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Radial growth of mature silver firs (Abies alba Mill.) fertilized in 1969. Interaction of climate and competition

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1 - Introduction

Supplies of mineral elements are much rarer in silvicultural than in agricultural practices. In forest, most of these supplies are carried out on young plantations, in order to improve seedlings installation and initial growth. But the use of fertilization in mature natural stands is still an exceptional practice, whose usefulness and profitability are not always obvious. Nevertheless, "forest decline" is now a cause for concern in many regions in Europe and North America, and this tends to revive the debate about the possible interest of this technique to check the decline of stands on some soils, that have been impoverished by previous crops and, more recently, by acid air pollution (Federer et al. 1988).

The efficiency of fertilization to improve the growth of mature stands on poor soils is not approved unanimously yet, especially with regard to the role of the various mineral elements. Somes studies stress the higher efficiency of nitrogen (Kenk & Fischer 1988). But other ones evidence a serious depressive effect from the same element (Nys 1989), and, on the contrary, a clear positive effect from calcium (Toutain et al. 1987, Nys 1989). The question of the short term or longer term efficiency of a calcium supply (liming) is still strongly debated (Persson 1988). Some studies do not evidence any improvement, as well on the growth as on the health of trees (Aldinger & Kremer 1985, Foster et al. 1988). Other ones show that liming should be supplemented by supplying other elements (Aronsson 1988, Nihlgard 1988). Lastly, other studies notice an effect changing over time, negative during the first years, then positive (Popovic 1988, Nihlgard 1988).

Old fertilization experiments on mature tree stands are rare. The one we have studied is nearly unique in the Vosges Mountains. It was installed in 1969 in an even-aged silver fir (*Abies alba* Mill.) forest, and was conceived with a high statistical rigour. We turned this opportuneness to profit, and, through a dendrochronological study, we have reconstructed the history of the radial growth of the stand. This study allowed to assess the effect of each mineral element as well as the interaction of other important parameters, such as weather conditions and intraspecific competition.

2 - Materials and methods

The "Hospices de Nancy" forest is situated in the Vosges Mountains, in northeastern France (48°09'N; 7°06'E), at 800 m above sea level. Average annual temperature is about 7.0 °C and annual precipitation amounts to 1600 mm. Soils are formed from a rough Hercynian granite, which is one of the poorest in the Vosges. They are ochreous brown soils, with moder humus type, or podzolic soils, with moder or mor humus type. In 1969, the main chemical characteristics of the A1 horizon, calculated from 9 soil profiles, were: S/T= 7.8 %; K= 0.25 m.eq./100g; Ca= 0.69 m.eq./100g; Mg= 0.20 m.eq./100g.

The experiment is installed in a pure and fairly even-aged silver fir stand. In 1969, the mean age was 110 years. The ground vegetation was mainly characterized by *Vaccinium myrtillus* L. and *Deschampsia flexuosa* (L.) Trin., secondarily by *Luzula sylvatica* (Huds.) Gaud. and *Luzula luzuloides* (Lam.) Dandy & Willm.

A 40 x 40 m grid was used to define 65 plot centres. All of the trees have been studied within a radius of 9 m around each center, but the fertilizers were spread within a radius of 14 m. The experiment includes 8 treatments and 5 replications, except for the control which has 30 replications. The treatments are:

1 - T: control, no fertilizer;

2 - N: nitrogen, 200 kg/ha, i.e. 12.3 kg per plot, in the form of ammonium nitrate;

3 - P: phosphorous, 150 kg/ha P_2O_5, i.e. 9.2 kg per plot, in the form of "superphosphate triple";

4 - Ca: calcium, 1500 kg/ha CaO, i.e. 92 kg per plot, in the form of slaked lime;

5 - NP: nitrogen + phosphorous, same respective doses as for treatments 2 and 3;

6 - NCa: nitrogen + calcium, same respective doses as for treatments 2 and 4;

7 - PCa: phosphorus + calcium, same respective doses as for treatments 3 and 4;

8 - NPCa: nitrogen + phosphorous + calcium, same respective doses as for treatments 2, 3 and 4.

Phosphorous and calcium supply was made in the automn of 1969, nitrogen supply in the spring of 1970.

