Journal of Arid Environments 186 (2021) 104400

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Soil carbon release enhanced by increased litter input in a degraded semi-arid forest soil

María Betania Naldini [*], Natalia Pérez Harguindeguy, Esteban Kowaljow

Instituto Multidisciplinario de Biología Vegetal (Consejo Nacional de Investigaciones Científicas y Técnicas – Universidad Nacional de Córdoba), Córdoba, Argentina

A R T I C L E I N F O

Keywords:
Chaco forest
Litter quality
Litter quantity
Priming effect
Organic carbon mineralization

A B S T R A C T

Land use change may modify litter inputs to soil, with important consequences for belowground processes such as organic carbon (C) mineralization. In this study, we experimentally tested the effects of changes on litter quantity and quality on CO_2 release in intensively used soils from the Chaco Forest. We applied leaf litter of two species (representing the highest and lowest litter C:N ratio of dominant woody species found in the system) in two doses (minimum and maximum litter fall recorded in the system) to the soil. We incubated the soil and measured CO_2 release on different dates. Litter quantity rather than litter quality was the fundamental determinant of soil CO_2 release rates in the Chaco forest. Accordingly, changes in litter input would have the potential to impact soil organic C dynamics, with positive feedback to the atmospheric C pool.

1. Introduction

Land use change is known to strongly affect soil organic carbon (SOC) content by altering the balance between C inputs and outputs (Wiesmeier et al., 2019). Land use change can modify the biomass and the characteristics of vegetation, thereby changing litter production and physicochemical characteristics (Guo and Gifford, 2002; Don et al., 2011). These changes in litter inputs, in turn, can affect the microbiota and have consequences on CO_2 release by microbial respiration (Lajtha et al., 2018). Although multiple studies devoted to analyzing those processes, the mechanisms by which changes in litter input affect the proportion of organic C that is mineralized from soils, as well as its consequences on soil C storage, are still a matter of debate (Prescott, 2010; Kögel-Knabner, 2017).

It is generally accepted that plant litter quality is a primary controller of the mineralization of organic C, since soil microorganisms preferentially use high quality litter (e.g., with low C:N) instead of low quality litter (e.g., with high C:N), as degradation of the latter requires more energy (Lützow et al., 2006; Prescott, 2010). However, an increase in litter input, regardless of its quality, can increase the likelihood of encounter between microorganisms and the substrate, stimulating microbial activity and leading to higher CO_2 release (Don et al., 2013). Then, litter quantity could be equally or even more relevant than litter quality in the regulation of organic C mineralization. Understanding the relative importance of these mechanisms is key to predict the effects of global change and to develop strategies that improve soil C sequestration (Fekete et al., 2017). This is particularly relevant for intensively managed ecosystems, where soil physical properties involved in SOC protection from mineralization seem to be seriously affected, making these soils more vulnerable to C loss (Six et al., 2002; Wiesmeier et al., 2019). That is the case of the Chaco forest in South America, where replacement of forests by open shrublands, as a consequence of historic logging and grazing, resulted in a dramatic reduction in aboveground and belowground C pools (Conti et al., 2014, 2016).

We evaluated the effects of changes in litter quantity and quality on CO_2 release from intensively used open shrublands soil of the Chaco forest. We expected that both the addition of litter of highest quality (because it requires less energy to be degraded) and in the highest quantity (because it increases the likelihood of substrate encounter) will trigger a significant increase in CO_2 release.

2. Materials and methods

We selected open shrublands located in the southernmost and driest portion of the Chaco forest, in central Argentina (31°15′-31°44′S 65°16′-65°40′W, mean annual precipitation of 600 mm and mean annual temperature of 18 °C). These soils are sandy-loam aridisols (Conti et al., 2016) with a pH of 7.5, low SOC content (5.9 g kg^{-1}) and high bulk

* Corresponding author. Instituto Multidisciplinario de Biología Vegetal (Consejo Nacional de Investigaciones Científicas y Técnicas – Universidad Nacional de Córdoba), Vélez Sársfield 1611, CC 495, X5000ZAA, Córdoba, Argentina.
E-mail address: betanaldini@gmail.com (M.B. Naldini).

https://doi.org/10.1016/j.jaridenv.2020.104400
Received 12 March 2020; Received in revised form 6 November 2020; Accepted 17 November 2020
Available online 1 December 2020
0140-1963/

Table 1
Leaf litter chemical properties (mean and standard error) of the species used in the experiment. Data extracted from Cuchietti (2016).

