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Nitrogen release from litter in relation to the disappearance of lignin

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Abstract. Nitrogen dynamics were followed in several decomposing forest foliage litters in two contrasting ecosystem types. Litter types showing a significant net accumulation before a net release started were subjected to a study on nitrogen release mechanisms. In all cases no net release of nitrogen took place until a decomposition of the recalcitrant lignin fraction had started. The use of lignin as a predictor for the onset of a net nitrogen release was found to be better than the C/N ratio.

Conventional wisdom suggests that the point at which nitrogen release from litter begins is determined by the carbon:nitrogen ratio of the litter (Mulder et al. 1969; Berg and Staaf 1981). However, the chemical composition of forest litters varies considerably among litter types and because of this we expect to see deviations in patterns of nitrogen accumulation and/or release in relation to C/N ratios.

Lignin and humic compounds, the latter formed during decomposition are slowly decomposed. Furthermore, nitrogen may be incorporated into humic substances during decay (Berg and Theander 1984). This led us to hypothesize that nitrogen dynamics in decomposing litter would be closely related to the dynamics of the lignin–humus fraction of the litter.

The purpose of this short communication is to present observations on the relationship between changes in the lignin–humus content and the onset of nitrogen release from some litter types studied in field incubations. Our field studies were carried out in two Scots pine forests of different nutrient regimes (site descriptions given by Axelsson and Bråkenhielm (1980) and Lundmark, Berg and Nilsson (1982), one lodgepole pine forest (Lundmark et al. 1982), and one deciduous forest (Wisconsin) dominated by sugar maple (Pastor et al. 1982).

Litter materials used in the Swedish studies included Scots pine (*Pinus sylvestris* L.) needles, white birch (*Betula pubescens* Ehrh.) leaves and lodgepole pine (*P. contorta* Dougl.) needles. Litter was collected on tarpaulins at time of senescence by gently shaking the trees. Samples weighing approximately 0.7 g (air-dry mass) were placed into terylene-net bags made of net with 1-mm mesh. Litter bags were distributed to 20 randomly located plots in each of the study sites and were held in place in the forest floor with metal pins. Three times a year viz. in May, late August and late October samplings were made and 20 bags were retrieved in each sampling and dried at 85°C. Contents were weighed, milled to pass a 1-mm sieve and pooled for chemical analyses.

Litter materials used in the Wisconsin study included white pine (*P. strobus* L.) and eastern hemlock (*Tsuga canadensis* (L.) Carr.) needles, aspen (*Populus grandidenta Michx.*), sugar maple (*Acer saccharum* March), red oak (*Quercus borealis* Michx.) and white oak (O. *alba* L.) leaves. Foliage litters were collected from a number of 1 × 30 m screens spread on the forest floor during the period of leaf fall in October 1980. Litter materials dried at room temperature and weighing approximately 4 g were placed in polyester litter bags with a mesh of 0.1 mm.

The different mesh sizes used for litter bags in the different studies may have influenced decomposition rates by creating different environmental conditions within the bags. However, a comparison of 0.1 and 2.0 mm mesh bags in Wisconsin revealed no differences in mass loss rates for a variety of litter types (Aber et al. 1984). A similar study in Sweden found similar mass loss rates for Scots pine needles incubated in 0.1 and 2.0 mm mesh bags (Maj-Britt Johansson, personal communication). Thus we assume that the different mesh-sizes had little effect on our results.

Methods of chemical analysis for lignin and nitrogen were similar in the Swedish and Wisconsin studies, but methods for the extractions differed slightly (see Berg et al. 1984). The protocol of Bethge et al. (1971) was used for the Swedish samples and that of Effland (1977) for the Wisconsin samples. The acid–insoluble substances (AIS) include both lignin and other non-hydrolyzable products that accumulate during decomposition (Berg and Theander 1984, Stevenson 1982).

The litter types selected for this analysis had a wide range of initial lignin and nitrogen concentrations (Berg et al. 1984). Initial lignin concentrations were similar among coniferous litters, except for lodgepole pine needles which had a higher initial lignin concentration. Deciduous leaf litters had much lower lignin concentrations except for birch leaves, which were similar to coniferous litters.

