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# The use of cellulose strips to study organic matter decomposition in boreal forested soils

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This paper addresses the use of cellulose strips (softwood pulp) as a method for studying the decomposition of soil organic matter. The eight study sites were located in four forested catchments in Finland (between 61°–69°N). The sites comprised mineral soil and peat soil plots subjected to minimal anthropogenic influence. The cellulose strips were placed on the soil surface, on the surface and covered with litter, and in the subsurface (0–5 cm) for 49 weeks and the weight loss measured. Significant, positive correlations were found between the weight loss of cellulose strips and the weight loss of local Scots pine needle litter (up to $r = 0.98$, $p < 0.001$), and between the weight loss of cellulose strips and basal respiration (up to $r = 0.65$, $p = 0.007$). The cellulose strip method can be easily and successfully used to measure cumulative decomposition activity over a period of time.

## Introduction

Organic matter decomposition is a key process in the cycling of nutrients in forest ecosystems. The Jenny index, i.e., the ratio between litterfall and forest floor biomass accumulation, has been used as an *in situ* method to estimate decomposition (Jenny *et al*. 1949, Olson 1963). The index has often been used in the absence of direct estimates of the decomposition rate. Mesh bags, in which specific litter material is retained for a certain period of time in order to determine the mass loss, are the most commonly used means of measuring decomposition rates (Berg *et al*. 1993, Bocock and Gilbert 1957, Johansson 1994).

In forest soil, litter is the largest source of organic material. The amount of carbon and nutrients subsequently returned to the soil from root turnover may equal or even surpass that returned through surface litter in many forests (e.g., Joslin and Henderson 1987, Raich and Nadelhoffer 1989). The amount and quality of forest litter vary with the species composition of the stand, soil and climatic conditions, and time. Therefore, the rate of litter decomposition can vary widely. The decomposition of a single organic substance, such as cellulose, which all higher plants contain, can be supposed to measure relative decomposition activity. Hoppe-Seyler (1883) and de Bary (1886) first reported that cellulose is decomposed in na-

ture (review by Eriksson *et al.* 1990). Today, cellulose is commonly used to measure decomposition in the field. In one method common in Scandinavian studies, strips of softwood pulp (Lähde 1974) are buried or placed on the soil surface and their weight loss is determined after a certain time. Although the cellulose strips method has been in common use in both mineral (e.g., Huhta 1976, Kubin 1983, Kurka and Starr 1997, Kurka *et al.* 2000) and peat soil site (e.g., Brække and Finér 1990, Hartman *et al.* 1998, Kurka and Starr 1997, Kurka *et al.* 2000, Minkkinen *et al.* 1999) studies, comparisons between the decomposition of cellulose strips and other methods of measuring decomposition are few.

Needles account for the majority (approximately 75%) of litterfall in Scots pine forests (review by Albrektson 1988). The objective of this study was to compare the weight loss of cellulose strips to that of local Scots pine needle litter in a range of mineral soil and peat soil sites in natural boreal forests. By burying the cellulose strips in the subsurface (0–5 cm) indications of the decomposition in the root litter zone may also be obtained. Moreover, the decomposition of cellulose strips was compared to laboratory measurements of basal respiration of humus (Of + Oh) and peat (0–5 cm) layers sampled from the same sites.

## Materials and methods

### Study areas

The study was carried out at eight plots (Table 1) distributed among four catchments located in national parks or otherwise protected areas in Finland (61°–69°N). Valkea-Kotinen and Hietajärvi catchments are located in the southern and central boreal regions, and Pesosjärvi and Vuoskojärvi in the northern boreal region (Fig. 1). The long-term (30 year) annual mean temperatures and annual mean precipitation for the catchments are: Valkea-Kotinen 3.6 °C and 619 mm, Hietajärvi 2.0 °C and 592 mm, Pesosjärvi –0.9 °C and 554 mm, and Vuoskojärvi –2.0 °C and 395 mm (Kurka and Starr 1997). The study plots represented various types of natural forests (Scots pine, Norway spruce and deciduous species). Therefore, the amount and quality of litter as well as micro-