	C:N	Lignin (%)	Lignin: N	Total fibre content	Decomposabilty (% dry mass loss after 180 days)
Senegalia gilliesi	11.15 (0.10)	12.55 (0.25)	2.99 (0.32)	27.00 (0.72)	57.70 (1.19)
Aspidosperma quebracho-blanco	22.31 (0.99)	14.10 (0.20)	6.26 (0.26)	32.70 (0.59)	25.15 (1.24)

density (1.4 g cm^{-3}). We identified four 50 m^2 plots at a distance of at least 1 km from each other. We collected a composite sample (consisting of 5 subsamples) from the first 10 cm soil of each plot and then pooled (homogeneously mixed) those composite samples to obtained one mixture. We air-dried and sieved by 2 mm mesh one fraction of fresh soil, and manually removed remaining fine roots to determine SOC using the Walkley & Black technique (Sparks et al., 1996). We sieved by 2 mm mesh the other fraction of fresh soil, and also manually removed remaining roots to determine soil CO_2 release. We evenly mixed ground leaf litter of two native species in two doses with subsamples of 50 g of soil. We used litter of *Aspidoperma quebracho-blanco* Schitdl for the low-quality treatment (hereafter Lq) and litter of *Senegalia gilliesi* (Steud.) Seigler & Ebinger for the high-quality treatment (hereafter Hq). These species represent the extremes of litter quality in terms of C:N ratio within dominant woody species in the system (Cuchietti, 2016) (Table 1). We used two litter input doses corresponding to the minimum and maximum litter fall recorded in the system (Conti et al., 2014): 150 g m^{-2} = 0.17 g of litter per container (low-dose treatment, hereafter D150) and 600 g m^{-2} = 0.44 g of litter per container (high-dose treatment, hereafter D600). We performed 5 repetitions for each treatment plus 5 controls (hereafter Ct) without litter addition. We adjusted soil humidity to field capacity (19%) and placed the soil samples in containers with a CO_2 alkali trap (NaOH 0.5 N), and incubated them at 25 °C for six weeks. We measured cumulative CO_2 release resulting from microbial respiration at weeks 1, 2, 4, and 6 to represent organic C mineralization (Lerch et al., 1992). Although the experimental design did not simulate natural conditions since roots were excluded and environmental conditions were maintained constant along the incubation, we selected this methodology because it maximizes microbial activity, it homogenizes the distribution of the added resources to the soil, and allow us to isolate the effects of plant litter quantity and quality on CO_2 release (Chao et al., 2019; Córdova et al., 2018).

We performed a two-way ANOVA to evaluate effects of litter quantity, litter quality and their interactions on cumulative CO_2 release. We performed multiple comparisons using Fisher's LSD post hoc test ($\alpha = 0.05$). We also tested if there were significant differences among the amount of C added and the amount of C release for each treatment by two-sample *t*-test ($\alpha = 0.05$). For these analyzes, we subtracted CO_2 release by controls from CO_2 release by treatments. We used Infostat v. 2017 Statistical Package (Di Rienzo et al., 2017).

3. Results and discussion

Litter addition increased CO_2 release throughout the incubation period (Fig. 1A). The high-dose litter treatment (D600) showed a greater release than the low-dose treatment (D150), whereas differences in litter

