpage value of a cubic metre growing in a 65-year old fertilized stand can be determined.

The results obtained by the felling value method can be seen from Figs. 3–5. Fig. 3 shows that fertilization of a 60-year old pine stand on a *Vaccinium* site was profitable at a 6 per cent rate of interest when 400 kg ammoniun sulphate was spread per hectare. The cost of fertilization was 133 mk/ha. This profitability assumes that the stand was situated in a demand area where the stumpage-price level was equal to that of Satakunta. With the North Karelian stumpage-price level, fertilization returns discounted at 6 per cent will not exceed costs until the stand is 65 years old. In both cases the returns from fertilization increased until the growing stock reached the age of 80.

Fig. 4 illustrates returns from fertilizating a spruce stand growing on a *Myrtillus* site with urea. The cost of fertilization in this case was 91 mk/ha. Even in a stand aged less than 60 years the returns, discounted at 6 per cent to the time of fertilization, exceeded the cost of fertilization. The returns reached their maximum at about 70 years.

Fig. 5 shows that ammonium sulphate fertilization also was profitable in a spruce stand on a *Myrtillus* site in both Satakunta and North Karelia when the rate of interest expected was 6 per cent. Returns calculated with the felling value method reached their maximum when the growing stock of the fertilized stand was 70 years old.

Calculations show that the average d.b.h. of the growing stock markedly affects the level of the returns to fertilization. The following figures illustrate the difference between returns to fertilization, discounted at 6 per cent, and the costs of fertilization in Satakunta.

Pine stand on Vaccinium site, ammonium sulphate fertilization

Arithmetic mean d.b.h., cm	18	21	24	26	28
Net returns to fertilization, mk/ha	0	51	86	63	66

Spruce stand on Myrtillus site, urea fertilization

Arithmetic mean d.b.h., cm	17	20	22	24	26
Net returns to fertilization, mk/ha	34	117	96	79	80

Spruce stand on Myrtillus site, ammonium sulphate fertilization

Arithmetic mean d.b.h., cm	17	20	22	24	26
Net returns to fertilization, mk/ha	31	141	112	90	91

Fertilization seems to be most advantageous when the growing stock has just reached the saw log stage. In a spruce stand the fertilization returns reach their maximum sooner than in the pine stand. The reason is that the ratio

$$\frac{\text{saw log stumpage price}}{\text{industrial roundwood stumpage price}}$$

is lower for spruce than for pine. In the Satakunta Forestry Board District, for example, the average price ratios of saw logs and pulpwood[1] were as follows:

$$\frac{\text{10 cu.ft spruce saw logs}}{\text{1 piled m}^3\text{ spruce pulpwood}^1} = 0.96$$

$$\frac{\text{10 cu.ft. pine saw logs}}{\text{1 piled m}^3\text{ pine pulpwood}^1} = 1.40$$

53. Results obtained with the method based on shortened rotation

Under the conditions described earlier, profitability calculations were also carried out using the method based on shortened rotation. The formulas presented in section 412 were used. The rates of interest were 2 and 4 per cent. The corresponding rotations were 100 and 80 years for pine stands and 110 and 80 years for spruce stands.

Fig. 6 compares the returns obtained by the felling value method and the method based on shortened rotation for a spruce stand on a *Myrtillus* site and fertilized with urea, using the 2 per cent rate of interest. The curves reveal that felling value method 20—30 years before the final cutting gives a very much higher net return on fertilization than the method based on shortened rotation. The methods give equal net returns when the final cutting takes place immediately after the fertilization looses its effect. The felling value method can only be used if the final cutting is assumed to follow immediately after the fertilization effects is over

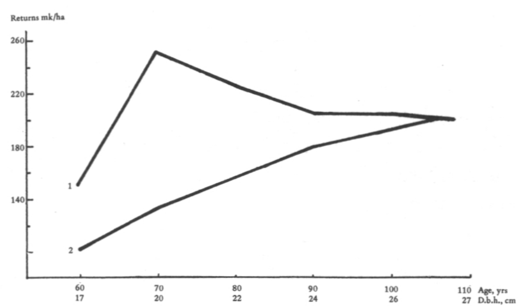

Fig. 6. Returns to urea fertilization calculated at the Satakunta stumpage prices by the felling value method (Curve 1) and by the method based on shortened rotation (Curve 2) for a *Myrtillus* spruce stand. Calculative rate of interest, 2 per cent.

