Transect Studies on Pine Litter Organic Matter: Decomposition and Chemical Properties of Upper Soil Layers in Polish Forests[1]

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Abstract

The relationship between litter decomposition rate, some chemical properties of upper soil layers (iron, manganese, zinc, copper, lead, mercury, nickel, chrome in humus-mineral horizon-A), and litter (the same eight elements in needle litter fraction) in pine forests of Poland was studied. Heavy metal content in organic-mineral horizon of soils was highly correlated with needle decomposition rate for copper (correlation coefficient 0.901), zinc (corr. coeff. 0.901), nickel (corr. coeff. 0.834), and iron (corr. coeff. 0.850). Heavy metal content in needle litter was highly correlated with needle decomposition rate (iron—corr. coeff. 0.83; zinc—0.80; lead—0.82; nickel—0.89), and with mixed litter decomposition rate (iron—corr. coeff. 0.71; zinc—0.66; lead—0.68; nickel—0.72). Significant correlations were not found between the rate of decomposition of wood or cones and their content of metals, except for chromium. When comparing decomposition rates with degree of litter pollution, it was shown that in the case of needle decomposition for six significant correlations, two were positive; in the case of mixed litter decomposition for five significant correlations, two were positive. In both cases decomposition reacted positively to the presence of iron and lead. When comparing decomposition rates with the degree of soil pollution, it was shown that in the case of needle decomposition, five significant correlations were positive; in the case of mixed litter decomposition, only one significant correlation was positive.

Introduction

Although the level of pollution in Poland has declined steadily in recent years (Breymeyer 1996, Przybylska 1995, Statistical Yearbook of Katowice Voivodeship 1992), pine stands have continued to be damaged by it (Wawrzoniak and Malachowska 1996, 1997). The saturation of litter layers and soils with heavy metals is still at a level harmful to the proper functioning of the forest ecosystem (Laskowski 1994).

Research on soils and the rate of decomposition of forest litter was carried out at 15 sites with pine forest (*Leucobryo-Pinetum* and *Peucedano-Pinetum*) or mixed pine forest *(Quercoroboris-Pinetum)* growing on the podsolic soils developed on the glaciofluvial and fluvial deposits (Degórski 1996a). The sites were distributed along two transects: one west-east across Poland at parallel 52° N (climatic or continental transect), and the other from Upper Silesia to the Bialowieza area (Silesian transect) (Breymeyer 1996).

The sites were slightly different in annual precipitation, while mean annual temperature was distinctly lower to the east (Smialkowski 1996).

The chemical properties of overlying humus layers were studied, as well as the mineral-organic horizons of soils, where organic matter accumulates and is mineralized and humificated. The sorption complexes are most vulnerable to the accumulation of heavy metals, and their buffering properties determine the geochemical balance of the whole ecosystem. Permanent circulation of soil organisms between upper soil horizons, humus, and litter creates one functional unit of layers.

This study analyzed the relationship between the rate of decomposition of forest litter and the chemical characteristics of the mineral-humus horizon-A of soils by using deposition measurements of pollutants from local emissions in both Upper Silesia and the continental transect sites in Poland.

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Methods

Rates of decomposition were measured using the common litter bags method (i.e., Pan-European Forest Ecosystem Research Program; Berg and Co 1993). Weighed portions of litter dried to constant weight were enclosed in bags (10 by 10 cm) made from 1 mm nylon netting. Bags were then located at the sites so that decomposition could take place. The surfaces on which the bags were placed were cleaned of moss and small shrubs to ensure that the exposed litter made contact with the upper layer of the soil. Sixty litter bags were placed simultaneously at each site: 20 with 1g of pine needles each, 20 with 1g of mixed litter, 10 with a single pine cone, and 10 with 1g of small twigs. The exposure of litter bags always began in autumn (October), with samples collected after two time periods: half after winter (in March or April) and the remaining half during the following autumn (October), when samples for the next year were placed on the soil. In every case only litter that had fallen to the forest floor during the previous year was used (litter plots were cleaned before the counted fall). Litter was collected from special demarcated areas, ensuring that the litter collected was always "of the same age." After field incubation, litter bags were transferred to the laboratory and cleaned of soil and plants overgrowing the netting. Litter was then dried to constant weight and weighed. The mass loss during incubation provided a measure of decomposition expressed in percentage terms or as the so-called "k" coefficient, which was calculated by applying the formula:

