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SPATIAL VARIABILITY OF LITTERFALL AND SOIL ORGANIC MATTER IN A BEECH STAND

DEN RUMLIGE VARIATION I LØVFALD OG I JORDENS ORGANISKE STOFINDHOLD I EN BØGEBEVOKSNING

BY

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1. INTRODUCTION

The link between the organic matter status of a soil and its productivity has devoted much attention to the content and dynamics of organic matter in soils. The balance between decomposition and accumulation of organic matter are of interest in evaluating impacts of chronic perturbations on ecosystems (e.g. fire, forestry operations, agricultural operations) (*Christensen & Malmros* 1979).

Attempts to characterize the decomposition of organic matter often include the determination of a *decay rate k*, which is the annual input of dead organic matter divided by the dead organic matter pool, assuming steady state conditions. The decay rate and *turn-over time* ($1/k$) estimates have been applied to the total soil organic matter pool as well as to components of the pool (e.g. *Olson* 1963, *O'Neill et al.* 1975, *Gosz et al.* 1976, *Swift et al.* 1976, *Lang & Forman* 1978, *Birk & Simpson* 1980).

The estimation of decay rates is associated with a number of difficulties. Problems arise in deliniating organic matter pools of relevance to a given input, and the size of different inputs can be difficult to measure, especially when belowground input and fall of stems and branches are considered. Furthermore, organic matter pools as well as inputs exhibit spatial and time-dependent variability, which may cause problems in substantiating the steady-state conditions of pools and inputs and in measuring their size accurately.

The present study examines the spatial variability of litterfall and of soil organic matter in a Beech stand considered to have reached steady-state. The influence of variability on the estimation of decay rates and turnover times is examined for carbon and nitrogen in the forest floor.

2. MATERIALS AND METHODS

The study was carried out in a mixed-aged mature Beech stand (*Fagus sylvatica L.*) at the Strødam Biological Field Station, North Zealand (55°58′ N, 12°16′ E). Stand age exceeds 120 years and maximum stand height averages 23 metres. Ground flora was very sparse within the plot. A general view of the stand is shown in Figure 1. The forest floor has well developed

F i g u r e 1. The examined area in the Beech stand at Strødam. December 1982.
F i g u r 1. Det undersøgte område i bøgebevoksningen ved Strødam.

mor horizons and the soil is freely drained. Some soil characteristics of the site are listed in Table 1.

The examined plot (50×50 metres) was selected randomly with regard to micro-relief and individual trees. As samples were collected from June 1978 to June 1979, the measured variation includes both seasonal and spatial variation.

T a b l e 1. Characteristics of the studied site at Strødam Biological Field Station. Yearly average precipitation and temperature are 650 mm and 8°C, respectively.
T a b e l 1. Jordbundsanalyser fra det undersøgte område ved Strødam. Den gennemsnitlige årlige nedbør og temperatur er henholdsvis 650 mm og 8°C.

Horizon (depth)	Average horizon thickness a)	Bulk density a)	pH_{H_2O}	Loss on ignition	Soil texture, % of mineral fraction			
					Clay	Silt	Fine sand	Coarse sand
cm	cm	g dw/cm³		% d.w.	$< 2\ \mu$	2—20 μ	20—200 μ	200—2000 μ
L (Litter layer)	n.d.b)	n.d.	n.d.	87.5	n.d.	n.d.	n.d.	n.d.
F (+10 to +6)	4	0.20	4.3	75.6	n.d.	n.d.	n.d.	n.d.
H (+ 6 to 0)	6	0.71	3.9	21.7	5.2	9.1	29.4	56.3
A_1 (0 to 20)	20	1.18	4.3	4.4	4.5	8.4	24.1	62.9
A_2 (20 to 60)	40	1.21	4.8	2.3	3.6	6.5	16.1	73.8
60 to 90	30	1.33	5.2	1.4	2.6	4.4	6.7	86.3
90 to 135	45	1.33	5.5	1.3	2.6	3.9	6.8	86.7

a) average values the ten examined profiles.
b) n.d. = not determined.

Litterfall was captured by ten litter traps systematically distributed over the plot. A littertrap consists of a squared wooden box (45×45×20 cm) with nylon net at the bottom (2 mm mesh). The traps were placed 20 cm above the forest floor. Litter was collected monthly except in periods with high litterfall, where weekly collections were applied. Each trap was sampled separately. No collections were made in the winterperiod, when litterfall was negligible.

