INTERNAL REPORT 137

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ABSTRACT

A litter decomposition model was developed as part of a watershed modeling effort. This model simulates weekly dry weight changes in woody and nonwoody litter (01), incorporated litter layer (02), and soil organic matter. Processes simulated by the model include: litterfall by component, root turnover, respiration, decomposition, and organic matter transport. Data from the A. E. Thompson Experimental Forest in Washington were used to test the model. Results were consistent with observed behavior and published values for the nonwoody litter and the two soil compartments. Results indicate that the woody litter compartment may need to be further divided according to particle size.

INTRODUCTION

Variations in the amount of organic material in the forest floor are the result of several interactive processes. Mathematical models have been proposed to describe the overall results of these variations for several forest types (Minderman 1968, Witkamp 1966, Olsen 1963). In coniferous forests, investigations have also been made of component processes, such as litterfall (Abee and Lavender 1972, Ando 1970, Dimock 1958), respiration (Hu et al. 1972), and decomposition (McFee and Stone 1966, Kendrick 1959). The model presented here integrates submodels of these component processes to describe the weekly weight changes of the forest floor.

The purpose of this model is to investigate a preliminary conceptual structure of the dynamic processes in the forest floor. The model or a refinement of it will be used in an energy dynamic model of the forest ecosystem. In this exercise the rates of the processes which result in annual equilibrium in the forest floor are discovered and the sensitivity of the organic components to changes in these rates is investigated.

THE MODEL

The model has a simple four-compartment structure (Figure 1). The compartments are defined as follows:

Woody litter--dead branches, stems, cones, and their associated microflora and fauna found in the 01 horizon.

Nonwoody litter--dead needles and leaves and their associated microflora and fauna found in the 01 horizon.

Organic soil horizon--the incorporated litter layer and organic matter-dominated mineral soil (02 and A1 horizons).

Mineral soil horizon--living and dead organic matter (exclusive of living roots) below the A1 horizon but still in the rooting zone.

A carbon dioxide sink is also included in the model structure to accumulate respiration products. The distinction between components was made on chemical composition and spatial position in the ecosystem--this division also reflects basic differences in respiration rates.

The changes in a compartment size are computed in difference equation form (Table 1). The transfer rates are computed by the submodels which represent processes of litterfall, respiration, decomposition, and leaching.

Litterfall

This process is primarily controlled by factors external to the forest floor system. For this reason, a strictly time-dependent function was thought to form an adequate description of the process. All parameters were derived from data taken at the A. E. Thompson Research Center in western Washington (Grier and Cole 1972). The trees in this area are second-growth Douglas-fir, established in 1931. Table 2 shows the total annual input of litter by component.

The components of litter have different patterns of fall. Some components, such as branches, have a fairly constant weekly input, while others show marked seasonality. A general beta function was used to simulate the seasonal patterns. All parameters were adjusted to give timing and annual total corresponding to the values found experimentally. Table 3 summarizes these equations.

Respiration

This process is modeled similarly for all four components. The main factors assumed to influence the rate of respiration are moisture and temperature. After defining optimum conditions of temperature and moisture for respiration, functions that represent deviations from this maximum rate under varying conditions were derived. Assuming each influence operates proportionally, the equation becomes:

$$\phi_{i5} = r_i \cdot t \cdot w \cdot x_i, \quad \text{for } i = 1, 2, 3, 4 \qquad (1)$$

where $_{i5}$ is the equivalent weight loss of the ith component to respiration, r_i, is the g/g/m^2 maximum respiration rate, t is the influence of temperature ($0 \leq t \leq 1$), w is the influence of moisture ($0 \leq w \leq 1$), and x_i is the biomass of the ith compartment. The equations for t and w are based on data presented by Griffin (1972). The respiration submodel is summarized in Table 4.

Decomposition

The process that transfers material from the fresh litter compartments to the organic soil horizon is not so much a matter of physical movement as it is a chemical change. When the decomposing litter is no longer recognizable by component, it is considered to be part of the organic soil. This transfer is assumed to be directly related to the rate of respiration of the organisms associated with the litter. Respiration is a measure of the rate of chemical change. Thus, proportionality factors between respiration and decomposition of the two litter compartments are needed. These were derived from repeated simulations to satisfy the assumption of no net annual change in organic content of the forest floor. Table 5 summarizes this submodel.

