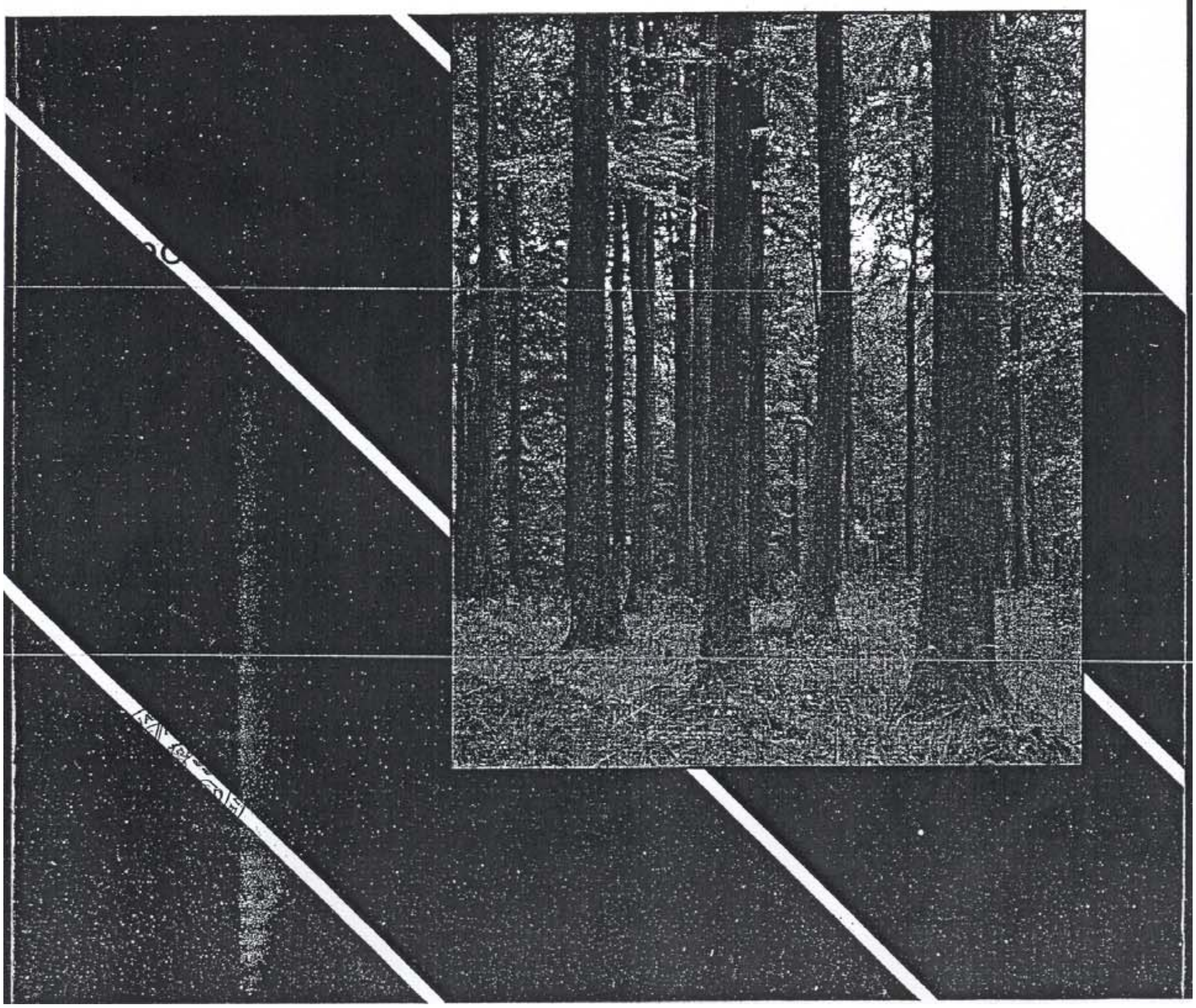
Department of Chemical Engineering II, Lund University

