The Role of Soil Organisms in the Decomposition and Synthesis of Organic Matter

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Soil organisms are mostly heterotrophic; i.e. their life and activities depend on the organic substances present in the soil. These organic substances are the resources for the cell constituents of heterotrophic organisms, and they also furnish the energy indispensable for bio-processes.

The organic substances in the soil have their primary origin in autotrophic organisms, particularly in green plants. The organic matter inputs onto/into the soil are numerous. The types and structure of these inputs depend on:

- the climatic zone /warm - cold - mild; humid - arid; persistent - seasonally changing; etc./;
- the soil properties /sandy - loam - clay; deep - shallow; acid - alkaline/;
- the type of ecosystem /natural biocoenosis - cultivated plants/;
- the type and intensity of land utilization /cropland - grassland - forest - orchard; fertilization; irrigation; reclamation; etc./.

The overall input of energy into the ecosphere is utilized in different ways in primary production /i.e. assimilation effect of green plants/.

The primary production ranges from zero or almost zero /in deserts and icy oceans/ to over 1200 g C /in continuously green tropical forests/ accumulated in a year on the area of one square metre /SCHUBERT, 1986; LARCHER, 1980/. But these data deal mostly with the harvestable parts of higher plants together with the blue-green algae /HOLLIDAY, 1960, 1976/. Recent results reveal the significantly high production in the subterranean parts of plants /VANCURA and KUNC,1988; ULEHLOVÁ et al., 1988/.

NOVÁK /1983a, b/ computed the probable inputs of organic substances into the soil within the intensive cropland in Central Europe. TESAROVÁ /1988/ performed similar computations for grassland. Information on these topics can be found in the Transactions of the International Symposia HUMUS et PLANTA /Prague, from 1962 up to 1988/ and Proceedings of the International Symposia on Soil Biology /Hungary/. A great number of papers have appeared in scientific journals and compendia.

According to estimations made by LYNCH and PANTING /1980/, the total organic input into the surface layer of an arable soil /0-5 cm depth amounts to 3540 kg C per ha per year, with root decomposition accounting for 400 kg, root exudation for 240 kg, straw residues for 2800 kg and autotrophic microbes for 100 kg.

However, the deeper layers, to a depth of at least 60 cm, must also be considered, as must the soil surface, where a significant amount of organic matter, introduced into the soil by tillage and/or the action of soil fauna, is retained. Taking into consideration several long-term field experiments /between 10 and 30 years/ in Czechoslovakia, NOVÁK /1988/ computed the probable mean organic inputs into the vegetation zone of arable soil, with the addition of litter and overground residues, at a production intensity of 60 grain units per ha per year within the traditional crop rotation /grain unit = food or fodder equivalent of 100 kg grain/ /Table 1/.

Table 1

Mean organic inputs into the vegetation zone of arable soil /NOVÁK, 1988/

Source	Input kg C/ha/year	Decomposition half-time
Root exudates	2400	2-5 days
Roots decaying during vegetation	1300	1-3 weeks
Harvest residues	3600	1-12 months
Farmyard manures	1800	
strawbed manure	-	3-12 months
slurry	-	4-12 weeks
green manure	-	1- 4 months
compost	-	4-40 months

The amount of organic inputs is a very important feature in the behaviour of soil organisms and, consequently, in the transformation processes in the soil. But it is not the sole factor in the establishment of the relationships between soil, organic inputs and soil organisms.

First of all, the chemical structure and physical properties of organic substances are of particular importance. The utilisability of organic substances is mostly connected with their affinity to water, but few water-soluble organic substances exist which are not easily utilisable by soil organisms. This is why the decomposition rate is a useful characteristic in determining the significance of organic inputs to soil organisms, particularly microorganisms.

The characteristic curve of the decomposition of water-soluble organic compounds is shown in Fig. 1. The deviations found in the laboratory experiments were slight but these may be condiserable in the field.

The shape of the decomposition curve indicates several phases of the decomposition process. The most conspicuous phases are indicated with tangents /Fig. 1/. Tangent /A/ demonstrates the rate of decomposition in the starting phase; this decomposition rate is low. Tg /B/ shows the decomposition rate during the most intensive part of decomposition. As a rule, the point representing the decomposition half-time is found in this part of the decomposition curve. The last phase of substrate decomposition is characterised by Tg /C/, where the decomposition rate is even lower than in the starting phase. Of course, many other tangents to the decomposition curve could be constructed, but they are unlikely to help in elucidating the problem of decomposition.