$$\ln \text{ (final mass / initial mass)} = -k$$

Sinusoidal transformation of the results obtained for decomposition was also applied:

$$(\sin^{-1} (x^{1/2}).$$

The pollution of the organic-mineral horizon-A of the soil was estimated on the basis of analyses of soil samples collected on a single occasion from 10 points on each mineral-organic horizon of a given profile, with the mean value presented. Contents of heavy metals, such as zinc (Zn), manganese (Mn), iron (Fe), lead (Pb), nickel (Ni), chromium (Cr), and copper (Cu), in soil organic matter were determined using an atomic adsorption spectrophotometer (AAS) after digestion of samples in 20 percent HCl. An index of accumulation was calculated on the basis of the results obtained for all mineral-humus horizon-A as a measure of their enrichment by the heavy metals. The index of accumulation was calculated as the ratio of the content of a given element in the organic-mineral horizon-A and in the parent rock, giving an indication of an exogenic origin n the surface layer of the soil (Gworek 1985; Degorski, [In press]).

Litter (needles, twigs, and cones) collected annually from all sites was chemically analyzed for the concentration presence of eight metals as described above for soil organic matter. Statistical calculations involved analysis of variance for the 10 elements and the 3 fractions.

Results

The Pollution of Litter

The concentrations of Pb and K were not statistically different among the litter fraction ($p > 0.05$). Concentrations of the remaining elements (Fe, Mn, Zn, Cu, Cd, Ca, Mg, and Na) did vary significantly from one litter fraction to another ($p < 0.05$). Some trends in the composition of litter along both transects were visible. Two clear groups of elements were present in pine needles (the dominant fraction in litter): Zn, K, and Na were at significantly lower levels along the transect of continentality; and Mg, Mn, Cu and Cd occurred at lower levels along the Silesian transect. The remaining three elements (Pb, Fe, and Ca) did not show clear trends.

The three fractions of litter (needles, twigs, and cones) did not show significant differences in the contents of the elements Pb and K ($p > 0.05$). Contents of all the remaining elements were variable.

It is not possible to determine whether the different concentrations of metals in the different fractions of litter resulted from the accumulation of elements within tissues or on the surfaces of dead fragments of the plants forming it; litter was not washed prior to analysis, so both possibilities remain. Therefore, we focused on only the existence of different accumulations of metals by the three litter fractions.

The Pollution of Soils

Indices for the accumulation of eight metals in the organic-mineral horizon-A of soils were determined from all 15 study sites (*fig. 1*). In western Poland and Silesia, manganese, nickel, and copper occurred in concentrations exceeding those in the parent rock (about six times), while Fe, Zn, and Cr did not. The lowest concentrations of the six metals were observed in eastern Poland. Lead accumulated more intensively in soil than the other metals (*fig.1*). Lead concentrations may be 100 to 200 times higher in soil than in the substratum. The pollution of the environment by lead is primarily caused by vehicles using leaded gasoline. However, none of the sites in this study were in the vicinity of busy stretches of road, only within forested areas. The source of the lead in these soils must be from another local source.

The indices of accumulation defined for all of the studied soils confirmed the spatial distribution of heavy metals and trace in organic-mineral horizon; the highest values for the index were attained for Pb, Mn, and Cu (*fig. 1*).