Figs. 7—9 show the returns to fertilization as they appear according to the method based on shortened rotation using rates of interest of 2 and 4 per cent. The returns were higher the larger the average d.b.h. and the nearer the final cutting age. They increased almost rectilinearly with the age of the growing stock.

1) 2-metre long; including bark.

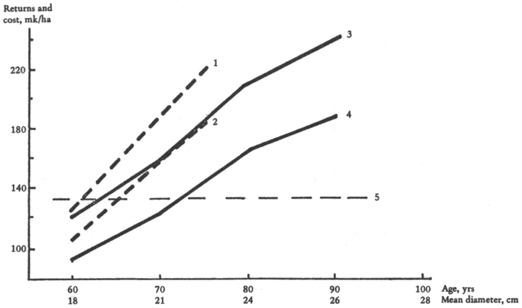

Fig. 7. Cost of and returns to ammonium sulphate fertilization in a pine stand on a *Vaccinium* site calculated by the method based on shortened rotation. Curve 1: additional returns at Satakunta prices; Curve 2: returns at North Karelian prices. Both use a calculative rate of interest of 4 per cent. Curves 3 and 4: the corresponding returns with 2 per cent rate of interest. Curve 5 indicates the fertilization level cost.

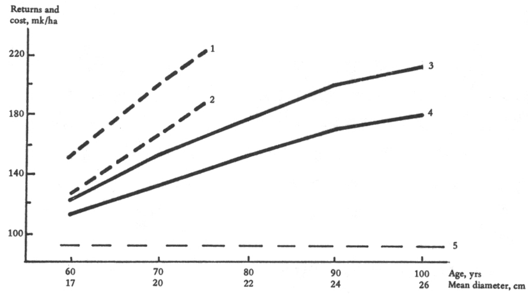

Fig. 8. Cost of and returns to urea fertilization in a spruce stand on a *Myrtillus* site. For definitions of the curves, see Fig. 7.

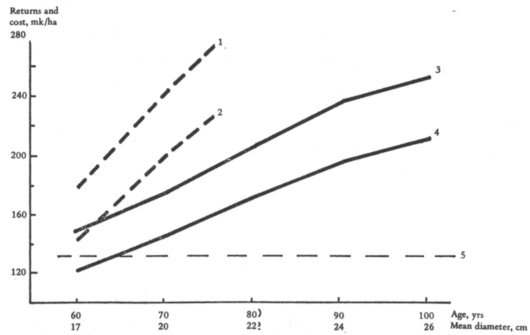

Fig. 9. Cost of and returns to ammonium sulphate fertilization in a spruce stand on a *Myrtillus* site. For definitions of the curves, see Fig. 7.

The following figures disclose how much higher the net returns to fertilization were at the stumpage prices of Satakunta than at those of North Karelia:

Pine stand on Vaccinium site, ammonium sulphate fertilization

interest rate	0.04,	rotation	80 years	22...31 mk/ha
» »	0.02,	»	100 years	27...50 „

Spruce stand on Myrtillus site, urea fertilization

interest rate	0.04,	rotation	80 years	25...34 mk/ha
» »	0.02,	»	110 years	19...32 »

Spruce stand on Myrtillus site, ammonium sulphate fertilization

interest rate	0.04,	rotation	80 years	34...45 mk/ha
» »	0.02,	»	110 years	26...42 »

The closer the time of fertilization was to the final cutting age of the stand the greater the difference realized between net returns calculated for the Satakunta and North Karelian stumpage prices. The results calculated using the felling value method produced comparable differences due to variations in stumpage prices.

The cost of fertilization seemed to hold the decisive position from the profitability point of view. Since nutrients other than nitrogen had no significant effect on the growth in the fertilization trials, the use of multinutrient fertilizer on mineral soils hardly seems sensible, at least for the initial fertilization. Fertilization with ammonium sulphate is more expensive than fertilization with urea. Although the former gave an increment increase which was more than 30 per cent greater than the latter, the net returns were approximately the same in both cases. In the trials, urea was used only in spruce stands on *Myrtillus* sites, and therefore it cannot be said whether urea equals ammonium sulphate on other site types or for pine.

6. RELIABILITY OF THE RESULTS

The above results concerning the effect of fertilization on growing stock increment are based on a relatively small body of experimental material and are therefore uncertain. The dependence of fertilization effects on stand characteristics in mature stands also requires further elucidation.

