

Control-Bag Correction for Forest Floor Litterbag Contamination

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ABSTRACT

Although contamination of litterbags by organic matter is potentially important, there are no standard methods to correct for it. Organic and mineral contamination of field-incubated forest floor litterbags was investigated using the standard ash-free dry mass (AFDM) correction and a correction based on increases in the mass of field-incubated litterbags filled with undecomposable control material. After 120 d, mineral contamination of Oi horizon litter averaged 5.2% of initial litter mass in stands ranging from 7 to 100 yr since cutting. There were no consistent changes in mineral contamination of Oe horizon litter. The mass of nylon control material increased by an average of 22% of initial litter mass after 120 d. Decomposition rates of Oi and Oe litter corrected using increases in control bag mass were significantly higher than uncorrected or AFDM-corrected rates. Forest stand age did not significantly affect mineral contamination, but mass gain after 120 d in the control bags was significantly higher in the 7-yr-old stand (32%) than in 13-, 32-, or 80- to 100-yr-old stands (17–20%).

CONTAMINATION OF field-incubated litterbags with mineral soil particles is a well-recognized phenomenon (Blair, 1988; Rustad, 1994; Herrick, 1995; Potthoff and Lofffield, 1998). Litter-mass loss can be underestimated in litterbag studies if not corrected for contamination. The traditional correction for mineral contamination is to compare the AFDM of litter before and after field incubation. The disadvantage of this method is that it cannot correct for contamination of litterbags by organic material. Earthworm (*Lumbricus terrestris*) casts (Cortez and Bouché, 1998), insect frass, and fragmented pieces of surrounding litter or particulate organic matter (Rustad, 1994) are all potential sources of organic contamination. Levels of organic contamination may significantly affect measured decomposition rates (Rustad, 1994; Cortez and Bouché, 1998).

There are no standard techniques for correcting for organic material contamination. One approach that shows promise is the use of litterbags filled with inert, undecomposable material (Rustad, 1994). A simple change in mass of these control bags after field incubation indicates the potential for total litterbag contamination, organic plus mineral.

The objective of the present study was to compare uncorrected, AFDM-corrected, and control bag-corrected rates of litter decomposition for forest floor litter

in stands of different age. Our initial hypotheses were: (i) calculated litter decomposition rates decrease in this order: control bag-corrected > AFDM-corrected > uncorrected; and (ii) the difference between control bag-corrected and AFDM-corrected litter decomposition rates increases with forest stand age as forest floor horizon development progresses.

MATERIALS AND METHODS

Study Site Description

The forest stands investigated in this study have previously been described with respect to location, climate, soils, and vegetation (Idol et al., 2000). Briefly, the study site was a temperate deciduous forest located on the unglaciated Crawford Uplands in southern Indiana, USA (Homoya et al., 1985). The soils are a mixture of fine-silty, mixed, mesic Ultic Hapludalfs and Typic Hapludults (Soil Survey Staff, 1980). All study plots were located on southwest-facing sideslopes with 10 to 20% slopes. The vegetation is a mixture of deciduous species, typically dominated by tulip poplar (*Liriodendron tulipifera* L.), black cherry (*Prunus serotina*), and red and white oak (*Quercus rubra* L. and *Quercus alba* L., respectively) in stands ranging in age from 5 to 10 yr since harvest. Mature stands are dominated by white oak in the overstory and sugar maple (*Acer saccharum*) in the understory. Stand ages, represented as years since the last clearcut harvest, were 7, 13, 32, and 80 to 100 yr at the beginning of the study—May 1998. Mean annual temperature at the site is 12.0 °C, and mean annual precipitation is 1170 mm. Although soil invertebrate and macrofaunal activity was not measured, the Oa forest floor horizon was generally well-mixed with the mineral soil, especially in the 80- to 100-yr-old stand. Thus, it can be inferred that there is an active soil faunal community at least in older forest stands.

Litterbag Composition

The Oi and Oe forest floor horizon litterbags were composed of native forest floor material collected from the individual stands, air-dried, sorted by horizon (and species for Oi horizon litter), and stored in closed paper bags in a greenhouse. This procedure was designed to prevent photodegradation of litter, but fluctuations in temperature and humidity may have led to some physical or abiotic litter degradation prior to field incubation. Conversely, air-drying may have inhibited initial decomposition in the field, until the moisture content of the incubated litter equilibrated with the surrounding forest floor litter.