The breakdown of organic inputs is mostly interpreted using the first-order equation of rate kinetics.

$$\frac{-\Delta A}{d\,t} = k \cdot A \qquad /1/$$

where: A = concentration of organic input; t = time; k = decomposition rate constant.

On integrating this equation we obtain:

$$\mathrm{Ln}\,\frac{A}{A_o} = k\,t \qquad /2/$$

where: Ln = natural logarithm; A_o = concentration of A at zero time.

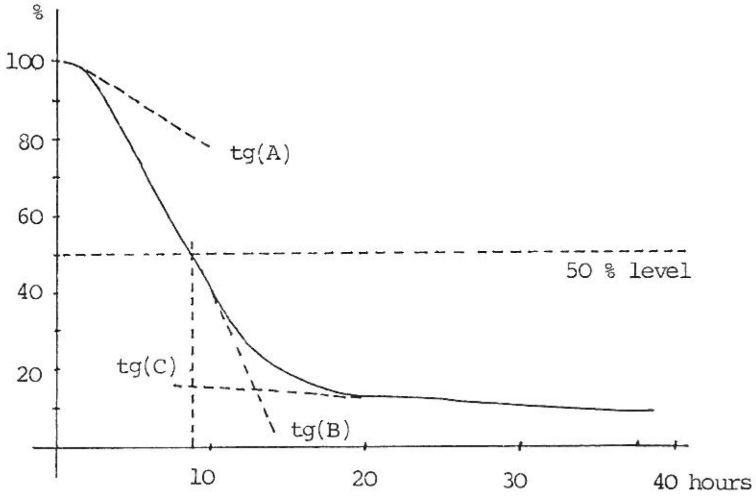

Fig. 1

Typical decomposition curve of wheat root exudates /simulated/ measured as CO_2 evolution in thermostatic model experiments. Arable layer of chernozemic clay-loam; 28°C; 20% humidity /w/w/; starting amount 0.1% C

It can be seen in Fig. 1 that the decomposition constant changes even on the addition of such simple substrates as simulated root exudates. When applying more complex substrates, like plant roots, leaves, stems, farmyard manure, municipal sludges, etc., the kinetics of decomposition become more complicated /Fig. 2/. The precise determination of the shapes of the decomposition curves is very laborious and time consuming, so various authors have attempted to simplify the measurements. One of the most frequently applied methods is the determination of the decomposition rate constant /k/ by plotting Ln /A:A_o/ against t. In the case of complex materials this constant should be based on a knowledge of their composition /HARPER and LYNCH, 1981a/. The significant groups of organic substances are: water-soluble materials, ether-soluble substances /mostly lipids and waxes/, cellulose, hemicelluloses, lignin and chitin. Chitin enters the soil from invertebrates, while the other substances are derived mostly from plants.

HARPER and LYNCH /1981b/ computed decomposition rate constants /k/ for the major components of ploughed-in wheat straw. The measurements were carried out for a complete year; the resulting data on the components, which are the mean values of the measurement of the discrete periods between individual determinations, are as follows: Hemicelluloses 0.0073 d^{-1}, cellulose 0.0074 d^{-1}, lignin 0.0005 d^{-1}.

A determination of the components of organic inputs and their decomposition rate constants provides useful information on breakdown dynamics. However, the determination itself is complicated and time-consuming.

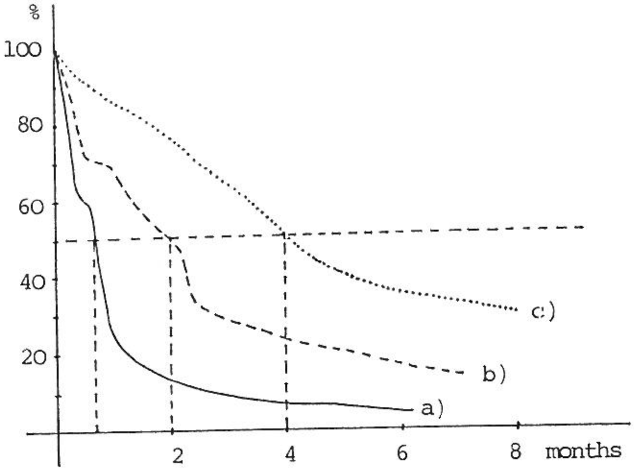

Fig. 2

Decomposition curves of selected complex organic materials measured as CO_2 evolution in thermostatic model experiments. Starting amount 1% C; otherwise as in Fig. 1. a/ Green manure, clover, herbage; b/ clover, roots; c/ wheat straw

