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Viewpoint

Decomposition: driven by nature or nurture?

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Aims and Scope. *Applied Soil Ecology* addresses the role of soil organisms and their interactions in relation to: agricultural productivity, nutrient cycling and other soil processes, the maintenance of soil structure and fertility, the impact of human activities and xenobiotics on soil ecosystems and bio(techno)logical control of soil-inhabiting pests, diseases and weeds. Such issues are the basis of sustainable agricultural and forestry systems and the long-term conservation of soils in both the temperate and tropical regions.

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Although the carbon flow involved in decomposition is approximately equal to that in primary production, the amount of research is far less. A recent symposium under the title ''Driven by Nature'' reviewed the role of plant litter quality in determining decomposition in terrestrial ecosystems, both in the tropics and in the temperate region (Cadisch and Giller, 1996). In as far as decomposition of plant residues is indeed fully 'driven by their nature', i.e. determined by the physical, chemical and biological qualities of the organic residue, a fairly small research attention might be justified. In practice, however, the biotic and abiotic environment in which decomposition takes place (the 'nurture') has a considerable modifying effect both on the rate at which decomposition occurs and on the end-products formed (CO_2, CH_4, humus, charcoal). The role of cell and tissue structure as well as 'secondary' metabolites during the life of the plant can now be connected to their effects during decomposition after death of the plant (or its parts).

There has been a lot of progress in the past 2 decades in understanding the principles and variations on the theme of decomposition (Swift et al., 1979; Woomer and Swift, 1994; Palm, 1995). Yet, the practical application of this knowledge falls short of expectations and the soil ecological research community may not have responded to all the current challenges. Such applied research may start with the questions: what's wrong with the way decomposition processes work: are they too fast or too slow? Do they yield the wrong end-products? If there is nothing wrong with decomposition, it is not a priority area for research. Decomposition research must shed its 'undertaker' image: dealing with the fate of dead plants and animals can lead to lively debates.

In my view, decomposition studies can contribute to solving some of the major issues of this time: sustainability and environmental side-effects of agricultural production, climate change (greenhouse gas emissions and C sequestration of today's and tomorrow's soils and vegetation) and the maintenance of biodiversity, especially where below-ground organisms (a considerable share of the total number of living species) are concerned.

Sustainability issues concentrate on the need for, and mechanisms of maintaining, adequate amounts of soil organic matter in pools with an intermediate turnover time, as well as on the time pattern of N mineralization in relation to uptake demands by plants. Several new soil fractionation techniques have been developed and tested, often based on a physical fractionation of the soil by size (aggregation) and physical density (degree of organo-mineral linkage) as the first step, followed by chemical characterization of the fractions. Considerable progress has been achieved in obtaining 'indicators' of the various dynamic pools hypothesized in current models of soil organic matter dynamics (Hassink, 1995), but actual measurements of the pool size have proven difficult to achieve as yet. The search for an 'active' soil organic matter resembles the search for the Holy Grail, or at least that of the Cheshire cat: the behaviour of soil organic matter in soils is determined

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both by its position relative to soil micro-structure and accessibility to soil organisms of various sizes, and by its chemical nature. Attempts to get the fraction in one's hands for measurement or manipulation are thus bound to fail, as fractionation essentially modifies the activity. Litter-bags have been widely used for quantifying the initial step of litter breakdown, but they tell us little about the subsequent fate of the material lost from the litter-bag. Combination of different mesh-sizes has been used to estimate the effects of macrofauna on the litters (Tian et al., 1993), but other methods are needed to follow the litter through the decomposition cascade. Respiration measurements and the tracers ^{14}C and increasingly ^{13}C are used for such work. New methods for in-situ measurements such as solid state NMR are still difficult in a real soil, due to effects of soil Fe. Most attention in 'litter quality' research has gone to predicting the short-term N mineralization. Whether 'low quality' material contributes more to soil organic matter pools than 'high quality' material is still a subject of debate. Maybe 'low quality' materials contribute to the same pools, but more slowly.