The absolute amount of AIS increased initially in all litter types with the exception of lodgepole pine needles that had a very large initial concentration of lignin (37%) that started disappearing at the beginning of the study. The pattern of build-up and decomposition of the AIS fraction was remarkably similar among needle litters (background data in Table 2 references). The maximum net increase of AIS in all the litter types was negatively correlated with the initial concentration of lignin ($r = -0.729$; $n = 9$; $p < 0.05$) (Scots pine needles used only once). Thus, the lower the initial concentration of lignin the more AIS was built up. At lower initial lignin concentrations the microorganisms have a better supply of more readily available carbon sources and consequently a decomposition of lignin should start later. Therefore there is simply a longer time-lapse during which a build-up of humic substances takes place and total AIS increases. Net decreases in the AIS fraction began at very different accumulated mass losses which may depend on the initial concentration of lignin in litter.

In order to trace a mechanism for nitrogen release, we used studies of all litter types in which there was a net accumulation of nitrogen followed by a clear release during the course of the incubation. There was such a net accumulation of nitrogen in all litters and the magnitude of the net accumulation varied between the litter types. The net accumulation of nitrogen in Scots pine needles at the Jädraås site was about 10% whereas it was about 47% at the Malung site as calculated from the lowest value after the natural initial leaching of soluble nitrogen. White birch leaves and white pine needles had a net uptake of about 36 percent. Whereas these values were measured, the maximum accumulation of nitrogen can be calculated from a model.

Aber and Melillo (1982) demonstrated in such a model that the amount of nitrogen accumulated per gram of initial dry matter of litter and the fraction of dry matter lost at the point of maximum nitrogen accumulation could be calculated from the linear relationship that exists between percentage of original dry matter remaining and percentage of nitrogen in the residue. Using their equations, we estimated the maximum nitrogen accumulation, which we have termed the "maximum nitrogen accumulation" and the fraction of dry matter remaining at the point when the critical amount was reached for ten different litter types in four forest systems (Table 1).

Table 1. Observed (OBS) and estimated (EST) values for percent mass remaining at the point of maximum absolute amounts of nitrogen and lignin (AIS). Data are for foliage litter types incubated at four sites. The number of measurements are given as well as regression coefficients for the models (all of them were highly significant; $p < 0.001$). Initial concentrations of lignin and nitrogen are also given.

Site and litter type	Initial concentration							
	Lignin (AIS) (%)				Nitrogen (%)			
	Model fix		Critical values given as mass rem. (%)		Model fix		Critical values given as mass rem. (%)	
	r	*n*	OBS	EST	*r*	*n*	OBS	EST
Jädraås								
Scots pine needles	−0.968	15	72.7	80.5	−0.974	15	64.3	59.2
White birch leaves	−0.899	11	65.8	82.6	−0.930	11	52.0	63.1
Malung — Scots pine site								
Scots pine needles	−0.978	11	84.9	99.1	−0.944	11	61.8	61.9
Malung – lodgepole pine site								
Lodgepole pine needles	−0.818	11	92.6	100.0	−0.947	11	71.7	60.9
Blackhawk Island								
Aspen leaves	−0.953	12	73.6	76.6	−0.992	12	73.6	67.6
White oak leaves	−0.963	12	77.7	82.2	−0.975	12	77.7	77.1
Red oak leaves	−0.975	12	87.6	85.4	−0.953	12	59.2	70.4
Sugar maple leaves	−0.973	12	58.5	65.3	−0.868	12	58.5	64.5
White pine needles	−0.985	12	86.5	87.9	−0.984	12	56.9	67.3
Eastern hemlock needles	−0.979	12	77.8	72.0	−0.958	12	54.9	63.5

The concentration of AIS was also negatively related to the percentage of original dry matter remaining. Thus we were able to calculate the critical amount of AIS and the corresponding fraction of dry matter remaining. The values estimated by this regression model were quite close to the observed values (Table 1, Fig. 1).

The model approach of Aber and Melillo (1982) has the advantage of being based on the trends of the entire data set rather than on a single value chosen as the maximum. In addition, the model is continuous over the range of data and one can estimate values between two observation points. Regardless of whether we use the observed or the estimated data we found that a net release of nitrogen never began before a net decrease in AIS was noted (Table 1, Fig. 1). In three cases they were coincident.

