Decomposition of cellulose in relation to soil properties and plant growth

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1 *Summary*
Cellulose decomposition in soil is often assessed on the assumption that it relates to the rate of decomposition of native soil organic matter and, consequently, to nutrient cycling and soil fertility.

This assumption was examined, in a pot experiment, by determining the weight loss of cellulose (as filter paper), the growth of 4 species of plants, and soil chemical and physical properties, on a range of 76 soils representative of 8 major soil groups collected from various parts of the UK.

There were highly significant, but low, correlations between the rates of decomposition of cellulose and the growth of all test plant species across all soils. These correlations appeared to be linked because there were also low, but highly significant, correlations between rates of cellulose decomposition and the soil properties, to which plant growth was related. However, the regressions between (i) rates of cellulose decomposition and plant growth, and (ii) cellulose decomposition and soil properties showed significant differences in intercept for various soil types. These findings point to strong interactions of soil type in the inter-relationships of cellulose decomposition, plant growth and soil properties. The interactions with soil type are important and need to be taken into account in any interpretation of cellulose decomposition in terms of soil fertility.

2 *Introduction*
Decomposer processes, being an essential part of nutrient cycling, can be expected to relate to soil fertility, and Swift *et al.* (1979) stress the importance of biological (ie decomposer) processes in the replacement of available soil nutrients. It can then be inferred that, because cellulose is a major part of fresh organic matter, its rate of decomposition should relate to the rate of decomposition of soil organic matter, and any measure of cellulose decomposition, such as the cotton strip assay, would therefore serve as an index of soil fertility. This interpretation is implied in some work, with some limited support of experimental work for its general validity, but the complexity of the links in the argument is quite obvious.

Berg *et al.* (1975) considered that a standardized type of pure cellulose could act as a 'model' substance for decomposition in tundra studies, and emphasized its use to separate environmental factors from effects of litter quality. Thus, direct comparison of decay of litters and of cellulose would identify differences due to litter quality, but also similarities related to climatic and soil factors, as shown by French (1988) when comparing weight loss of litters and cotton strip decay.

Thus, only a general similarity between relationships for decomposition of cellulose (cotton strips) and of plant litters is shown by Heal *et al.* (1974), comparing regression surfaces with site components for a range of tundra sites. Fox and Van Cleve (1983) have found a curvilinear relationship between loss in weight of filter paper and Jenny's 'k' measure of soil organic matter decomposition.

To what extent, then, can the rate of cellulose decomposition in soils provide any index of their fertility? This concept is further examined in this paper by relating directly the rate of decomposition of a single cellulose substrate (filter paper) and the growth potential of 4 plants with some chemical properties in a range of soils in a pot experiment. The results are considered relevant to the interpretation of the cotton strip assay, which was originally described only as providing a comparative index of cellulose decomposition rates in soils.

3 *Method*
Seventy-six UK soils (a subset of 104 soils) representing 8 different soil types (see Figure 1), with 8–10 of each type, were taken from the top 20 cm (the plant

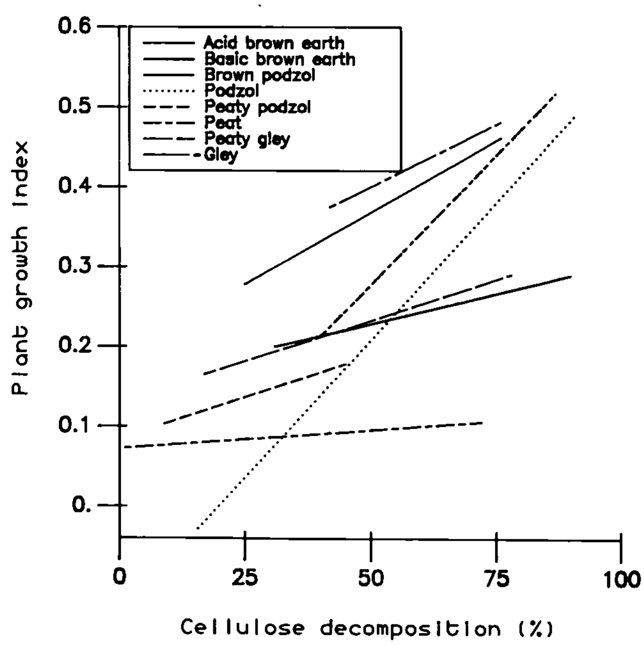

Figure 1. Interaction of soil type in the relationship of plant growth index to cellulose decomposition in 8 soil types