All the trees, whatever their competition status, were bored to the pith at breast height (1.30 m), i.e. 493 trees, which are respectively distributed as follows into the 8 treatments: 194, 42, 43, 46, 41, 34, 45, 48. Two cores were extracted from each tree. The ring widths of the 986 cores were measured with a computer-assisted device. Their right dating has been checked by comparison with a previous regional chronology (Becker 1987). After averaging the two series of every tree, all the individual time series were standardized by using a technique previously described (Becker 1989), in order to remove the "noise" due to ageing: every ring width was converted into a growth index, which is the ratio, expressed as a percentage, of the actual width to the adjusted mean width observed in the Vosges at the same current age. Finally, in order to make the comparison of the treatments easier, the synthetic time series calculated for every treatment has been corrected so that it coincides with the series of the control during the 10 years that precede the fertilization, i.e. 1960-1969.

3 - Results

Figure 1 shows the radial growth calculated from the 194 control trees since 1905, and the mean radial growth of silver fir in the whole Vosges mountains (Becker 1987). The variability of this mean growth is known to depend closely on weather conditions. Providing that 6 years lag effects are taken into account, climate, and especially precipitations, allow to explain about 80 % of the variance (Becker 1989). Strong similarities, but also clear discrepancies can be noted between the two chronologies. The crises encountered for about 30 years, i.e. the growth reductions due to weather conditions, have been deeper and more sustained in the forest studied here. In particular, the depression during the 60s, that is hardly perceptible at the regional scale, is much accentuated, and the recovery of the stand before the deep depression that occured during the 70's is weak. Moreover, the recovery during the last years is developing much more slowly, after a relapse in 1979-1982. The results from another study on silver fir in the Vosges Mountains (Lévy & Becker 1987) lead to think that the higher susceptibility of this forest is due not only to the poorness of the soils, but more probably to an excessive stand density, responsible for the development of ill-formed crowns and for an increased competition for water.

The mean behaviour of the trees in every treatment as against the control shows that:

- a mature silver fir high forest, that virtually has reached the rotation age, is still able to react to fertilization;
- whatever the treatment, the effect is perceptible only from the second vegetation season following the supply of fertilizers;
- all the mineral elements have an influence on radial growth, but its extent and its time dynamics varies greatly according to the element or element combination that was supplied.

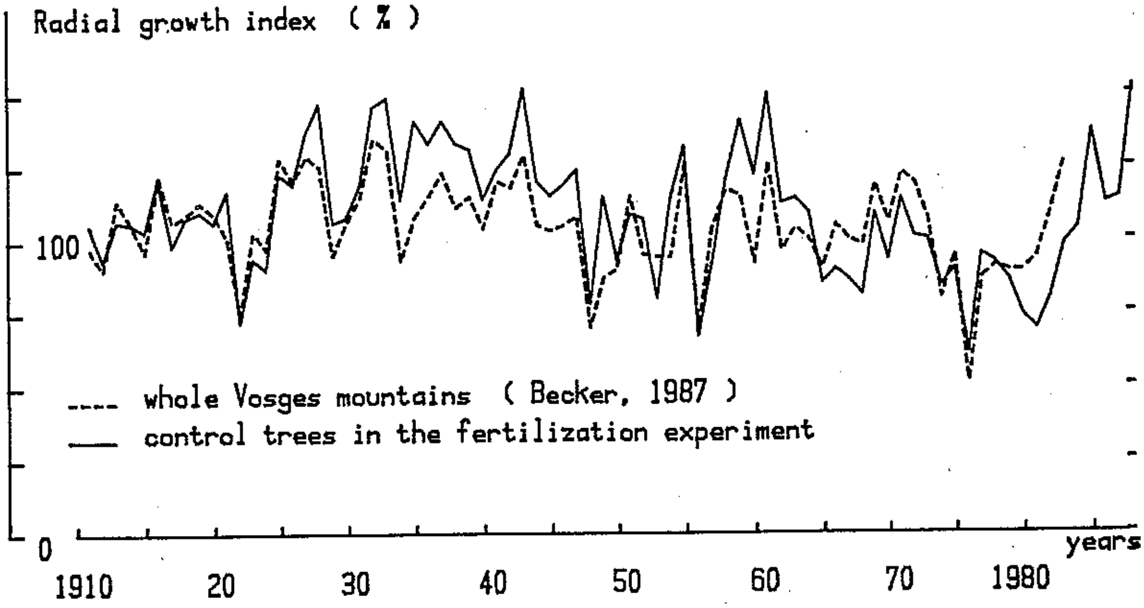

Fig. 1. Mean radial growth of silver in the whole Vosges region and in the control plots of the fertilization experiment.

