N-EXCESS IN THE FOREST : EFFECTS AND POSSIBLE MEASURES

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ABSTRACT

In Western Europe, high amounts of nitrogen, originating from traffic, industry and agriculture, invade the forest and result in various, often negative, effects. It can be expected that nitrogen excess will cause serious damage of trees and even threaten the forest in the near future. Different prophylactic and curative measures are proposed and discussed.

INTRODUCTION

Nitrogen is undoubtedly the most important nutrient for plant growth. This element is essential for the production of proteins and of components of wood like lignine.

In agriculture, it has been known for a long time that N is one of the major factors of soil fertility. From the Middle Ages onwards until the general propagation of the use of artificial fertilisers, forest litter was a common source of N for agriculture. This transfer of N from the forest to the arable lang lasted for centuries and caused serious degradation of the forest (REHFUESS 1981). It resulted in bad-growing shrubwoods of pioneer tree species and vast heathlands.

After the gradual extinction of the litter removal practices (ANONYMUS 1904) forest productivity slowly increased towards its original level. This restoration was accelerated by atmospheric N-immissions increasing since the beginning of the Industrial Revolution.

At the beginning of the Industrial Revolution the annual N-depositions in Middle-Europe amounted to 6-8 $kg.ha^{-1}.yr^{-1}$ (SIMBREY 1987), 120 years ago about 11 kg and in 1970 7-20 kg (KREUTZER 1972, in REHFUESS 1981). At the moment, as a consequence of increasing NO_x-emissions by traffic and industry but mainly due to NH_3-emissions by intensive agriculture and cattle breeding, the immissions in Belgium and the Netherlands have reached an average of 30-40 kg with peaks up to 100-200 kg in the direct vicinity of industrial pig farms (DUMONT & al. 1990, VAN DEN BURG 1990). It appears that these excessive N-depositions are harmful to the forest and that what initially seemed to enhance growth and vitality now leads to acidification and N-excess.

In Belgian forests, we could recognize N-excess assessing certain vegetation changes :

- Overgrowing of *Pinus sylvestris*-stands with *Prunus serotina* or *Deschampsia flexuosa*;
- Appearance of *Dryopteris dilatata* in *Pinus nigra*-stands on poor sandy soils;

- Extension of *Rubus fruticosus* and *Pteridium aquilinum* in deciduous forests on base-poor substrates;

- Appearance of *Corydalis claviculata* in the forest edges on sandy substrates. The edges receive extra high N-amounts through crown interception;

- Overgrowing of rich deciduous forests with *Galium aparine*.

EFFECTS OF EXCESSIVE N-ENRICHMENT IN THE FOREST

Soil acidification

Soil acidification due to N-depositions has two main causes. On the one hand, HNO_3 (nitric acid) is formed when NO_x meets H_2O. On the other hand, ammoniacal N is transformed in the soil into nitrate which is accompanied with the formation of protons.

Alimentary derangements

Forest soils are often naturally poorly provided with base cations (Ca, K, Mg). N-excess therefore causes nutrient desequilibria. Antagonism between NH_4^+ and other cations may lead to inhibition of their uptake. This was made clear by needle analysis after N-fertilisation in a Pinus sylvestris stand (table 1). N-fertilisation of *Picea abies* stands on base-poor soils in the Ardennes caused chlorosis due to Mg-deficiency and increment losses while fertilisation on richer sites induced growth stimulating effects (DELINCÉ & ANDRÉ 1978, WEISSEN 1988).

Table 1 : Needle composition of *Pinus sylvestris* as a function of increasing N-dose (HOFMANN & Al. 1990).

