Chapter 23

The Scandinavian Experience in Forest Fertilization Research and Operations

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ABSTRACT. The results of 234 fertilizer field trials including 933 treated plots on mineral soils in Sweden were compiled for use in predicting expected five-year growth increases from nitrogen fertilization of Scots pine and Norway spruce. Findings include information on growth disturbance from boron deficiency, effects of refertilization, the relation between thinning and fertilization, the effects of whole-tree thinning, and environmental impacts of fertilization in watershed areas. The extent of operational fertilization in Finland, Norway, and Sweden since the early 1960s and cooperative research projects shared by the three countries since the mid-1970s are also discussed.

By the end of the 1950s, knowledge about possibilities for increasing forest growth by fertilization had reached practicing foresters in Scandinavia. On mineral soils nitrogen fertilizer had shown a positive effect during the first five years after application, but on drained peat soils phosphorus and potassium were needed as well to produce a satisfactory response. Because the size of the growth increase was very uncertain, many forest companies in Sweden began to establish field trials using different nitrogen fertilizers in various doses in order to determine the growth response on their own forest lands. This research proved to be more complicated than expected and in 1967, when the Institute for Forest Improvement was founded with support from the Swedish forest industry, these trials were handed over to the institute for evaluation and further testing.

Growth Response

In 1978 the results from 234 field trials including 933 treated plots on mineral soils throughout Sweden were compiled for a five-year period (Figure 1). These results made it possible to predict the expected growth increase in m^3/ha for the first five-year period after nitrogen fertilization in different stands of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). Fertilization with NPK gave no better response than nitrogen alone in pine but did produce some additional improvement in spruce.

This prediction function (Rosvall 1979) will not be presented here, because there is little probability that it would work acceptably for other species and in different climates. It might, however, be of some interest to take note of the eight independent variables that had a significant influence on growth response: the amount of nitrogen used, the nitrogen source, the current growth of the stand, site index, latitude, altitude, stand age, and tree species. How the amount and kind of nitrogen fertilizer used influence response on sites of different quality, when all other variables are held constant, can be seen in Figure 2. Response is significantly lower with urea than with ammonium nitrate. The increase in growth response with increased dose is strongly dependent on site index, expressed as the height of the stand at age 100. In the same way the importance of the current growth increment of the stand can be studied (Figure 3), but it must be kept in mind that using a model to study the effect of a single variable, while holding all the others constant, can give a somewhat false picture, because most of the variables are interrelated. For example, it is unlikely that two stands of the same age, one on a nutrient-poor and the other on a nutrient-rich site, will have the same current growth. If they do, the nutrient-rich site must have had improper silvicultural treatments which reduced basal area and needle biomass. The correct way is to use the prediction function, now also available as a PC program for computer calculation, to make a forecast for each stand. The production cost per cubic meter can be calculated and decisions made about the net value of fertilization. These calculations must

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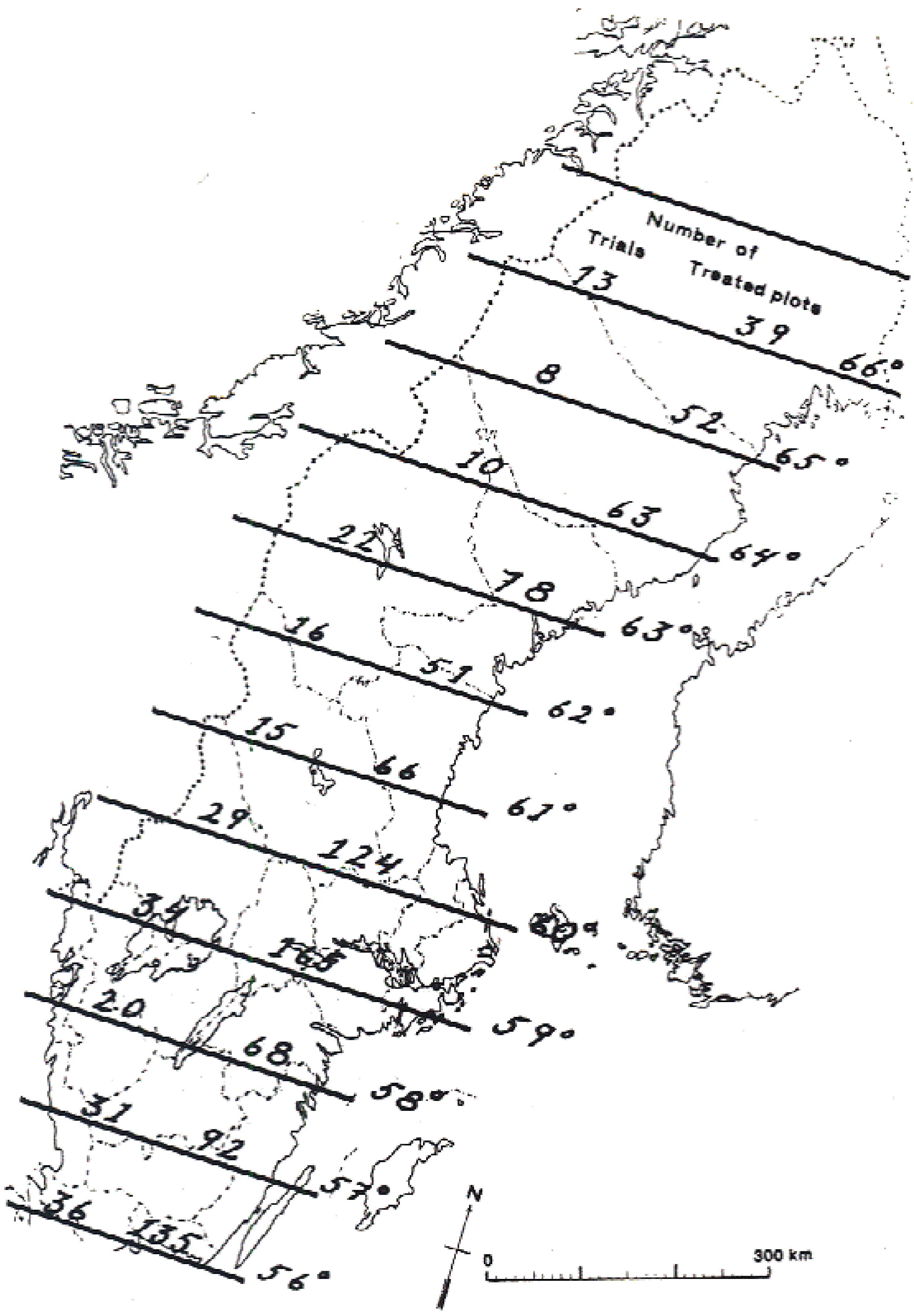

Figure 1. Distribution of the 234 field trials including 933 fertilized plots carried out over a five-year period in Sweden and used in 1979 as the basis for predictions of growth increase of Scots pine and Norway spruce stands.

also take into account the value of the average diameter increases of the stand from the fertilization and the lower logging costs. This means that the economic effect of fertilization can be divided into two parts: volume effect and dimension effect (Figure 4).

In certain areas, growth disturbances from boron deficiency after nitrogen fertilization have been observed on mineral soils, especially after repeated fertilization. These effects generally occurred during the second or third growing season after fertilization and often led to death of the apical bud and needle cast in the upper crown. These disturbances occurred when the foliar boron concentration was below 4 to 5 ppm; Kolari (1979) has given a value of 1 to 4.2 ppm as a deficiency level. Nitrogen fertilization with 150 kg N/ha as ammonium

