Symbiosis, 9 (1990) 117–123
Balaban Publishers, Philadelphia/Rehovot

The Role of the Rhizosphere on C and on N Cycles in a Plant-Soil-System*

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Abstract

A plant-soil system (Wheat grown under $^{14}CO_2$ atmosphere on a soil diversely amended with labelled-N material) was used to study the link between C and N fluxes. Root-derived C supports most of the microbial metabolism when rhizospheric activity is important: close to the flowering stage. "Rhizosphere effect" enhances the N mobilization rate. When root-derived C is the main energy source, it affects the mineralization-reorganization equilibrium. Comparison between ^{15}N enrichments of the different compartments indicates that microbial biomass-N is an actual source of plant-N. "Rhisosphere effect" favours immobilization process (into plant material and microbial biomass). Plants therefore improve soil N management.

Introduction

Rhizosphere of living plants is a zone where "active" double-directed fluxes take place:
- plant→soil fluxes, which concern carbon compounds;
- soil→plant fluxes for nutrients.

In a plant-soil system, the transformations of soil nitrogen compounds (driven by the soil microflora) greatly depend on the energy supplied by the living roots. The rhizosphere therefore constitutes the ideal interface to study the link between the nitrogen and carbon fluxes.

The aim of the present paper is to focus on a few representative aspects of "rhizosphere effect" on C and N cycles in a plant-soil system.

Materials and Methods

The experiments were carried out in the laboratory with a leached brown soil

*Reviewed

(pH = 7.1, C-content = 0.84%, N-content = 0.09%). 4 experimental combinations were examined:

(1) Unamended soil.

(2) Soil amended whith ^{15}N-labelled wheat straw (1% w) mixed to it 15 days before the beginning of the experiment.

(3) Soil amended whith ^{15}N-labelled wheat straw mixed to it 8 months before the beginning of the experiment.

(4) Soil amended whith $^{15}NO_3^-$ + glucose (200 mg glucose-C.100 g^{-1}DW; C:N = 25) added 3 weeks before the beginning of the experiment.

Wheat plants (*Triticum aestivum*) were sown (3 seedlings per pot of 1 kg moist soil:80% of its WHC; 2 replicates for each experimental combination) in a growth chamber with 16 h light at 25 ± 2°C and 8 h dark at 16 ± 2°C. The plants were exposed to $^{14}CO_2$ atmosphere (specific activity of 2.68. 10^6 Bq g^{-1} C). The soil moisture was maintained throughout the experiment by weight adjustment.

Correspondent control soils were incubated under the same conditions in order to estimate "rhizosphere effect" by difference between cultivated and uncultivated soil values.

The CO_2 released from the pots was trapped in columns with 50 ml NaOH 1.0 N, sampled 3 times a week.

4 destructive samplings were made during the experiment in order to determinate:

– soil and plant material-C: total C by dry combustion at 900°C with a Carmhograph 12-A and ^{14}C by liquid scintillation counting (Bottner and Warembourg, 1976);

– soil and plant material-N: total N by Kjeldahl digestion (Bremner, 1965a) and ^{15}N atom % excess (E%) by optical spectroscopy (Guiraud and Fardeau, 1980);

– soil inorganic N: measured in K_2SO_4 1.0 N extracts steam distilled with Devarda's alloy-MgO mixture (Bremner, 1965b) and atom % enrichments of the distilled NH_4^+-N determined as for total N samples;

– C and N of the microbial biomass (MB-C and MB-N): estimated by the fumigation-incubation method (Jenkinson and Powlson, 1976; Voroney and Paul, 1984).

Each analyse was conducted on triplicate subsamples; coefficients of variation ([standard deviation/mean] × 100) were in the range of 2 to 10%. Unless otherwise stated, the results are expressed on a 100 g oven-dry soil basis.

Results and Discussion

1. "Rhizosphere effect" and C fluxes

Figure 1 presents $^nCO_2$(^nC = non labelled-C) and $^*CO_2$ ($^*C$ = labelled-C) release and MB-C (^nC and $^*C$) for the cultivated and for the non cultivated unamended soil (soil (1)).