**Table 1**. Description and characteristics of the study plot stands.

| Catchment | Plot | Plot size (ha) | Elevation (m a.s.l) | Soil unit and group[a] | Humus form | Site type[b] | Stand dominant/ nondominant species[c] | Stem volume trees ($m^3$/ha)[d] | Age of dominant trees (years)[d] |
|---|---|---|---|---|---|---|---|---|---|
| Valkea-Kotinen | VK2 | 0.16 | 156 | Terric Histosol | Peat | Mtkg | S/D,P | 407 | 190 |
| | VK6 | 0.16 | 161 | Dystric Cambisol | Mor | MT | S/P,D | 292 | 120 |
| | VK10 | 0.08 | 164 | Dystric Cambisol | Moder | OMT | S,D/P | 600 | 160 |
| Hietajärvi | H8 | 0.09 | 167 | Fibric Histosol | Peat | TR | P | 8 | 150 |
| | H10 | 0.16 | 167 | Haplic Podzol | Mor | EVT | P/D,S | 288 | 230 |
| Pesosjärvi | P8 | 0.12 | 293 | Haplic Podzol | Mor | HMT | S/D,P | 190 | 240 |
| Vuoskojärvi | V5 | 0.09 | 146 | Haplic Podzol | Mor | sELiPIT | Bt/P | 13 | 150 |
| | V6 | 0.16 | 162 | Haplic Podzol | Mor | Lichen woodland | P/Bt | 70 | 180 |

[a] FAO 1990. [b] Mtkg = *Vaccinium myrtillus* drained peatland forest, MT = *Myrtillus* type, OMT = *Oxalis–Myrtillus* type, TR = *Eriophorum vaginatum* pine bog, EVT = *Empetrum–Vaccinium* type, HMT = *Hylocomium–Myrtillus* type, sELiPIT = subalbine *Empetrum–Lichenes–Pleurozium* type and Lichen woodland = Lichen woodland rich in mosses (*see* Cajander 1926, 1949, Eurola *et al.* 1984). [c] According to stem volume. P = Scots pine (*Pinus sylvestris*), S = Norway spruce (*Picea abies*), D = decidious species and Bt = Mountain birch (*Betula pubescens* ssp. *tortuosa* ). [d] The tree for plots VK2 and VK6 are from Kurka and Starr (1997). The same methods were used to obtain the data from other plots (Finnish Forest Research Institute / Integrated Monitoring programme, unpublished data).

climatic factors varied greatly within the plots. This was taken into account by dividing the experimental units into subplots, located on the edges of the study plots. The sites were established as part of the UN-ECE ICP Integrated Monitoring programme (Bergström 1998, Bergström *et al.* 1995, Ukonmaanaho *et al.* 1998).

## Decomposition of cellulose strips

This study employed a cellulose strip (softwood pulp) based method (Lähde 1974). The ECF pulp material (softwood pulp, Sunila Ltd.) consisted of sheets of cellulose bleached without elementary chlorine. The material was composed of pine and spruce pulp in a 50:50 ratio (Sunila Ltd./Tea Sundén pers. comm.).

The rate of cellulose decomposition was determined as the weight loss (%) of oven dried (24 h at 105 °C) cellulose. Five cellulose strips (1 mm thick, 30 mm by 47 mm) were placed in separate, end-to-end compartments in a nylon net bag of 1 mm pore size. In the field, the bags were systematically placed in two subplots (a and b) along plot edges. There were five groups of bags along each subplot at 2-m intervals. Within each group, eight cellulose strips were placed on the soil surface and two strips were inserted into the soil to a depth of 5 cm. The surrounding litter material was used to cover half of the cellulose bags on the soil surface. Thus, there were a total of 40 cellulose strips on the soil surface and 10 strips inserted into soil in each subplot. The cellulose bags were anchored to the ground by stainless steel pegs.

The bags were placed out in September–October (1995) for 49 weeks. At the end of the study period, the bags were retrieved, roots and mosses were removed, and adhering material removed by washing with water. Each cellulose strip was then oven dried and weighed. The cellulose decomposition was calculated as the weight loss (%) on an oven dry basis.