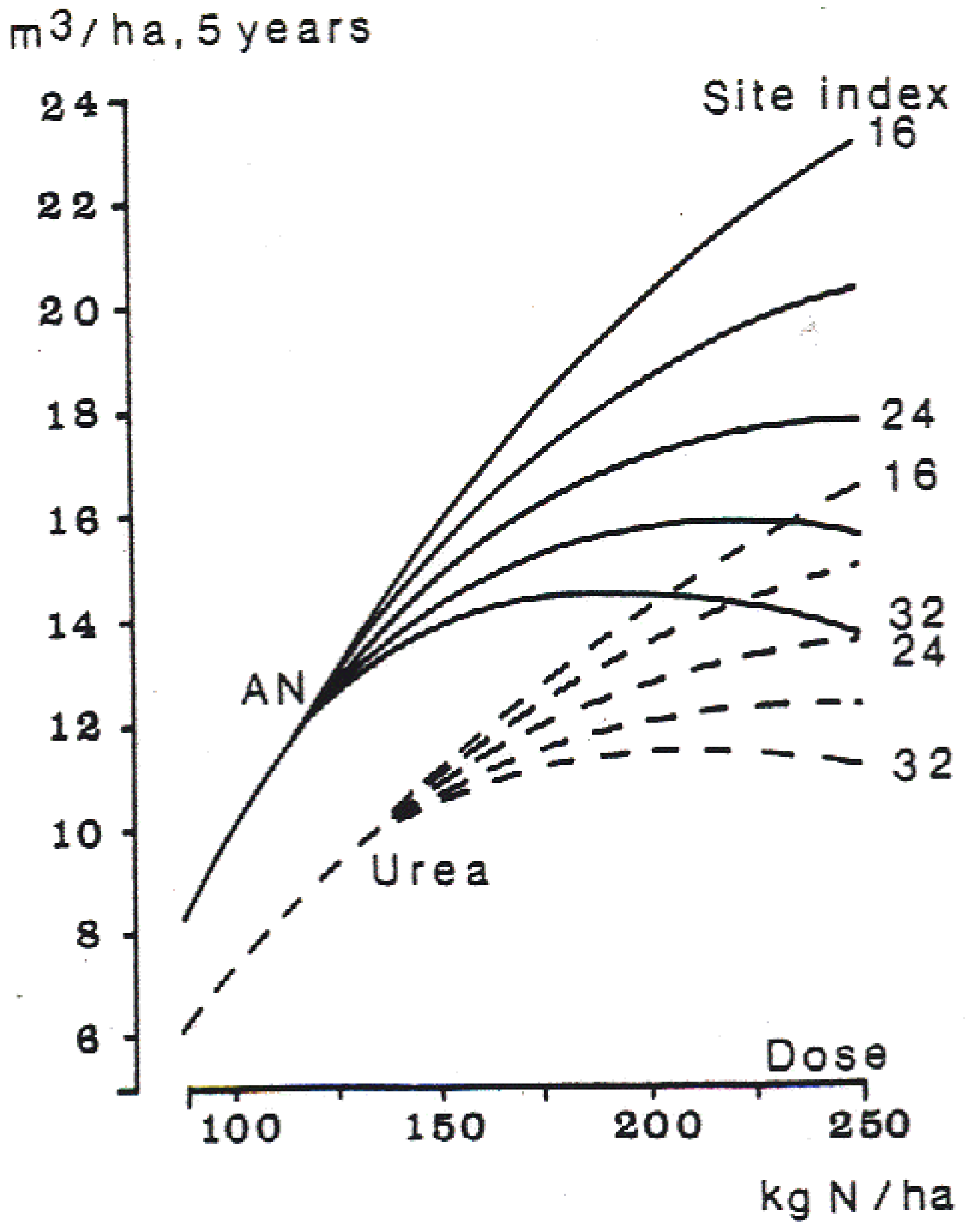

Figure 2. Growth response correlated with nitrogen dose, source of nitrogen, and site index (with other independent variables held constant). AN = ammonium nitrate.

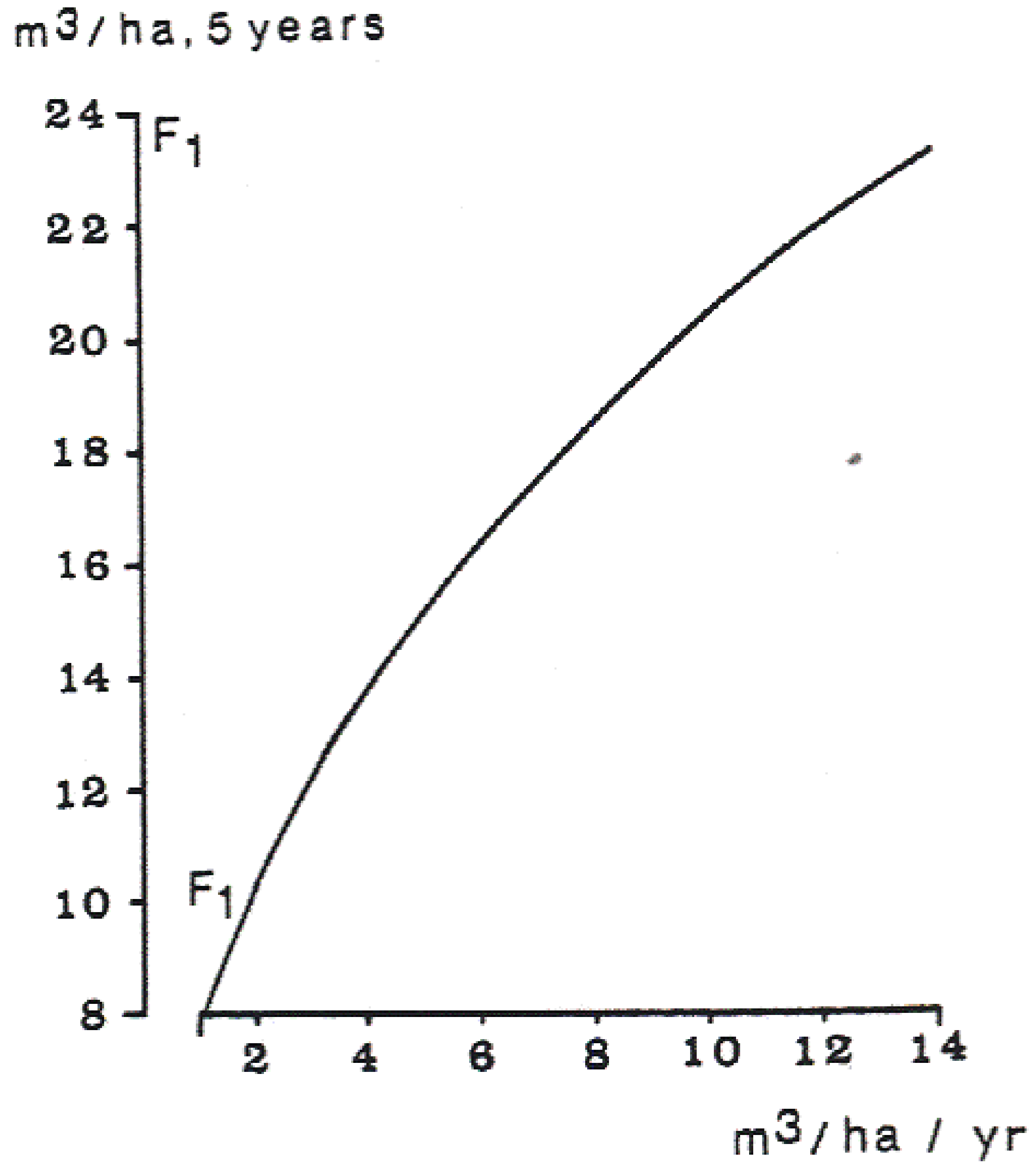

Figure 3. Influence of the stand's current growth increment on fertilization response when other independent variables are held constant.