$^*CO_2$ evolution is the sum of the respirations of the roots and of the microflora metabolizing root-derived C. It is therefore representative of the kinetics of the

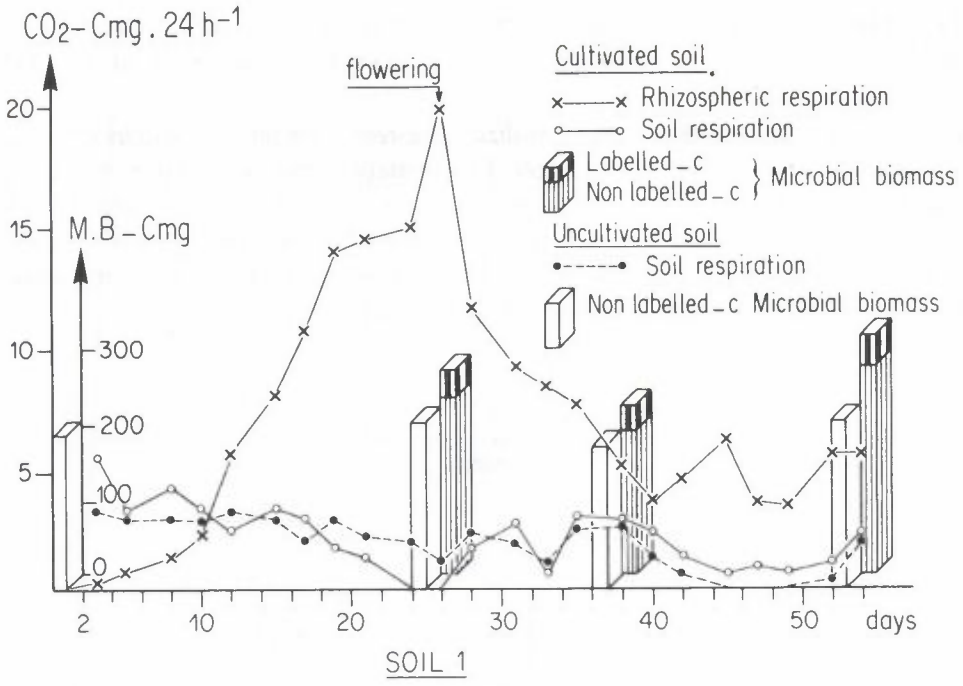

Figure 1. Daily evolution and MB-C of the cultivated and the uncultivated soil (1).

rhizospheric activity, the maximum of which is shown to be close to the flowering stage.

As it is evident from the comparison of the $^n CO_2$ evolutions of the cultivated and the uncultivated soil, the microbial metabolism of non labelled-C (soil C) is significantly depressed in the cultivated soil when rhizospheric activity is important (days 18 to 26). At the same time, there is a significant ($P = 0.05$) increase of the MB-C of the cultivated soil, with incorporation of *C.

In a non-amended soil, the major source of available C is root-derived C. The available C from dead microbial cells is a comparatively spare source. We may believe that *C input is sometime large enough to support most of the microbial metabolism.

The increase of the size of MB-C with incorporation of *C shows that root-derived C is not only used for energy requirements but for anabolism too. Concurrently, the organization of extra-^{n}C in comparison with uncultivated soil MB-C observed at the late sampling shows that metabolism of native organic matter never stops.

2. *"Rhizosphere effect" and N fluxes*

Soil N compounds transformations are essentially conducted by the microflora. We have just noticed that living roots provide the microorganisms with large quantities

of C compounds, available for their metabolism. What could be the consequences on the N cycle and on the sharing of this nutrient between the plant and the microflora?

N mobilization rates and mineralization-reorganization equilibrium in 2 contrasting combinations: soil (1) and soil (4). Potentially biodegradable N is considered as the sum of MB-N (which is the organic part) and of inorganic N to which we add plant-N in cultivated soils, because we know that wheat absorbs essentially NO_3-N. Figure 2 presents N mobilization rates (values of the sampling made at the flowering stage: maximum of the rhizospheric activity) for soil (1) and for soil (4).