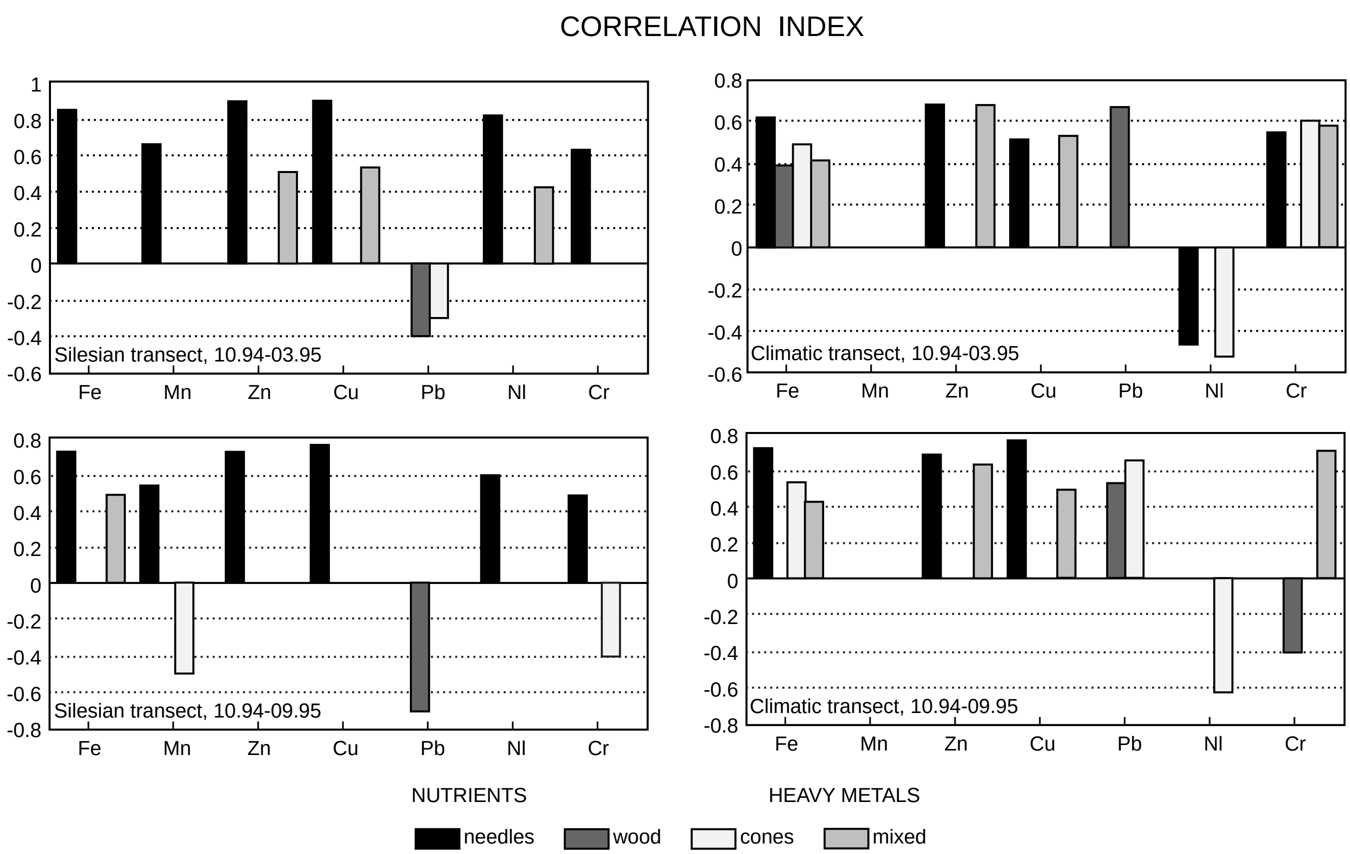

Figure 1 — Accumulation index for organic-mineral horizon-A of some chemical elements (*A*) with volume between 0-10 percent, and (*B*) with value over 10 percent (Breymeyer 1996). K= continental transect S= Silesian transect.

The Decomposition of Litter

The annual rate of decomposition of litter amounts to just over 30 percent and is higher in the first half of the exposition year (*fig. 2*). The mean annual rates of decomposition for the two transects were not statistically different. The course of these means over time showed a 4 percent difference between the transects (with more rapid decomposition on the climatic transect) after half a year. This difference had, however, disappeared after 12 months. The sites along the Silesian transect showed greater differences in the course of decomposition.

Analysis of the rates of decomposition of the different fractions of the litter revealed that the rate of breakdown of the woody fractions (cones and twigs) was clearly lower than the mixed litter, especially needles (*fig. 2*). After 12 months needle litter mass decreased more than 30 percent, compared to about 20 percent of mixed litter and 10 percent of the mass loss of cones and twigs.