The whole post-fertilization period, 1970-1988, may be divided into three subperiods in relation to the recent climatic crisis in the Vosges forests: (1) 1970-1975, approximately "normal" period preceding the phase of acute crisis; (2) 1976-1983, the crisis period strictly speaking; (3) 1984-1988, period of recovery in most stands.

Figure 2 summarizes the balances of the various treatments during the three periods.

Nitrogen has a high positive effect during the period 1 (+18 %), but this effect lessens rapidly, and even turns negative during the period 2 (-8 %), particularly during the three years following the drought in 1976. A noticeable positive effect (+10 %) is found back during the period 3, but the overall balance against the control is only +5 % since 1970.

Calcium has a clear effect from the period 1 onwards (+14 %), but more progressive than with nitrogen. And, what is more important, this positive effect increases during the period 2 (+29 %) and keeps high high during the period 3 (+19 %). The overall balance (1970-1988) is very high (+22 %).

Phosphorous is rather intermediate between nitrogen and calcium: its effect is clearly positive during the period 1 (+19 %), then it progressively decreases and vanishes during the periods 2 and 3. The overall balance is +8 %.

When two mineral elements are combined, it appears that their effects rather add up during the periods 1 and 2, then practically vanish during the period 3. The effect of treatment NPCa remains fairly positive during the whole period 1970-1988. The overall balances of treatments NP, NCa, PCa and NPCa, respectively +11, +15, +15 and +14 %, are clearly lower than with Ca alone.

Trees have been split up into three categories according to their competition status within the stand, i.e. dominant, codominant and dominated. For each category, various synthetic time series were calculated in respect of the treatments. They clearly show that competition is an important parameter affecting the reaction of trees to fertilization, and that this reaction varies according to the element supplied as well. Moreover, the threshold from which interaction arises, does not stand between codominant and dominated trees, as we might have thought, but between dominant and codominant ones.

Figure 3 summarizes the results obtained by distinguishing the dominant trees from the "undominant" ones (codominant + dominated). Every subset has its own control. In the main, it is noticeable that competition status emphasizes more clearly the respective effect of each of the mineral elements.

- Nitrogen: In the dominant trees (n=21), the overall balance (1970-1988) is practically null; but the depressive effect is much accentuated during the climatic crisis (period 2). In the undominant (n=21), the overall balance is positive (+8 %), without depression period.