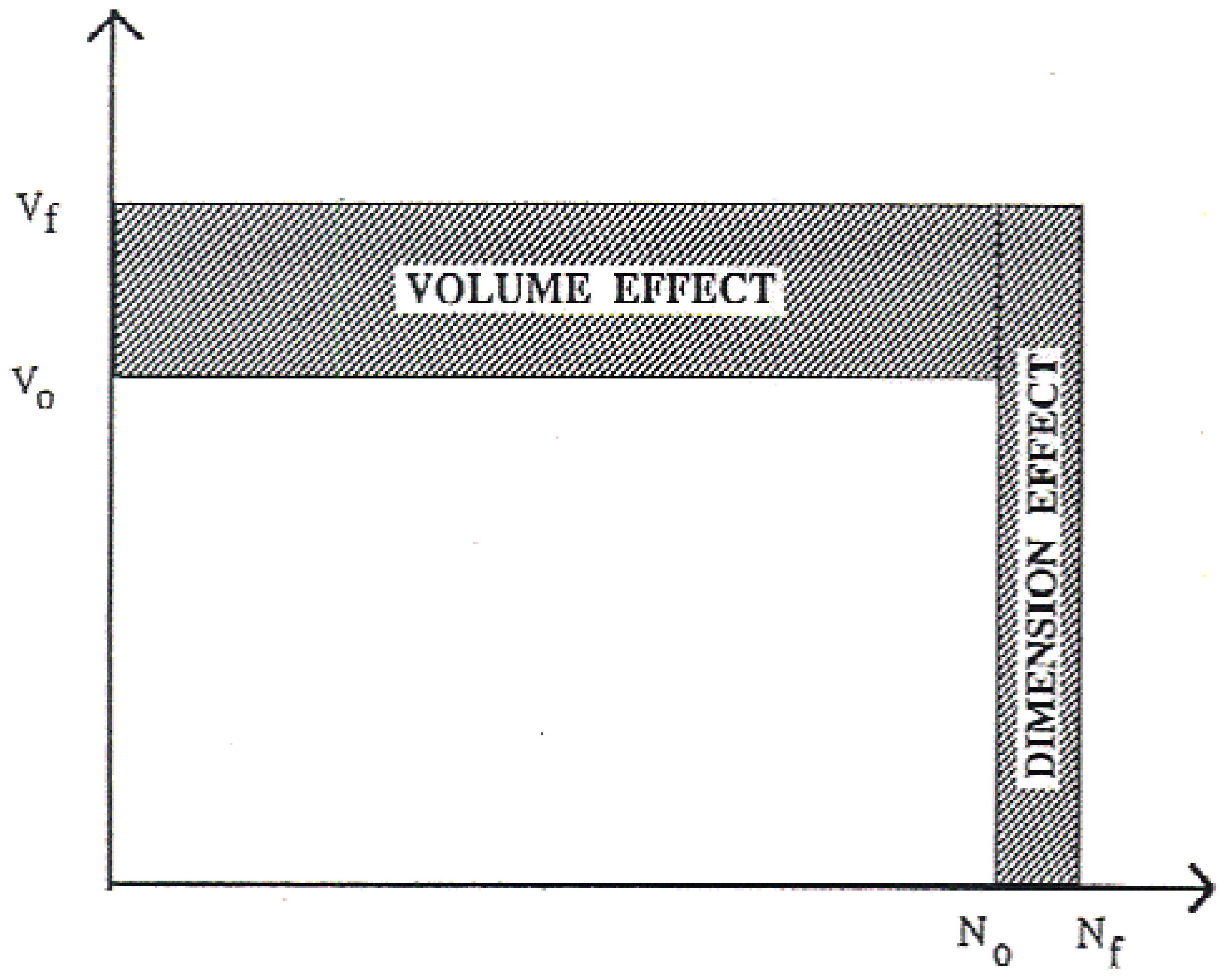

Figure 4. The economic benefit of forest fertilization largely depends on the net value per cubic meter of the growing stock. *Vertical axis*: Vf = volume of growing stock eight years after fertilization. V_o = volume of growing stock without fertilization. *Horizontal axis*: N_f = net value/m³ of the trees that result from fertilization. N_o = net value/m³ of these trees without fertilization.

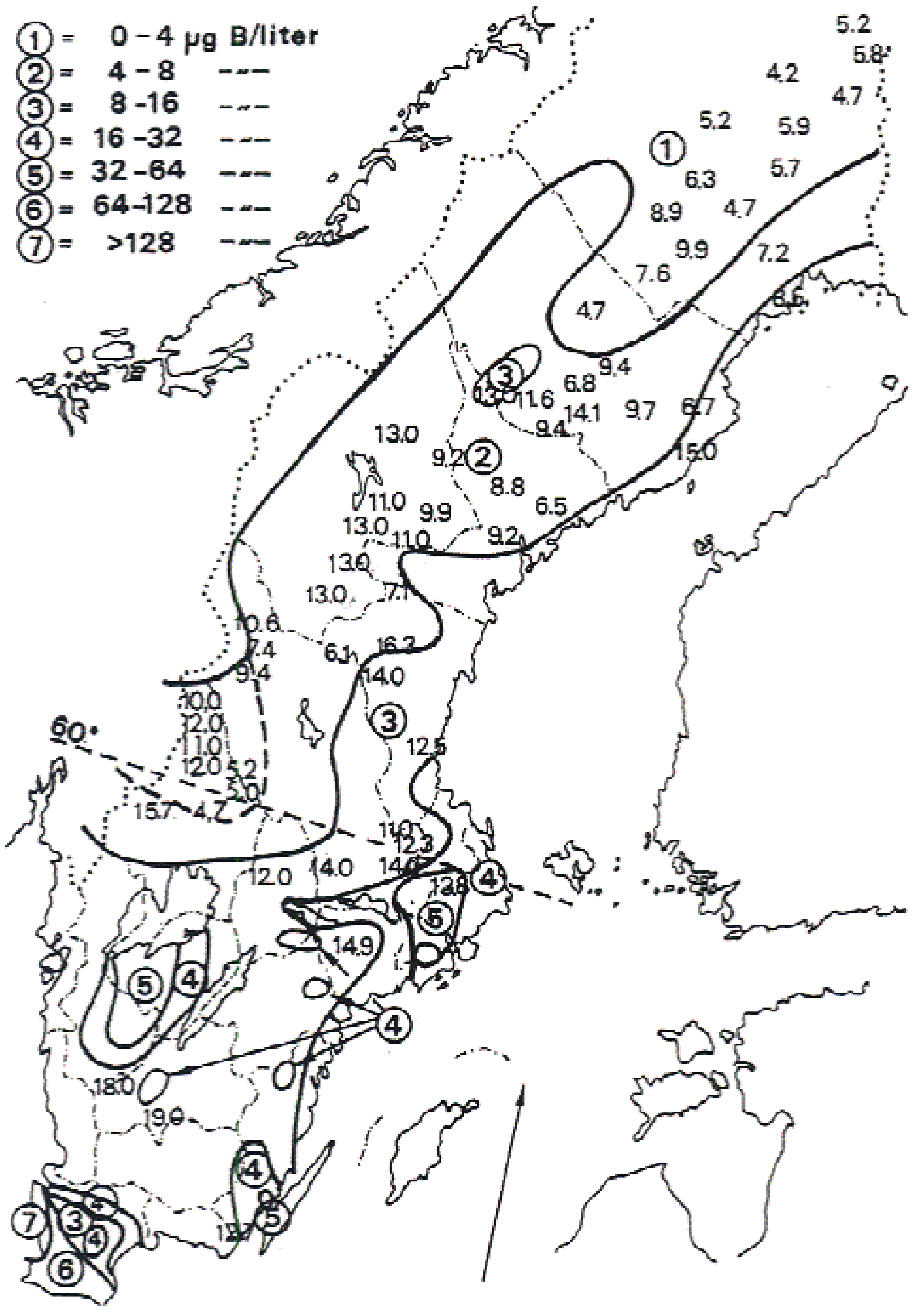

Figure 5. Foliar boron concentrations (ppm) thoughout Sweden and measurements of boron in lake water of seven zones (µg B/L).

nitrate has been shown to decrease the boron concentration in the needles by 3 to 6 ppm (Möller 1982). Thus when the natural needle boron concentration is 10 ppm or less, there is a risk of boron deficiency with resulting disturbances. A Swedish countrywide investigation of boron concentrations in 1980-81 showed wide variations (Figure 5), with very low concentrations in the north. Results from this study correlated well with an earlier investigation of boron concentrations in streams and lakes. Therefore, recommendations can be made about where to apply boron. Combining boron with nitrogen fertilizer is easily done, since field trials showed that 1 kg B/ha was enough to maintain and even increase the foliar boron concentration after nitrogen fertilization (Möller 1982).

Effects of Refertilizations

Duration of growth response from a single fertilizer application has proved to be longer in spruce than in pine stands. Response varies with many factors but it usually lasts 5 to 10 years. If refertilization is done before the effect of the first application has ceased, the volume growth increase of the second application will be smaller than that obtained from the first one. In order to study the magnitude of this smaller effect for different time intervals between fertilizations, 51 field trials were established at 150 kg N/ha. Time between applications varied from 3 to 8 years. The results from these trials made it possible to develop a function describing the annual growth increase in m³/ha in different stands when the number of years between fertilizations varied (Eriksson and Jansson 1980). For example, fertilization of a certain stand over 28 years at four-year intervals at 150 kg N/ha each time will produce an average annual growth increase of 2.5 m³/ha, or a total of 70.0 m³/ha. With seven-year fertilization intervals the average growth increase is 1.9 m³/ha, or 53.2 m³ for 28 years. In the first case the total amount of applied nitrogen will be 7 x 150 = 1,050 kg/ha; in the second, 4 x 150 = 600 kg. For the four-year regime, 15.0 kg N were used for each extra m³ of wood; but only 11.3 kg N/m³ were used for a seven-year interval regime. The choice of which regime to use is an economic question. Two different forest owners may come to quite different decisions and both may be right depending on the economic considerations.