## Decomposition of local Scots pine brown needles

Brown needles, which were just about to fall, were collected from living Scots pine trees in each

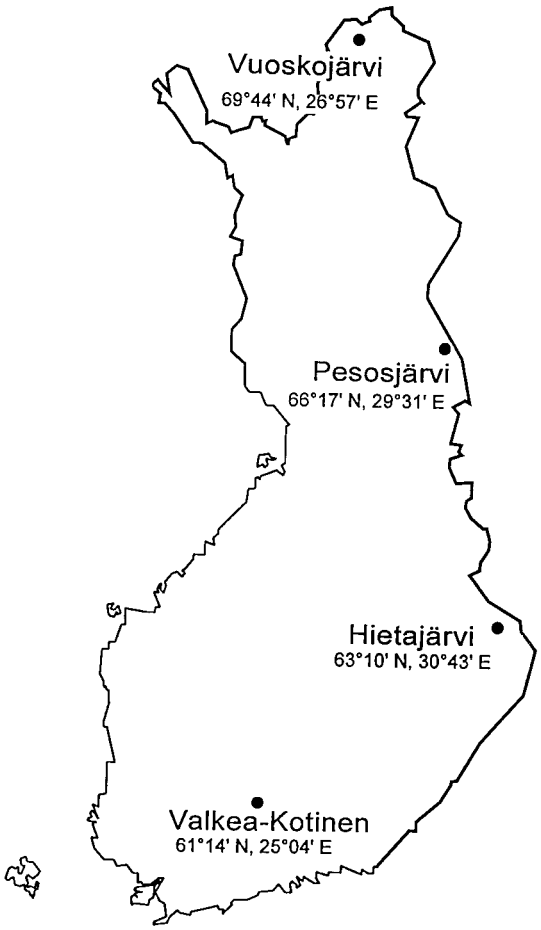


**Fig. 1**. Location of study catchments.

catchment a year before (1994) the start of the decomposition study. The needles were dried at room temperature and transferred to a desiccator containing dry silica gel for 4 days. Room temperature was used to minimise the disturbance to the microbial population. The needles and the silica gel were not in direct contact with each other, a piece of thin porous paper was placed in between them. Silica gel dehydrated the starting moisture for the needles. After four days, 1.00 g of the needles were placed into a nylon bag (10 cm $\times$ 5 cm, 1 mm pore size). The bags were anchored to the ground by stainless steel pegs. At each subplot, needle bags were placed on the soil surface near each group of cellulose bags. At the end of the experimental period (the same period as for the cellulose strips), the needles were air dried and cleaned with a brush. The needles were then placed in a desiccator and weighed after four days.

The decomposition was calculated as the percentage weight loss.

### Basal respiration

Humus (Of + Oh) and peat (0–5 cm) were sampled from the subplots using a 52 mm diameter stainless steel corer. This was done in autumn on the same day as the cellulose and needle litter bags were placed. Ten cores were taken at a distance of 5–10 cm from each group of the decomposition bags. Composite samples from each group were taken along the subplots a and b (fifty soil cores each) flanking the plot edges. The soil samples were stored in cool and dark (≤ 5 days), green plant material removed and the humus samples sieved (pore size 2.8 mm). The dry matter content was determined after drying for 20–24 h at 105 °C. Organic matter content was measured as the weight loss on ignition of the dried samples at 550 °C for 4 h.

Soil (2 g dry matter) was moistured to 60% of water holding capacity, placed in glass bottles (100 ml) and incubated at 14 °C for 45–47 h. Concentrations of $CO_2$ were measured by gas chromatograph (Varian 3600) equipped with a thermal conductivity detector and Megapore GS-Q column of 30 m (J & W Scientific) using He (6.4 ml $min^{-1}$) as the carrier gas. The injector, column and detector temperatures were 120, 30, and 150 °C, respectively. The results are presented as the average of four sequential measurements done during 2 weeks. The bottles were aerated between the measurements. The method was the same as used by Smolander *et al.* (1994).

### Statistical analyses

The decomposition data were analysed with ANOVA (a split-plot design used for the cellulose data). Pearson correlations were calculated to describe the relationship between cellulose decomposition, needle litter decomposition and basal respiration. All the statistical analyses were performed using the SYSTAT® statistical package.