N %	P %	K %	Ca %	Mg %
1.38	0.147	0.51	0.26	0.093
1.80	0.131	0.48	0.22	0.087
2.35	0.117	0.45	0.19	0.081
3.06	0.105	0.43	0.16	0.076

Mycorhiza

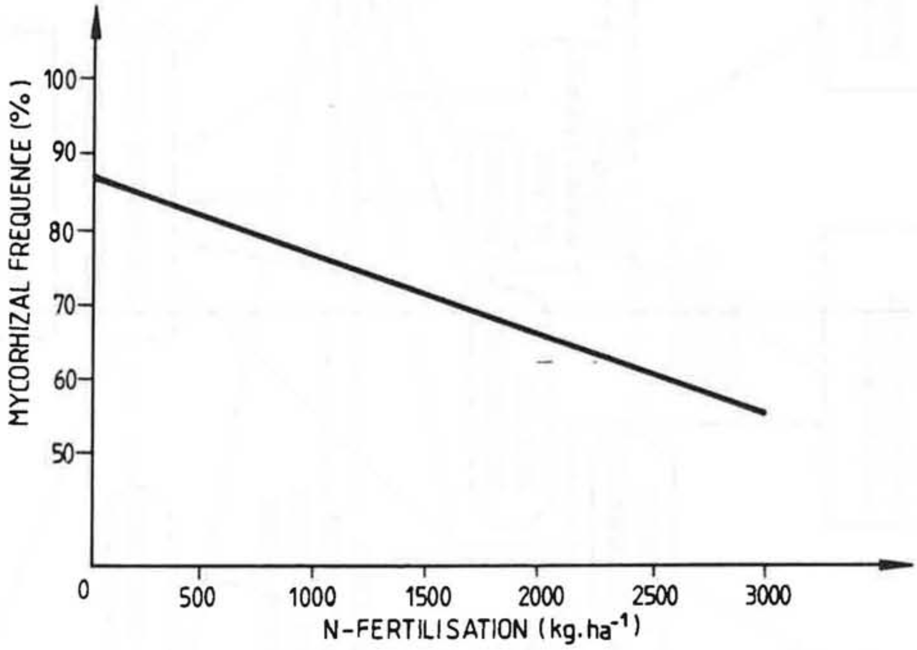
Most mycorhizal fungi disappear with increasing N-concentrations (Figure 1). As a consequence, the uptake of nutrients and water, especially in the case of pioneer species strongly decreases. It leads to mineral deficiencies and water stress (RITTER & TÖLLE 1978, RITTER 1990), increased vitality of pathogenous fungi such as *Armilariella melea* (HOFMANN & al. 1990) and also the appearance of more exigent tree species such as oak and beech, which are less mycorhyza-dependent.

Other consequences

Increased N-concentrations in the needles cause limited winter hardiness and promote fungal diseases such as *Brunchorstia* on *Pinus nigra* (RONSE & al; 1986, VAN DEN BURG 1990).
As mentioned before, increased N-inputs also lead to strong extension of N-demanding herbal and lignous species such as *Prunus serotina* and *Deschampsia flexuosa* in pine forests. Their high water consumption, rather than their relatively high mineral demands, are the cause of stress for the pine trees.

The effects of N-excess in pine forests are summarized in figure 2.

Figure 1 : Mycorhizal frequence as a function of N-import (RITTER & TÖLLE 1978).



POSSIBLE MEASURES

External measures

These measures have to limit the N-pollution by realising a policy which imposes rules on the pollutors. Belgium wants to reach a maximal deposition of 14 $kg.ha^{-1}.yr_{-1}$ on non-sensitive systems and 6 kg on sensitive systems including most forests by the year 2010 (DUMONT & al. 1990). When comparing this goal with the present 34 kg it can be feared that the object will not be reached in time and ecosystem-internal measures, if possible, will be necessary.

Internal measures

These measures become more imperative as external measures fail.