rooting depth) of the profiles sampled from various parts of the country (Harrison & Hornung 1983). The soils were mixed, passed, in the fresh condition, through a 19 mm mesh sieve screen (Benham & Harrison 1980), and potted, the pots being placed outside in a replicated, randomized block design on gravel beds. Cellulose decomposition rates were determined by burying 3 pieces, each 8 cm^2, of Whatman no. 1 filter paper in 5 mesh nylon bags (5 cm x 2 cm), in separate unplanted pots of the soils for 12 months. After this period, the percentage dry weight loss of the cellulose was determined, and was used as the measure of decomposition.

Four plant species, radish (*Raphanus sativus*), common bent-grass (*Agrostis capillaris*), white clover (*Trifolium repens*) and birch (*Betula pendula*), were grown, in separate pots, on each of the soils, radish for 6 weeks but the other species for 16 months. The productivity of each plant species was determined as total dry weight of both shoots and roots per pot. A plant growth index, which has been used as a single combined measure of relative soil fertility, was assessed as follows. For each species, an average rank value was calculated from ratios of the mean dry weight production per pot of each soil to the highest value for that species. The average rank value was then derived by calculating the mean for the 4 species, and this measure is referred to as the plant growth index. The growth of each of the 4 species was highly significantly intercorrelated over all the soils, so there was little distortion in this pattern compared to that of each individual plant species. Physical and chemical soil properties were analysed on subsamples taken after the sieving stage (see Appendix to this paper).

4 *Results*

4.1 The relationship between cellulose decomposition and plant growth

Cellulose decomposition rate and plant growth were positively and significantly related over all 76 soils, but the overall proportions of variation accounted for were less than 35% (Table 1). The poor, though still significant, relationship for birch is possibly explained by its slower growth rate. Using multiple regression, 50.3% of the variation in cellulose decomposition could be accounted for by the productivity of all 4 plant species. However, covariance analysis showed significant differences in slope and intercept of the regressions for the various soil types, indicating that there were strong interactions of soil type in the relationship between the cellulose decomposition and plant growth (Table 2 & Figure 1). These interactions account for the low r^2 values in the relationships between the individual plant species, over all the soils (Table 1).

Table 1. Relationships between plant productivity and cellulose decomposition on 76 soils of 8 soil types. The plant growth index is used as the measure of plant productivity

Species	r^2	F ratio (df = 1, 74)	F ratio for significance of departure from linear regression (df = 1, 73)
Bent-grass	+0.32	35***	NS
Birch	+0.07	6*	NS
Clover	+0.31	33***	NS
Radish	+0.33	36***	NS
Plant growth index	+0.37	43***	NS

NS, not significant; *P <0.05; **P <0.01; ***P <0.001

Table 2. Interaction of soil type in the relationship of plant growth to cellulose decomposition as shown by covariance analysis of 8 soil types

Species	F ratios Slope (df = 7, 60)	Intercept (df = 7, 67)
Bent-grass	1.7 NS	3.9 **
Birch	0.7 NS	1.6 NS
Clover	2.4 *	6.4 ***
Radish	0.5 NS	2.8 *
Plant growth index	1.2 NS	4.0 ***