Leaf litter used for the Oi litterbags was collected in the fall of 1995 (September–December) from litter traps installed in the stands. The four most abundant species were used to create a natural litter mixture. The percentage of litter from each species placed in the litterbags was massed by the relative mass abundance of each species collected in the litter traps (Table 1). Woody litter and litter that could not be identified to species was not used. The Oe horizon litterbags were composed of Oe material collected from forest floor cores taken in the different-aged stands in November 1996. No attempt

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Abbreviations: AFDM, ash-free dry mass.

was made to separate Oe material by species. A well-mixed sample was used to create Oe horizon litterbags. The control material was a rough-textured 100% nylon fabric purchased from a local fabric store (JoAnn’s Fabrics, West Lafayette, IN). The fabric was cut into pieces that approximated the size and shape of the Oi litter material.

Field Incubation

Five grams of air-dried Oi, 3 g of air-dried Oe, and 5 g of control material were weighed into separate 12 by 12 cm² 1-mm mesh nylon litterbags. Forest floor litterbags were then placed back in the stand of origin only. Forest floor litterbags and control bags were placed in a grid pattern within a 5 by 5 m² plot between the Oi and Oe forest floor horizons at each site on 30 May 1998. Five Oi, five Oe, and three control bags per site were then randomly collected 30, 90, and 120 d later and immediately sealed in plastic bags prior to transport. After initial installation, three Oi and Oe litterbags were taken back to the laboratory for determination of handling and transportation losses. Final litter mass was corrected for these losses.

Laboratory Analysis

After collection, litterbag samples were air-dried in a greenhouse to constant mass (~1 wk). Although no oven-dry corrections were made for calculations of mass loss, greenhouse temperature conditions were maintained at consistent levels throughout the 120-d decomposition period. No plants were growing within the greenhouse bay during drying; thus, greenhouse humidity was kept consistently low. Differences in air-dried litter moisture content before and after incubation, therefore, should be minimal. After drying, all material inside the litterbags was weighed to the nearest milligram. All samples of incubated and five samples per site of unincubated Oi and Oe litter were ground in a Wiley mill to pass through a 1-mm mesh screen and oven-dried at 65 °C to constant mass (at least 48 h). Ash-free dry mass was determined on a 1-g subsample of each litter sample by heating in ceramic crucibles in a muffle furnace. The furnace temperature was gradually increased to 500 °C and maintained for 4 h. Dry-ashed samples were cooled to <200 °C in the muffle furnace and transferred to a dessicator. After samples had cooled to ambient temperature, they were weighed to the nearest 0.1 mg.

Correction for mineral contamination was determined by subtracting from the final litter mass the average gain in ash content within a site at a particular time interval, according to Eq. [1]:

$$Mass_{t-AFDM} = Mass_t - [(Mass_t - AFDM_t) - (Mass_i - AFDM_i)] \quad [1]$$

where subscript i refers to initial samples and t refers to the time interval under consideration.

Because the AFDM_i values were based upon an average calculated from several subsamples of litter, AFDM_t values were also based upon an average calculated for all bags within a site collected at a particular time.

Correction for total (mineral + organic) contamination was determined by subtracting the average gain in control bag mass in each site at each time period, according to Eq. [2]:

$$Mass_{t-CB} = Mass_t - [\Sigma(CB_t - CB_i)/3] \quad [2]$$

where CB refers to the control bags.

Because 5 g of control material, but only 3 g of Oe litter was placed into litterbags, the average change in control bag mass in Eq. [2] was multiplied by 3/5 to correct for litterbag contamination of Oe litterbag samples:

Table 1. Litterbag composition for Oi horizon litter across a 100-yr chronosequence of upland temperate hardwood forests.