At five-week intervals one profile was excavated close to a randomly selected littertrap. The depth of the excavation averaged 150 cm. Samples (0.5 to 1 kg) were taken from each recognizable horizon and designated L, F, H, A_1, A_2, 60—90 cm or 90—135 cm. Ten profiles distributed as the l'ttertraps were sampled during the study. From the A_1-horizon of a separate pit, ten replicate samples were collected in order to determine the horizontal variability within the area of a single pit (1 m^2).

Samples were dried at 105°C for 24 hours. The dry weight of the individual littersample, was determined and the litter caught by the ten littertraps were then pooled to give one sample for each sampling date. Samples from below the F-horizon were passed through a 2 mm mesh before grinding. All samples were ground through a 0.5 mm mesh and stored in airtight containers.

The organic matter was characterized by its carbon and nitrogen content as loos-on-ignition was found to be unreliable (*Christensen & Malmros* 1982). Carbon content (C-content) was determined by a wet combustion technique (*Enwezor & Cornfield* 1965), and nitrogen content (N-content) was determined by a semi-micro Kjeldahl procedure.

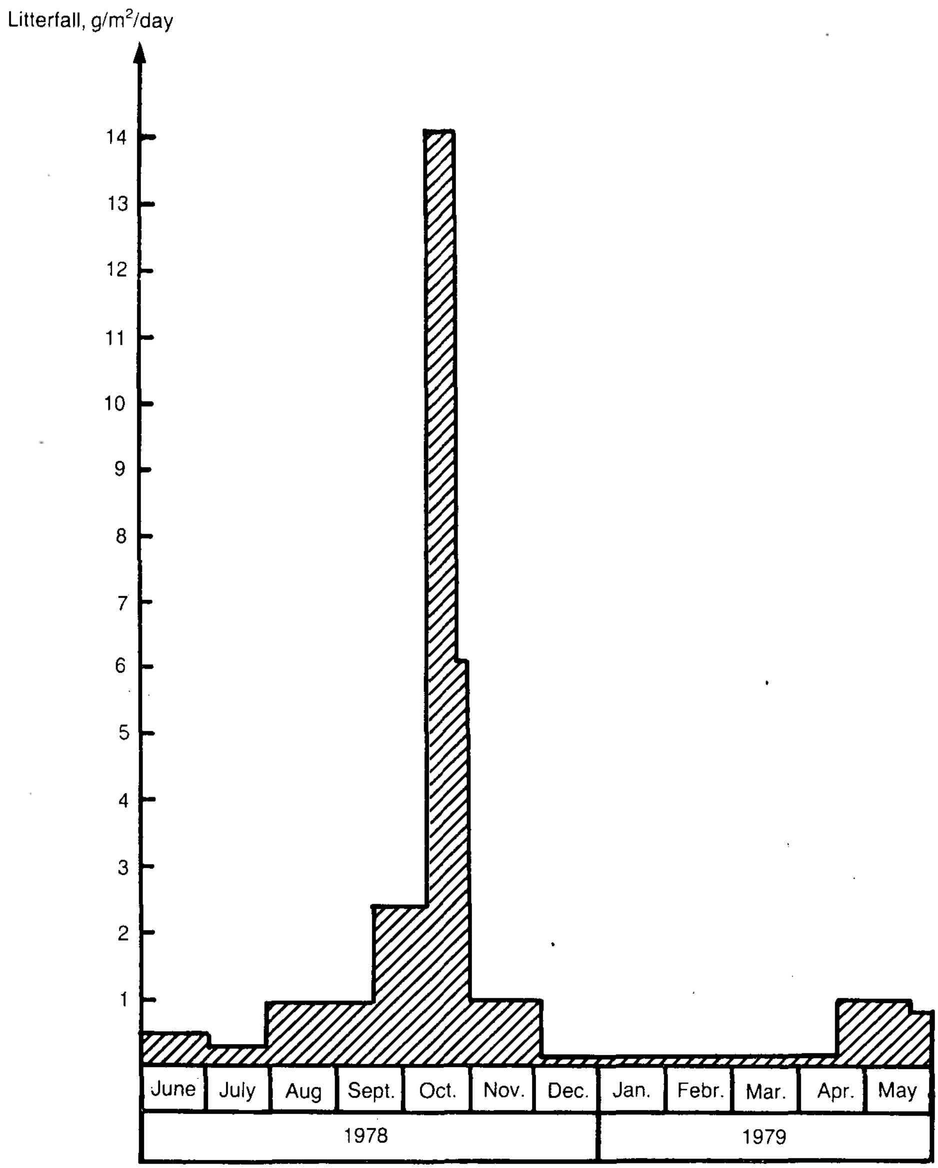
To determine the total analytical error, ten determinations of C-content and N-content were performed on one of the ten replicate samples from the A_1-horizon. Standard error of the mean was below 1 % for both analytical procedures. All determinations were run in duplicate and data presented are the mean value of two determinations.