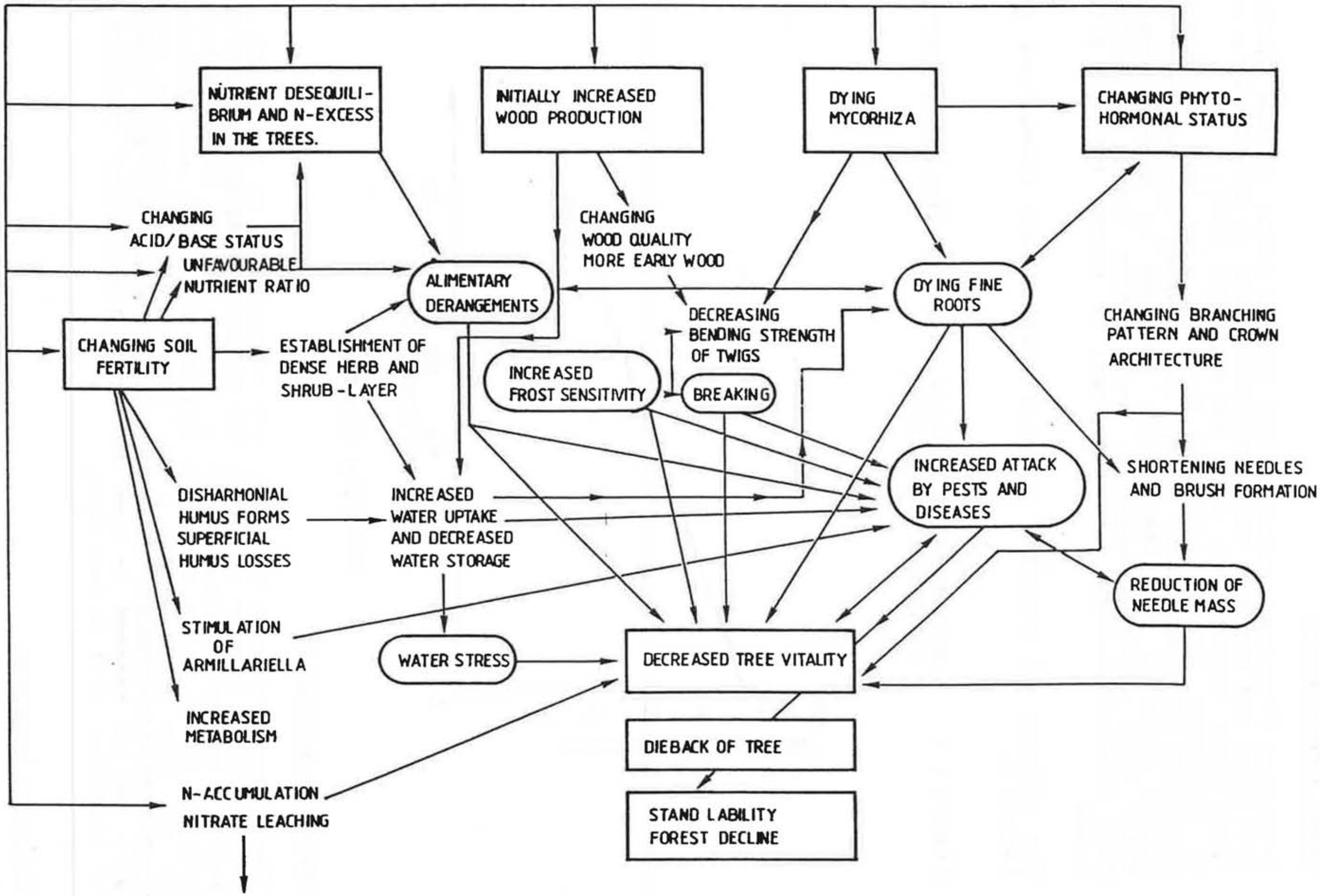


Figure 2 : Effects of N-excess on a pine forest on sandy substrate (HOFMANN & al. 1990).