In the present study, the fertilization effect was assumed to last for five years. The results of the latest fertilization trials made by the Forest Research Institute suggest, however, that the fertilization effect, at least in spruce stands, actually lasts longer, from six to seven years.

In additions to the general uncertainty associated with the future level of stumpage prices it should be noted that the stepping of saw log prices may not correspond to the present situation. The prices used in the calculations naturally are not meant to forecast the future prices. Every forest owner must estimate for himself the price at which his trees may be sold.

One of the purposes of the study was to investigate whether the current increment and structural series provide a suitable basis for profitability calculations of this type. So far we have too few growth and yield studies fit for this purpose. For this reason it was necessary to use in calculating the returns, yield tables in which the growing-stock volume was considerably higher and increment greater than in the stands from which the increment increase due to fertilization was measured. Since the pre-fertilization volume increment of the stand explained poorly the increment increase due to fertilization, and the stand volume was an even poorer explaining variable, the use of these tables in a preliminary study can be defended. On the other hand, according to the results of fertilization studies carried out in Sweden the increment increase in spruce and pine stands of final cutting age on moderately productive sites rather often has a positive correlation to the current annual volume growth (see, for example, MÖLLER 1967, p. 2). Accordingly, the increment increases used in the calculations might be under rather than overestimates for stands compatible with the tables.

Owing to these shortcomings and weaknesses associated with the research material and the final results, it is advisable to adopt a conservative attitude concerning the *absolute* results the study quotes for the profitability of fertilization. On the other hand, the calculations concerning the *relative* profitability of using various fertilizers and fertilizing stands of varying ages apparently give a more reliable picture.

7. CONCLUSIONS

The present study reviewed forest fertilization from the economic point of view, considering it as an investment. Factors to be taken into consideration when fertilization is planned were first analyzed. The discussion of the returns and costs occasioned by fertilization was limited to apply to the fertilized stand alone, but it was concluded that in working out the rate of interest expected when fertilization is undertaken it is also necessary to consider the remaining part of the forest enterprise. The rate of interest expected by the forest owner is affected by the sources of finance at his disposal, his economic standing, his attitude to the uncertain future, and his other economic objectives and investment possibilities.

On the basis of fertilization trials made by the Department of Soil Science of the Forest Research Institute, calculations were carried out concerning the profitability of fertilization in Scots pine and Norway spruce stands nearing their final cutting age. According to the trials, nitrogen alone had a statistically significant influence in the stands on moderately productive mineral soils. In these mature pine and spruce stands the effect of fertilization was found to be rather poorly correlated with the pre-fertilization increment or volume of the growing stock. The increment increase produced by fertilization with ammonium sulphate (82 kg/ha N) in pine stands on *Vaccinium* sites totalled 5.3 m^3/ha excluding bark in five years. In spruce stands on *Myrtillus* sites the same fertilizer produced an increment increase of 7.5 m^3/ha. The increment increase produced by urea fertilization (92.6 kg/ha N) in spruce stands on *Myrtillus* sites was 5.7 m^3/ha excluding bark in five years.

Various calculations were carried out concerning the profitability of fertilization on the basis of growth and yield tables for stands treated with repeated thinnings. They were made using two different methods: the felling value method and the method based on shortened rotation. If the final cutting of the stand takes place immediately as fertilization loses its effect, the methods give approximately similar results. In a mature stand, with the final cutting fertilization, at a calculative rate of interest of 2 and 4 per cent the felling value method overestimates the returns and shows a profitability in excess of the true profitability, the results of the calculations are presented in Figs. 3—9.

The two nitrogen fertilizers used in the trials, ammonium sulphate and urea, proved to be almost equally advantageous in spruce stands on *Myrtillus* sites. The pine stands on *Vaccinium* sites were fertilized with ammonium sulphate alone.

According to the results obtained, f e r t i l i z a t i o n is more profitable the larger the average d. b. h. of the remaining rotation after fertilization loses its effect.

An objective of the present study was also to find out whether information on the development of the stumpage value of a tree as a function of age and d.b.h., indispensable for studies of this type, is available. It was necessary to use investigation results dating back to the 1930s to determine the stumpage price of saw logs, that is to say, results which are hardly valid under present conditions. It was also considered useful to analyze whether the available growth and yield tables for Finnish forests are adequate for research work of this type. The tables for stands treated with repeated thinnings were the only serviceable ones for Scots pine and Norway spruce present. For detailed calculations concerning the profitability of fertilization it is essential to carry out accurate measurements of the structure of the growing stock in the stands in which fertilization trials are carried out. For each stand, the distribution of growing stock by timber assortments must be studied separately. The dates and felling quantities of future removals must be forecast in the best manner possible.