One possible way of simplifying decomposition kinetics is the introduction of the decomposition half-time /NOVÁK, 1933a/. This term could be criticised because it does not denote half the time needed for complete breakdown, but the time required to achieve half the decay of the organic compounds under consideration. As a rule, the first half of the substrates is broken down in a significantly shorter time than the remainder /Figs. 1, 2/.

When estimating a single substrate, or a mixture of substrates where the utilisability of the individual components is similar, as in the case of root exudates /Fig. 1/, there are no problems in the interpretation of the decomposition half-time. When estimating complex organic inputs, it must be considered that the more easily utilised parts of the substrate are decomposed more rapidly than the others, and the overall feature of the decomposition half-time is changed.

The decomposition of organic substances is the first step towards their overall bio-transformation. The decomposition processes furnish the synthesis of new organic substances with indispensable organic monomers and also with free energy.

Since contemporary systems of soil cultivation favour the breakdown of soil organic matter, the formation of stable humus substances is desirable.

The humification of primary organic substances has been described in earlier papers /NOVÁK, 1963, 1974, 1978, 1979, 1981/. The intensity and productivity of humification depend on the chemical structure of the substrates, on the organisms involved and on the nutritional and ecological factors affecting the soil organisms.

Among the naturally occurring substances /see above/, root exudates are the most easily decomposed and are consequently poor sources of humus substances for the soil. They are only significant in enhancing the development of rapidly growing saprophytic rhizosphere microflora, thus preventing the colonization of root surfaces with parasites. A further function is the control of plant nutrient transformations, including that of nitrogen immobilization and remineralization and phosphorus mobilization. Root exudates also facilitate the co-metabolic decomposition of xenobiotic substances in the root zone.

On the other hand, harvest residues of cereals and some types of manures /especially well-ripened composts/ are relatively persistent in the soil and a considerable amount of humus substances may be formed during their slow transformation if the nutritional and ecological conditions are favourable.

Some humus substances may be formed by a random effect without biological action /SWABY and LADD, 1962, 1963; MANGENOT and JACQUIN, 1964; MARTIN, 1977/. SWABY and LADD /1963/ explain the high stability of humus substances by the non-periodical sequences of monomers caused in humus macromolecules by random synthesis. However, these sequences are not entirely random /FLAIG et al., 1975/. KUBÁT and NOVÁK /1973/ found evidence of enzyme action during humification in large microbial cells in starving and fed cultures. This confirmed previous findings /NOVÁK and FRANKLOVÁ, 1964a, 1964b; APFELTHALER and NOVÁK, 1967; NOVÁK, 1967/ on the activity of microbial enzymes and enzymatically conditioned metabolic pathways in the formation of humus substances.

The formation of humus substances is a very complex process. Regardless of whether enzymes are involved or not, many steps have to be considered. The number of steps increases with the chemical dissimilarity of the substrate compared to the humus compounds. In the case of enzymatic catalysis, almost every step demands the input of free energy, and the more complex process consumes more energy, with the overall result of a decrease in humification productivity. This is a further reason why simple, easily utilizable substrates produce less humic substances than complex substrates.

Focusing our attention on biochemical humus formation, we have to accept the fact that one single bacterium, or a microbe of similar size, cannot contain either a complete set of essential enzymes or the complete mechanism to induce their synthesis. Large microorganisms, like fungi or yeasts, have a better chance. The most reliable way of gaining all the essential enzymes is to rely on a multi-species soil microflora. This microflora has proved an effective type of inoculation for composting, i.e. for controlled humification within organic manures.

Many of the simple degradation products of harvest residues and plant roots exert a harmful effect on plant seedlings and other organisms /WALLACE and ELLIOTT, 1979, etc./. Detoxification can occur in two different ways /NOVÁK, 1974/: either due to further decomposition or due to the incorporation of these substances into the macromolecules of humus compounds. Both paths involve the active participation of soil microorganisms.

There are many other pathways for the bio-transformation of soil organic matter, and a great number of mutual effects between soil microbes and soil organic compounds, many of which need further elucidation.

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