Stand age	Species	% Litter mass
7	<i>Quercus alba</i>	31
	<i>Q. rubra</i>	29
	<i>Liriodendron tulipifera</i>	28
13	<i>Carya spp.</i>	12
	<i>Cercis canadensis</i>	31
	<i>Q. rubra</i>	30
	<i>Acer saccharum</i>	27
32	<i>Q. alba</i>	12
	<i>A. saccharum</i>	36
	<i>Prunus serotina</i>	26
	<i>Q. alba</i>	21
80–100	<i>Q. rubra</i>	17
	<i>Q. alba</i>	60
	<i>Carya spp.</i>	17
	<i>A. saccharum</i>	16
	<i>Q. rubra</i>	7

$$Mass_{t-CB} = Mass_t - \{[\Sigma(CB_t - CB_i)/3] \times (3/5)\} \quad [3]$$

Statistics

Mineral contamination of forest floor horizon litterbags and total contamination of control litterbags were compared by analysis of variance using Proc GLM in SAS (SAS Institute Inc., 1988). Stand age and days in the field were used as treatment variables in the analysis. Total mass loss after 120 d calculated from uncorrected, AFDM-corrected, and control bag-corrected data were also compared with analysis of variance. Where significant differences were indicated in the analyses, means were separated using the Waller-Duncan multiple comparison test (SAS Institute Inc., 1989).

RESULTS AND DISCUSSION

Levels of mineral and total contamination of litterbags are given in Table 2. Mineral contamination of Oi litter (as indicated by changes in ash residue) was ~ 4 to 7% of initial litter mass after 30 d, but generally did not change from 30 to 120 d. Analysis of variance indicated no significant difference in mineral contamination over 120 d (Table 3). There were also no significant differences in mineral contamination of Oe litter—the ash residue content of field-incubated Oe litter was less than unincubated litter. Control bag mass, averaged across all stands, increased ~1 to 6% after 30 d, showed little change from 30 to 90 d, then increased significantly

Table 2. Forest floor litterbag contamination in forest stands of different age in southern Indiana, USA.

Stand age	Time	Mineral contamination		Total control bags
		Oi	Oe	
		g kg ⁻¹ initial mass		
7	30	51.0 (21.9)†	-29.2 (35.3)	55.9 (39.4)
	90	49.6 (27.1)	-7.36 (40.0)	52.1 (13.0)
	120	31.9 (2.72)	1.94 (55.2)	318 (19.8)
13	30	39.8 (21.6)	-84.4 (6.48)	14.1 (0.48)
	90	43.7 (36.2)	-14.0 (21.5)	34.4 (3.35)
	120	42.5 (17.9)	18.4 (51.8)	195 (6.73)
32	30	68.8 (14.0)	-10.6 (17.7)	25.8 (8.12)
	90	47.3 (12.5)	-22.9 (9.86)	35.4 (11.8)
	120	93.1 (19.2)	23.5 (36.6)	169 (21.5)
80–100	30	36.7 (3.71)	9.58 (20.6)	18.2 (2.24)
	90	11.8 (11.0)	5.07 (16.7)	40.0 (2.56)
	120	29.6 (6.37)	8.96 (10.8)	188 (4.42)

† Standard error of the mean in parentheses.

Table 3. Effect of time and stand age on levels of mineral ash-free dry mass (AFDM) and total (control bag) forest floor litterbag contamination.

Dependent variable	Source	df†	F-value	P > F
AFDM (Oi)	Stand age	3	2.79	0.052
	Time	2	0.58	ns‡
	SA × T	6	0.52	ns
AFDM (Oe)	Stand age	3	0.39	ns
	Time	2	1.85	ns
	SA × T	6	0.58	ns
Control	Stand age	3	12.2	**
	Time	2	187	**
	SA × T	6	4.50	**

** Significant at the 0.01 probability level.

† Degrees of freedom.

‡ Not significant.

(17–32%) after 120 d. Visual inspection of control bags showed both mineral soil and organic contamination after 120 d.

In general, the AFDM-corrected decomposition rates were not significantly different from uncorrected rates (Table 4). Control bag-corrected decomposition rates, however, were significantly higher than AFDM-corrected or uncorrected litter decomposition rates for both Oi and Oe litter in all age stands. This was generally not the case, however, at 30 or 90 d (data not shown).