Recently it has been observed that repeated nitrogen fertilization on some sites can result in smaller growth rates compared with the first fertilization, even when refertilization is done after effects of the first application have ceased. This seems to be true especially for higher

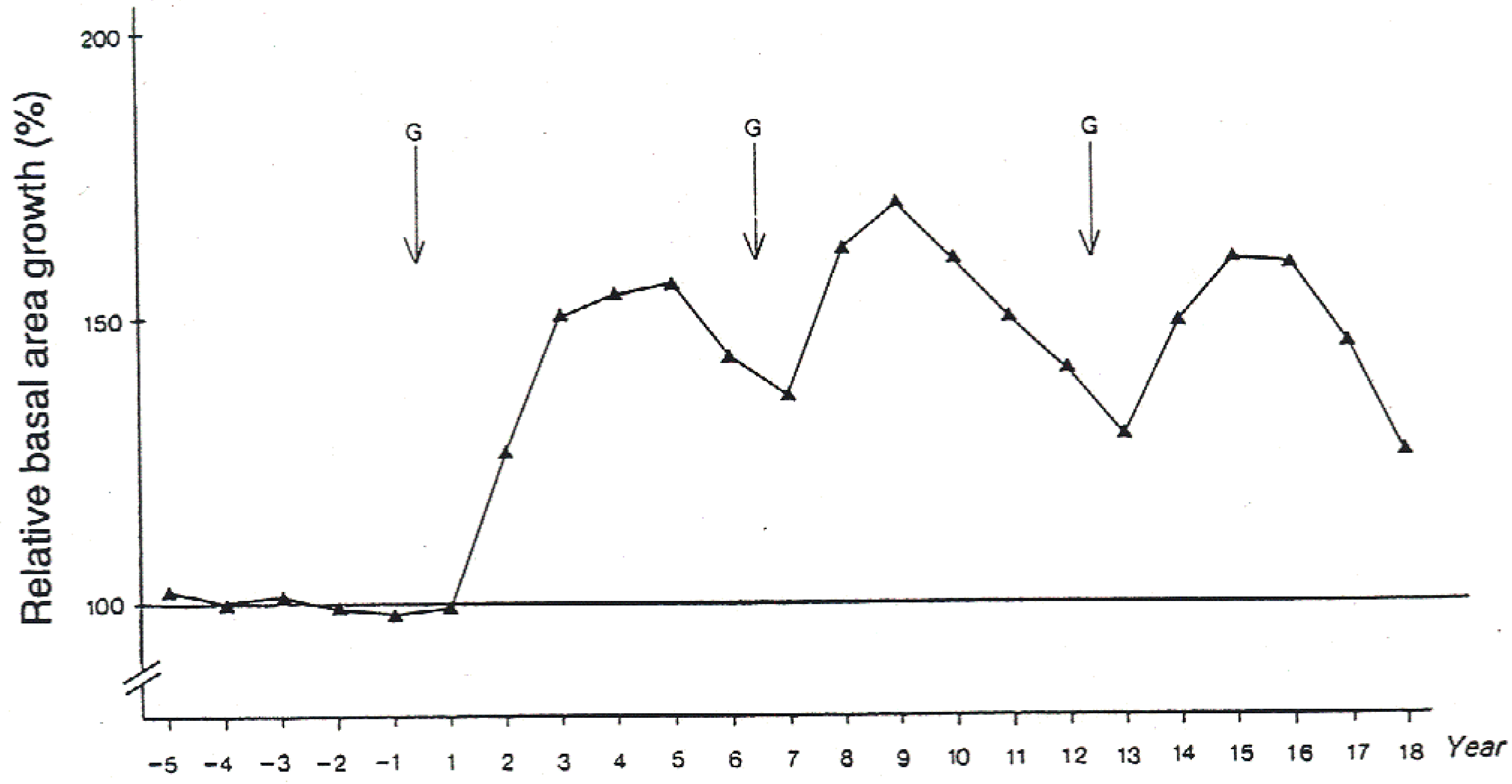

Figure 6. Relative basal area growth response after fertilization. Average of five trials with a fertilization interval of six years. G = time for fertilization with 100 kg N/ha as urea.

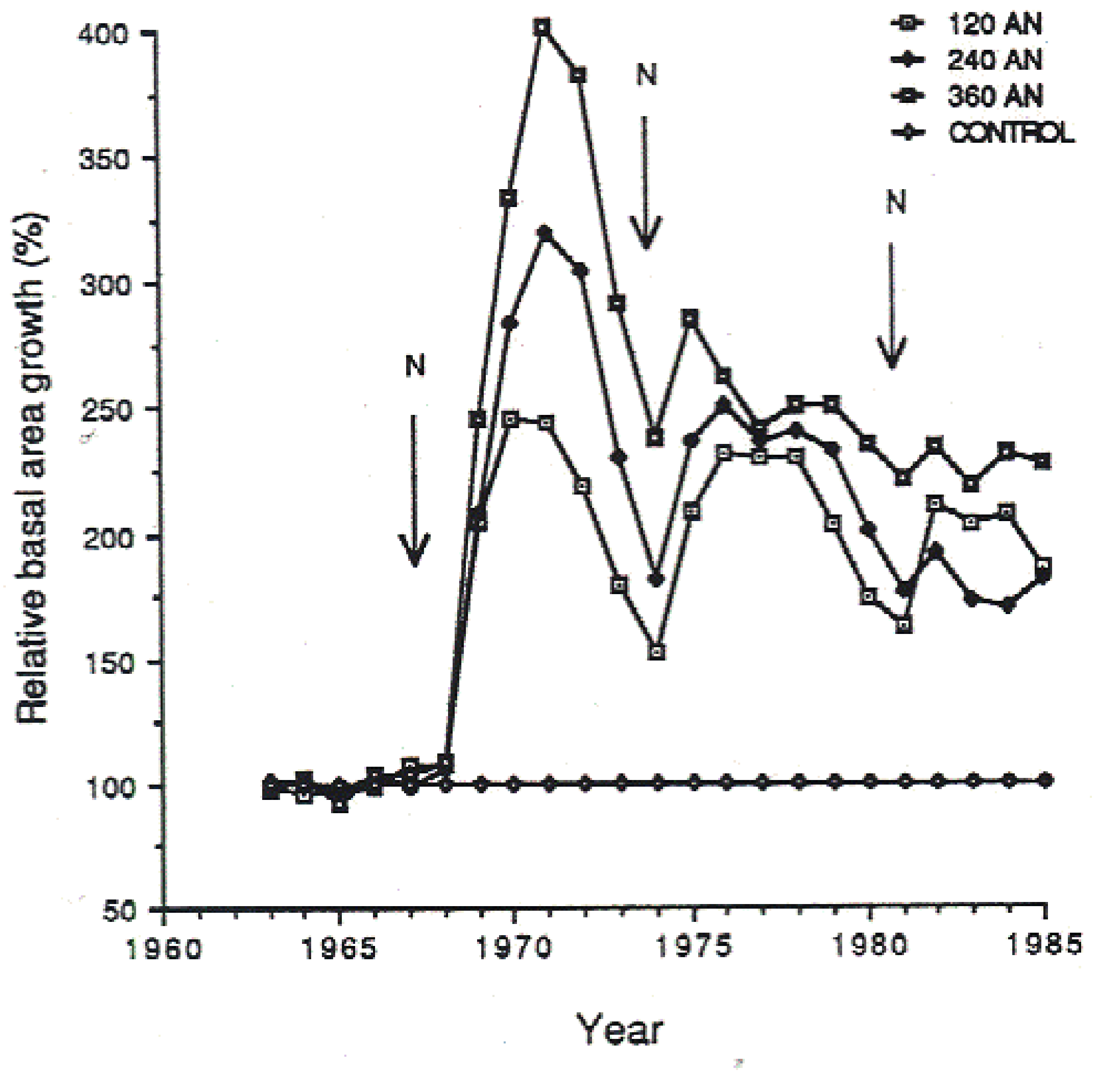

Figure 7. Relative basal area growth response in a pine trial after repeated nitrogen fertilization with different doses of ammonium nitrate. Stand age 100 yr, site index 19 m.