Sustainable Forestry in Temperate Regions

Proceedings of the SUFOR International Workshop
April 7-9, 2002 in Lund, Sweden

Editor Lena Björk



Nutrient Sustainability

Nutrient Sustainability

Prof. Richard Waring, Dept. of Forest Science, College of Forestry
Oregon State University, Corvallis, OR 97331, USA
E-mail: waring@fsl.orst.edu

Abstract

Fast growing plantations require a sustained supply of nutrients in addition to nitrogen. As nitrogen becomes increasingly available, allocation to growth is shifted proportionally from fine roots and mycorrhizae toward foliage and stems; this shift results in reduced uptake of phosphorus, bases, and micronutrients. For conifers, leaf nitrogen concentrations above 1.5% generally signify that free amino acids are increasing while the concentration of defensive compounds is being reduced. This shift in biochemistry makes plantations more susceptible to outbreaks of diseases and insects.

Over the long term, nitrogen additions, whether obtained through atmospheric deposition, through symbiotic N-fixation, or through commercial application, will tend to make other nutrients less available. Sustainable practices that minimize nutrient imbalances include: (1) favoring a mix of species that recycle bases and (2) imposing practices that reduce the relative availability of nitrogen while increasing the decomposition of woody material rich in bases.

Introduction

The recognition that intensively managed plantations can meet the world's demand for most types of wood products on a few percent of the present forested area is appreciated and applauded by environmental skeptics (Lomborg 2001), foresters (Boyle et al. 1999), and conservationists (Wilson 2002). Yields between 10 to 50 m^3/ha/yr are rarely attained, however, without the application of commercial fertilizer. The exceptions are in areas such as northern Europe, where high levels of atmospheric N deposition are recorded (Schulze 1989, Edfast et al. 1990, Emmett and Reynolds 1995), and in the Pacific Northwest region of the U.S.A., where a wide variety of native symbiotic nitrogen-fixing species abound (Waring and Franklin 1979). The question arises "how sustainable are these yields without application of additional nitrogen and other essential nutrients?"

In this paper, I describe the key role that nitrogen plays in determining wood production, and explain why somewhat less than optimal levels of nitrogen are recommended to reduce the danger from outbreaks of insects and diseases. I also recommend practices for slash disposal and for maintaining a mix of species that should improve nutrient cycling and help maintain growth rates through future rotations.

Key role of nitrogen in determining wood production

Nitrogen influences the growth of wood in three ways:

- By increasing the photosynthetic capacity of leaves
- By shifting the allocation of growth away from fine roots into stem wood
- By increasing the total leaf area, which results in the interception of more light

What is striking about these three responses is that over a wide range in nitrogen availability, the relationships are linear (except for light interception). Photosynthesis may be increased by more than 3-fold in proportion to leaf nitrogen concentrations (Meir et al. 2002). Similarly, through incremental addition of nitrogen, Beets and Whitehead (1996) showed that the fraction of growth allocated to fine-roots was reduced from 0.6 to 0.2, while wood production increased 3-fold from 15 to 45 m^3/ha/yr in *Pinus radiata* plantations in New Zealand. Foliage mass and leaf area showed a similar 3-fold increase with additions of nitrogen (Beets and Madgwick 1988).

Why foliar nitrogen levels should be maintained below optimum for growth

Tamm et al. (1999) provide a comprehensive review and synthesis of a series of major research projects involving optimum balanced and imbalanced additions of fertilizers to Scots pine plantations in Sweden. Linder (1995) provides a similar synthesis for Norway spruce with details on adjusting for seasonal variation in starch reserves. Both studies indicate that the optimum concentration of nitrogen in foliage to obtain maximum tree growth is between 1.4-1.7%. I will argue that it is ill advised to allow conifer foliage to exceed 1.5% N or hardwoods 2.0% N because biochemical changes occur in the proportion of nitrogen associated with the photosynthetic machinery, and that in more soluble forms such as amino acids (Table 1).