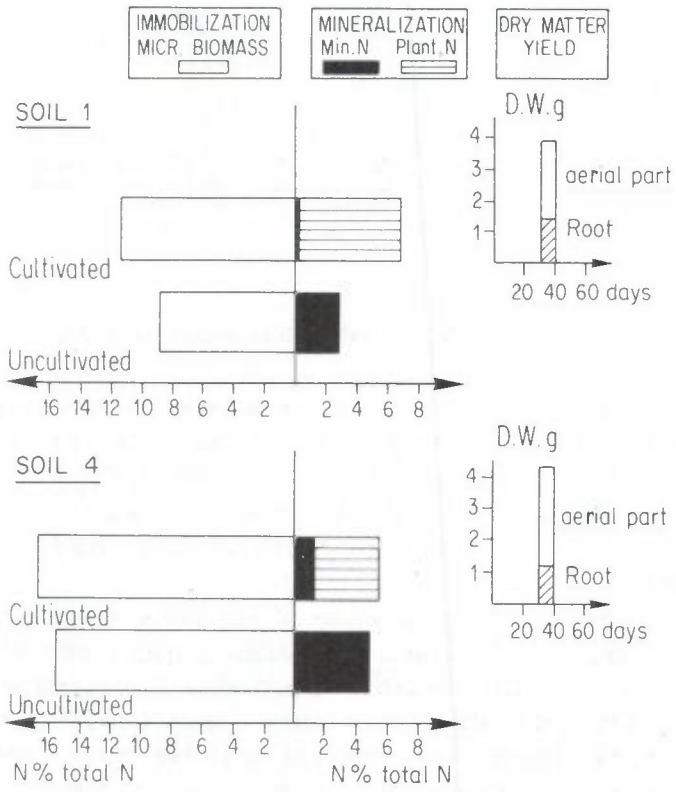

Figure 2. Mobilization rates and mineralization-reorganization equilibrium in 2 contrasting combinations: soil (1) and soil (4). The dry matter yield is equivalent in the 2 combinations.

The presence of the plant (dry matter yield equivalent in the 2 soils) obviously increases the N mobilization rates in the 2 combinations, but this increase is 5 times larger in soil (1) than in soil (4). Concurrently, in comparison with uncultivated soil

values, "rhizosphere effect" does not change the proportions of inorganic N + plant-N and of MB-N, i.e. the mineralization-reorganization equilibrium of the "active" N fraction in soil (4). On the contrary, we observe a displacement of this equilibrium in the aid of the mineralization part in soil (1).

We probably have to keep in mind that the biotic capacity in soil (4) has been enhanced by the amendment. This soil being less energy-limited than soil (1), the smaller impact of root-derived C on N mobilization rate is logic.

In soil (4) where the microflora is not exclusively dependent on C-rich inputs from the living roots, "rhizosphere effect" results in a global stimulation of the N cycling. The case of soil (1) is quite different in the sense that the "rhizospheric" microflora is mostly dependent on root-derived C. The displacement of the active sites of exsudation when roots grow probably leads to an accelerated turnover time of the microbial biomass with an increase of net mineralization. In fact, the importance of "rhizosphere effect" on N mobilization depends on the existence of an available "non rhizospheric" energy source.

MB-N as an actual source of plant-N. Comparison between E% of the plant material and the E% of soil compartments (MB, inorganic N and humus) can give informations