For comparison, we calculated the C/N ratio at the point where net nitrogen release begins (critical C/N ratio). Assuming that litter is 50% carbon, we noted that the observed critical C/N ratios ranged from 29 to 80 (c.f. McClaugherty et al. 1985). Clearly, C/N ratios were not good predictors for the onset of net nitrogen release for the types of litters examined. This probably is due to the fact that the C/N ratios does not consider the quality of either the carbon or nitrogen constituents in the litter. It should be noted that when a net release of nitrogen had started it was linear both for litter and for AIS mass loss (Table 2).

Although little work has been done on the chemistry of the carbon compounds in decomposing litter, Bosatta and Berendse (1984) described the effect of limiting carbon-source availability on nitrogen mineralization. The approach

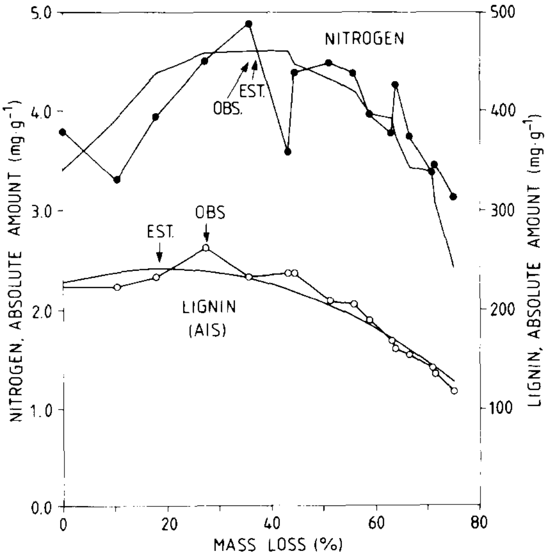

Fig. 1. Measured net changes in lignin (○) and nitrogen (●) in decomposing Scots pine needle litter (Malung site). The graphs without symbols give the estimated function for the dynamics (McClaugherty et al. 1985). The observed and estimated markings are indicated (cf Table 1).

Table 2. Linear relations between the net release of nitrogen (mg g^{-1}) and both litter and AIS mass losses (percent) for some litter types.

Site and litter type	Correlation coefficient		Literature reference
	Litter mass loss	Lignin (AIS) mass loss	
Jädraås			
Scots pine needles	0.983	0.964	Staaf and Berg (1982)
	$n = 12$	$n = 9$	Berg et al. (1982)
	$p < 0.001$	$p < 0.001$	
White birch leaves	0.892	0.992	Berg and Staaf (1986)
	$n = 7$	$n = 7$	Berg and Wessèn (1984)
	$p < 0.01$	$p < 0.001$	
Malung			
Scots pine needles	0.776	0.756	Berg and Lundmark (1985)
	$n = 9$	$n = 9$	
	$p < 0.05$	$p < 0.05$	
Lodgepole pine needles	0.767	0.821	Berg and Lundmark (1985)
	$n = 9$	$n = 9$	
	$p < 0.05$	$p < 0.01$	
Blackhawk Island			
Aspend leaves	0.963	0.932	Aber et al. (1984)
	$n = 6$	$n = 6$	
	$p < 0.01$	$p < 0.01$	
White oak leaves	0.930	0.896	Aber et al. (1984)
	$n = 6$	$n = 6$	
	$p < 0.01$	$p < 0.05$	
Red oak leaves	0.927	0.487	Aber et al. (1984)
	$n = 4$	$n = 4$	
	$p < 0.1$	n.s.	
Sugar maple leaves	0.953	0.924	Aber et al. (1984)
	$n = 6$	$n = 6$	
	$p < 0.01$	$p < 0.01$	

presented by them, although made from a smaller set of supporting data, agrees with the observation presented here. Bosatta and Berendse (1984) supported their model with the observation that a lowered CO_2-evolution was correlated with an increase in nitrogen mineralization. Such a decrease in CO_2-evolution could very well be connected with the start of lignin decomposition as observed in the present study.

Even if the composition of AIS in late stages is, at present, poorly defined we suggest that AIS plays a significant role in regulating nitrogen dynamics in litter and that further study is warranted.

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