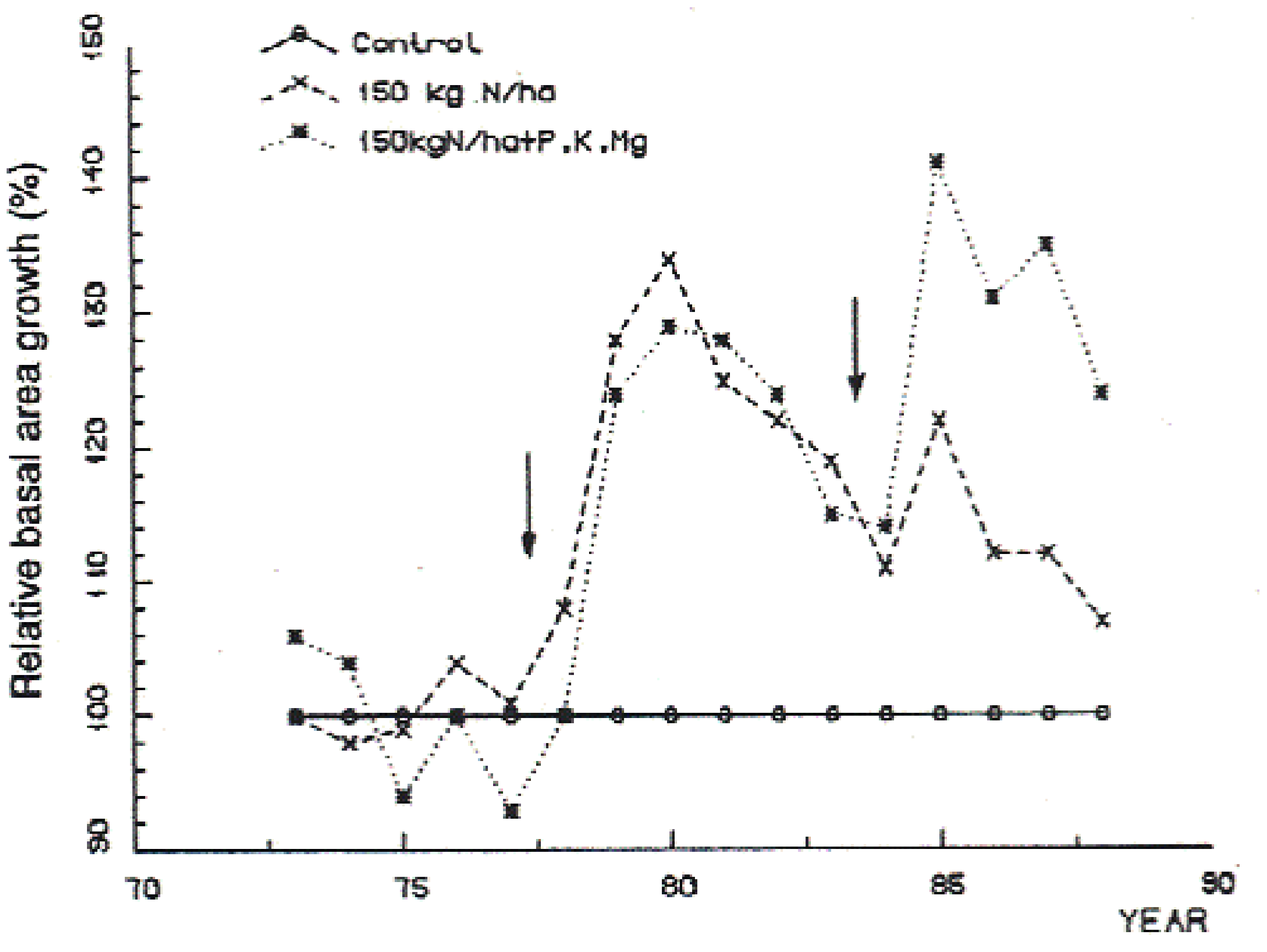

Figure 8. Relative basal area growth response in a spruce trial after refertilization with N and NPKMg. Stand age 70 yr, site index 30-34 m. Nitrogen given as ammonium nitrate.

doses of nitrogen. The normal response in basal area growth after fertilization with 80 to 100 kg N/ha as urea at six-year intervals is shown in Figure 6. This is an average for five trials and shows relative increase compared with the controls. However, some sites respond differently, as illustrated in Figure 7. In this pine trial, doses of 120, 240, and 360 kg N/ha as ammonium nitrate were applied at six-year intervals. The decreased effect of the second and third applications is obvious, especially for the higher doses. In a similar trial with spruce (Figure 8), two different treatments were tried six years after the first application of 150 kg N/ha as ammonium nitrate. One treatment refertilized with ammonium nitrate but the other included phosphorus, potassium, magnesium, and micronutrients with the nitrogen. Nitrogen alone produced less growth than the first application, but the combination of elements produced more growth response than the first fertilization. This indicates that the decreased effect of nitrogen refertilization on some sites may be due to the deficiency of some other nutrient. The Institute for Forest Improvement has recently initiated a project to predict those areas where decreased effects of a nitrogen refertilization can be expected and what other elements may be needed.

Time Adjustment of Fertilization and Thinning

Thinning is used in Scandinavia to improve sawlog volume and quality. An important question is how to combine thinning operations with fertilization to maximize sawlog production and volume growth. In order to study this question, a cooperative research project was established in the mid-1970s between the Finnish Forest Research Institute, the Norwegian Forest Research Institute, and the Institute for Forest Improvement in Sweden. With economic support from the Nordic Forest Research Cooperation Committee, 19 field trials were established during 1976-79 in different climatic zones within the three countries. These trials are still under way but a first remeasurement was made nine years after establishment, and results are summarized in Figure 9 and have been reported by Möller et al. (1991). The greatest volume growth per hectare in spruce stands is obtained when fertilization is done immediately after thinning. Fertilization three years before or three years after thinning gave a lower total production per hectare. In pine stands the results indicate that the highest total production is to be expected when fertilization is done three years after the thinning. The lowest production occurred with fertilization three years before the thinning. However, variation in growth response to the same treatment was large between the different trials. At the final measurement, increment cores will be taken for annual ring-width measurements and an analysis will be done of possible correlations between growth response and different stand and site variables.

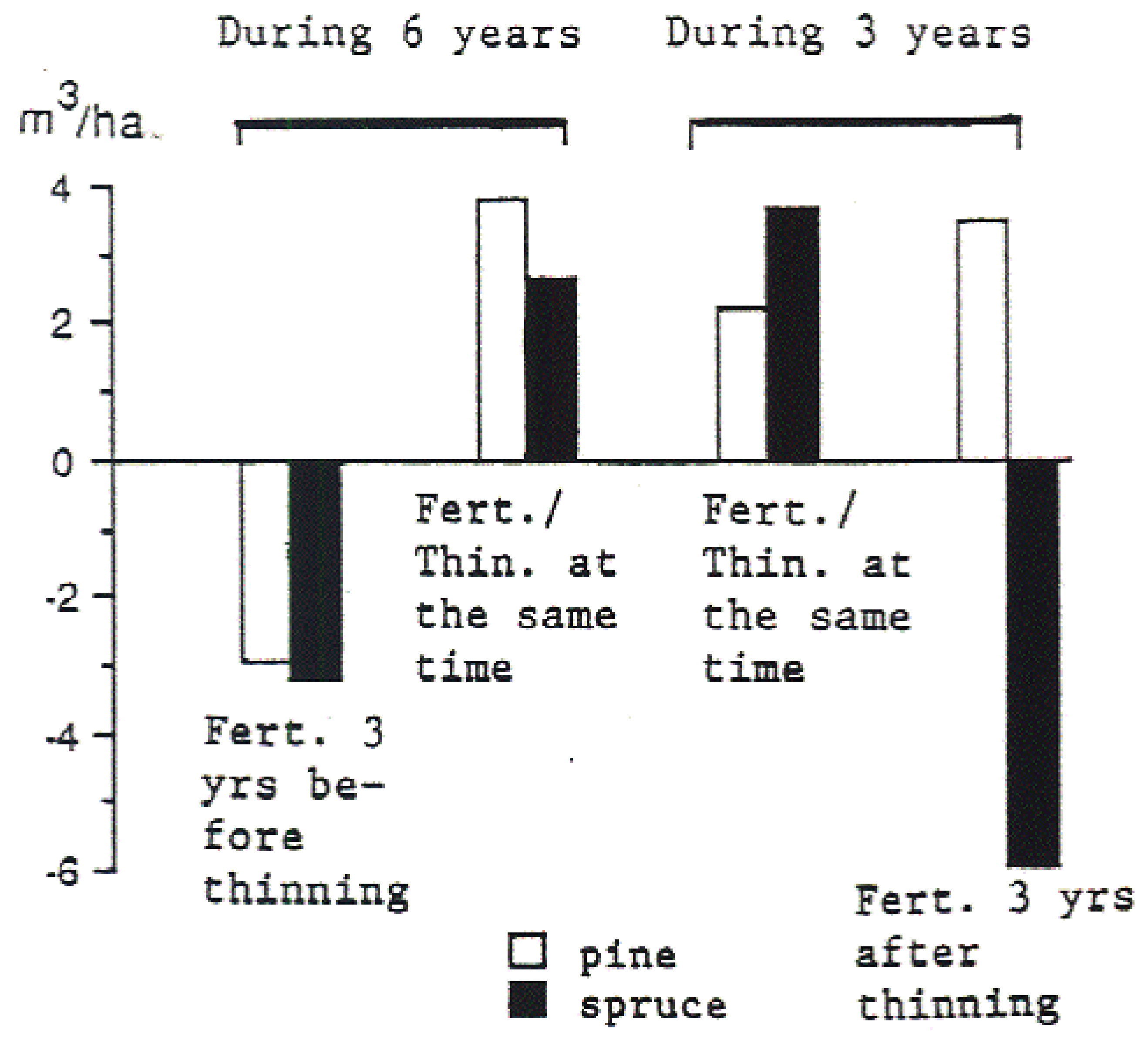

Figure 9. Change in volume growth (m^3/ha) after fertilization three years before, at the same time, and three years after thinning; comparison with fertilization without thinning. Measurements reflect results of field trials the first nine years after establishment in an ongoing cooperative research project in Finland, Norway, and Sweden.

Nutrient Compensation after Whole-Tree Thinning

In 1983 another cooperative research project was established by the Scandinavian countries to study the effect of whole-tree thinning on the growth of the remaining stand and the use of fertilizer to reduce an expected growth decrease. Fifteen trials were established during 1983-87 for this study. Measurements after the first five-year growth period have been done and results from three of the Swedish trials (one in spruce, two in pine stands) are available. Investigated treatments are: (1) conventional thinning (slash left), (2) whole-tree thinning (slash removed), (3) whole-tree thinning plus fertilization with the same amounts of N, P, and K as are removed with the slash (= compensation), (4) conventional thinning plus fertilization with 150 kg N/ha (+ 30 kg P/ha in spruce stands), and (5) whole-tree thinning plus fertilization with 150 kg N/ha (+ 30 kg P/ha in spruce stands).