Leaching

The transfer of material from the organic soil horizon to the mineral soil horizon is assumed to be related to the rate of water moving through the soil. The expression used in this submodel was derived by assuming that the precipitation rate is directly related to the infiltration rate, when water potential is greater than -0.3 bars. Also, it was assumed that below -0.3 bars, 0.5 cm/m^2 of water would not be leached through the organic soil horizon, and below -2 bars no water would leach. Again the proportionality factor between this rate of water movement and organic material leached from the organic soil horizon was needed. It was derived by repeated simulations and the resulting equation is given in Table 5.

RESULTS

The model was run using temperature, water potential, and precipitation records and initial values of the state variables from the A. E. Thompson Research Center data. Repeated simulations were made varying the proportion parameters related to decomposition and leaching until the beginning and ending values of the state variables coincided for the one year simulation. The balanced seasonal pattern is the one that was basically expected (Figure 2).

The sensitivity of the model output to changes in the parameters related to decomposition was tested. Figures 3 and 4 show the results of variations of these parameters on the seasonal pattern of the woody and nonwoody litter, respectively. Sums of the squared differences between the balanced case and the cases with the altered parameters were computed. Figure 5 shows the relative sensitivity of the total respiration to changes in each of these parameters. Apparently total carbon dioxide is more sensitive to the rate of decomposition of woody litter in this model formulation.

DISCUSSION

The model gives the expected seasonal pattern for the state variables. It demonstrates the slow decomposition of nonwoody litter during the winter months and the more rapid decay in the spring. Woody litter appears to build up during the winter and decays fastest in the spring and fall. Seasonal variation is minimal in the soil layers. This is because conditions favoring input into these compartments also favors respiration and the effect is counterbalanced.

The nonwoody decomposition parameter, which was estimated by repeated simulations, implies that 40% of the nonwoody litter is respired in the litter layer. This value compares favorably with the findings of Kendrick (1959). He found 47% of the dry weight of needles had disappeared by their incorporation into the F2 layer. Also, Witkamp (1966) found 40% of the weight of deciduous leaves was gone after a year in the litter layer.

For the woody litter, the model predicts a loss of 50% of its weight in the litter layer. This is not on a one year time scale, but represents the ultimate loss. Although the authors have no direct data on the weight loss of woody litter, this value seems too high. The combining of large logs with small branches in this compartment may account for this value. The large pieces of wood remain in the litter layer much longer than the relatively more refactory small pieces. This difference indicates that this compartment needs to be divided into two compartments based on particle size.

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Table 1. State difference equations (see Figure 1).

$\Delta X_1 = z_{0\,1} - \phi_{1\,5} - \phi_{1\,3}$

$\Delta X_2 = z_{0\,2} - \phi_{2\,5} - \phi_{2\,3}$

$\Delta X_3 = z_{0\,3} + \phi_{1\,3} + \phi_{2\,3} - \phi_{3\,4} - \phi_{3\,5}$

$\Delta X_4 = z_{0\,4} + \phi_{3\,4} - \phi_{4\,5}$

$\Delta X_5 = \phi_{1\,5} + \phi_{2\,5} + \phi_{3\,5} + \phi_{4\,5}$

where:

X_1 is woody litter (dry weight g/m^2),

X_2 is nonwoody litter,

X_3 is the organic soil horizon,

X_4 is the mineral soil horizon,

X_5 is the accumulated respiration pool,

$z_{0\,i}$ is the weekly influx of biomass to the ith compartment from outside the system,

$\phi_{i\,j}$ is the weekly transfer of biomass from the ith compartment to the jth.

Table 2. Estimated total litter input (after Grier and Cole 1972).

Component	Annual rate (dry weight g/m^2)
Nonwoody litter	
Needles	197
Understory leaves	10
Woody litter	
Boles	140
Branches	192
Cones	25
Understory woody stems	13
Dead roots	67
TOTAL	644

Table 3. Equations describing weekly litter input.