NS, not significant; *P<0.05; **P<0.01; ***P<0.001

4.2 The relationships between cellulose decomposition and soil properties

Cellulose decomposition rate was highly significantly related to a number of soil physical and chemical properties (Table 3), the rate being negatively related to soil organic matter content and positively related to the rest. Total soil nitrogen showed no significant relationship with cellulose decomposition over all the soils, because the relationship was confounded by a positive relationship for peat soils but a negative curvilinear relationship for the other soils. No soil property accounted for more than 40% of the variation in cellulose decomposition rate, but the fact that it related to many soil properties indicates the complexity of the soil system. Using multiple regression, it was possible to account for a total of 63.4% of the variation in cellulose decomposition by the measured soil properties. However, as with the plant relationships above, covariance analysis showed significant differences in slope and intercept of the regressions for the various soil types (Table 4 & Figure 2), indicating strong interactions of soil type in the relationships between cellulose decomposition and soil properties.

Despite the complications introduced by the soil type interaction, the soil properties which appeared to be most strongly associated with cellulose decomposition across the 76 soils were the organic matter (negative), sand, pH, total phosphorus (P), extractable potassium (K) and calcium (Ca) contents (all positive), though it has to be stated that the relative importance of the soil properties varied for the soils of different soil types. In a laboratory experiment with mainly non-organic soils and relatively high pH, Szegi *et al.* (1984) accounted for 47% of the variability in cellulose decomposition in a multiple regression analysis, includ-

Table 3. Relationships between cellulose decomposition or the plant growth index with soil properties in 76 soils of 8 soil types. Quadratic regression was used for relationships with a significant departure from linear regression. F ratio is for the linear, or quadratic (bracketted) regression with each property, df = 1, 75 (linear), 2, 73 (quadratic)

Property	Cellulose decomposition r^2	Cellulose decomposition F ratio	Plant growth index r^2	Plant growth index F ratio
Physical				
Organic matter	−0.39	(23 ***)	−0.31	34 ***
Sand	+0.36	(20 ***)	+0.37	22 ***
Silt	+0.23	23 ***	+0.44	29 ***
Clay	+0.17	(8 ***)	+0.29	15 ***
Stones	+0.18	(8 ***)	+0.08	6 NS
Chemical				
pH	+0.36	41 ***	+0.41	52 ***
Total P	+0.20	19 ***	+0.57	49 ***
Total N	0.01	1 NS	+0.12	5 *
Total Fe	+0.19	17 ***	+0.32	34 ***
Extractable Ca	+0.23	(11 ***)	+0.40	25 ***
Extractable K	+0.38	(22 ***)	+0.58	50 ***

In Tables 3 and 4, all values expressed litre^{-1} soil, except organic matter expressed kg^{-1} soil
NS, not significant; *P <0.05; ***P <0.001

Table 4. Interaction of soil type in the relationship of cellulose decomposition, or the plant growth index, to soil properties, as shown by covariance analysis of 8 soil types

Property	Cellulose decomposition F ratio Slope (df = 7, 60)	Cellulose decomposition F ratio Intercept (df = 7, 67)	Plant growth index F ratio Slope (df = 7, 60)	Plant growth index F ratio Intercept (df = 7, 67)
Physical				
Organic matter	0.8 NS	2.9 **	1.5 NS	3.2 *
Sand	1.4 NS	4.9 ***	1.6 NS	6.4 ***
Silt	1.3 NS	4.3 ***	1.5 NS	2.2 *
Clay	0.8 NS	6.2 ***	1.3 NS	4.7 ***
Stones	5.0 ***	6.7 ***	1.3 NS	6.7 ***
Chemical				
pH	1.2 NS	5.5 ***	3.1 *	3.8 *
Total P	1.1 NS	5.2 ***	7.5 ***	1.5 NS
Total N	0.7 NS	8.3 ***	1.7 NS	8.6 ***
Total Fe	0.8 NS	5.1 ***	0.4 NS	2.7 **
Extractable Ca	2.1 NS	6.4 ***	9.7 ***	4.9 **
Extractable K	3.1 **	5.5 ***	7.4 ***	2.9 NS

NS, not significant; *P <0.05; **P <0.01; ***P <0.001

ing available nitrogen (N) and phosphorus, magnesium (negative), pH, and clay. In a further respiration experiment with added N, P, K, and cellulose powder, N, P, K, and pH accounted for 76% of the cellulose decomposition. The poor relationship of cellulose decomposition with nitrogen recorded in our study was no doubt due to our use of analyses for total nitrogen, most of which would be unavailable in many of the organic soils used.