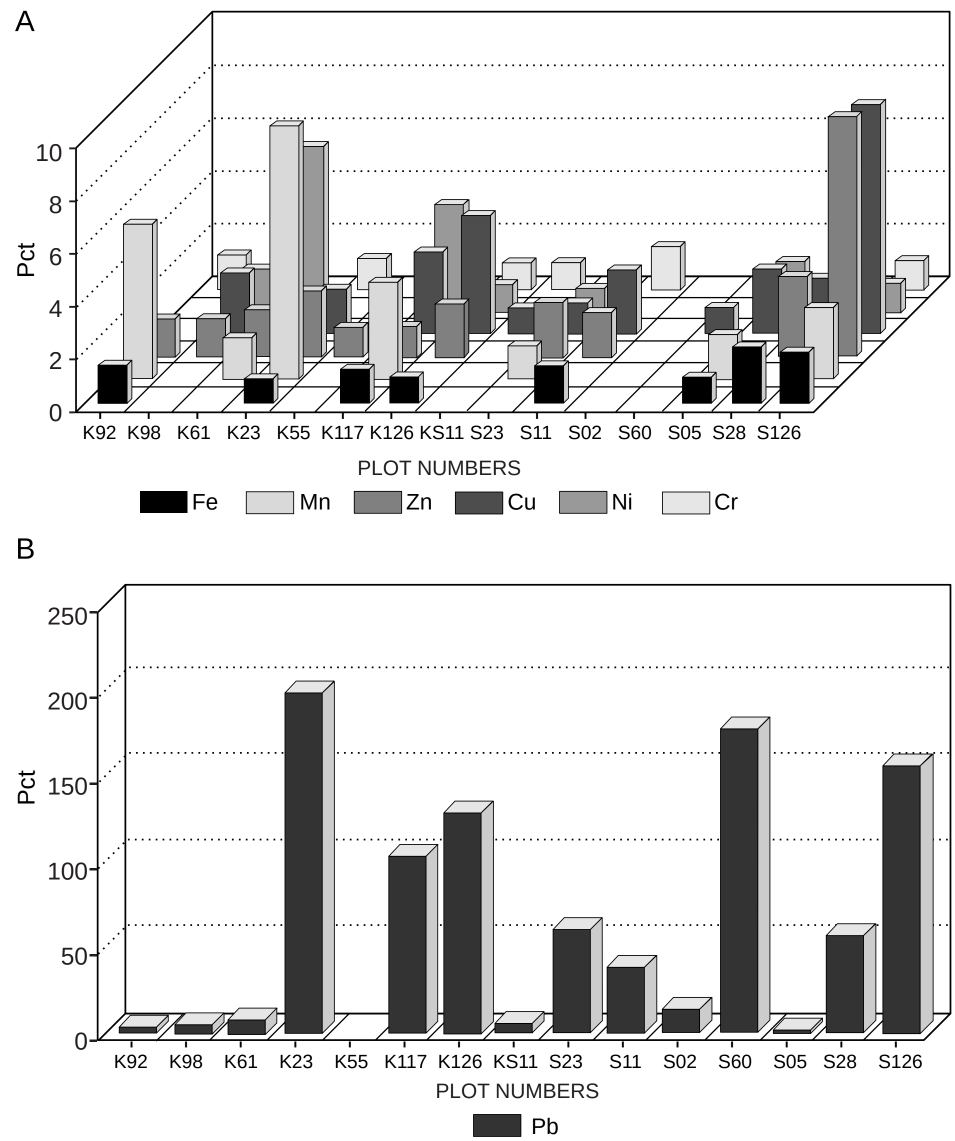

Figure 2 — Decomposition rates during the incubation year. The incubation year always begins in October when previous- year litter-fall packed into nylon-net bags is exposed in the stands; the bags are collected after 6 months and 12 months. (A) Average differences among litter fractions across all sites on continental transect. Solid line represents the mean values. (B) Differences among sites on Silesian transect.

Concentration of Metals in the Mineral-Organic Horizons of Soils and in Litter

Correlation index values between accumulated heavy metals in soils and the rates of litter decomposition were calculated (*figs. 3, 4*). The first consistent and notable result was the high prevalence of positive correlations between the breakdown of litter and the concentration of a metal in the soil. Among the calculations for material from the two transects for decomposition in winter and the whole year, a negative correlation was only noted for lead (*fig. 3*). Among the calculations for each transect separately, negative values for the coefficient were again noted for lead, as well as for nickel and chromium (*fig. 4*). In consequence, the rate of litter decomposition and the accumulation of a metal in the upper layer of the soil are most often correlated positively.