Woody litter:

$$z_{0\,1} = a_1 + a_2 + a_3 + a_4$$

a_1 = weekly branch input

$$= 3.7$$

a_2 = weekly bole input

$$\begin{aligned} &= 0 && ;\ k^{\dagger} < 27 \\ &= 123418 \left[\left(\frac{k - 27}{52}\right)^2 \left(\frac{39 - k}{52}\right)^2 \right] && ;\ 27 \leq k \leq 39 \\ &= 0 && ;\ k > 39 \end{aligned}$$

a_3 = weekly cone input

$$= 0.025 \cdot b_1$$

a_4 = weekly understory stem input

$$\begin{aligned} &= 0 && ;\ k < 38 \\ &= 48298 \left[\left(\frac{k - 38}{52}\right)^2 \left(\frac{46 - k}{52}\right)^2 \right] && ;\ 38 \leq k \leq 46 \\ &= 0 && ;\ k > 46 \end{aligned}$$

Nonwoody litter:

$$z_{0\,2} = b_1 + b_2$$

b_1 = weekly needle input

$$\begin{aligned} &= 0.1 && ;\ k < 33 \\ &= 500082 \left[\left(\frac{k - 33}{52}\right)^2 \left(\frac{48 - k}{52}\right)^2 \right] && ;\ 33 \leq k \leq 48 \\ &= 0.1 && ;\ k > 48 \end{aligned}$$

b_2 = weekly leaf input

$$\begin{aligned} &= 0 && ;\ k < 28 \\ &= 66956 \left[\left(\frac{k - 38}{52}\right)^2 \left(\frac{46 - k}{52}\right)^2 \right] && ;\ 38 \leq k \leq 46 \\ &= 0 && ;\ k > 46 \end{aligned}$$

Table 3. (cont'd.).

Organic soil horizon:

$z_{0\,3}$ = root death

$= 0 \quad ; \quad k < 28$

$= -44.0 + 1.57 \cdot k \quad ; \quad 28 \leq k \leq 39$

$= 0 \quad ; \quad k > 39$

Mineral soil horizon:

z = root death

$= 0.5 \cdot z_{0\,3}$

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†k is the number of iteration (i.e., simulated weeks) since the beginning of the simulation, where k = 1 represents the first week of the year.

Table 4. Respiration submodel.

$o_{i\,5} = r_i \cdot t \cdot w \cdot X_i$

t = influence of weekly mean temperature (T) on rate of respiration

$$= \frac{0.32}{1 - 32.3e^{-0.32T}} \; ; \quad T \leq 25°$$

$$= 2.0 + 0.04T \; ; \quad T > 25°$$

w = influence of weekly mean water potential (Ψ) on rate of respiration

$= 1.0$

$= 2.0 + 0.05\Psi \; ; \; -40 \leq \Psi \leq -20$ bars

$= 0 \; ; \; \Psi \leq -40$

r_i = weekly respiration rate under optimum environmental conditions (g/g litter/m^2).

$r_1 = 0.055$

$r_2 = 0.063$

$r_3 = 0.037$

$r_4 = 0.003$

Table 5. Transport submodels.

Decomposition:

$$\phi_{1\,3} = c_1 \cdot \phi_{1\,5}$$

c_1 = proportional rate of decomposition of woody litter

= 1.05 (balanced case)

$$\phi_{2\,3} = c_2 \cdot \phi_{2\,5}$$

c_2 = proportional rate of decomposition of nonwoody litter

= 1.50 (balanced case)

Leaching:

$$\begin{aligned} \phi_{3\,4} &= 0.0002 \cdot p \cdot X_3 & ; \quad & \Psi > -0.3 \\ &= 0.0002(p - 0.5)X_3 & ; \quad & -2.0 \leq \Psi < -0.3 \\ &= 0 & ; \quad & \Psi < -2.0 \end{aligned}$$

p = weekly precipitation rate (cm/m^2)