## Results and discussion

The weight loss of all cellulose strips and needle litter bags was < 100%, and was therefore usable for analyses. The mean weight loss of the cellulose strips at each subplot ranged from 7% to 95% and that of the needle litter, from 15% to 30% (Table 2). Statistical analysis using ANOVA (Table 3) revealed that there were significant differences among subplots within catchments in the decomposition of both cellulose and Scots pine needles. The analysis also revealed significant differences between the weight loss of cellulose strips on the soil surface, on the surface covered with litter, and in the subsurface (Table 3). The cellulose strips on the soil surface were decomposed less than those on the surface covered with litter or those buried (Table 2). This was probably due to differences in nutrients, moisture and radiation conditions. The cellulose strips covered with litter or buried in soil, may have been more easily attacked by microbes from the surrounding litter or soil.

The decomposition of Scots pine needle litter was significantly and positively correlated with that of cellulose strips on the surface ($r$ = 0.75, $p$ = 0.005), on the surface covered with litter ($r$ = 0.70, $p$ = 0.011) and buried ($r$ = 0.96, $p$ = 0.001) (Fig. 2). Fox and Van Cleve (1983) found a similar positive relationship between the annual weight loss of cellulose filter paper and Jenny's index of decomposition rate in a study conducted in forest stands in the Alaskan taiga. Heal *et al.* (1974) also found a positive relationship between decomposition of cotton strips and plant litters in tundra sites.

When the respiration rate (also called basal respiration) is measured in the laboratory, plants roots are usually removed from the soil. The basal respiration results are presented in Table 2 and were also significantly and positively correlated to weight loss of cellulose strips. The correlation coefficients for cellulose strips on the surface, on the surface covered with litter, and buried were ($r$ = 0.60, $p$ = 0.014) (Fig. 3), ($r$ = 0.65, $p$ = 0.007) and ($r$ = 0.51, $p$ = 0.043), respectively. A similar positive relationship between the decomposition

of litter and soil respiration has been reported earlier. For example, Zwolinski (1994) suggested that measurements of $CO_2$ evolution provide a valid estimate of decay rate. However, many consider that carbon dioxide production alone is an insufficient measure of decomposition rate (Killham 1994). There are several reasons, for instance, organic matter in a substrate does not entirely change into carbon dioxide in short-term experiments (Trumbore 2000). Furthermore, long-lasting laboratory measurements may not reflect the situation *in situ*, because the structure of the soil microbial community can change during an extended incubation in the laboratory. It should

**Table 2**. The weight loss of cellulose strips and Scots pine needles (for 49 weeks) and the basal respiration rates for each study subplot (means and standard deviations).

| Catchment | Plot | Subplot | Weight loss, % | | | | Respiration[d] μg $CO_2$ $g^{-1}$ o.m $h^{-1}$ |
|---|---|---|---|---|---|---|---|
| | | | Cellulose strips | | | Bags with needles | |
| | | | Surface[a] | Surface covered with litter[a] | Subsurface 0–5 cm[b] | Surface[c] | |
| Valkea-Kotinen | VK2 | a | 64 ± 24 | 85 ± 17 | 72 ± 15 | 27 ± 5 | 11.1 ± 1.5 |
| | | b | 72 ± 22 | 88 ± 12 | 78 ± 21 | 26 ± 6 | 6.9 ± 0.9 |
| | VK6 | a | 53 ± 16 | 81 ± 14 | 89 ± 12 | | 9.9 ± 0.7 |
| | | b | 73 ± 18 | 93 ± 13 | 87 ± 25 | | 15.2 ± 1.0 |
| | VK10 | a | 58 ± 20 | 81 ± 17 | 76 ± 29 | 26 ± 5 | 17.6 ± 1.2 |
| | | b | 73 ± 19 | 94 ± 7 | 95 ± 6 | 29 ± 5 | 10.4 ± 0.7 |
| Hietajärvi | H8 | a | 7 ± 6 | 19 ± 11 | 16 ± 7 | 15 ± 1 | 1.5 ± 0.1 |
| | | b | 23 ± 20 | 30 ± 24 | 21 ± 15 | 17 ± 1 | 1.5 ± 0.1 |
| | H10 | a | 37 ± 15 | 57 ± 21 | 80 ± 25 | 30 ± 3 | 7.3 ± 0.5 |
| | | b | 36 ± 17 | 52 ± 19 | 82 ± 13 | 29 ± 3 | 7.2 ± 0.5 |
| Pesosjärvi | P8 | a | 60 ± 18 | 83 ± 19 | 82 ± 22 | | 11.1 ± 0.6 |
| | | b | 68 ± 21 | 87 ± 13 | 82 ± 21 | | 6.2 ± 0.5 |
| Vuoskojärvi | V5 | a | 29 ± 20 | 43 ± 20 | 44 ± 22 | 18 ± 2 | 13.1 ± 0.3 |
| | | b | 50 ± 18 | 61 ± 20 | 45 ± 27 | 23 ± 2 | 13.7 ± 0.3 |
| | V6 | a | 22 ± 11 | 32 ± 17 | 46 ± 26 | 19 ± 3 | 5.1 ± 0.4 |
| | | b | 18 ± 11 | 32 ± 11 | 39 ± 13 | 20 ± 4 | 5.9 ± 0.4 |