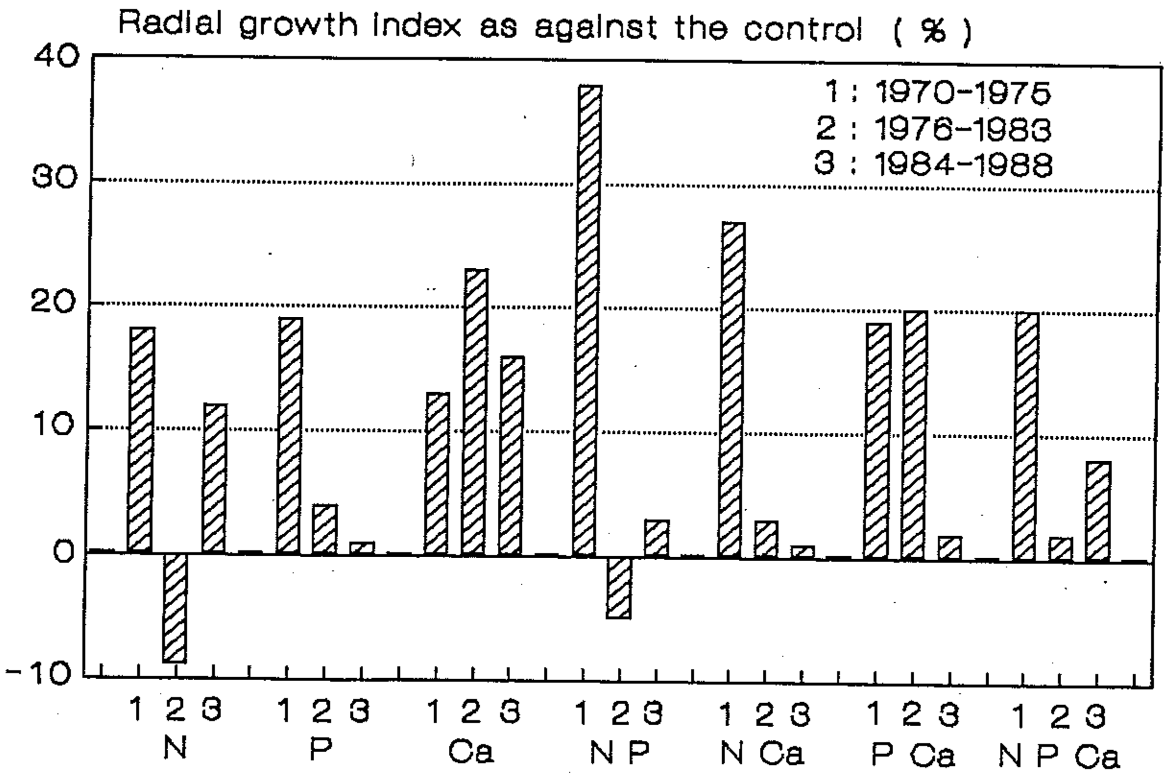

Fig. 2. Mean radial growth of silver fir according to the fertilizing treatment and to the post-fertilization subperiod (1: "normal" period preceding a phase of acute crisis; 2: crisis period due to drought years; 3: period of recovery).

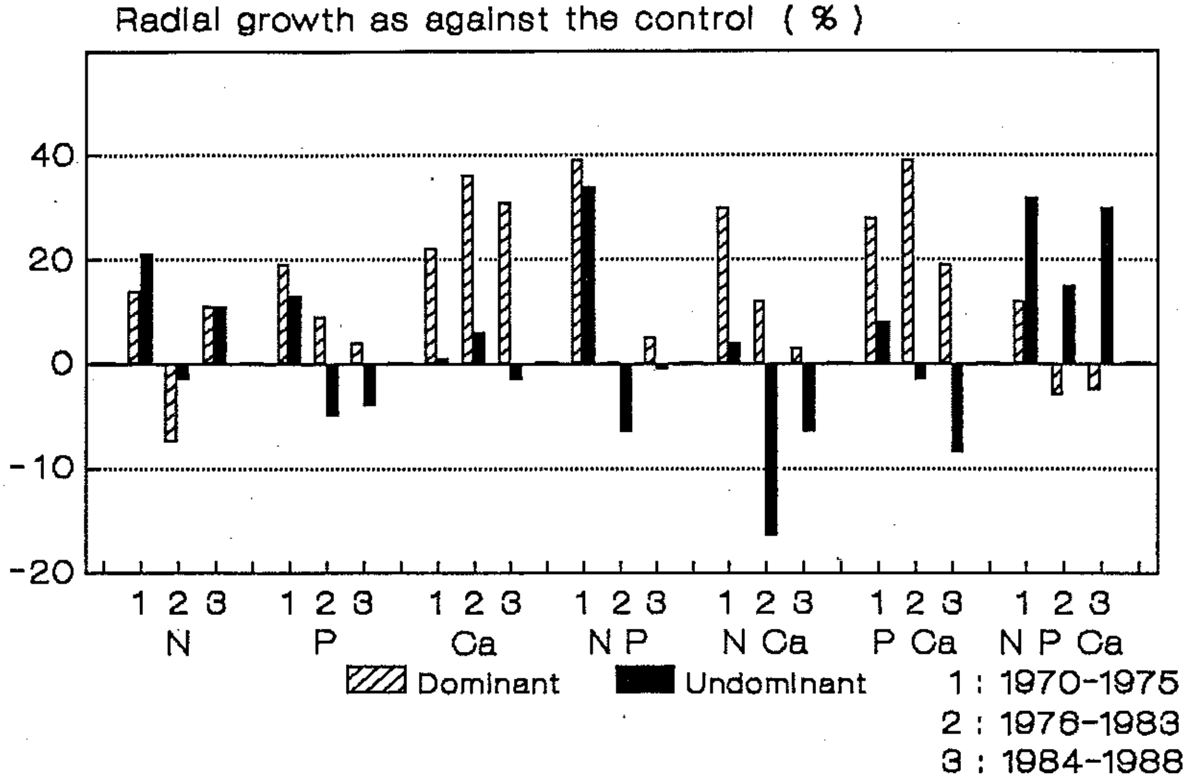

Fig. 3. Mean radial growth of silver fir according to the fertilizing treatment, to the post-fertilization subperiod and to the competition status of each tree within the stand.