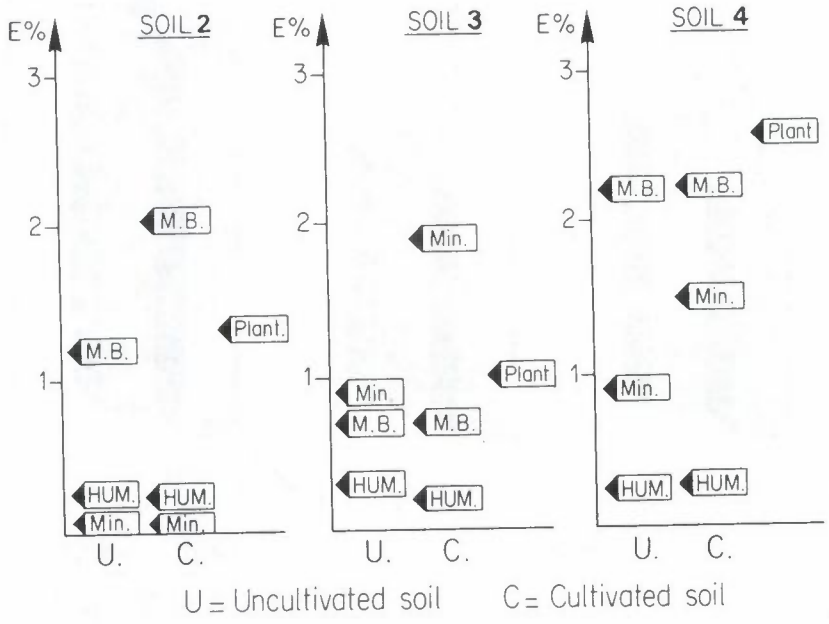

Figure 3. ^{15}N atom % excess (E%) of the microbial biomass, inorganic N, humus and plant material (aerial parts). Values determined at the flowering stage for the soils (2), (3) and (4).

about the main source of plant-N. Fig. 3 shows that, for the 3 combinations tested, MB is the compartment where E% is the closest to plant material E%.

If we admit that the inputs from the living roots support a "rhizospheric" microflora with an accelerated turnover time, we may assume that plants mainly absorb N coming from the mineralization of N constituents of dead microorganisms.

"Rhizosphere effect" improves soil N management. Figure 4 illustrates the *N-contents of the uncultivated and of the cultivated soil at the end of the experiment, in comparison with the initial values. Roots *N-content is added to soil *N-content for the cultivated soils.

It is evident from this figure that plants, though exporting nutrients, favours soil N conservation.

In the one hand, root-derived C could be a factor of enhanced denitrification. But on the other hand "rhizosphere effect" favours the organization of soil N (into plant

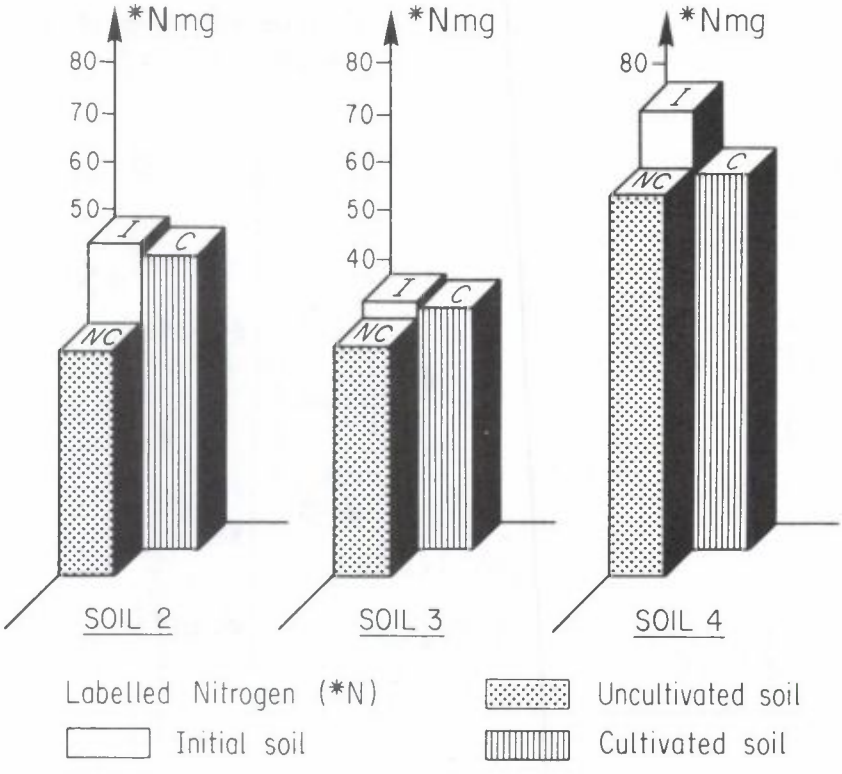

Figure 4. *N content of the uncultivated and of the cultivated soils (soils (2), (3) and (4)) at the end of the experiment, in comparison with the initial values.

material and microbial biomass) and leads to a concurrent depletion of the NO_3^- compartment.

Conclusion

It is somewhat surprising that living roots stimulate the soil microflora, which is a competitor for nutrients. In fact, we have to keep in mind that the soil N compounds transformations are driven by the soil N microflora. Root-derived C favours microbial activity and enhances organization processes. Plant reduce by this way the possibilities of soil N losses.

"Rhizosphere effect" is therefore materializing a type of association with mutual benefits.

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