Table 1. The amino acid (arginine) increases much more than the foliar nitrogen in Scots pine following additions of N fertilizer (Näsholm and Ericsson 1990).

Foliar N%	0.8-1.2%	1.5-2.0%	2-2.5%
Arginine, % of N	0%	7-16%	10-27%

In deciduous hardwoods, a similar relationship between foliar N% and increasing amounts of amino acids exists (Pahlsson 1992). Along with an increase in soluble forms of nitrogen, there is a decrease in the concentration of defensive compounds such as phenolics. In Scots pine, the concentration of defensive compounds (procyanidins) decrease by 45% while the fraction of arginine in the amino acid pool increases by nearly 400% as foliage N concentrations increase. The problem may be enhanced by air pollution through ozone damage, but occurs in areas without significant pollution, such as Australia (Turner and Lambert 1986) and in the Pacific Northwest of the U.S.A. (Fig. 3).

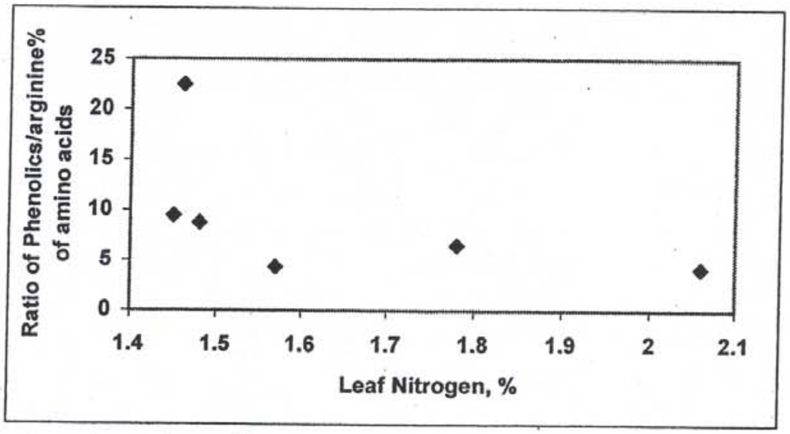


Fig. 2. In Scots pine plantations, the ratio of defensive compounds (procyanidins) to the fraction of total amino acid pool composed of arginine drops significantly at leaf N% ≥1.5% (Kätzel and Löffler 1995, 1997).

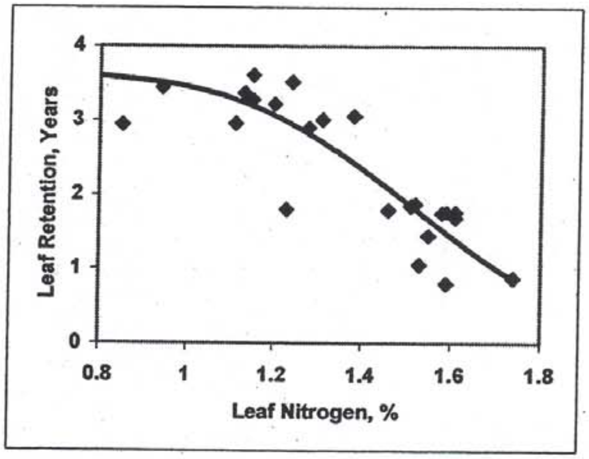


Fig. 3. In Douglas-fir plantations foliar retention is significantly reduced by a needle-cast fungi (Phaeocryptopus gaeumanii) when leaf N% exceed 1.5% (Waring et al. 2000).

Although insect outbreaks are often associated with trees under stress, with very low growth rates (Coyea and Margolis 1992, Christiansen et al. 1998, Waring et al. 1992), insect damage may also increase in stands where growth rates are enhanced through application of fertilizer. For example, spruce stands in British Columbia, when provided incremental increases in available nitrogen and other nutrients, suffered a five-fold increase in weevil shoot damage (Fig. 4).