The spruce trial is established in a 30-year-old stand on a fertile soil with a site index of 32 m. The two pine trials, one in southern and one in middle Sweden, are in 35-year-old stands on average sites, with a site index of 26 m. The thinning grade was 28-30% of the growing stock. In the spruce stand 12 Mg/ha (dry matter) were removed with the slash, while 6.2 Mg/ha were removed in the pine trials as an average. This corresponds to a nitrogen removal of 85 kg/ha in the spruce stand but only 35 kg/ha in the pine trials.

Results show that whole-tree thinning decreased the volume growth by 3.6 m^3/ha in the spruce trial com-

Table 1—Results from three of the Swedish trials in the Scandinavian cooperative whole-tree thinning project. Pine values are means for the two pine trials. Three replications in each trial.

Treatment	Change in Five-year Volume Growth Compared with Conventional Thinning (m^3/ha)	
	Spruce	Pine
Whole-tree thinning	- 3.6	- 0.2
Whole-tree thinning plus compensation for removed N, P, and K	+ 6.9	+ 4.4
Whole-tree thinning plus 150 kg N/ha	+ 6.0	+ 14.3
Conventional thinning plus 150 kg N/ha	+ 6.5	+ 13.3

pared with conventional thinning, but only 0.2 m^3/ha in the two pine trials (Table 1). Compensation with the same amounts of N, P, and K as removed with the slash increased the growth by 6.9 m^3/ha in the spruce trial and 4.4 m^3/ha in the two pine trials compared with the growth after conventional thinning and no fertilizer. When treatments of 150 kg N/ha were applied after conventional and whole-tree thinning, the growth response was not significantly different between the two in either the spruce or the pine trials (Table 1). These growth results, together with foliar analysis, indicate that the growth decrease after whole-tree thinning mainly depends on the amount of nitrogen removed with the slash, and that the volume growth can be maintained by nitrogen fertilization.

Environmental Impacts

Environmental impacts of forest fertilization have been studied in several projects. In a field trial with ^{15}N labeled fertilizers, Melin (1986) showed how the use of different sources of nitrogen resulted in differences in the uptake of the applied nitrogen in three coniferous ecosystems, and also different losses. Stand age and density, as well as the amount of nitrogen applied, also influenced nitrogen uptake. Calcium nitrate produced the greatest uptake but also the greatest leaching to deeper soil layers or goundwater (Table 2). Urea produced the smallest uptake and the greatest immobilization in the humus layer and soil, while ammonium nitrate produced an intermediate response.

These differences in behavior between ammonium and nitrate ions in the soil can help to explain the differences in volume growth response from urea and ammonium nitrate shown in the prediction function. Five watershed studies were performed during 1982-88 in order to evaluate the effects of forest fertilization on surface water (Nohrstedt 1989). Operational fertilizations with 150 kg N/ha as ammonium nitrate were performed in different watersheds on areas comprising between 4 and 25% of the total watershed. Water samples were taken upstream and downstream of the fertilized area, with sampling initiated before any fertilization in order to establish the water chemistry of two points in each stream. Sampling continued for three years after the fertilization.

The average pH of the water sampled ranged from 5.5 to 7.0 and the average alkalinity from 0.03 to 0.16 meq/L. Fertilization caused a decrease in alkalinity of 0.04 meq/L in four of the five streams, lasting at least three years. The decrease in alkalinity was related to the acidity at the 50 cm depth in the mineral soil. Such an effect is explained by a greater ammonium ion concentration in the soil solution because of the fertilization, which in turn results in increased acidity of the soil solution. The increased nitrogen activity in the solution causes an increased transport of hydrogen ions to surface water, overcoming the buffering capacity. Calculations from the results obtained showed that a decrease in pH, harmful to fish and other living organisms, could be expected in four out of five watersheds if all watershed areas were fertilized and not just parts of them. In another watershed study where the fertilization was performed with calcium ammonium nitrate, the pH in the surface water increased as much as 0.5 during the two months following fertilization (Nohrstedt 1988).

When fertilizer is applied using fixed-wing aircraft or helicopters, some of the fertilizer will generally fall

Table 2—Recovered fertilizer nitrogen in the ecosystem two growing seasons after fertilization with 150 kg N/ha (Melin 1986).

Source of Nitrogen	Percentage Recovered			Percentage Not Recovered (volatilized and leached)
	Trees and roots thicker than 20 mm	Field layer and bushes	Humus, soil, and roots thinner than 20 mm (depth 0 - 35 cm)	
Calcium nitrate	44	1	31	24
Ammonium nitrate	33	1	54	12
Urea	20	1	66	13

directly into the water of small streams. In watershed studies this has been shown to lead to an increase of inorganic nitrogen in the stream water of up to 56 mg/L of nitrate-N and 70 mg/L of ammonium-N. Such elevated levels last only a few days, but small increases have been observed up to two months after fertilization (Nohrstedt 1986).

Different species of ground vegetation are adapted to sites with different nitrogen supplies. After nitrogen fertilization, the supply of plant-available nitrogen will be changed for some time, possibly leading to a change in the floral composition. Nitrogen-demanding species will increase and species adapted to nitrogen-poor sites will decrease. How big these changes will be depends on the original composition of the ground vegetation and the applied amount, as well as source, of nitrogen.

In 1985 an investigation in two older fertilization trials was performed which showed that soil carbon content, microbial biomass, and respiration rate will be affected by nitrogen fertilization (Nohrstedt et al. 1989). One of these trials was established in 1974 with 150 and 600 kg N/ha of both urea and ammonium nitrate, and the other in 1977 and refertilized in 1984 with 150 kg N/ha as ammonium nitrate. By 1985 the absolute amount of carbon per square meter of the forest floor was greater in fertilized areas compared with the control plots. The microbial biomass and the respiration rate were less in all investigated horizons when expressed in amount per gram of carbon; but since the carbon per square meter had increased, there were no differences on an areal basis between fertilized and control plots.

Since up to 60% of applied nitrogen can be immobilized in organic matter in the soil, there have been apprehensions that all that stored nitrogen could be released at once after clearcutting a heavily fertilized stand and thus pollute the groundwater. In order to investigate that question, one of the oldest field trials belonging to the Institute for Forest Improvement and fertilized three times over a 20-year period with different amounts of ammonium nitrate was selected for special investigation. In the autumn of 1987 the total stand was clearcut and suction lysimeters installed in different plots. Some of these plots had received 600 kg N/ha three times (= 1,800 kg/ha) applied as ammonium nitrate during the previous 20 years. The aim of this investigation was to study the leaching of nitrogen after clearcutting in relation to the previous fertilizations. During the summer before clearcutting and six years after the last fertilization, an intensive sampling of forest floor and top mineral soil was also performed to determine the impact of the previous fertilizations on different soil properties (Nohrstedt 1990). The results obtained so far show a substantial accumulation of organic matter in the forest floor. At the dose giving the maximal growth response the humus layer had almost doubled its content of carbon and nitrogen compared with control plots. The pH was unaffected in the humus and eluvial layers but had decreased 0.2 to 0.3 units at intermediate doses in the upper part of the spodic horizon. The amount of exchangeable base cations was not changed and there were no differences in soil water pH between the different treatments. No increase in soil water inorganic nitrogen could be detected before clearcutting or during the first two growing seasons after the clearcutting for nitrogen doses up to 1,350 kg N/ha. However, the investigation is still under way.

Operational Fertilization

Forest fertilization on an operational scale started in the early 1960s in Scandinavia. In Sweden it reached its highest point, with almost 190,000 ha/yr in 1976 and 1977. It then dropped and stabilized at about 130,000 ha/yr until 1988, when it suddenly dropped to 95,000 ha. In 1989 and 1990 about 80,000 ha were fertilized each year (Figure 10).

Forest fertilization in Sweden is done mainly by the big forest companies and the State Forest Service. Few areas have been fertilized by the small private forest owners. The reason for that is not understood, since about 50% of the forest land is owned by small private owners and fertilization of selected stands has shown to be one of the most economic silvicultural treatments that can be performed in forestry. Only 1,000 to 3,000 ha/yr of forests on peat soils have been fertilized.

