Evaluation of the Soil Biological Activity Under Forest Stands on the Basis of Organic Matter Turnover — A Mathematical Model —

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Good forest management requires the knowledge of all factors which influence the success of forestation or the growth of forest stands. An important factor is the biological activity in the soil and forest litter. Though several methods have been recommended, immediate, simple and inexpensive ways of assessing biological activities are still needed: like the analysis of gross organic matter turnover. A very simple model has been created and the estimated rate constants of litter decomposition are compared in three Scotch pine forest stands.

The structure of the model

A number of compartments are usually distinguished in the models for organic matter turnover. For example, in a sophisticated model for arable land /JENKINSON et al., 1987/ there are six compartments of soil organic matter. In forest litter decomposition models the litter is also divided into compartments /EDWARDS et al., 1988/. However, in order to create a model, as simple as possible, forest litter has not been divided into compartments in this study. It has been considered as a uniform layer of decaying organic matter.

The fall of leaves /in our case needles/ is the main source of the litter. In even-aged monoculture forests the amount of the annual litterfall depends on the age and the density of the stand, and on the site conditions. Litterfall increases from year to year in young stands and normally stabilizes after canopy closure. Its amount is approximately equal to the current annual average of wood increment, at least under the climatic conditions of this country /JÁRÓ, 1958/.

Current annual average wood increment data as a function of age are known for most of the tree species in the form of increment tables. Consequently, sufficient estimates of the annual litterfall can be formed. Having taken an appropriately wide time-window, the rate of litterfall can be considered as a continuous function of the time, the phases of which can be approximated by linear functions. The increment of litter due to litterfall /dL_{Lf}/ in a dt period is:

$$dL_{Lf} = (k_1 t + c)dt \qquad /1/$$

where: k_1 = the raise of the linear function /$kg \cdot ha^{-1} \cdot year^{-1}$/;
t = time passed;
c = constant.

In young even-aged monoculture forests $k_1>0$ before canopy closure, the litterfall increases with time. $k_1 = 0$ after the canopy closure.

The decrease of the litter on an area unit due to decomposition /dL_{Ld}/ in a dt period is proportional to the current amount of the litter layer /L/.

$$dL_{Ld} = - k_2 L\, dt \qquad /2/$$

where: k_2 = the rate constant of decomposition.

The differential balance of the litter organic material is:

$$dL/dt = k_1 t + c - K_2 L \qquad /3/$$

The solution of /3/ for the phase before canopy closure is:

$$L = \frac{k_1}{k_2}t - \frac{k_1}{k_2{}^2}(1-e^{-k_2 t}) + (L_o - \frac{c}{k_2})e^{-k_2 t} + \frac{c}{k_2} \qquad /4/$$

where: L_o comes from the initial condition that if $t = 0$ then $L = L_o$.

Let t_1 be the time of canopy closure. At time $t > t_1$ $k_1 = 0$, thus

$$L = \frac{c}{k_2}(1-e^{-k_2 (t-t_1)}) + L_c e^{-k_2 (t-t_1)} \qquad /5/$$

where L_c is the amount of the litter at t_1.

If $t>>t_1$ then the second term of the right side expression and the expression in brackets can be neglected. So in the steady-state phase of the system

$$L = \frac{c}{k_2} \qquad /6/$$

The mean resident time /MRT/ of the organic carbon in the forest litter in this steady-state phase is:

$$MRT = \frac{L}{c} \qquad /7/$$

and the rate constant of litter decomposition is

$$k_2 = \frac{c}{L} = \frac{1}{MRT} \qquad /8/$$

On basis of observations, the annual litterfall and the amount of the litter per unit of the area k_2 can be estimated. The higher the biological activity /i.e. the rate of decomposition of the organic matter in the litter/ the thinner the litter layer is on the forest floor and the lower the MRT of the organic carbon is.

Humus is the other compartment of organic matter in the model. STEVENSON's practical humus definition has been accepted: humus is the organic matter in the soil excluding higher plants and animals and the undecayed remains of them, but including dead and living soil biomass and non-humic substances which cannot be separated from the humic substances before the wet oxidation normally used for humus determination in soil laboratories /STEVENSON, 1982/.

If the rate constants of humification /k_3/ and humus mineralization /k_4/ can be sufficiently estimated, the model may be extended to the humus compartment. dH change of the amount of humus on a unit area in a dt period is

$$dH = (k_3L - k_4H)dt, \qquad /9/$$

where: L comes from /4/. The input of H from roots and decayed soil inhabiting animals has been supposed to be directly proportional to the annual average litterfall.

The solution of /9/ is a little more complex than equation /4/. However, long-term changes in the humus content of the forest soil can be described. The main problem is the determination of k_3 and k_4.

Comparison of forest stands

Though the model was set up to simulate the transient phases of the system, the in vivo mean rate constant of litter decomposition can easily be estimated in the steady-state phase of the organic matter turnover in the forest litter.

Litter decomposition was observed in three Scotch pine forest plantations standing under different climatic conditions and on different sites. The annual average temperature and precipitation calculated from the data of a 30-year period /1956-1985/ show that, among the three sites, the lowest annual average temperature and the highest precipitation were found at Farkasfa, while the highest temperature and lowest precipitation were observed at Kerekegyháza. At Gödöllő the annual average temperature and the precipitation ranged between the figures of the other two sites /Table 1/.

The age of the stands was 22-23 years at the time when the litterfall and forest litter were measured.

Table 1

Data of litter decomposition in three different Scotch pine stands

	Temperature °C	Precipitation mm	L_f [a]	Litter $kg \cdot ha^{-1}$	MRT [b] year	k_2 [c]
Farkasfa	9.0	760	4000[d]	14,600	3.7	0.27
			6000[e]	14,600	2.4	0.41
Gödöllő	9.3	577	5500	34,800	6.3	0.16
Kerekegyháza	10.3	548	6100	48,000	7.9	0.13

[a] annual average litterfall in $kg \cdot ha^{-1} \cdot year^{-1}$; [b] mean resident time; [c] rate constant of litter decomposition in $year^{-1}$; [d] measured value in a newly thinned stand; [e] estimated value for closed-canopy stand.

Five collecting baskets with an upper opening of 1 m^2 each were set up in each stand to assess the litterfall. Litter was taken out from the baskets and weighed every month. The amount of the litter was measured three times a year for two years. Three or five plots of 0.25 m^2 each were selected and all litter collected. Litter samples were weighed, air-dried in the laboratory and their organic matter contents were determined by ignition losses.

At Farkasfa a heavy thinning was carried out just before the observations started. So the litterfall is about 30 per cent less than it was before the thinning and will be after the next canopy closure. The annual litterfall is most likely to be about 6000 $kg \cdot ha^{-1} \cdot year^{-1}$ in a closed canopy stand. While the litterfall in the three stands are very similar, MRT or the rate constants of litter decomposition show characteristic differences among the stands. The humidity of the litter might be the limiting factor of decomposition /Table 1/.

Conclusions

The gross organic matter turnover can easily be simulated even in the transient phases with the aid of a very simple model. In a steady-state phase of the system the litter decomposition rate constant, calculated from a few data, is an overall index of the biological activity in the litter of forest plantations.

References

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