Silvicultural practices

Slash disposal

In high yielding plantations, thinning is usually practiced. At the time of thinning, the slash produced consists of green foliage and woody material. These two sources of detritus have different C:N and other mineral ratios and require different treatment to meet the goal of maintaining site nutrient balance (Van den Driessche 1984, Ericcson 1994). The foliage, if on sites receiving an excess of the nitrogen, can be piled and later

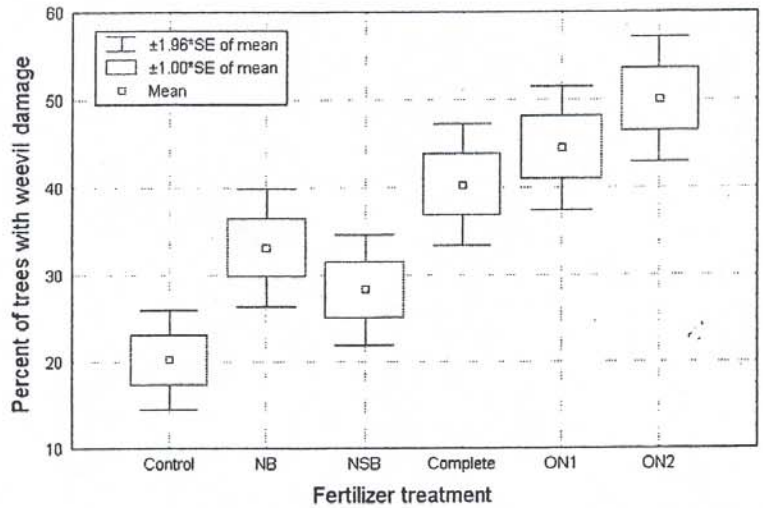


Fig. 4. Additions of fertilizer, even when complete, still lead to increased weevil damage to spruce plantations in British Columbia (Van Akker 2002). ***Control*** *- not fertilized (foliar N concentrations at1.1%;* ***NB,*** *- fertilize every 6 years with (kg/ha): 200N, 1.5B;* ***NSB*** *- fertilize every 6 years with (kg/ha): 200N, 50S, 1.5B;* ***Complete*** *- fertilize every 6 years with (kg/ha): 200N, 100P, 100K, 50S, 25Mg, 1.5B;* ***ON_1*** *- yearly fertilization to maintain foliar N concentration at 1.3% and other nutrients and nutrient ratios within the "optimum" range;* ***ON_2*** *- yearly fertilization to maintain foliar N concentration at 1.6% and other nutrients and nutrient ratios within the "optimum" range (Brockley 1999).*

burned. During ignition, a considerable amount of nitrogen and sulfur will be volatilized, leaving ash rich in bases: Ca^{++}, Mg^{++}, K^{+} (Wan et al. 2001). The woody material, if left on the surface, will decay very slowly. If chipped, however, the woody material is soon incorporated into the soil (Turner 1977). Because the C:N ratio of woody material is high (>200:1), nitrogen will be further immobilized (Paustian et al. 1992), and root growth will increase, along with mycorrhizal activity, which improves uptake of other nutrients. With decomposition of wood, calcium from cell walls is mineralized, and replaces hydrogen on soil cation exchange sites. This raises soil pH, which improves the availability of P and other nutrients (Chandler 1941, Carreira et al. 1997).

Species diversity

R.R. Chandler in 1941 was one of the first Americans to document that mineral concentrations in the foliage of various tree species differed consistently, regardless of the soil on which the trees grew. He noted, for example, that the calcium content in the litter of *Tilia*, *Prunus*, and *Liriodendron* was high, whereas that in the leaf litter from *Fagus*, *Quercus*, and *Acer* was low. Many others have recognized the potential to manage nutrient availability and carbon sequestration in soils through manipulation of species composition (Fyles and Fyles 1993,Vesterdal and Raulund-Rasmussen 1998).