4.3 The relationships between plant growth and soil properties

The plant growth index was significantly related to a

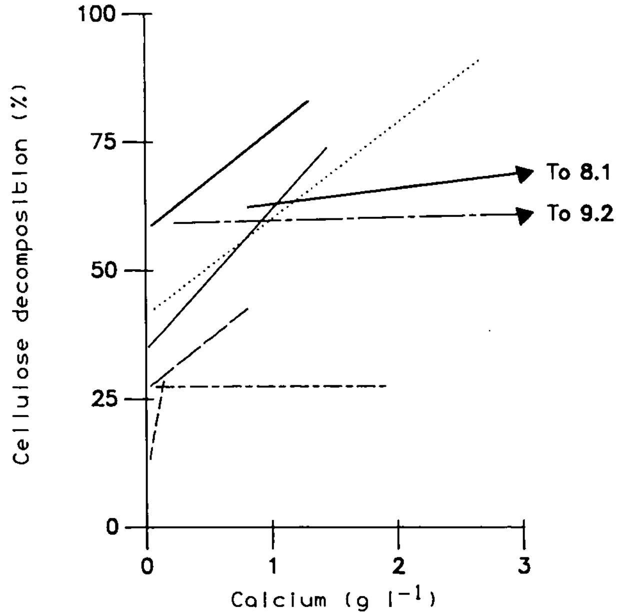

Figure 2. Interaction of soil type in the relationship of cellulose decomposition to soil calcium (extractable in ammonium acetate at pH 7.0) in 8 soil types. Key as for Figure 1

number of soil physical and chemical properties (Table 3), being related negatively to organic matter but positively to others. The proportion of variation of plant productivity which could be accounted for by each of the soil properties was generally slightly higher than for cellulose decomposition. Using multiple regression, a total of 68.6% of the variation in plant productivity could be accounted for by all the soil properties included in the analysis. However, as with cellulose decomposition above, covariance analysis showed significant differences in slope and intercept of the regressions for the various soil types (Table 4 & Figure 3), indicating that strong soil type interactions occurred in the relationships between plant pro-

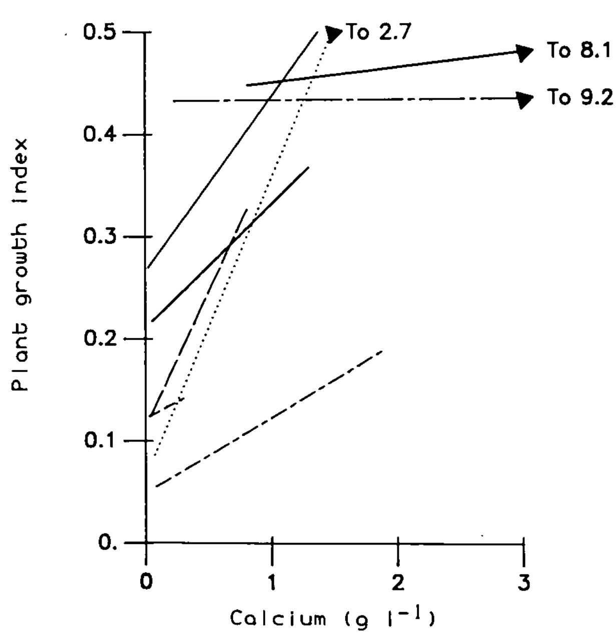

Figure 3. Interaction of soil type in the relationship of plant growth index to extractable soil calcium in 8 soil types. Key as for Figure 1

ductivity and soil properties. Despite the soil type interaction effects, the properties which appeared to be most strongly associated with plant productivity across all 76 soils (Table 3) were sand, silt, total phosphorus, extractable potassium, calcium contents and pH, but, as with cellulose decomposition, there were differences in the relative importance of properties for the various soil types.

