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Differential contribution of soil biota groups to plant litter decomposition as mediated by soil use

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Abstract

Plant decomposition is dependant on the activity of the soil biota and its interactions with climate, soil properties, and plant residue inputs. This work assessed the roles of different groups of the soil biota on litter decomposition, and the way they are modulated by soil use. Litterbags of different mesh sizes were filled with standardized dried leaves and placed on the same soil different use intensities: Naturalized grasslands, recent agriculture, and intensive agriculture fields. During sixth months, litterbags of each mesh size were collected once a month per system with five replicates. The remaining mass was measured and decomposition rates calculated. Differences were found for the different biota groups, and they were dependant on soil use. Within systems, the results show that in the naturalized grasslands, the macrofauna had the highest contribution to decomposition. In the recent agricultural system it was the combined activity of the macro and mesofauna, and in the intensive agricultural use it was the mesofauna activity. These results underscore the relative importance and activity of the different groups of the edaphic biota and the effects of different soil uses on soil biota activity.

Key Words: litterbags, organic matter turnover, soil fauna, soil use

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The edaphic biota is the main factor directly responsible for soil organic matter turnover and nutrient cycling due to the diversity of processes in which it takes part (Lavelle and Spain, 2001; Lavelle et al., 2006; Brussaard et al., 2007; Culliney, 2013). Among these, the fragmentation and incorporation of plant residues into the soil; the construction and maintenance of the structural porosity and soil aggregation, are some of the processes the edaphic biota is involved with that have effects on other organisms (Lavelle et al., 2006; Culliney, 2013). This way, multiple interactions with other organisms are developed, on different scales and through the entire range of chemical, physical, and biological processes that support the generation and maintenance of ecosystem services by the soil (Brussaard et al., 2007; Culliney, 2013). Lavelle et al. (1993) found that the activity of macroorganisms is particularly important in the regulation of the decomposition process because interactions between macro and microorganisms are much intense in areas where climate is more constant, and this biological regulation is associated with the energy source, microbial communities of fungi or bacteria and macroorganisms which create conditions suitable for optimal microbial activity. When environmental traits like the climate are not limiting (drought or flooding) and clay minerals are not very reactive (or do not make a significant contact with the biota), the biological regulation systems take a predominant role in the decomposition of leaf litter (Lavelle et al., 1993).

The edaphic biota is classified according to the size of the adults into three groups: the microfauna, the mesofauna, and the macrofauna (Lavelle and Spain, 2001; Eisenbeis, 2006; Lavelle et al., 2006). Each component fulfills a specific role in its specific ecological niche that is hard to replace with other components present in the system (Lavelle et al., 2006) taking part in different processes affecting soil fertility in at least two main ways. Firstly, by promoting decomposition directly through the conversion of plant litter into
their own tissues, and indirectly transforming the plant litter physically and chemically into substances amenable to further degradation by microflora. Secondly, by their effects on the physical structure of the soil (Culliney, 2013) that may be affected by agricultural soil use (Baker, 1998; Bardgett and Cook, 1998).

Agro-ecosystems are continuously under the anthropic impact of different agricultural practices, which causes changes in their biotic and abiotic components both in time and in space. These changes in turn, affect the structure and function of the soil biota, thus mediating the biological processes in the soil, which affects the flow of matter and energy in the entire system (Lubchenko et al., 1991). The soil fauna responds to the agricultural management as a result of the physico-chemical disturbances that are produced in its habitat, of the distribution of the residues, and of the plant communities present (Lavelle and Spain, 2001; Kautz et al., 2006).

In order to understand in greater detail the role of the different soil fauna groups in the decomposition process, the hierarchical model proposed by Lavelle et al. (1993) was followed. To isolate the effects of different agricultural management practices, fields with the same soil and climate in three levels of agricultural use intensity were selected, and factors such as resource quality were standardized. To assess the different contributions of the soil fauna in the decomposition process the technique of the litterbags (Crossley and Hoglund, 1962) was used.