Monitoring Canopy N concentration

With the recognition that nitrogen concentrations in foliage may exceed a critical ratio with defensive compounds that is well below optimum for growth, and that unknown amounts of nitrogen can be provided to ecosystems through atmospheric deposition and symbiotic fixation, it is worth noting that foliar nitrogen concentrations can be monitored and mapped from space using fine-resolution imaging spectrometers (Martin and Aber 1997).

Conclusions

The main points of this paper can be summarized as five recommendations:

- Keep N concentrations below optimum for growth
- Use amino acid assays to indicate nutrient imbalances or other stresses
- Consider burning green slash and chipping woody debris
- Use a mixture of species to provide a balanced litter nutrient content
- Monitor foliar N concentration via remote sensing

Literature Cited

Beets, P. N., and D. Whitehead. 1996. Carbon partitioning in *Pinus radiata* in relation to foliage nitrogen status. *Tree Physiology* 16: 131-138.

Beets, P.N., and H.A.I. Madgwick. 1988. Above-ground dry matter and nutrient content of *Pinus radiata* as affected by lupins, fertilizer, thinning and stand age. *New Zealand Journal of Forestry* 18: 43-64.

Boyle, J.K. Winjum, K. Kavanagh, and E.C. Jensen (eds.).1999. Planted Forests: Contributions to the Quest for Sustainable Societies. Kluwer Academic Publishers, Dordrecht, Netherlands.

Brockley, R.P. 1999. Intensive fertilization to increase productivity of interior forests. Assoc. B.C. Professional Foresters, Vancouver. *Forum* 6:18-19.

Carreira, J.A., A.F. Harrison, L.J. Sheppard, and C. Woods. 1997. Reduced soil P availability in Sitka spruce (*Picea sitchensis* (Bong.) Carr.) plantations induced by applied acid-mist: significance in forest decline. *Forest Ecology & Management* 92:153-166.

Chandler, R.F., Jr. 1941. The amount and mineral nutrient content of freshly fallen leaf litter in the hardwood forests of central New York. *Journal of the American Society of Agronomy* 33:859-871.

Christiansen, E., R. H. Waring, and A. A. Berryman. 1987. Resistance of conifers to bark beetle attack: searching for general relationships. *Forest Ecology and Management* 22: 89-106.

Coyea, M. R., and H. A. Margolis. 1994. The historical reconstruction of growth efficiency and its relationship to tree mortality in balsam fir ecosystems affected by spruce budworm. *Canadian Journal of Forest Research* 24: 2208-2221.

Edfast, A.-B., Näsholm T., and Ericsson, A. 1990. Free amino acids in needles of Norway spruce and Scots pine trees on different sites in areas with two levels of nitrogen deposition. *Canadian Journal of Forest Research* 20:1132-1136.

Emmett, B.A., and B. Reynolds. 1996. Nitrogen critical loads for spruce plantations in Wales: Is there too much nitrogen? *Forestry* 69: 200-214.

Entry, J.A., K. Cromack, Jr, R.G. Kelsey, and N.E. Martin. 1991. Response of Douglas-fir to infection by *Armillaria ostoyae* after thinning or thinning plus fertilization. *Phytopathology* 81: 682-689.

Ericsson, T. 19994. Nutrient dynamics and requirements of forest crops. *New Zealand Journal of Forestry Science* 24:133-168.

Fyles, J.W., and I.H. Fyles. 1993. Interaction of Douglas-fir with red alder and salal foliage litter during decomposition. *Canadian Journal of Forest Research* 23: 358-361.

Kätzel, R. and S. Löffler. 1995. Untersuchungen zur Erholung von Kiefernbestanden im ehemaligen Stickstoffeintragsgebiet Lichterfelde/Britz:2. Teil:Vitälitat der Kiefern nach physiologischen und biochemischen Parametern. Beitrage für Forstwirtschaft und Landschaftsökologie 29: 89-93.