The C/N ratio was calculated for each individual sample and was treated as a quality parameter of the organic matter.

3. RESULTS

3.1 Litterfall

The annual litterfall (components < 45 cm) was 442 ± 26 g dry matter/m^2 (mean ± 95 % confidence limits). The seasonal distribution of the litterfall is shown in Figure 2. Of the annual litterfall, 68 % occurred during the period late September to early December, when the main constituent was brown leaves (autumn leaf fall). During May and June litterfall was mainly made up of budscales and flowers, respectively.



F i g u r e 2. The seasonal distribution of litter fall (g/m²/day) in the period June 1978 to June 1979.

F i g u r 2. Løvfaldsmængdens fordeling over året (gram/m²/dag) for perioden juni 1978 til juni 1979.

The annual litterfall contained 211 ± 12 g C/m^2 and 4.94 ± 0.34 g N/m^2 (means ± 95 % confidence limits), the autumn leaf fall containing 71 % of the C and 64 % of the N. Most of the seasonal variation in the C/N ratio of the litterfall (mean C/N = 42, CV% = 30) was due to the different N-content in the different litter constituents (CV% = 33), whereas the C-content showed less variation (CV% = 8). The lowest C/N ratio was recorded in flowers (C/N = 20), while the budscales (C/N = 53) and the brown leaves (C/N = 47) had the highest ratios.

The variance in the mean capture of the ten littertraps was compared with regard to date of collection. No significant difference was found between the variances (Barlett's test, $P < 0.05$). A Kruskal-Wallis one-way analysis of variance showed that the total amount of litter captured by each of the ten litterrraps during the study can be regarded as the same ($P >$ 0.99).

The litterfall can therefore be considered as evenly distributed over the forest floor, although the final deposition of the litter in the L-horizon is unknown due to e.g. transport by wind and water.

3.2 Soil organic matter content

The C-content, N-content, and C/N ratio of the litterfall and the various soil horizons are presented in Table 2. The C- and N-contents of the forest floor horizons were considerably higher than those of the underlying mineral soil horizons. The C-content gradually declined from the litterfall to the H-horizon, whereas the N-content attained a maximum value in the F-horizon, giving a declining C/N ratio down through the forest floor (C/N

Table 2. The carbon content, nitrogen content, and C/N-ratio of the litterfall and the various soil horizons.

Tabel 2. Indhold af kulstof og kvælstof samt C/N forhold i løvfaldet og de forskellige jordlag.

	C-content % d.w.			N-content % d.w.			C/N ratio		
	Mean a)	s.d. b)	CV% c)	Mean	s.d.	CV%	Mean	s.d.	CV%
Litterfall	46.4	(3.8)	8	1.21	(0.40)	33	42	(12)	30
Soil Horizons									
L (Litter layer)	44.2	(4.9)	11	1.32	(0.20)	15	34	(5)	15
F (+10 to +6 cm)	39.3	(6.3)	16	1.65	(0.25)	15	24	(2)	9
H (+ 6 to 0 cm)	11.6	(7.4)	64	0.64	(0.42)	65	18	(2)	9
A_1 (0 to 20 cm)	1.98	(0.61)	31	0.100	(0.026)	26	20	(2)	10
A_2 (20 to 60 cm)	0.80	(0.28)	35	0.041	(0.013)	31	20	(3)	15
60 to 90 cm	0.30	(0.27)	90	0.018	(0.013)	72	15	(3)	23
90 to 135 cm	0.22	(0.19)	85	0.015	(0.009)	61	13	(5)	35

a) mean value (n = 10, except for L where n = 8)
b) s.d. standard deviation
c) CV% = coefficient of variation (expressed as percentage).

in litterfall = 42, C/N in H-horizon = 18). From the H-horizon towards the subsoil the C- and N-contents decreased with increasing depth, whereas the C/N ratio changed but little below the F-horizon.