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ABBREVIATIONS USED

AFF = Acta Forestalia Fennica
FF = Folia Forestalia
MA = Metsätaloudellinen Aikakauslehti.
MTJ = Metsäntutkimuslaitoksen julkaisuja. Communicationes Instituti Forestalis Fenniae.

SUOMENKIELINEN SELOSTUS

Laskelmia metsän lannoituksen edullisuudesta

Tutkimuksessa käsitellään metsän lannoitusta taloudelliselta kannalta – investointikohteena. Aluksi analysoidaan lannoituksen edullisuuteen vaikuttavia tekijöitä. Lannoitustuottojen ja -kustannusten tarkastelu rajoitetaan koskemaan pelkästään lannoitettavaa metsikköä. Sen sijaan todetaan, että investointiin ryhtymiseen vaadittavaa korkotavoitetta harkittaessa on myös muu osa metsälöstä aiheellista ottaa huomioon.

Metsäntutkimuslaitoksen maaosaston tekemien lannoituskokeiden perusteella suoritetaan laskelmia kertalannoituksen kannattavuuden kehittymisestä puuston järeytyessä yli 60-vuotiaissa runsaspuustoisissa ja hyväkasvuisissa puolukkatyypin männiköissä ja mustikkatyypin kuusikoissa. Kokeissa käytetyt typpilannoitteet ovat ammoniumsulfaatti (400 kg/ha) ja urea (n. 200 kg/ha). Rahalaskelmat tehdään käyttäen Satakunnan ja Pohjois-Karjalan piirimetsälautakunnissa vallinneita keskimääräisiä hakkuuvuosien 1963/64 – 1968/69 kantohintoja. Lannoitustuotot määritetään kahdella eri tavalla, hakkuuarvomenetelmällä ja kiertoajan lyhenemiseen perustuvalla menetelmällä. Menetelmät antavat saman tuloksen, jos puuston päätehakkuun oletetaan tapahtuvan välittömästi lannoitusvaikutuksen päättymisen jälkeen. Sellaisessa varttuneessa metsässä, jossa päätehakkuu tapahtuu runsaasti lannoitusvaikutuksen päättymisen jälkeen, hakkuuarvomenetelmä yliarvioi tuotot ja antaa liian hyvän kannattavuuden (kuva 6).

Saatujen tulosten mukaan lannoitusinvestoinnille on mahdollista saada sekä Satakunnassa että Pohjois-Karjalassa vallinneita kantohintoja laskelmissa käytettäessä lähes aina jo 60-vuotiaassa metsässä 6 %:n korko. Satakunnan kantohintoja käytettäessä investoinnin sisäinen korko on keskimäärin 4 prosenttiyksikköä korkeammalla tasolla kuin Pohjois-Karjalassa. Jos päätehakkuu tapahtuu heti lannoitusvaikutuksen päätyttyä, lannoitus osoittautuu edullisimmaksi puolukkatyypin männikössä n. 80 v:n iällä ja mustikkatyypin kuusikossa n. 70 v:n iällä (kuvat 3–5). Puuston järeytyessä ja päätehakkuuajankohdan lähestyessä lannoitustuotot kasvavat lähes suoraviivaisesti (kuvat 7–9). Lannoitus osoittautuu sitä kannattavammaksi mitä järeämpi on lannoitettavan metsikön puusto ja mitä lyhyempi jäljellä oleva kiertoaika.

SELVITYKSESTÄ ON TARKOITUS LAATIA LAAJAHKO SUOMENKIELINEN ARTIKKELI, JONKA ON MÄÄRÄ ILMESTYÄ METSÄ JA PUU -LEHDESSÄ SYKSYN 1970 KULUESSA.

Appendix 1. Distribution of growing stock and thinning removals into timber assortment in Vaccinium site pine stands over 60 years old.