[a]$n$ = 20 per subplot, [b]$n$ = 10 per subplot, [c]$n$ = 5 per subplot, [d]calculated as mean of 4 sequential measurements during 2 weeks.

**Table 3**. Analysis of variance for the decomposition of cellulose strips and Scots pine needles (the observations are subplot means).

| Material | Source of variation | Mean squares | Degrees of freedom | $F$ | $p$ |
|---|---|---|---|---|---|
| Cellulose | Subplot | 3410 | 7 | 256 | < 0.001 |
| | Error 1 | 13 | 7 | | |
| | Surface/Surface covered/Subsurface | 1690 | 2 | 18 | < 0.001 |
| | Error | 96 | 31 | | |
| Scots pine needle | Subplot | 55 | 5 | 17 | < 0.002 |
| | Error | 3 | 6 | | |

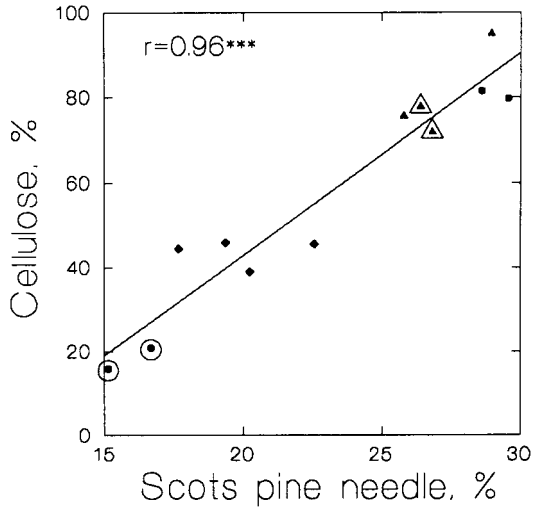


**Fig. 2**. Relationship between weight loss (%) of cellulose strips buried in (0–5 cm) and Scots pine needle litter. Symbols: ▲ = Valkea-Kotinen, ● = Hietajärvi, and ◆ = Vuoskojärvi. Data points representing peatland plots are framed.

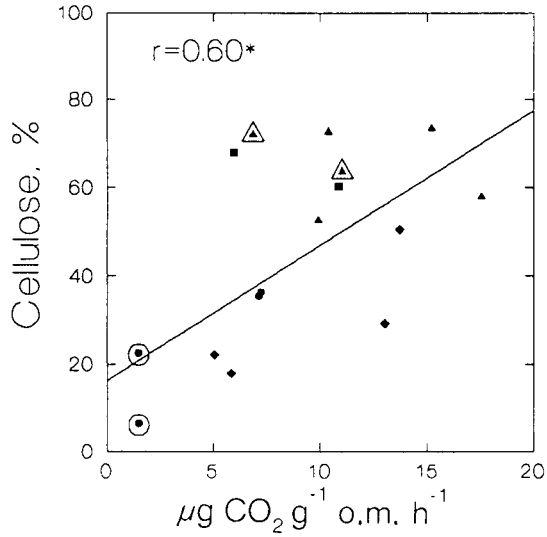


**Fig. 3**. Relationship between weight loss (%) of cellulose strips placed on surface and basal respiration. Symbols: ▲ = Valkea-Kotinen, ● = Hietajärvi, ■ = Pesosjärvi, and ◆ = Vuoskojärvi. Data points representing peatland plots are framed.