Except for the two lower horizons, the CV values of the C- and N-contents showed no big difference within the individual horizon. The H-horizon had very high CV values for both C- and N-contents, while the CV value of the C/N rato was low and similar to that of the F- and A_1-horizons.

The variation in the C- and N-contents of the A_1-horizon depends on the size of the sampling area, whereas the variation in the C/N ratio is rather constant (Tab. 3). Differences in the variances of the C- and N-contents are all highly significant ($P < 0.01$, F-test). Although samples used for determination of the variation within the experimental plot were collected at 5-week intervals, seasonal variation in the A_1-horizon is assumed not to have a significant influence on the observed increase.

Table 3. The coefficient of variation (CV%) for C-content, N-content, and C/N ratio in samples from the A_1-horizon. For all groups of samples n = 10.
Tabel 3. Variationskoefficienten (CV%) for kulstofindhold, kvælstofindhold og C/N forhold i prøver fra A_1-laget. For alle prøvegrupper er n = 10.

	CV% C-content	N-content	C/N ratio
A: within samples	2.93	2.88	3.53
B: within pit	9.19	10.68	14.03
C: within plot	30.92	26.10	11.23

A: analytical error (variation within a sample)
B: replicate samples (variation within one square metre)
C: samples from the ten profiles (variation within the experimental plot)
A: Analysefejl (variationen indenfor een prøve).
B: Gentagne prøveindsamlinger (variationen indenfor een m² prøveflade).
C: Prøver fra de 10 profiler (variationen indenfor hele prøvefladen (50×50 m)).

The amount of carbon and nitrogen contained in the forest floor (L-, F-, and H-horizons) was calculated as follows. The average weight of the L-horizon was calculated from the relation $LF/(LF + L) = 0.3$, where LF is the weight of the annual litterfall and L is the weight of the L-horizon. This relation was established for a Swedish mor-type Beech stand by *Nihlgård & Lindgren* (1977). The weight of the F- and H-horizon was calculated using the average value for horizon thickness and bulk density (Tab. 1). The weight of the individual horizon was multiplied by the carbon and nitrogen content obtained at each sampling date, and finally values of all forest floor horizons were added for each profile. Calculated this way the forest floor was found to contain 8.47 ± 2.37 kg C/m² and 0.42 ± 0.13 kg N/m² (mean ± 95 % confidence limits).

By using mean carbon and nitrogen contents from Tab. 2 and horizon thickness and bulk density values from Tab. 1, the total amounts of carbon and nitrogen in the forest soil profile were calculated to 19.7 kg C/m^2 and 1.02 kg N/m^2.

3.3 Organic matter turover of the forest floor

The annual fractional weight loss or *annual decay rate k* and the *turnover time 1/k* were calculated for the amount of carbon and nitrogen in the forest floor. The forest floor was assumed to have reached steady state, and it was further assumed that the input to the forest floor pool could be related to the annual litterfall measured in this study (components < 45 cm).

Mean values for k and $1/k$ are given in Table 4 together with 95 % confidence limits and coefficients of variation for these properties, both calculated according to *Colquhoun* (1971, p. 293—297).

Table 4. Annual fractional weight loss (k) and turn-over times ($1/k$) for carbon and nitrogen in the forest floor.
Tabel 4. Den årlige omsætningsrate (k) og omslagstid (1/k) for kulstof og kvælstof i skovbunden (L, F og H-lagene).

	k Annual fractional weight loss ($year^{-1}$)	$1/k$ Turn-over time (years)	CV Coefficient of variation (%)
Carbon, mean value	0.0249	40.2	40
95 % c.l.[a])	0.0198—0.0331	30.2—50.5	
Nitrogen, mean value	0.0119	83.9	46
95 % c.l.	0.0092—0.0167	60.0—108.3	

a) 95% c.l. = 95 % confidence limits

It is seen that the mean turnover time for nitrogen is 84 years, which is nearly twice the turnover time for carbon. The coefficients of variation are 40 % for carbon and 46 % for nitrogen.