There were no strongly significant differences by stand age in mineral contamination as calculated by changes in AFDM (Table 3). For the 32-yr-old stand, mineral contamination in the Oi horizon was somewhat higher at 120 d (9.31% of initial mass) than in the other stands (3–4%) ($P = 0.052$). It was initially hypothesized that litterbags incubated in younger forest stands would have a higher level of mineral contamination because of the thinner, less well-developed forest floor in these stands. This was not the case during the first 120 d of incubation in the field (Table 2). However, since a different litterbag composition was used for each age stand, differences (or a lack thereof) in mineral contamination by stand age are confounded with differences in litter types.

Changes in control bag mass, on the other hand, can be compared by stand age because a standard material was used in each site. Increases in control bag mass at 120 d were significantly higher in the 7-yr-old stand (32%) than in the 13-, 32-, and 80- to 100-yr-old stands (17–20%) (Table 3). This led to significantly higher con-

trol bag-corrected mass loss at 120 d in the 7-yr-old stand (~36%) than in the other stands (~20–23%) (Table 4).

The close correspondence between changes in litter-ash residue and control-bag mass over the first 90 d lends support to the use of control bags as indicators of actual mineral contamination of litterbags and not just as an indicator of potential contamination (Rustad, 1994). The increase in control bag mass from 90 to 120 d was surprising, but it may have been because of an increase in growth of fungal hyphae and an influx of surrounding litter fragments, both of which were more visible in control litterbags after 120 d. Unfortunately, it was not possible to determine the relative contributions of the different organic contaminants or to separate them from the control bag material.

Because there is no standard method for estimating organic contamination levels, it is not known how accurate control bags are in estimating organic contamination of litterbags. Rustad (1994) found a steady increase in control bag mass with time over a 57-mo field incubation period. The final mass was ~24% greater than the initial material mass. The majority of this contamination was organic, not mineral. She recognized that organic material that enters into litterbags might just as easily leave litterbags if not trapped on larger litter surfaces or between adjacent pieces of litter. Thus, differences in total surface area and surface characteristics (e.g., texture, electrostatic charge, chemical reactivity, moisture content, etc.) between control and litter material may result in a different ability to hold organic material that falls into litterbags. Additionally, because control material is generally inert, the growth of fungal hyphae, colonization by bacteria, and material left by the activity of soil arthropods and earthworms is likely to be lower on control material than on litter material. Thus, control bags may actually be a conservative estimate of total litterbag contamination.

In future studies, it would be helpful to use control material that resists combustion (e.g., fiberglass fabrics) so that an AFDM can be determined. This would allow for a determination of mineral versus organic contamination of control material. Alternatively, experiments with ¹³C-labeled litter in which C mineralization as well as mass loss is measured may allow for more direct measures of litter contamination and better evaluations of AFDM and control bag corrections.

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Table 4. Comparison of 120 d decomposition of Oi and Oe forest floor horizon litter calculated from uncorrected, ash-free dry mass (AFDM)-corrected, and control bag-corrected data.

Stand age	Horizon	Uncorrected	Mass loss g kg ⁻¹	
			AFDM-corrected	Control bag-corrected
7	Oi	38.2a†	83.1a	357b
13	Oi	16.6a	53.1a	202b
32	Oi	37.6a	139b	193c
100	Oi	38.5a	74.6a	225b
7	Oe	-117a	-114a	142b
13	Oe	-118a	-110a	54.9b
32	Oe	-99.8a	-76.8a	36.8b
100	Oe	-104a	-91.3a	54.9b

† Values within a row followed by the same letter do not differ significantly, using the Waller-Duncan multiple comparison test ($\alpha = 0.05$).