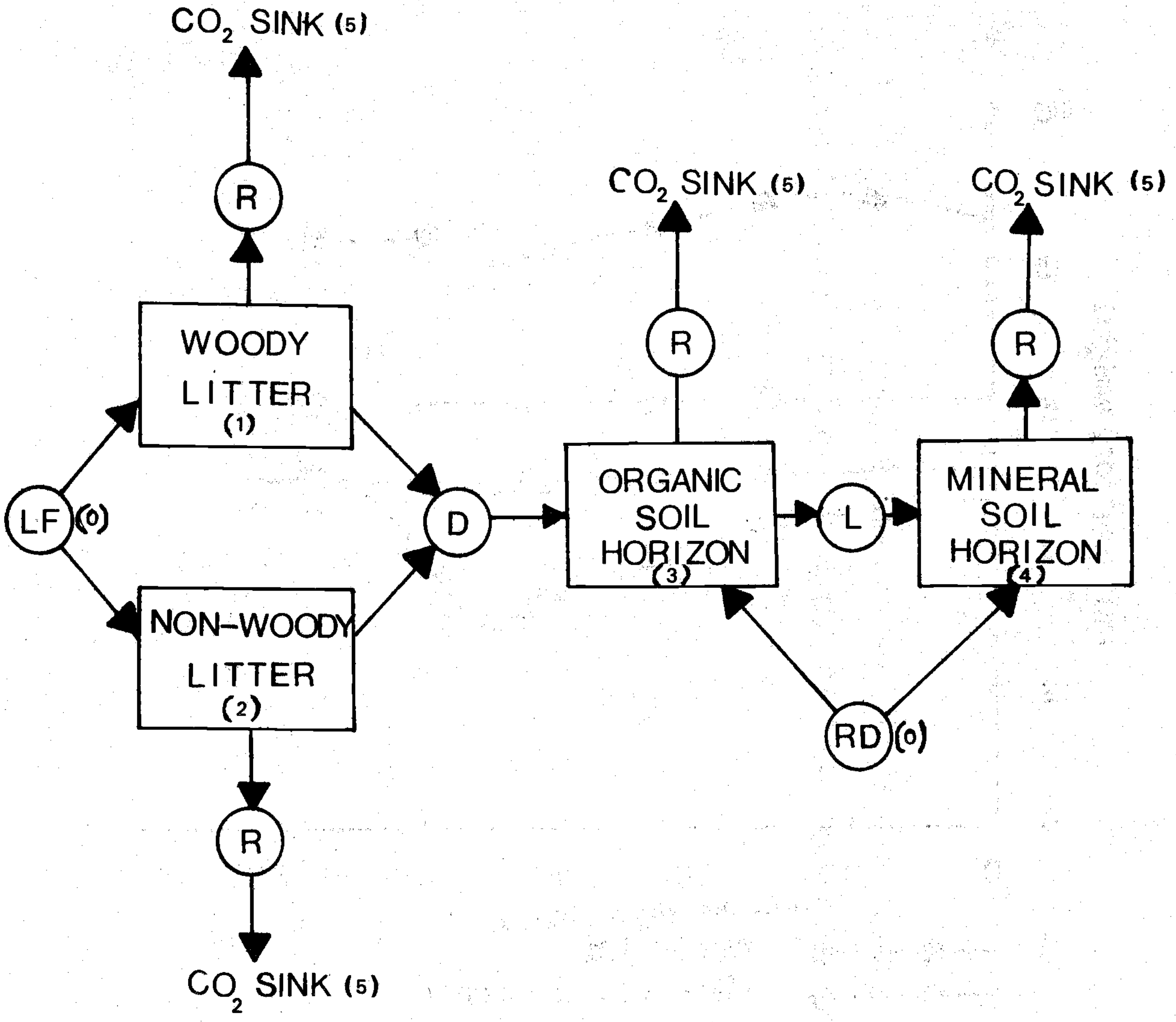

Figure 1. A diagram of the transfer of materials in the forest floor and soil system. The circles represent processes of transfer: litterfall (LF), respiration (R), decomposition (D), root death (RD), and leaching (L) (see Table 1).