4. DISCUSSION

The annual litterfall estimated in this study is similar to published estimates of litterfall in various Beech stands (Tab. 5). The seasonal distribution of the litterfall at the Strødam site (Fig. 2) is similar to that of other Beech stands (e.g. *Nihlgård* 1972, *Nielsen* 1977). As the annual litterfall (components < 45 cm) was evenly distributed over the forest floor, the litterfall is considered to be representative for the experimental site.

In a comprehensive study of a large number of Danish Beech stands, *Møller* (1946) found no significant influence of the yield class on the leaf litter production. Further, he observed only a slight change in leaf litter

T a b l e 5. The annual litterfall of various Beech stands. Data included are based on litter from littertraps of similar sizes.

T a b e l 5. Den årlige løvfaldsmængde i forskellige bøge bevoksninger. De anførte værdier er baseret på løvfald fanget i løvfælder af sammenlignelig størrelse.

Site and approx. age of stand (years)		Litterfall (g dw./m²/yr)	Source
Strødam (DK)	> 120	442	This study
Hestehaven (DK)	90	410	Nielsen 1977
Kongalund (S)	90	515	Nihlgård 1972
Öved (S)	90	440	Nihlgård & Lindgren 1977
Långaröd (S)	100	380	Nihlgård & Lindgren 1977
Wytham Wood (UK)	150	427	Mason 1970

production, when stand age increased from 20 to 120 years. Cutting intensity did not influence the production of leaf litter unless stand closure was severely affected. Small-scale variation in stand factors within the examined plot are therefore not likely to cause horizontal variation in leaf litter production.

Nielsen (1977) examined the year-to-year variation of the litterfall in a 90 year old Beech stand and found for a period of nine years an annual leaf litter fall ranging from 243 g dw/m² to 303 g dw/m². If all litter components less than 58 cm is considered, the difference is larger. Similar year-to-year variations have been reported for Swedish Beech stands (*Nihlgård* 1972, *Nilsson* 1978). Thus, the contribution from this source of variation may be significant.

Compared with the reduction of the C/N ratio in the forest floor, changes in the mineral soil were small (Tab. 2). The changed trend of the C/N ratio coincides with a changed morphology of the organic matter. The organic matter in the L- and F-horizon was mainly present as litter remains of recognizable origin with only a small mineral content. In the H-horizon the organic matter was present as a black amorphous mixture with a highly variable mineral content as indicated by the high CV values for C- and N-contents. The decomposition taking place in the forest floor resulted in a marked change in the quality as well as a reduction in the quantity of the organic matter. In the mineral soil the organic matter content was further reduced, whereas the quality expressed by the C/N ratio changed but little. This may indicate that the type of organic matter transformation taking place in the forest floor and in the mineral soil differ as proposed by *Schlesinger* (1977). Consequently separate measurements of the input to the forest floor and to the mineral soil may be needed in order to make more accurate estimates of the total soil organic matter turnover.

The variability in C- and N-contents generally increased with depth in the profile and with increased sampling area. The C/N ratio showed smaller differences in CV values and the value did not increase with increased sampling area (Tab. 2 and 3). This is interpreted as an increasing variability in organic matter content, whereas the composition of the organic matter remains relatively unchanged. The variability in C- and N-contents experienced over a relatively small area and the increase in variability with increased sampling area (Tab. 3) agree with results reported for different natural and agricultural ecosystems (e.g. *Beckett & Webster* 1971, *Bracewell et al.* 1979, *Broadbent et al.* 1980).

Considerable variation was found in the amount of carbon and nitrogen contained in the forest floor. The variation estimated in this study considers only the influence from variations in the C- and N-contents and is therefore regarded as a minimum estimate. The variation in horizon thickness and bulk density was not included for F- and H-horizons, and seasonal variation in the weight of the L-horizon was excluded too. These sources of variation are known to increase the total variation in pool estimates (e.g. *McFee & Stone* 1965).

The variation in the weight of the L-horizon can be significant. For a Canadian wood lot dominated by *Fagus grandifolia* Ehrh. and *Acer saccharum* Marsh., *Dwyer & Merriam* (1981) found an average surface litter accumulation ranging from 416 g dw/m^2 on high sites to 2438 g dw/m^2 on low sites.

The variation in the organic matter content is due to variation in decomposition rates caused by variation in microclimate, microtopography, and to input of litter components with an erratic appearance (e.g. branches, stems and stumps). Wooden components produce when disintegrated, a highly localized input to the forest soil and may account for a significant part of the total litter input (*Møller et al.* 1954, *Swift et al.* 1976). Finally, the input from roots contributes to the variation in the forest soil organic matter pool, but no data for Beech stands were available.