- Calcium: In the dominant (n=21), the effect is spectacular; the overall balance is +30 % (+36 % during the period 2). In the undominant (n=25), on the contrary, the overall balance is null (+6 % only during the period 2).

- Phosphorous: the effect is somewhat comparable to that of calcium: positive in the main in the dominant (n=26; +11 %), but vanishing with time; null in the undominant (n=17; positive, then negative).

For the treatment NP, it appears that the effects of nitrogen and phosphorous are approximately additive. The overall balance is higher in the dominant (n=19) than in the undominant (n=22), respectively +14 % and +5 %. The treatment NCa is particularly unfavourable: the overall balance drops to +15 % in the dominant (n=20), and to -16 % in the undominant (n=14), in which the period 2 has been quite critical (-33 %). The treatment PCa seems rather comparable to the treatment Ca, but slightly less favourable, particularly in the undominant.

The results concerning the treatment NPCa are somewhat disconcerting. In comparison with the treatment Ca, the response of the dominant (n=25) and of the undominant trees (n=23) is inverse. The growth of the undominant is greatly improved (+24 % on average), even during the crisis period (+15 %), contrary to that of the dominant, whose overal balance is null.

4 - Discussion and conclusions

On the whole, the treatment 2, i.e. calcium alone, is by far the most favourable to produce a lasting improvement of silver fir radial growth in the Vosges Mountains. The effect is rather progressive in the beginning and must be rather indirect than direct. It results in a betterment of humus biological activity. From the moder and mor type, humus has developed into an acid mull type since 1969, while ground vegetation has become more and more neutro-nitrophilous (Becker et al., in preparation). Such deep modifications due to liming have already been reported, in particular in beech forests (Toutain et al. 1987).

On the contrary, nitrogen supply may have harmful effects on tree vitality. This is consistent with conclusions about Picea abies in the French Ardennes (Nys 1989), where a nitrogen supply has led to a deterioration of health and productivity, while a calcium supply has been revealed highly beneficial.

It is obvious that the weather conditions, especially precipitations, during the years following a fertilization have a significant influence on the response of trees. In the Black Forest (Germany), fertilization has been already demonstrated to cause clear effects on Norway spruce during wet years only (Spiecker 1987). The present study allows to widen the conclusions. Nitrogen, and to a smaller extent phosphorous, are responsible for these various responses to climate. Conversely, calcium is characterized by a more lasting efficiency, which is even increased during drought induced crises. On the other hand, calcium is one of the mineral elements that are the most in danger of dwindling as a result of past intensive cuttings and, more recently, of acid depositions (Federer et al. 1988).

And yet the consequences of liming are still much debated. Persson's assumptions (1988) to reconcile the various results reported in the forest literature appear to be not applicable to silver fir in the Vosges. On the other hand, the present study shows clearly that competition among trees has to be considered: a calcium supply is profitable to dominant trees only, and this must lead to an accelerated social differentiation within stands.

Conversely, a nitrogen supply tends to be more profitable to codominant and dominated trees, and thus to reduce the social differentiation; this can even lead to threaten the health of the dominant trees during climatical crises. Strangely, the same tendency seems to be reinforced when nitrogen is combined with calcium and phosphorous, whereas the opposite tendency emerges when it is combined with calcium only. No satisfactory explanation was found to explain this result.

Thus, the apparent discrepancies among the results reported in the forest literature about the efficiency of fertilization on mature trees, might be explained not only by initial differences in the availability of mineral elements, but also by the weather conditions during the following years, particularly precipitations, and by the competition status within the stand. In the soil and climatic context of the Vosges Mountains, a supply of calcium alone is the most advisable solution. It allows to hope for a lasting improvement of silver fir radial growth, whatever the weather conditions. The expected average growth increase amounts to about 22 %, and to 30 % if dominant trees only are considered.

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