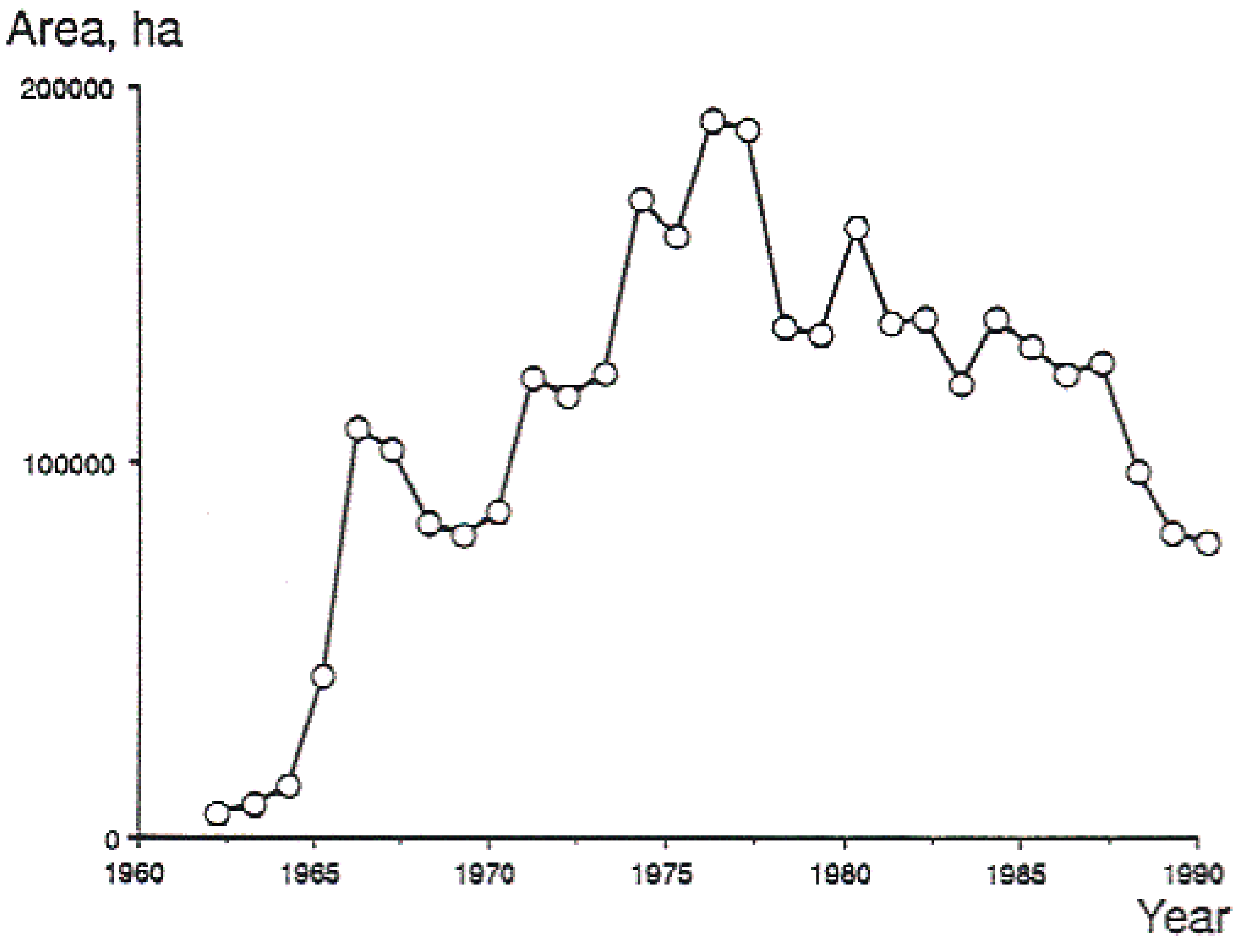

Figure 10. Forest fertilization in Sweden, 1962-90.

The development of forest fertilization in Finland shows almost the same picture as in Sweden (Figure 11). The greatest difference is that of the fertilized area in Finland more than half belongs to private forest owners. Another divergence is that forest fertilization in Finland had been largely on peat soils until 1989, when this decreased and the fertilized area of mineral soil exceeded that of peat soil for the first time.

In Norway, forest fertilization has been much less extensive, but from 1987 to 1989 the fertilized area increased from 3,500 ha to 6,000 ha, a trend quite opposite that of Sweden and Finland. Almost all the fertilization in Norway is done by a few big forest companies.

However, to give a correct picture of forest fertilization in the different countries, the fertilized areas should be considered in relation to the total area of productive forest land in each country. Total forest area in Sweden, Finland, and Norway is 23.4, 20.1, and 6.6 million ha, respectively. This means that when the fertilized area was at its largest in the mid-1970s, it was about 1% of the total forest land in Sweden and Finland but only 0.1% of Norway's.

Fertilizer spreading techniques have changed during the last 20 years. Initially fertilization was performed only by fixed-wing aircraft, but now helicopters or tractors are used (Figure 12). The problem in spreading is to achieve an even distribution. Investigations have shown that applications of nitrogen in different parts of a fertilized stand can vary considerably from the average dose for the whole stand (Aregger and Pettersson 1986), and be quite different from the intended average dose. This is of minor importance when fertilizing stands on poor or average sites with normal doses but is a great disadvantage when fertilizing stands on good sites or when applying heavy doses. This occurs because the volume growth response is almost directly correlated to the nitrogen dose on poor sites but has a curvilinear relationship to more fertile sites.

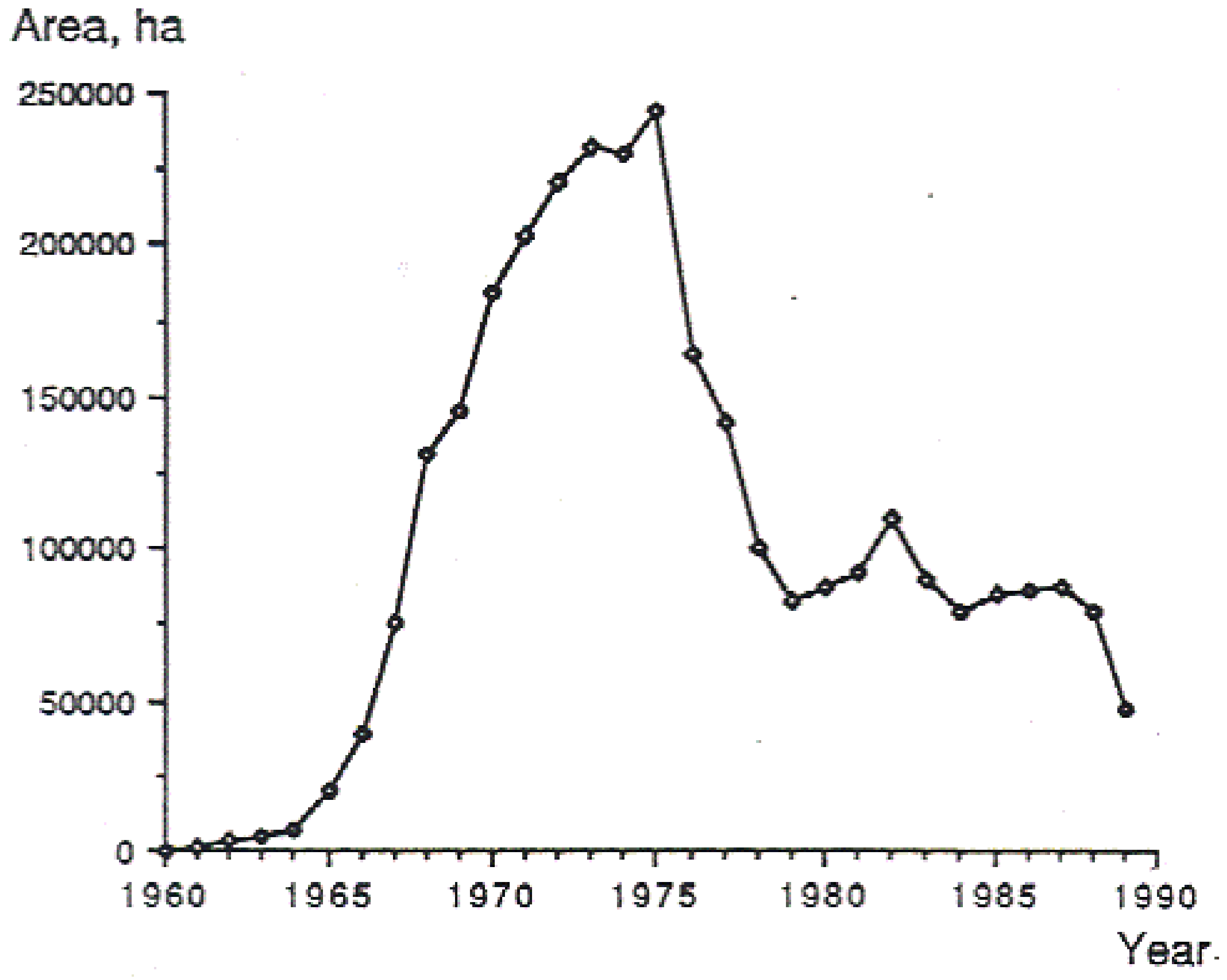

Figure 11. Forest fertilization in Finland, 1960-89.