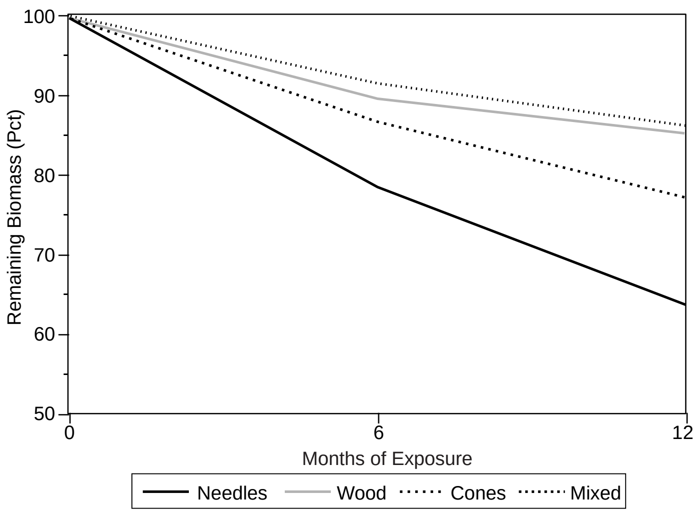

Figure 3 — Correlation index between heavy metals in organic-mineral soil horizon-A and litter decomposition rate (litter bags). Mean values for two transects.

Correlation index values between rates of litter decomposition and concentrations of the 8 elements were determined (*table 1*). A prevalence of positive correlations was again noted, but greater negative values were found than for soil correlations. Thus, pollution of the litter may hold back the process of decomposition much more often than the pollution of soils.

Table 1 — *Correlations between needle litter element concentrations and decomposition rate of different forms of organic deposition for the annual (1994-1995) exposure period on both the climatic and Silesian transects.*[1]

Element in litter	Mixed litter	Needles	Cones	Wood
Fe	[2] 0.71	[2] 0.83	0.06	- 0.38
Mn	[3] - 0.42	[3] 0.44	0.01	0.13
Zn	[2] - 0.66	[2] - 0.80	-0.08	0.4
Cu	- 0.25	- 0.34	-0.08	0.24
Pb	[2] 0.68	[2] 0.82	0.08	- 0.4
Cd	0.06	0.13	0.07	- 0.14
Ni	[2] - 0.72	[2] - 0.89	-0.08	0.36
Cr	[2] - 0.51x	[2] - 0.42x	[2] - 0.56x	[2] - 0.63

[1] A $\sin^{-1}(X^{1/2})$ transformation was performed before analyses; x = only winter (1995) exposure period.

[2] -$p<0.001$.

[3] -$p<0.05$.