also be remembered that soil respiration displays considerable seasonal variation in the field (Joshi *et al.* 1991). Live root respiration may account for most of the total soil respiration (Kelliher *et al.* 1999, Raich and Schlesinger 1992).

Decomposition of cellulose in forest soils is mediated by enzymes on the outer surface of cells or completely detached (i.e. extracellular enzymes). Soil enzymes are often entrapped in soil organic and inorganic colloids. There is therefore a large pool of extracellular enzymes in the soil which is not directly associated with the microbial biomass (Paul and Clark 1989, Sinsabaugh 1994, Sinsabaugh *et al*. 1992, 1993). Cellulases are an important class of enzymes that hydrolyse cellulose (Ljungdahl and Eriksson 1985), and are mainly produced by fungi. The yields of cellulases from bacteria are generally much lower than those from fungi (Eriksson and Wood 1985). Soil animals may also have cellulase activity in the gut (Scrivener and Slaytor 1994, Slaytor 1992, Treves and Martin 1994), however, mainly because of cellulolytic activity of gut microbes (Chararas *et al.* 1983, Zimmer and Topp 1998). In a study by Huhta (1976), the decomposition of cellulose strips was associated with the activity of soil animals, *Enchytraeidae* and *Lumbricidae*, in spruce stands in Finland.

The activities of cellulose degrading enzymes have been found to increase together with leaf and needle litter decomposition in forest soils (e.g., Joshi *et al.* 1993, Kshattriya *et al*. 1992, Linkins *et al.* 1990, Lähdesmäki and Piispanen 1988). Ohtonen *et al.* (1993) found no correlation between the decomposition index of cellulose cardboard strips (composition not reported) in the field and an index of cellulase activity in humus measured in the laboratory. They considered the decomposition of cellulose cardboard strips exposed in the field for one year as too insensitive for the purpose of measuring a change in microbial activities (Ohtonen *et al.* 1993).

It is difficult to extrapolate results from cellulose utilization studies from the laboratory to the field (Widden *et al.* 1989). The cellulolytic enzyme situation which exists during microbial growth under one set of conditions may not exist under another, and may change with time (Coughlan and Mayer 1992, Romero *et al.* 1999). It is thus important to determine the decomposition activity in field conditions.

Several authors have proposed cellulose decomposition as a general index of decomposer potential (e.g., Brække and Finér 1990, Harrison *et al.* 1988). According to Howard (1988) and

French (1988), cellulose material may be used for assessing relative microbial activity, but not the absolute decomposition activity. The positive correlation between weight loss of cellulose strips and that of needle litter material, and between weight loss of cellulose strips and basal respiration found in this study, suggests that the use of the cellulose strips method is adequate for this purpose.

The cellulose strip method has the following advantages:

- the method measures the relative decomposition activity in a cumulative manner,
- the substrate is homogeneous and chemically definable,
- the material does not contain any soluble substances which could bias the result,
- the strips can be made of a desired size,
- the pore size of the nylon bags can be selected to exclude certain soil organisms,
- it is easy to apply in the field and causes minimal disturbance to the soil profile when the bags are inserted into the soil,
- the transfer of moisture from one strip to another can be prevented by separating them in the bag, and
- the costs of material are low.

As a litterbag method, the cellulose strip method provides a measure of cumulative decomposition activity in the field integrated over a period of time, whereas most other microbiological methods (e.g., basal respiration and cellulase enzyme activity) give information only about one sampling event. Furthermore, the weight loss of cellulose strips not only indicates the activity of living soil microorganisms, but also the extracellular enzyme activity already accumulated in the soil, and thus reflects the relative decomposition potential of the soil.

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