Three litterbag mesh sizes were used to hierarchically exclude each group of the edaphic biota according to size. Therefore, the contribution of each group to organic matter decomposition was evaluated.

The working hypothesis was that plant litter decomposition rates would differ between the different soil fauna groups, and that those differences would be modulated by the different soil use intensities.
The study was carried out in the rolling pampas of central Argentina, one of the biggest and most productive plains in the world. Three agroecosystem types with different intensities of soil use were selected as treatments. The agroecosystems were located near Chivilcoy city in the Buenos Aires province, Argentina (35°03'00" S; 59°41'00" W). The soil for all treatments was a mollisol from the typical arguidoll group (USDA, 2010). In increasing order of soil use intensity, the selected agroecosystems were: 1- Naturalized grasslands with no anthropic impact in almost 50 years (NG), 2- Cattle-grazing fields turned into agriculture 2 years before the start of the study (RA), and 3- Intensive Agriculture fields with 40 years of continuous and intensive agriculture (IA). All the fields were left fallow during the duration of this experiment.

Five different sites per treatment (agroecosystem) were selected as replicates. At each site, decomposition bags (20 x 20 cm) were placed with three different mesh sizes for the selective exclusion of the soil organisms according to size: 4 mm mesh size (Microfauna + Mesofauna + Macrofauna, hereafter Total Biota); 2 mm mesh size for the selective exclusion of the Macrofauna (Microfauna + Mesofauna); and 0.25 mm mesh size to further exclude the Mesofauna (hereafter Microfauna). These different size-excluded groups represent three different complexity groups of the soil biota. In each bag 5 g of dry, senescent soybean leaves (*Glycine max* L.) were placed. Soybean leaves were used to standardize the litter material offered, because it was the last crop in the agricultural systems, and it has been the most common crop in the region during the last ten years. The senescent leaves were collected in the field on autumn before harvest and dried at 30 °C. The bags were placed on the surface of the soil and covered lightly with plant residues after harvest to improve the natural decomposition of this crop in the pampas on end-autumn, winter and spring. Bags were retrieved at 17; 53; 94; 126; 171 days after the bags
were placed. Every sampling date, one bag of each mesh size was retrieved per replicate (5) and management system (3). The material was then dried at 30 °C to constant weight. The remaining material was weighted and the percentage of remaining mass (%RM) calculated.

With these data, we performed a two-way ANOVA for discriminate the effects of both factors mesh-size and agricultural use, in case of found any difference, the decomposition rate for each case was calculated, assuming a negative exponential model following Olsen (1963):

\[ \text{RM} = \text{IM} \times e^{-kt} \]

Where:

\( \text{RM} \) = Remaining Mass
\( \text{IM} \) = Initial Mass
\( t \) = Time (Days)
\( k \) = Decomposition rate

This exponential model was linearized using the natural logarithm of the remaining mass (%RM) and the transformed data were analyzed with ANCOVA to compare the slopes of each case with the Tukey test (HSD) between different cases with a 95% confidence interval.

All the statistical analysis were performed under the R language environment for statistical computing (2010).

3. Results and Discussion

The results of percentage remaining mass (%RM) found for each edaphic biota group within agricultural systems analyzed by two-way ANOVA can be seen on table 1.
Statistical differences were found for the mesh size factor. No differences were found for agricultural use alone, or the interaction between main factors.

These results allow for the analysis of the slopes of the decomposition rates between different mesh sizes within agricultural uses (Figs. 1, 2, and 3). A covariance analysis using the natural logarithm values of the remaining mass (ln %RM) measured for the different groups of the soil fauna showed statistically significant differences for the different groups within each soil use (Tukey LSD, p<0.05).

In the less disturbed system, the Naturalized Grassland (Figure 1), the decomposition rate (k) calculated for the Total Biota was significantly higher and differed (p < 0.05) from the other two groups, with no differences between them. In the Recent Agriculture system (Figure 2), the decomposition rate (k) of the Total Biota was significantly higher than that of the Microfauna alone, while the Microfauna + Mesofauna group did not differ with the other two groups. In the Intensive Agriculture, the decomposition rate of the Microfauna was significantly lower than the other two groups, that did not differ from each other (Figure 3).