Age of growing stock, years	Saw logs			Pulpwood[1]			Small-sized wood		
	Growing stock		Thinning removals	Growing stock		Thinning removals	Growing stock		Thinning removals
	cu. ft.			piled m^3			piled m^3		
	(1)	(2)[2]	(3)	(4)	(5)[2]	(6)	(7)	(8)[2]	(9)
60	1200	1840		131			23		
65		1840	260		141	40		24	11
70	2316			106			14		
75		3130	370		103	30		14	5
80	3540			67			10		
85		4200	480		64	21		10	3
90	4430			42			7		
95		5030	580		41	15		7	2
100	5000			26			6		
105		5550	670		26	9		6	2
110	5350			18			5		

1) The pulpwood quantities refer to 1-meter, partly barked wood.
2) The figures refer to the growing stock volume prior to thinning.

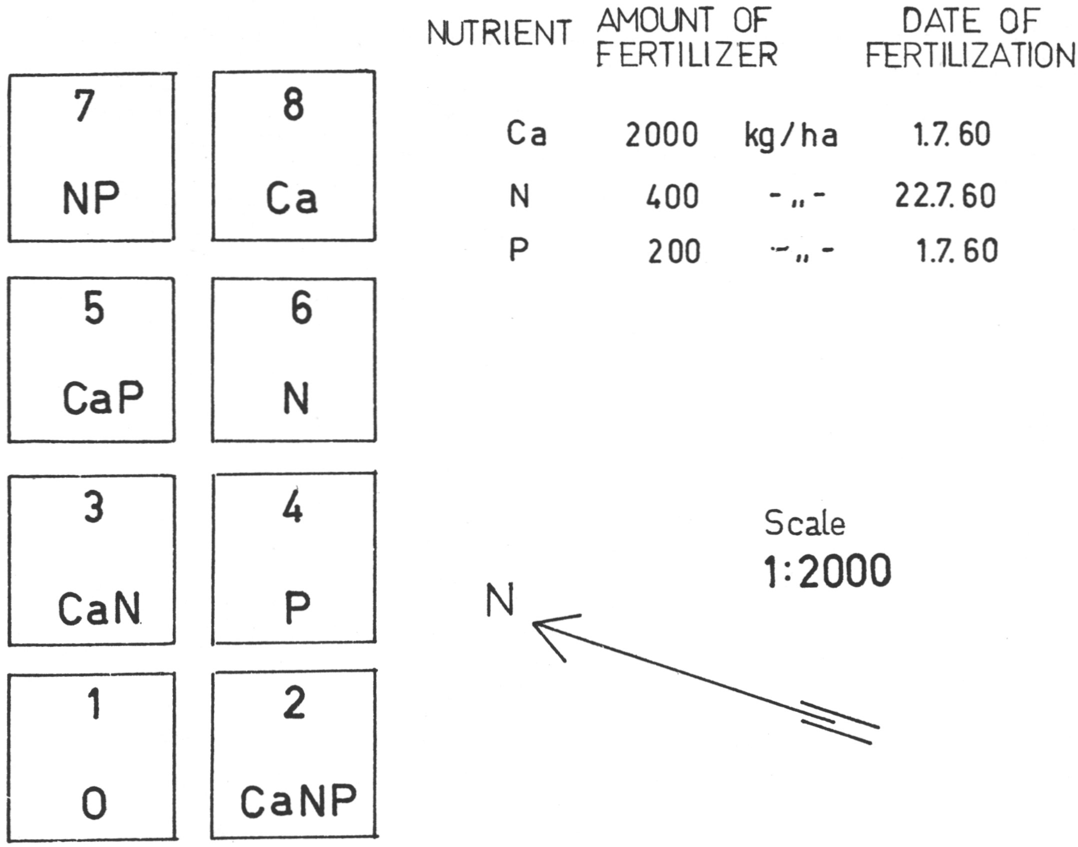
Source: Calculations by SIVONEN for the Committee on Forest Regeneration Costs. Manuscript.

Appendix 2. Distribution of growing stock and thinning removals into timber assortments in Myrtillus site spruce stands over 60 years old.