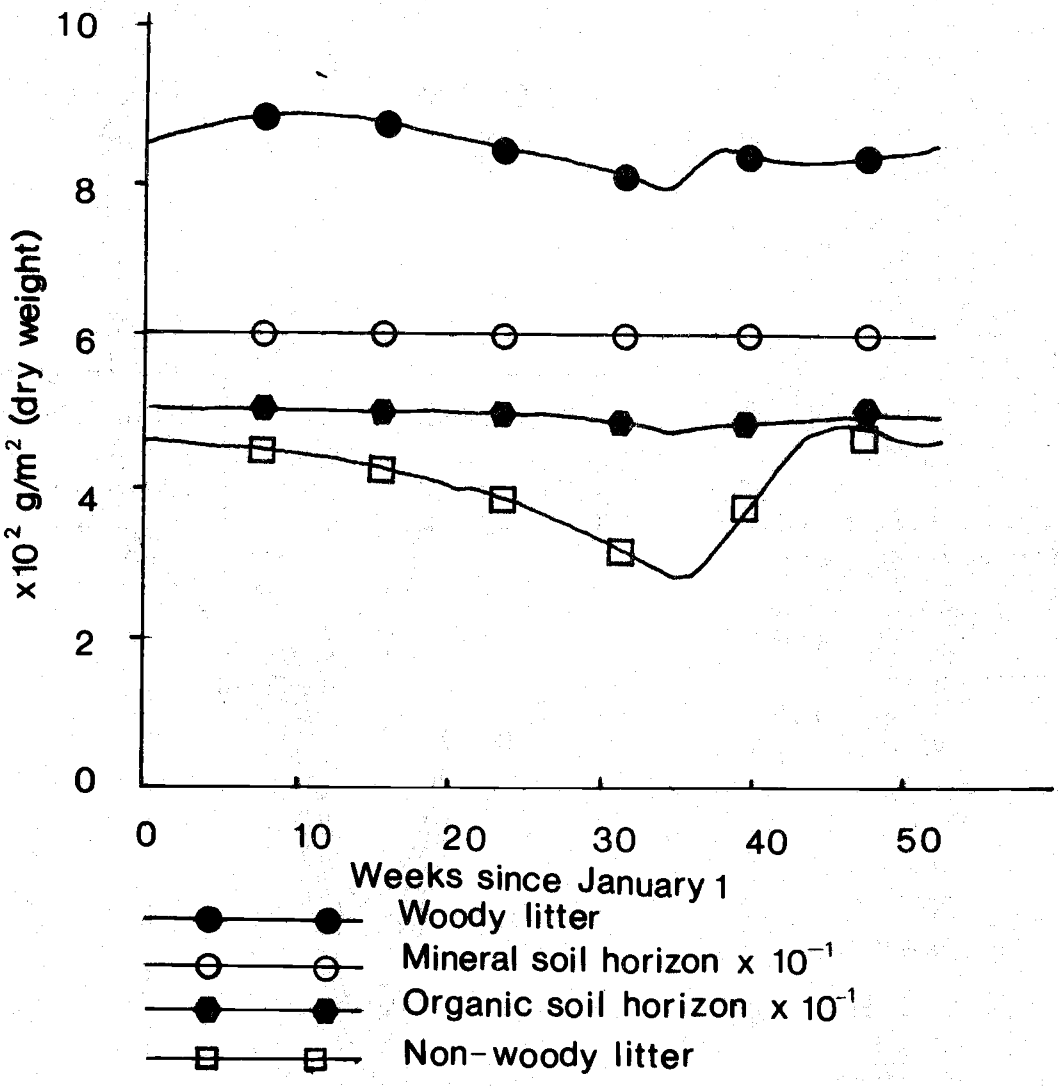

Figure 2. The balanced seasonal pattern of weight changes in the components of the forest floor and soil system.