1. Litter removal

Inspired by the classical heather management techniques it was suggested in Holland to export the N-excess and its detrimental effects by removing the N-saturated litter layer.
Litter removal principally leads to N-decrease (KREUTZER 1972, in REHFUESS 1981) but simulaneously removes important quantities of other minerals (WITTICH 1951, FIEDLER & al. 1962). Together with the litter, the fine roots and the decomposing fauna and flora are removed which leads to further acidification and loss of soil structure (FIEDLER 1962). Litter removal therefore issues in a loss of stability, productivity and diversity of the forest stand and is a direct threat for its survival.
It can be concluded that litter removal must be rejected as an unsuitable corrective measure. The conservation of specific plant species, connected with the presence of oligotrophic environments or the turning of the succession back to the pioneer phase can be achieved by litter removal but forest improvement is out of the question with this method (VERSTRATEN & al. 1989).

2. Clearcutting and soil tillage

Altough most modern silvicultural theories argue for small-scale management on bio-ecological basis, HOFMANN & al. (1990) noticed that clearcutting in combination with complete soil tillage yields the desired N-losses up to 400-800 $kg.ha^{-1}$ (REHFUESS 1981). It must be observed however that the remarks made hereabove concerning the litter removal are equally valid in this case : losses of other minerals, humus desintegration and structural degradation can be expected. Moreover, the excessive N is not removed and recycled, it is washed out and pollutes surface and ground water.

3. Stand architecture, stand treatment and choice of tree species.

As a consequence of their important filtering potentials forest absorb quantities of N 1.3 times higher than the free field, the forest edges even 2-3 times higher quantitites (HOFMANN & al. 1990). To optimize the absorbing surface of the stand edges, they should be kept as closed as possible. Round about stands with sensitive tree species like pine, 5-10 m wide strips of N-resistent broadleaved species must be created, as many of which already exist in many state owned forests in Belgium for other reasons (fire). In too closed pine stands a revitalising thinning must be executed. The branches must be left scattered out over the forest floor to avoid overgrowing by grasses and consecutive water-stress.
The present tree species succession on sandy substrates clearly evolves from pioneer species, principally pine to more exigent broadleaved species like oak and beech. Under the given circumstances, the idea that beech is only adapted to

rich, loamy sites is in fact rendered out of date. Following this reality, the choice of tree species must be tuned to species with higher N-resistance because of higher N-needs. Oak and maple can be introduced in clusters, beech and hornbeam can be underplanted under the pine shelterwood. In areas with deposition levels over 50 $kg.ha^{-1}.yr^{-1}$ even oak and beech are unadapted (HOFMANN & al. 1990). In this case, better results may be reached with linden or *Robinia*.

4. Base cation compensation and stabilisation

Currents N-excess in forests is not a proper fertilisation but rather disharmonisation between different nutrients because this process is simultaneously attended by acidification and leaching of principally Ca and Mg.
In Belgium compensation liming was until now considered Argus-eyed because of its possible negative side-effects. In Germany on the contrary, it is practically unanimously seen as the last remedy against the complete dieback of the forest.
Liming removes deficiency symptoms, increases the pH-value and stimulates the soil's biological activity and consequently decomplishes a general revitalisation. The induced microbial activity, however, can cause high N-mobilisation and leaching of nitrate into the groundwater. To reduce such effects the following directives are important :

- The liming operation has to be considered as a corrective action, not as fertilisation with increased productivity as its prime objective. Medium gifts up to 4000 $kg.ha^{-1}$ are recommended;

- Aggressive products such as CaO are undesirable because they cause too fast litter mineralisation, root damages (BEESE 1985) and soil fauna destruction (BUSCHINGER 1990). Slow-working, Mg-containing products such as dolomite are recommended;

- Liming must be executed in a closed stand; used after a clearfelling it causes nitrate pollution of the groundwater;

- In the presence of deep-burrowing earthworm species, all nutrients stay under disposable form in the root zone and no soil degradation occurs. Liming stimulates their activity on the condition that they still occur in the acidified forest environment. On the somewhat loamy substrates, an earthworm reintroduction acompanying the liming operation may be the key to positive long-term effects (MUYS 1989, MUYS & GRANVAL, in press).

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