The results show then, that in the Naturalized Grassland, the less anthropized system, the only significant difference was found when the Macrofauna was excluded. This is an indication that it was this group the one that contributed most significantly to decomposition in this system, since no difference was found when the Mesofauna was further excluded. In the system with intermediate anthropic impact, Recent Agriculture, the only statistical difference occurred when comparing Total Biota with Microfauna alone. This result indicates that the significant contribution to decomposition in this system is the interaction of the Macrofauna with the Mesofauna together. Indeed, no difference was found when only de Macrofauna or only the Mesofauna were excluded. In the Intensive Agriculture system the group that significantly contributed to the decomposition was the
Mesofauna because the only significant difference in this agro-ecosystem occurred with its exclusion.

When examined within systems, only the Microfauna presented significant differences between agroecosystems (Figure 4). This group showed significantly higher decomposition rate in the less impacted system when compared to both intermediate and high anthropic impacts. No significant differences were found between systems for either Total fauna or Mesofauna + Microfauna groups. This result underscores the sensitivity of the Microfauna to anthropic activities.

4. Conclusions

The results obtained in this work clearly show that the different groups of the soil biota contribute differently to litter decomposition and that this differential contribution is being mediated by the differences in soil use. Interestingly enough, these groups present complementary activities depending on soil use intensity, since no differences in decomposition rates were found between uses when the decomposition rates of the entire soil biota were compared. However, the contribution of each group of the soil fauna to the total litter decomposition changed across soil uses.

Being the less disturbed system, the Naturalized Grassland is the closest to the original, pristine condition of the soil systems studied. In these conditions, the Macrofauna is the relevant group as reflected by the lowering of the decomposition rate brought about by its selective exclusion with no further effect when the Mesofauna was also excluded. Indeed, results from previous authors (Brussaard et al., 2007; Kampichler and Bruckner, 2009) indicate that in the less disturbed ecosystems, the contribution of the Mesofauna to litter decomposition is only marginal respect to that of the Macrofauna. Those results are in agreement with the ones presented in this work.
In the Recent Agriculture system, of intermediate disturbance, the combined effects
of both the Macrofauna and Mesofauna are relevant, since the only significant difference is
the result of their exclusion together.

The results from the most disturbed system, the Intensive Agriculture, show the
Mesofauna as the relevant group, for the only significant decrease in decomposition rate
takes place when this group is excluded. These results are thoroughly consistent with the
hierarchical model proposed by Lavelle et al. (1993).

When analyzed across systems the results for the Microfauna showed higher
decomposition rates for the least anthropized Naturalized Grasslands when compared to
both agricultural systems. No differences were found for the Total Fauna or the Macro +
Mesofauna across systems. These results suggest a negative effect of the agricultural
practices on the Microfauna in particular. This is consistent with previous research
showing evidence that agricultural management affects the structure of the microbial
community (Wakelin et al., 2009; Zhong et al., 2010). Results by Lavelle et al. (2006) also
indicates that this particular group is very sensitive to any disturbance in the soil
environment.

Despite their recognized importance, the interactions between the different groups
of the soil biota are still largely unknown and one of the most studied topics in soil ecology
(Hättenschwiler et al., 2005; Fitter et al., 2005; Kampichler and Bruckner, 2009; Culliney,
2013). Coûteaux et al. (1991) and Bradford et al. (2002) found a significant increase in the
decomposition rates when these three groups (micro, meso and macrofauna) were found
acting together, when compared to less complex soil fauna groups.

It was also found that under organic agricultural management, the Mesofauna
increases its abundance (Kautz et al., 2006; Peredo et al., 2009) possibly due to the
specialization in the consumption of the sources of litter left by crops (Kautz et al., 2006;
Milcu et al., 2006). The results presented here also support that assumption.