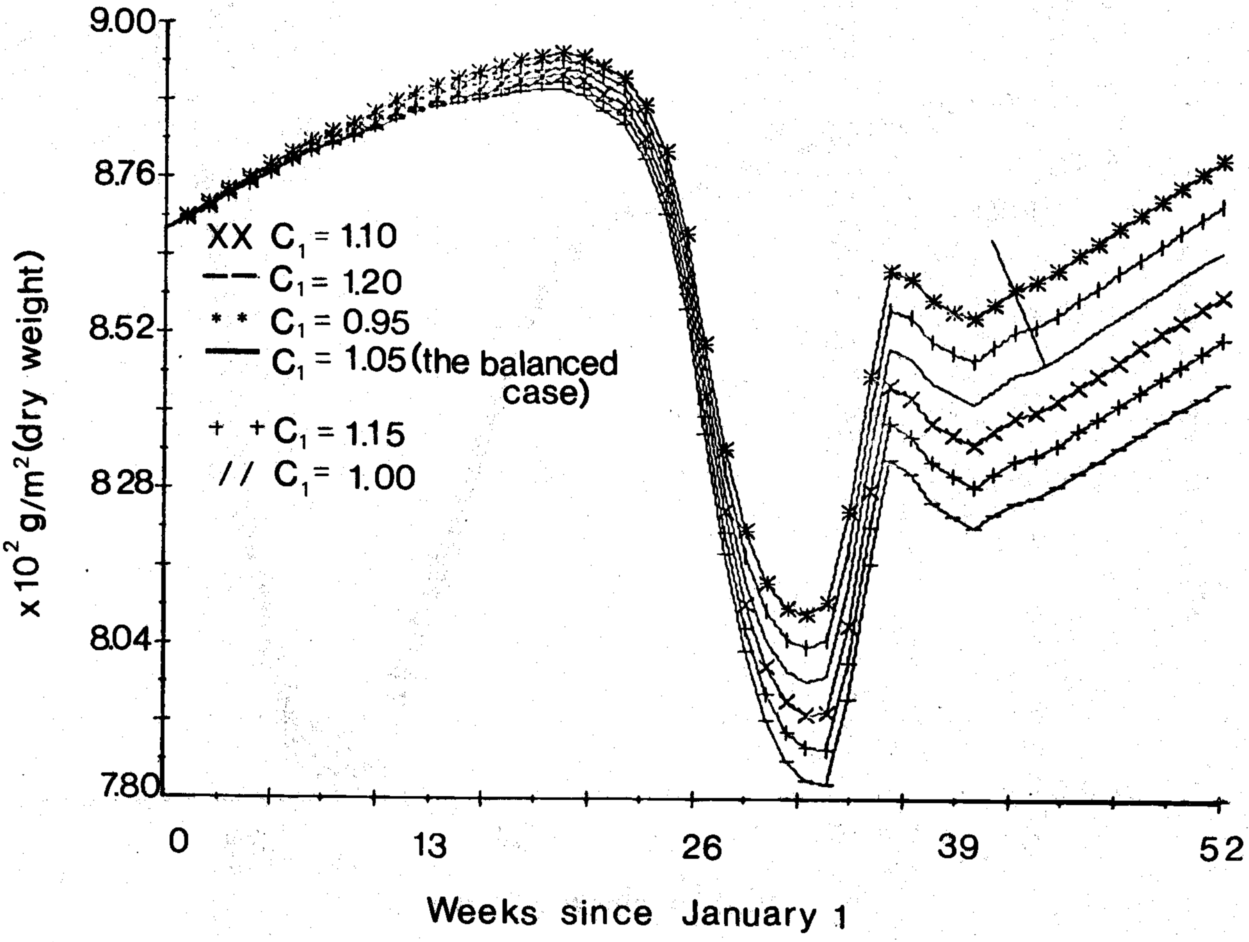

Figure 3. The influence of changes in the woody litter decomposition parameter (c_1 in Table 5) on the season pattern of woody litter.