The variation observed in the forest floor and mineral soil indicates that interpretation of data based on samples from only a few profiles is limited. This well known observation is often met by adopting a bulk sample or composite sample technique. However, this will not always improve the applicability of the results but may introduce a loss of information about the system under investigation. A more close examination of the different sources of variation and an evaluation of their contribution to the observed total variation is needed in order to produce more sound estimates of soil organic matter pools and eventually their turnover.

When the variations in litterfall and forest floor pool estimates of this study are considered, large variation in k and $1/k$ is obtained (Tab. 4). This variation in k and $1/k$ is disregarded in most studies applying these properties to decomposition and turnover of nutrients and organic matter.

The size of the variation may invalidate their applicability as ecosystem characteristics or ecosystem constants, which they often are claimed to be. There seems to be good reason to take interest in the influence of variability on these estimates before they are used in comparisons between the decomposition in different compartments or even different ecosystems.

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SUMMARY

The amount and variability of litterfall and soil organic matter have been estimated for a mature Danish Beech stand.

The annual litterfall was 442 ± 26 g dry matter/m² or 211 ± 12 g C/m² and 4.94 ± 0.34 g N/m² (mean ± 95 % conf. lim.). The litterfall was evenly distributed over the plot surface and was similar to values reported from various Beech stands with regard to amount and seasonal distribution.

Considerable variation was found in the C and N contents of horizons below F, whereas minor variation occurred in the C/N ratio of the L, F, H, A_1 and A_2 horizon. Variation in C and N contents generally increased with depth and with increased sampling area.

The forest floor contained 8.5 ± 2.4 kg C/m² and 0.42 ± 0.13 kg N/m² (mean ± 95 % conf. lim.). The total amount of C and N in the profile (depth 150 cm) averaged 19.7 kg/m² and 1.02 kg/m², respectively. The annual fractional weight loss of C and N contained in the forest floor falls in the range 0.0198—0.0331 for C and 0.0092—0.0167 for N.

It is concluded that a more careful evaluation of the impact of variability on estimates of decay rate and turn-over time must preceed their possible use as ecosystem characteristics.

RESUMÉ

Den rumlige variation i løvfaldsmængden (løvfaldskomponenter < 45 cm) og i jordbundens indhold af organisk stof er bestemt for en gammel bøgebevoksning i Strødam-reservatet, Gadevang, Nordsjælland. Ved løvfald forstås i denne sammenhæng ikke alene bladfald, men nedfald af overjordiske plantedele mindre end 45 cm (blade, knopskæl, blomster, frugter, kviste).

Det årlige løvfald udgjorde 442 ± 26 g tørstof/m², eller 211 ± 12 g kulstof/m² og 4,94 ± 0.34 g kvælstof/m² (gennemsnit ± 95 % konfidens grænser). Det registrerede løvfald var jævnt fordelt over prøvefladen (50 × 50 m) og var i overensstemmelse med resultater fra andre bøgebevoksninger med hensyn til mængde og fordeling over året.

Betydelig variation i kulstof- og kvælstof-indholdet registreredes i jordlagene under F-laget, hvorimod C/N forholdet udviste mindre variation i lagene L, F, H, A_1 og A_2. Generelt øgedes variationen i jordens indhold af kulstof og kvælstof med dybden i profilen og med størrelsen af prøvefladearealet.

Skovbunden (L, F og H lagene) indeholdt 8,5 ± 2,4 kg kulstof/m² og 0,42 ± 0,13 kg kvælstof/m², og den totale mængde af kulstof og kvælstof i hele profilen (dybde 150 cm) udgjorde henholdsvis 19,7 kg/m² og 1,02 kg/m². Størrelsen af den årligt omsatte del af kulstof og kvælstof mængden i skovbunden beregnedes til at ligge i intervallet 0,0198—0,0331 pr. år for kulstof og 0.0092—0.0167 pr. år for kvælstof.

Det konkluderes, at en nøjere kvantitativ vurdering af kilderne til variationen i løvfaldsmængden og jordbundens organiske stofindhold må gå forud for en anvendelse af disse estimater ved beregning af omsætningsrater.

Vigtigheden af denne vurdering øges, hvis de beregnede omsætningsrater anvendes som økosystem karakteristika.

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