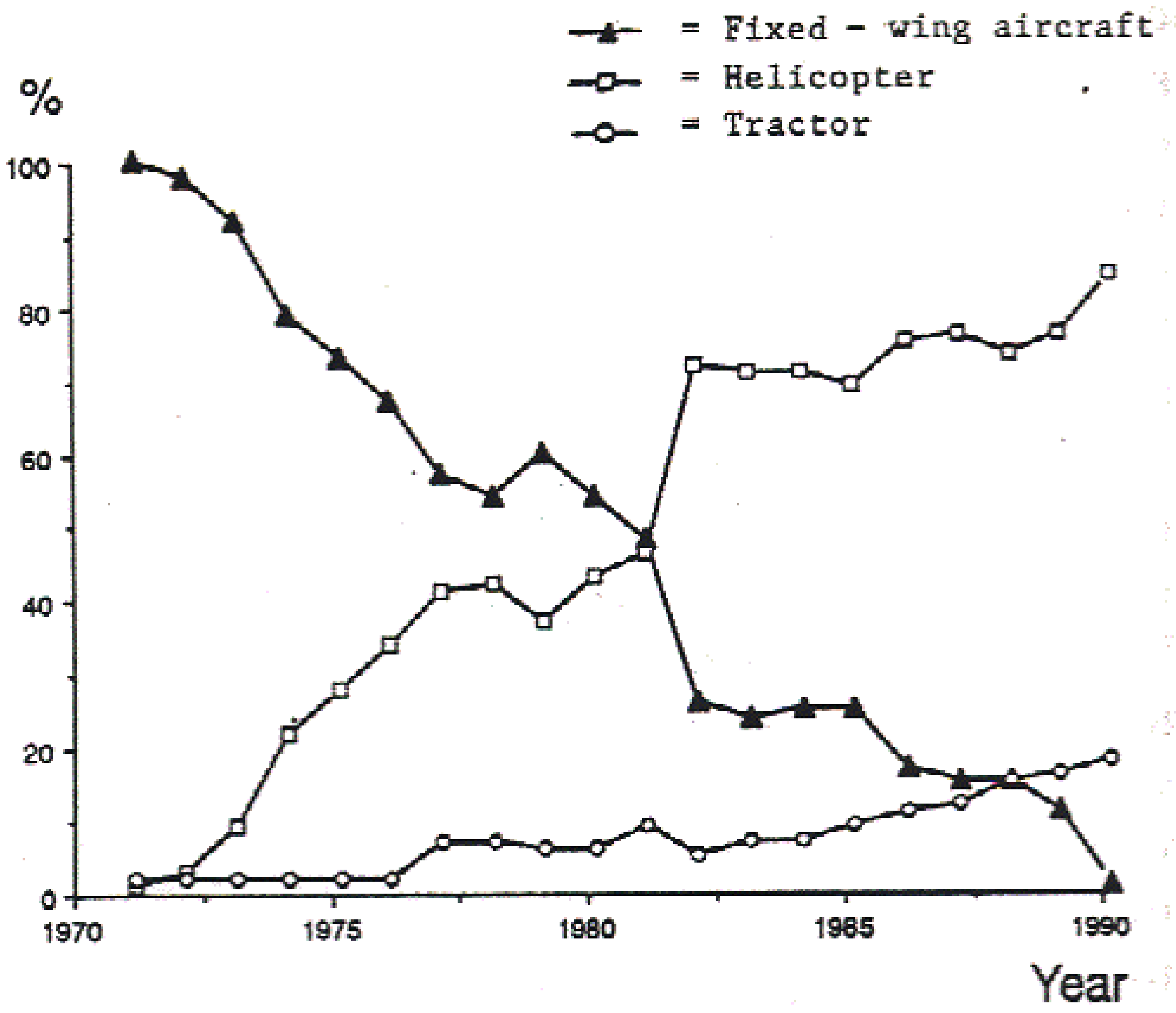

Figure 12. Development of application methods in Sweden in percentage of fertilized areas.

Various forest companies as well as the State Forest Service have performed checks of the achieved volume growth responses from their operational forest fertilizations (Pettersson 1990). Stands selected for operational fertilizations were divided into halves, one of which was not fertilized. Five years after fertilization, ten circular plots of 10 m radius were randomly selected in both parts of the stand. Height and diameter of all trees within the plots were measured and increment cores taken for annual ring-width measurements and volume-growth calculations. The results are shown in Table 3. The achieved volume growth responses averaged 97% of what could be expected from the prediction function. For the single stand, however, response varied between 69 and 130% of the predicted effect. The nitrogen dose on each circular plot was not measured, but it is obvious that there was a rather large variation in amount of applied nitrogen, judging from the large variation in volume growth response between the different circular plots in the same stand.

Table 3—Measured and predicted volume-growth effects of operational fertilization (m^3/ha, 5 years).

Fertilized Stand Number	Measured Effects		Predicted Effects[1]	Result of Predicted Effect (%)
	Min. - Max.	Mean		
1	4.4 - 9.9	6.6	8.9	74
2	5.0 - 16.0	11.4	9.6	119
3	0 - 11.5	6.5	8.7	75
4	3.4 - 19.3	7.0	10.1	69
5	1.7 - 14.2	10.0	9.1	110
6	0 - 16.3	8.6	9.3	93
7	3.8 - 17.2	9.5	10.3	92
8	0 - 21.9	10.8	10.6	102
9	0 - 15.7	8.2	8.7	94
10	5.6 - 21.6	12.2	11.5	106
11	6.9 - 19.9	14.7	13.8	107
12	0 - 32.7	12.2	8.9	137
13	1.8 - 18.3	8.6	8.6	100
14	0 - 16.3	8.4	10.6	79
Mean	2.3 - 17.9	9.6	9.9	97
Standard error	±0.7 - 1.5	±0.6	±0.4	±5

[1] According to the prediction functions with an assumed standard error in fertilization dose between different parts of the stands of 60 kg N/ha.

Literature Cited

Aregger, M. and F. Pettersson. 1986. Dålig spridningsjämnhet vid flyggödsling [Poor uniformity of fertilizer dose after application by aircraft.] Institutet för Skogsförbättring, Gödslings-information 2, 1985-86.

Eriksson, A. and G. Jansson. 1980. Gödslingsintervallets betydelse för tillväxtökning och gödslingsekonomi. [Function for the prediction of fertilizer responses after different fertilization intervals.] Föreningen Skogsträdsförädling, Institutet för Skogsförbättring, Årsbok 1980, pp. 41-58.

Kolari, K.K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa: kirjallisuuskatsaus. [Micronutrient deficiency in forest trees and dieback of Scots pine in Finland: a review.] Folia Forestalia 389:1-37.

Melin, J. 1986. Omsättning och fördelning av gödselkväve i tre barrskogsekosystem i mellansverige. [Turnover and distribution of fertilizer nitrogen in three coniferous ecosystems in central Sweden.] Swedish University of Agricultural Sciences, Department of Forest Soils, Report 55.

Möller, G. 1982. Borbristskador efter upprepad kvävegödsling på fastmark. [Growth disturbances from boron deficiency on mineral soil after refertilization with nitrogen.] Föreningen Skogsträdsförädling, Institutet för Skogsförbättring, Årsbok 1982, pp. 47-70.

Möller, G., B. Tveite, H.G. Gustavsen, and F. Pettersson. 1991. Gödslingens tidsmässiga anpassning till gallring: delresultat från en 9-årig samnordisk studie. [Time adjustment of forest fertilization to thinning: first results from a nine-year-old cooperative study in Scandinavia.] Institutet för Skogsförbättring, Report 20. *In press.*

Nohrstedt, H.-Ö. 1986. Vad händer med bäckvattnet efter gödsling. [What happens with the brook water after fertilization.] Sveriges Skogsvårdsförbunds Tidskrift 1/1986, pp. 55-65.

_____ . 1988. Ytvattenkemiska effekter av en skogsgödsling med kalkammonsalpeter i ett försurat område. [Chemical effects on surface water by a forest fertilization with calcium ammonium nitrate in an acidified area.] Institutet för Skogsförbättring, Report 5.

_____ . 1989. Air pollution as stress factor in the Nordic forests. Norsk Institutt for Skogforskning, Meddelse 42:167-176.

_____ . 1990. Effects of repeated nitrogen fertilization with different doses on soil properties in a *Pinus sylvestris* stand. Scand. J. For. Res. 5:3-15.

Nohrstedt, H.-Ö., K. Arnebrant, E. Bååth, and B. Söderström. 1989. Changes in carbon content, respiration rate, ATP content, and microbial biomass in nitrogen-fertilized pine forest soils in Sweden. Can. J. For. Res. 19:323-328.

Pettersson, F. 1990. Gödslingseffekter i praktiken: en jömförelse med Skogsförbättrings prognoskurvor. [Growth response in operationally fertilized stands.] Institutet för Skogsförbättring, Information Växtnäring - skogsproduktion 3, 1990-91.

Rosvall, O. 1979. Prognosfunktioner för beräkning av gödslingseffekten. [Functions for the prediction of fertilizer responses in Sweden.] Föreningen Skogsträdsförädling, Institutet för Skogsförbättring, Årsbok 1979, pp. 70-130.