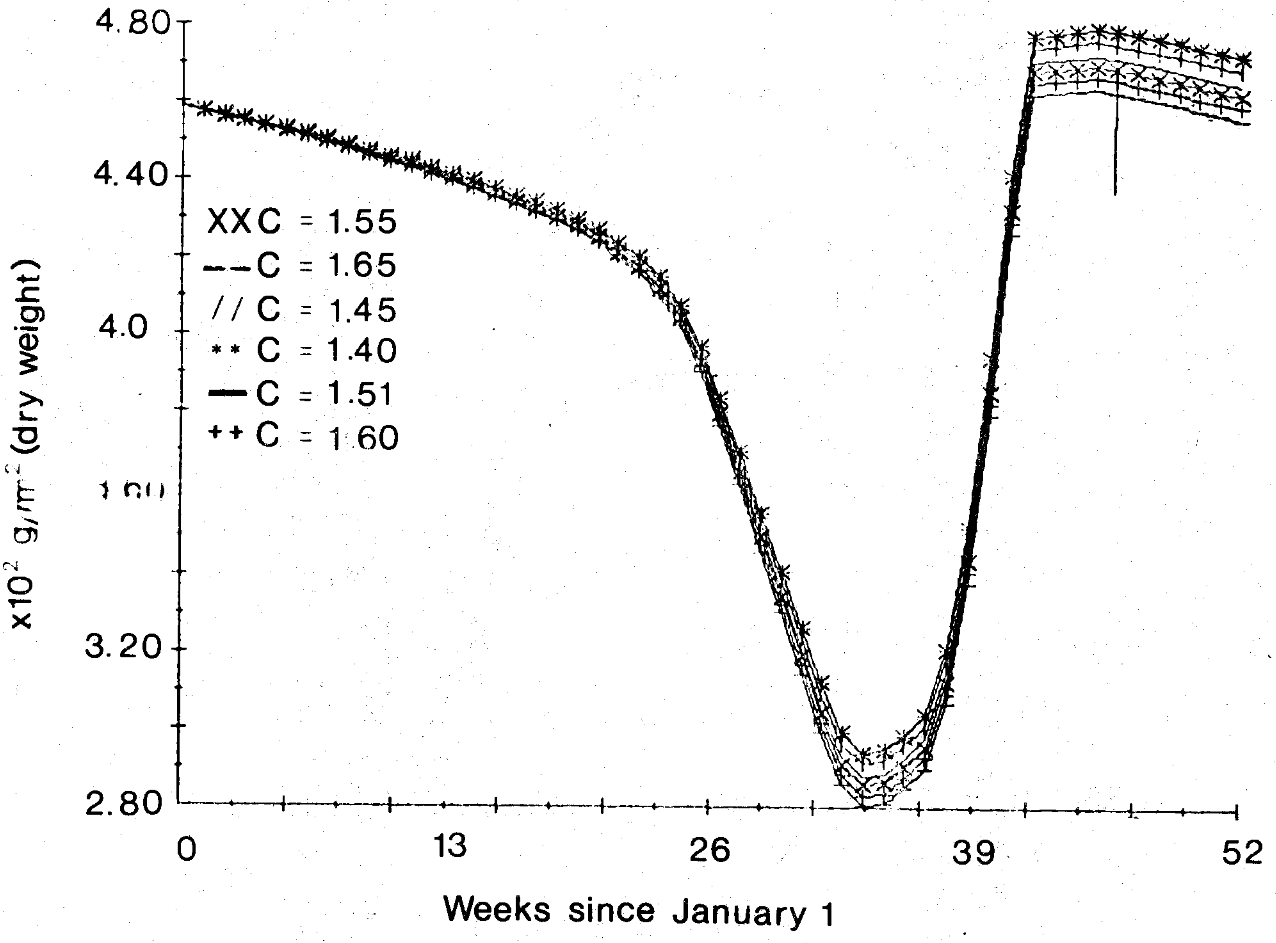

Figure 4. The influence of changes in the nonwoody litter decomposition parameter (c_2 in Table 5) on the seasonal pattern of nonwoody litter.

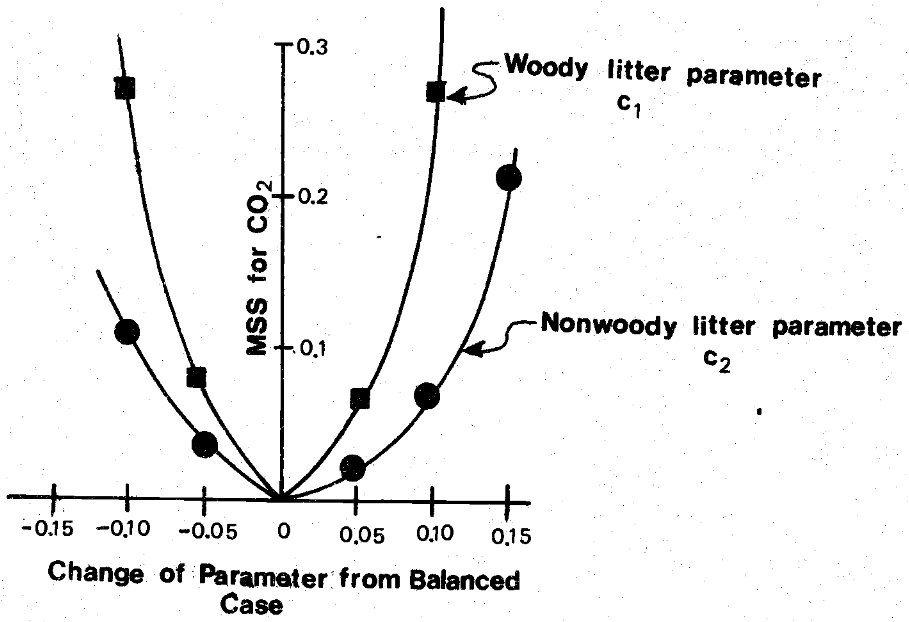

Figure 5. The sensitivity of the total respiration sink to changes in woody and nonwoody litter decomposition rates.