5 *Discussion*

The results of this study showed that decomposition of a cellulose substrate was, in broad terms, related to the plant growth potential of 4 plants over a wide range of soil conditions. In addition, both cellulose decomposition in and plant productivity on the 76 UK soils appeared to be related, superficially at least, to similar soil properties (Figure 4). Thus, it appeared that cellulose decomposition in soils was indirectly related to plant productivity by virtue of their common dependence on the same soil properties, about 65% of the variation in each being explained by the same soil factors. Unfortunately, soil moisture, upon which both decomposition and plant growth depend heavily, was not monitored in this experiment. Variation in soil moisture conditions — water retention capacity of different soils varies in relation to their physical condition, mainly their organic matter content — may have accounted for some of the unexplained variation in decomposition.

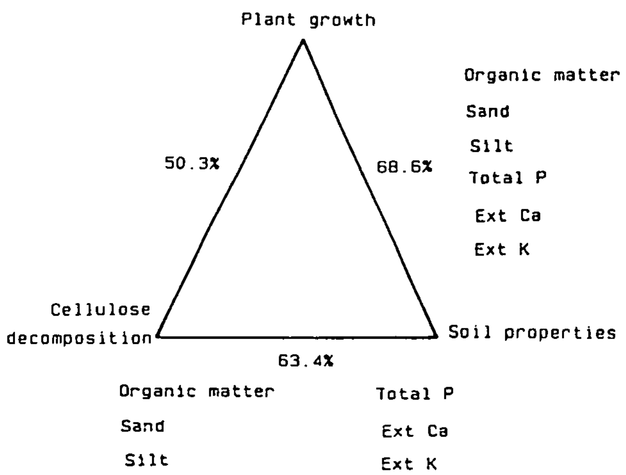

Figure 4. Diagram summarizing intercorrelations between plant growth, cellulose decomposition and soil properties in the 76 soils

There were strong interactions of soil type in the relationships of both cellulose decomposition and plant productivity to soil physical and chemical properties, and the patterns among the regressions for the 8 soil types for some soil properties were similar for both cellulose decomposition and plant growth, eg Figures 2 and 3 for extractable Ca. So, the occurrence of strong soil type interactions limits any simple interpretation of cellulose decomposition rates in terms of soil fertility across soil types, unless considerable background information is available to help in the interpretation.

6 *References*

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7 *Appendix*

Soil physical and chemical analyses were carried out as follows.

Organic matter as % loss in weight following ignition (LOI %) of oven dried <2 mm soil at 550°C for 2 h.

Sand, silt and clay by a differential sedimentation procedure using a Bouyoucos hydrometer (Allen *et al.* 1974); if organic matter was greater than 20%, organic matter was oxidized with boiling H_2O_2 prior to the procedure.

Bulk density (used to calculate results litre^{-1} soil) was estimated from the equation Y = 1.558 – 0.728 ($\log_{10}$ LOI %) (Harrison & Bocock 1981), with adjustment by the value obtained for stone volume.

% stone volume as the volume of water displaced by the >2 mm fraction of the 19 mm sieved soil.

Soil pH by making a paste from fresh soil moistened to saturation point, and measuring after 30 min with a dual electrode.

Total P by nitric-perchloric-sulphuric acid digestion of air dry soil, followed by colorimetric determination by the ammonium molybdate method (Allen *et al.* 1974).

Total N by Kjeldahl digestion procedure followed by colorimetric determination by the indophenol blue method (Allen *et al.* 1974).

Total Fe by digestion in concentrated nitric-hydrofluoric acid and determination using inductively coupled plasma analysis, by N Walsh, at Kings College, London.

Extractable Ca and K by extraction in neutral ammonium acetate and determination by atomic absorption spectrometry (Allen *et al.* 1974).