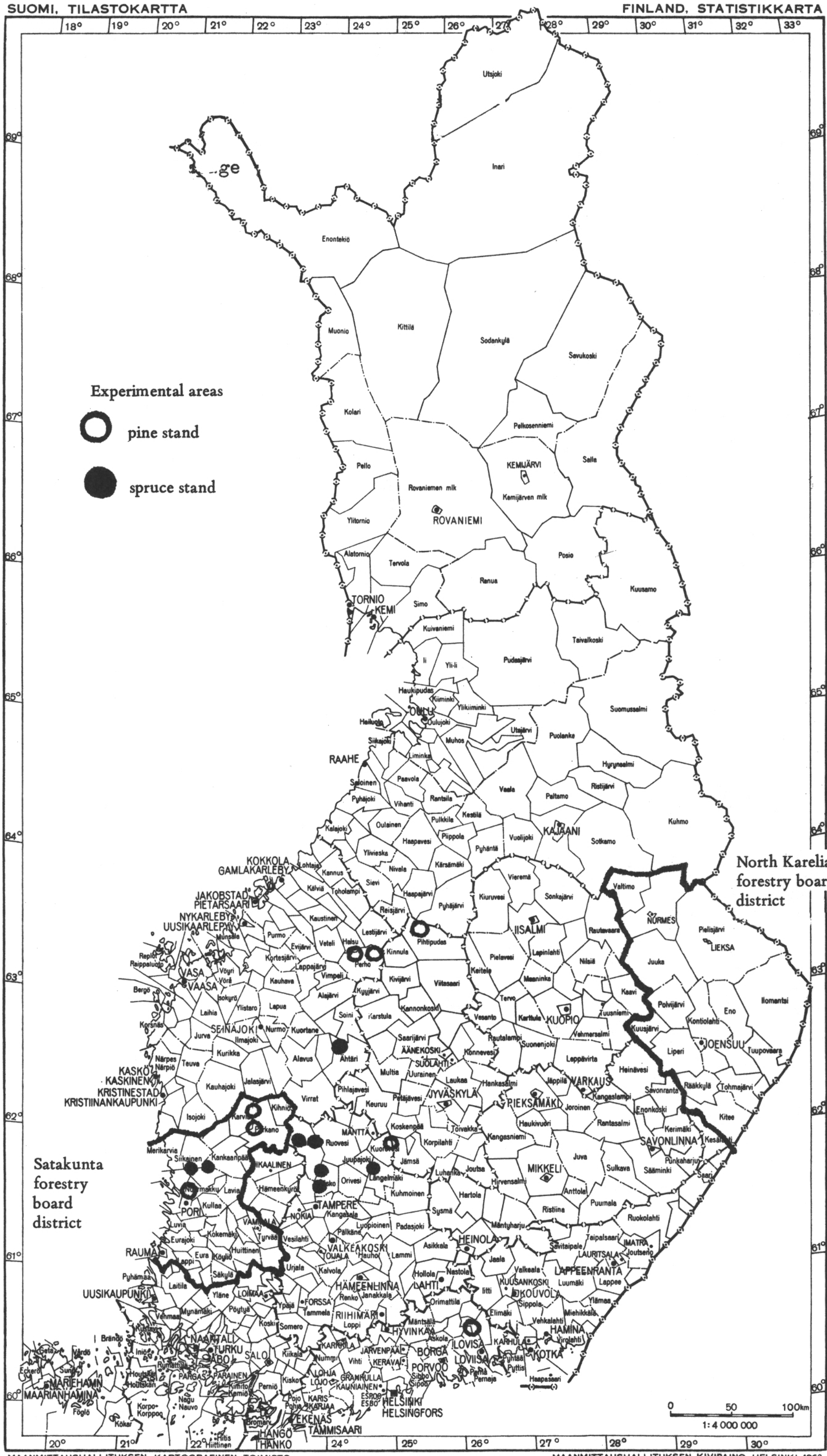
Age of growing stock, years	Saw logs			Pulpwood[1]			Small-sized wood		
	Growing stock		Thinning removals	Growing stock		Thinning removals	Growing stock		Thinning removals
	cu.ft.			piled m^3			piled m^3		
	(1)	(2)[2]	(3)	(4)	(5)[2]	(6)	(7)	(8)[2]	(9)
60	1000			159			26		
65		1765	360		177	42		25	5
70	2500			144			19		
75		3805	735		149	34		19	5
80	4200			117			15		
85		5270	920		117	27		15	3
90	5250			90			12		
95		6100	1100		89	21		12	3
100	5750			67			9		
105		6550	1260		65	15		9	2
110	6050			48			7		

1) The pulpwood quantities refer to 1-meter, partly barked wood.
2) The figures refer to the growing stock volume prior to thinning.

Source: Calculations by SIVONEN for the Committee on Forest Regeneration Costs. Manuscript.



Appendix 3. Example of a fertilization sample plot experiment of the Department of Soil Science, Forest Research Institute. A 2^3 factor trial.



Appendix 4. Location of fertilization experimental areas and the two forestry board districts used for determine stumpage prices.

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