Kätzel, R. and S. Loffler.1997. The influence of atmospheric NH_3 on Scots pine (*Pinus sylvestris* L.). In: G.M.J. Mohren, K. Kramer, and S. Sabaté (eds.). In: Impact of Global Change on Tree Physiology and Forest Ecosystems. pp. 81-86. Kluwer Academic Publishers. Dordrecht, Netherlands.

Linder, S. 1995. Foliar analysis for detecting and correcting nutrient imbalances in Norway spruce. *Ecological Bulletins* 44:178-190.

Lomborg, B.2001. The Skeptical Environmentalist: Measuring the Real State of the World. Cambridge University Press, Cambridge, U.K.

Martin, M.E., and J.D. Aber. 1997. High spectral resolution remote sensing of forest canopy lignin, nitrogen and ecosystem processes. *Ecological Applications* 7: 431-443.

Meir, P., B. Kruijt, M. Broadmeadow, E. Barbosa, O. Kull, F. Carswell, A. Nobre, and P.G. Jarvis. 2002. Acclimation of photosynthetic capacity to irradiance in tree canopies in relation to leaf nitrogen concentration and leaf mass per unit area. *Plant, Cell & Environment* 25:343-358.

Näsholm, T., and A. Ericsson. 1990. Seasonal changes in amino acids, protein and total nitrogen in needles of fertilized Scots pine trees. *Tree Physiology* 6: 267-281.

Pahlsson, A.-M.B. 1992. Influence of nitrogen fertilization on minerals, carbohydrates, amino acids and phenolic compounds in beech (*Fagus sylvatica* L. leaves. *Tree Physiology* 10:93-100.

Paustian, K., W.J. Parton, and J. Persson. 1992. Modeling soil organic matter in organic-amended and nitrogen-fertilized long-term plots. *Soil Science Society of America Journal* 56:476-488.

Schulze, E.-D. 1989. Air pollution and forest decline in a spruce (*Picea abies*) forest. *Science* 244: 776-783.

Tamm, C. O., A. Aronsson, B. Popovic, and J. Flower-Ellis. 1999. Optimum nutrition and nitrogen saturation in Scots pine stands. Studia Forestalia Suecica, Report No. 206. Uppsala, Sweden.

Turner, J. 1977. Effects of nitrogen availability on nitrogen cycle in a Douglas-fir stand. *Forest Science* 23:307-316.

Turner, J., and M. J. Lambert. 1986. Nutrition and nutritional relationships of *Pinus radiata*. *Annual Review of Ecology and Systematics* 17: 325-350.

Van Akker, L. 2002. The effects of fertilization on the resin canal defenses and susceptibility of spruce to attack by the white pine weevil, *Pissodes strobi. M.Sc. Thesis*. University of British Columbia.

Van den Driessche, R. 1984. Nutrient storage, retranslocation and relationship of stress to nutrition. In: G.D. Bowen and E.K.S. Nambiar, eds), pp. 181-209. Nutrition of Plantation Forests. Academic Press, Orlando, Florida.

Vesterdal., L. and K. Raulund-Rasmussen. 1998. Forest floor chemistry under seven tree species along a soil fertility gradient. *Canadian Journal of Forest Research* 28:1636-1647.

Wan, S., D. Hui, and Y. Luo. 2001. Fire effects of nitrogen pools and dynamics in terrestrial ecosystems: a metal-analysis. *Ecological Applications* 11:1349-1365.

Waring, R. H., T. Savage, K. Cromack, Jr., and C. Rose. 1992. Thinning and nitrogen fertilization in a grand fir stand infested with western spruce budworm. Part IV. An ecosystem management perspective. *Forest Science* 38: 275-286.

Waring, R. H., J. Boyle, K. Cromack, Jr., D. Maguire, and A. Kanaskie. 2000. Researchers offer new insights into Swiss needle cast. *Western Forester* 45: 10-11.

Waring, R. H., and J. F. Franklin. 1979. Evergreen coniferous forests of the Pacific Northwest. *Science* 204: 1380-1386.

Wilson, E.O. 2002.The Future of Life. Cambridge University Press, Cambridge, England.