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DIVISION S-8—NUTRIENT MANAGEMENT & SOIL & PLANT ANALYSIS

Predicting Phosphorus Desorption from Mid-Atlantic Coastal Plain Soils

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ABSTRACT

Pollution of surface waters by P from agricultural areas is a water quality issue in Delaware. The FHANTM 2.0 computer model can help identify areas with a high potential for P loss, but the model's representation of P desorption from soils to runoff waters needs re-evaluation. The equation, $P_d = K P_o t^\alpha W^\beta$, has been proposed to predict such P desorption, but equations originally proposed to predict values for the constants K , α , and β from the ratio of soil clay content/soil organic C content may not be accurate for Delaware soils. Therefore, we measured P desorption for 23 sandy Delaware soils for times of 5 to 180 min, water/soil ratios of 10 to 1000 L kg⁻¹, and three initial levels of soil desorbable P. Values for the constants K , α , and β were calculated and related to soil properties. We found that K , α , and β values were not well related to clay/OC, but were better related to the ratio of oxalate-extractable Fe/OC content (α) or the sum of oxalate extractable Fe and Al (β and K). These results can be used to help refine the FHANTM 2.0 model in predicting P loss from agricultural areas in Delaware and similar landscapes in the Mid-Atlantic Coastal Plain.

THE NONPOINT SOURCE POLLUTION of surface waters by P is an international environmental quality issue. In Delaware, water quality in the Inland Bays national estuary, which consists of the Rehoboth, Indian River, and Little Assawoman Bays, has been impaired by P to such an extent that the state must now comply with regulations of the Clean Water Act (United States, 1967). As part of this compliance, total maximum daily loads (TMDL) have been established as the level of pollution below which the Inland Bays will meet water quality standards. One goal of the TMDLs is a 70% reduction of nonpoint source P loads to the Inland Bays (State of Delaware, 1995). Because agriculture has been identified as a significant nonpoint source of P in the Inland Bays watershed (Ritter, 1992), it is necessary to identify agricultural areas that have a high potential for P export.

Field-scale nutrient transport models have been proposed as a means to characterize the environmental risk

of agricultural P to water quality. In Florida, FHANTM 2.0 (Field Hydrologic and Nutrient Transport Model, version 2.0; Fraisse and Campbell, 1997) was developed to simulate water and P movement from individual fields as part of an effort to reduce P loads to Lake Okeechobee. The hydrology of FHANTM 2.0 is based on DRAINMOD (Skaggs, 1980), and the nutrient components are based on GLEAMS (Leonard, 1987). Because Florida's physical and hydrologic conditions of flat fields, high water tables, and high P sandy soils are similar to those in Delaware, FHANTM 2.0 could potentially be used in Delaware to simulate field-scale P export. However, several of FHANTM 2.0's mathematical representations of soil P processes were designed either for pesticide transformations in soils for GLEAMS or for specific chemical and physical properties of Florida soils. Therefore, to use FHANTM 2.0 in Delaware, its P components must be modified to more accurately represent the chemical and physical processes in Delaware soils. One such modification is the representation of P desorption to runoff waters. Currently in FHANTM 2.0, the quantity of P in the topsoil available for runoff, $(C_{av})_p$ (mg kg⁻¹), is calculated with the equation

$$(C_{av})_p = (CPLAB) \exp \{[-(Pr - Q - AWS)] / [(SSG) K_d (1 - POR) + POR]\}, \quad [1]$$

Abbreviations: Al_{ox}, acid ammonium oxalate-extractable Al; AWS, amount of rainfall needed to saturate the topsoil layer in the FHANTM 2.0 model; B , extraction coefficient used in the FHANTM 2.0 model; $(C_{av})_p$, quantity of P in the topsoil available for runoff used in the FHANTM 2.0 model; CPLAB, quantity of desorbable P in the topsoil used in the FHANTM 2.0 model; $(C_w)_p$, concentration of P in runoff used in the FHANTM 2.0 model; Fe_{ox}, acid ammonium oxalate-extractable Fe; FHANTM, Field Hydrologic and Nutrient Transport Model; OC, organic C; OM, organic matter; UDSTP, University of Delaware Soil Testing Program; K , empirical constant in soil P desorption equation; K_d , partitioning coefficient used in the FHANTM 2.0 model; P_d , amount of P desorbed from the soil; P_o , initial concentration of desorbable P in soil; POR, porosity used in the FHANTM 2.0 model; Pr, value for precipitation used in the FHANTM 2.0 model; Q , value for runoff used in the FHANTM 2.0 model; SSG, soil specific gravity used in the FHANTM 2.0 model; t , time of P desorption; TMDL, total maximum daily load; W , water/soil ratio during P desorption; α , empirical constant in soil P desorption equation; β , empirical constant in soil P desorption equation.

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