In terrestrial ecosystems, the empirical evidence is scarce but it is known that when a soil community has a high diversity of functional traits, it has effects that facilitate interactions promoting decomposition (Gessner et al., 2010). More evidence from size-exclusion studies is needed in order to thoroughly assess to what extent agricultural practices affect soil fauna diversity (Hättenschwiler et al., 2005; Gessner et al., 2010; Culliney, 2013) and to improve agricultural practices for soil biota conservation that ensure decomposition and mineralization processes in agro-ecosystems.

The continuous disturbances in the studied agricultural systems could be selectively pressing certain organisms or groups over others. In this way, disturbances would allow for the establishment and development of soil biota adapted to anthropized systems, in detriment of the original soil biota, most likely close to the one in the Naturalized Grassland system.

From the results presented here, it can also be concluded that the Microfauna is the most sensitive group to anthropic disturbances, and therefore, it should be the group to be taken particularly into account when devising sustainable agricultural practices.

Lastly, the results shown in this work point to a replacement of the relative contribution to decomposition of the different faunal groups as use intensity increases. In the less disturbed environments, it is the Macrofauna the group contributing the most to decomposition, which is consistent with the hierarchical model presented by Lavelle et al. (1993). As intensity of use increases, the Mesofauna activity gains in relative importance, being the most important group in the most disturbed environment.

In conclusion, when looked at them separately the different soil uses studied in this work strongly modulate the decomposition activity of each group of the soil fauna, even though the total decomposition rate remains the same for all the studied systems when the
whole soil biota is present. These differences are likely due to changes in the structure and functioning of each one of the faunal groups of the soil biota studied, brought about by the different soil use intensities.

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Table 1: Two-Way ANOVA for both treatments evaluated

| Two-Way ANOVA | SS     | GDL | MS     | F    | p-value  |
|---------------|--------|-----|--------|------|----------|
| Intercept     | 4758.675 | 1   | 4758.675 | 19980.80 | 0.000000 |
| Agricultural Use | 0.682  | 2   | 0.341  | 1.43 | 0.240816 |
| Mesh-size      | 6.427  | 2   | 3.214  | 13.49 | 0.000003 |
| Agr-use *Mesh-size | 0.685  | 4   | 0.171  | 0.72 | 0.579533 |
| Error         | 62.160 | 261 | 0.238  |      |          |

Table 1: Two-way ANOVA for Mesh size, Agricultural use and the interaction. No significant interaction, mesh size significant effect main effect found.
**Figure 1**: Results for remaining mass (%) found for the Naturalized Grassland. A significant reduction in decomposition rate occurs when the Macrofauna is excluded. Negative exponential curve and $R^2$ values are shown for each fauna group. Decomposition rate (k) corresponds to the loss of mass per day. Different letters indicate significant differences (In MR%) through covariance analysis contrasted with Tukey HSD test ($\alpha<0.05$).
Figure 2: Results for remaining mass (%) found for the Recent Agriculture. Significant reduction in decomposition rate occurs when both Macro and Mesofauna are excluded together. Negative exponential curve and $R^2$ values are shown for each fauna group. Decomposition rate ($k$) corresponds to the loss of mass per day. Different letters indicate significant differences (In MR%) through covariance analysis contrasted with Tukey HSD test ($\alpha<0.05$).
**Figure 3**: Results for remaining mass (%) found for the Naturalized Grassland. Significant decrease in decomposition rate occurs when the Mesofauna is excluded. Negative exponential curve and $R^2$ values are shown for each fauna group. Decomposition rate ($k$) corresponds to the loss of mass per day. Different letters indicate significant differences (In MR%) through covariance analysis contrasted with Tukey HSD test ($\alpha<0.05$).
Figure 4: Results for remaining mass (%) found for the Microfauna when compared across treatments; Decomposition rate due to Microfauna activity is higher in the less anthropized system when compared to both agricultural ones. No significant differences were found for the macro or the Mesofauna across systems. Negative exponential curve and $R^2$ values are shown for each agricultural system. Decomposition rate ($k$) corresponds to the loss of mass per day. Different letters indicate significant differences (In MR%) through covariance analysis contrasted with Tukey HSD test ($\alpha<0.05$).