Both too rapid and too slow rates of N mineralization can reduce the efficiency of N recycling. The 'synchrony' hypothesis formulated 10 years ago has stimulated a large amount of research on the topic, but only in a few instances has this so far led to clear management strategies at farm level. Several methods are available for slowing down initial N mineralization where it is too fast, e.g. mixing residues of 'high' and 'low' quality, but there are fewer options for speeding up mineralization at will when it becomes too slow. Research on the decomposition of mixed residues has advanced, and has yielded examples both of increased and decreased N mineralization: synergy may be common where residues of different C/N ratios are mixed and N mineralized from low C/N ('high quality') residues can be used by organisms attacking the low quality litters; inhibiting effects may occur where substances such as soluble polyphenolics from one residue affect decomposition of nearby other organic sources (Handayanto et al., 1995).

In temperate agriculture under high input conditions, the time course of N mineralization from above- and below-ground crop residues remains difficult to predict in its seasonal and year-to-year variability. Thus, mineral fertilizer recommendations tend to be based on conservative estimates of the amount to be mineralized and are therefore too high on average, contributing to groundwater pollution (Whitmore and Van Noordwijk, 1995). If farming aims at maximum yields without nitrate leaching, a more complete control over the mineralization process may require further technical steps, such as controlled composting. A parallel exists in pasture management where the extreme patchiness and low predictability of urine and manure inputs is a major reason for the low N use efficiency. Technical control requires zero-grazing systems, and machines which do a better job at regularly spreading the inputs than the cows would do themselves. Is this the future of intensive agricultural production? How much reduction in average productivity do we have to take for granted given the incomplete predictability and control?

Climate change – The effects of temperature and soil moisture content on decomposition have long been studied, both at the level of ecosystem studies along climatic gradients and at the level of controlled laboratory. studies. Global warming may have dramatic effects on decomposition in the arctic regions, releasing large amounts of CO_2 into the atmosphere. The effects of the different litter qualities to be expected under increased atmospheric CO_2 levels have been subject to considerable debate. The decreased decomposition rates, measured so far for tomorrow's plant litter, can be largely explained by the increased C/N ratio of the residues. In most experiments, the increased growth in a high CO_2 environment was not matched by an increased N supply, resulting in an increased C/N ratio. One may argue, however, that experiments with tomorrow's residues in today's soil may not be fully convincing. The lower rate of decomposition found with litters grown under elevated CO_2 might be compensated by changes in the decomposer community.

From a C-sequestration point of view, one might argue that decomposition is a most harmful process – as it releases (nearly) all the C 'sequestered' via primary production of forests and other vegetation. It, thus, counteracts the efforts to recapture into biomass the C released into the atmosphere from fossil fuels, produced in geological eras when decomposition could not keep pace with plant growth. It is not realistic, however, to expect decomposition to be stopped. The gaseous end-products of decomposition, CO_2 or CH_4, and the emission of NO_x, however, can be modified by the environment in which decomposition takes place. Recent evidence for methane oxidation in (forest) soils suggests that the net greenhouse gas emissions to the atmosphere from litter decomposition do depend on land use and soil management. The substantial amounts of charcoal found in many (sub)tropical soils, especially of savanna ecosystems with frequent fire, show that long-term carbon sequestration may be based on other processes than so far envisioned by environmental policy makers. Fires might contribute more to C sequestration in the long term than natural vegetation and its nearly complete processes of decomposition.

Biodiversity – Conserving the biodiversity of soil organisms may be based on their current in-situ usefulness for soil processes such as soil structure formation, decomposition and antagonism to soil-borne diseases. Another type of argument is based on the potential ex-situ roles of soil organisms or their genes by some form of biotechnology, e.g. in mitigating soil pollution with organic substances. A third argument could be based on the 'intrinsic' value of soil organisms, apart from any utility, but soil organisms are not cuddly enough to be a prime focus of that type of attention.

Increased understanding of below-ground food-webs helps to see the links involved. A continuous and diverse food supply by litters of different qualities and composition is needed if soil biodiversity is to be maintained (De Ruiter et al., 1995). The response of below-ground diversity to land use and soil management is still poorly understood, but the general impression is that soil organisms are more robust than organisms which stick their heads above the ground and, thus, a relatively large share of the original biodiversity of soil organisms is maintained under agricultural use and intensification. The question remains unanswered whether or not there are 'critical thresholds' in this gradual decline of soil biodiversity (Giller et al., 1996).

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