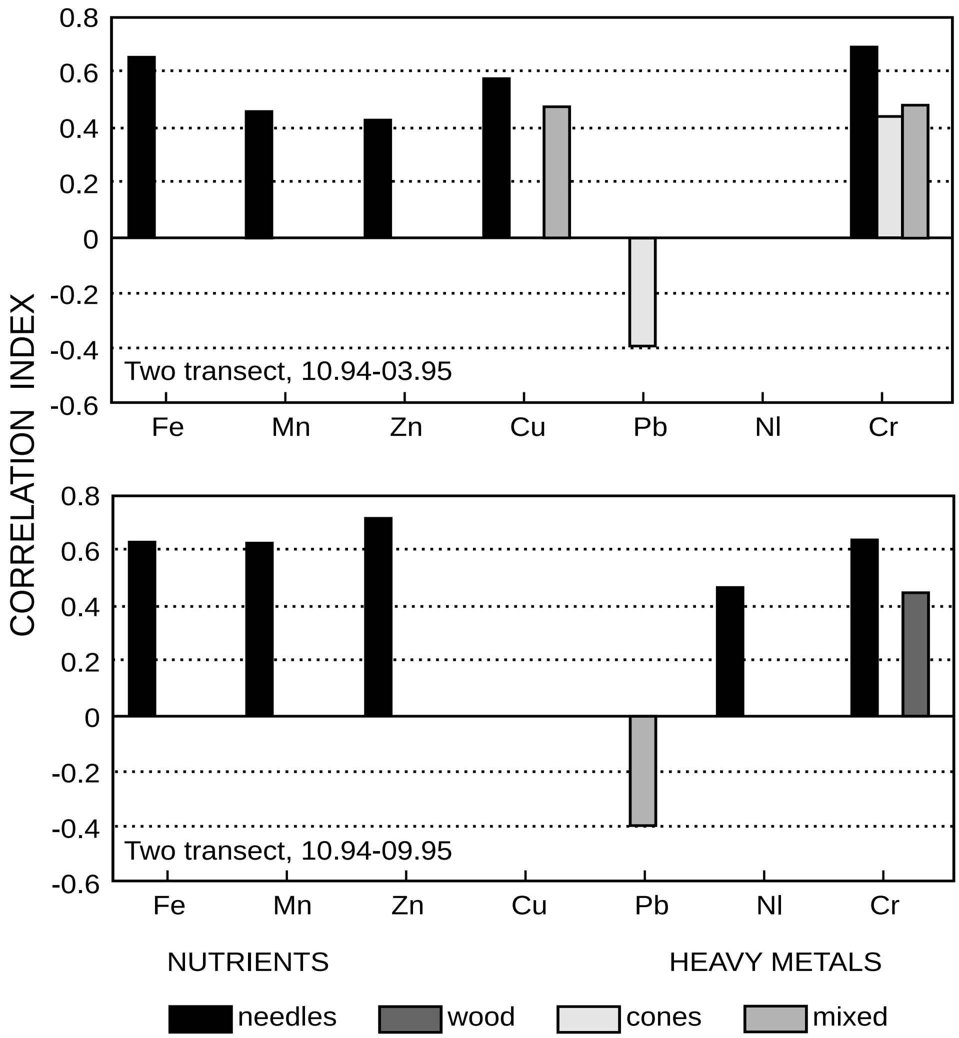

Figure 4 — Correlation index between nutrients and heavy metals in organic-mineral soil horizon-A and litter decomposition rate (litter bags) in the Silesian and climatic transect for 1994-1995 study.

These results indicate that a higher concentration of some of the heavy metals in the studied organic and mineral-organic soil horizons of poor coniferous forest habitats positively influence the transformation of organic matter.

Conclusions

The study found that decomposition of pine needles is similar along the climatic and Silesian transects. The mean rate is higher along the climatic transect in the first 6 months of the year, but mean rates for the transects do not differ significantly after 12 months. The different fractions of litter decompose at different rates: the slowest breakdown characterizes lignified parts (i.e., cones and twigs) resulting in statistically significant differences (*fig. 2*).

The accumulation of heavy metals in the upper layer of the soil showed that at the majority of sites, only lead occurs in amounts several tens or even several hundreds of times greater than in the parent rock (*fig. 1*). High concentrations of heavy metals in litter are most frequent in Silesia, and in the western sites along the climatic transect (i.e., in the western-border area of the country). The highest correlations between heavy metal contents in litter were found for needle litter decomposition and Fe (corr. coeff. 0.83), Zn (corr. coeff. 0.80), Pb (corr. coeff. 0.82), Ni (corr. coeff. 0.89), as well as for mixed litter decomposition and Fe (corr. coeff. 0.71), Zn (0.66), Pb (0.68), and Ni (corr. coeff. 0.72). There were not significant correlations between the rate of decomposition of wood or cones and the content of metals in litter, except for Cr (*table 1*). The highest correlation between heavy metals content in organic-mineral horizon of soils and needle decomposition was determined for Cu (corr. coeff. 0.901), Zn (corr. coeff. 0.901), Ni (corr. coeff. 0.834), Fe (corr. coeff. 0.850) (*fig. 4*).

In some cases the correlations between decomposition rate and metal contents were positive. Comparing decomposition rates with the degree of litter pollution showed that in the case of needle decomposition for six significant correlations, two were positive; in the case of mixed litter decomposition for five significant correlations, two were positive. In both cases decomposition reacted positively to the presence of Fe and Pb. Decomposition rates compared with degree of soil pollution showed that in the case of needle decomposition for five significant correlations, all were positive; in the case of mixed litter decomposition, only one significant correlation was positive.

Thus, these results suggest that the pine forest ecosystems can react positively to the addition of pollution elements to the substratum and litter by enhancing the cycling of matter in the ecosystem as measured by the rate of litter decomposition.

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