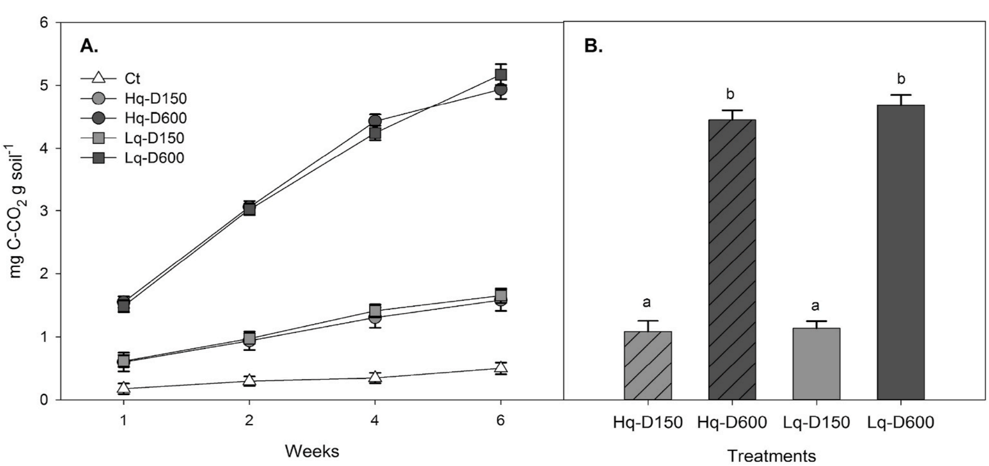

Fig. 1. A) Cumulative CO_2 release (mg C–CO_2 g $soil^{-1}$) during incubation for the control (Ct) and the treatments: *Hq-D150:* high quality in low dose, *Hq-D600:* high quality in high dose, *Lq-D150*: low quality in low dose, *Lq-D600*: low quality in high dose. **B)** Cumulative CO_2 release (mg C–CO_2 g $soil^{-1}$) at the end of the incubation period (6 weeks) for all treatments (Note: CO_2 release by controls (0.50 ± 0.02 mg g^{-1}) was subtracted from CO_2 release by treatments). Symbols and bars indicate the mean and the standard error. Different letters indicate significant differences among treatments.

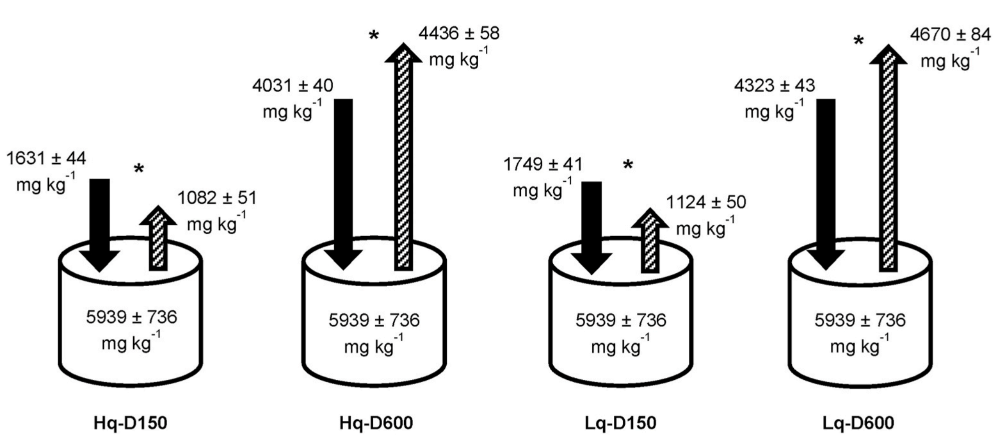

Fig. 2. Amount of C added (mean and standard error - black arrows) to soil trough litter compared to the amount of C released (mean and standard error - striped arrows) from mineralization after 6 weeks of incubation for the following treatments: *Hq-D150:* high quality in low dose, *Hq-D600:* high quality in high dose, *Lq-D150*: low quality in low dose, *Lq-D600*: low quality in high dose. An asterisk indicates significant differences between added C and released C. Note: C released from the Control soils (501 ± 15 mg kg^{-1}) was subtracted from the mineralization of all the other treatments.

quality (Lq and Hq treatments) did not affect CO_2 release (Fig. 1B). There was no significant interactive effect of litter quality and litter quantity on CO_2 release.

The lack of effect of litter quality treatments on CO_2 release could be due to soil microorganisms can be highly adaptable and able to mineralize any SOC that they encountered if they are under starvation conditions with sporadic substrate supply in time and space (like in arid and semiarid lands) (Dungait et al., 2012). However, we do not discard that higher differences in litter quality than the ones considered here may generate a response in microbial activity and CO_2 release (Nuñez et al., 2001).

If litter quality is not a limitation for organic C mineralization, as seems to be the case of our results, mineralization would depend on the temporal and spatial co-occurrence of substrate and microorganisms, which should increase as litter input increases (Don et al., 2013). This pattern is what can be observed in Fig. 1B. Greater availability of substrate and energy would stimulate microbial activity, and as a result, organic C mineralization could be even higher than expected based on the litter input. This phenomenon, called priming effect, has been described in several studies, although its underlying causes and mechanisms are still a matter of debate (Fontaine et al., 2003; Blagodatskaya and Kuzyakov, 2008; Kuzyakov, 2010). Since the addition of a high litter dose to the shrubland soil resulted in an increased release of C (+10%) than the added amount, our results could be evidence of priming effect (Fig. 2). While low-dose litter treatment released less C (−35%) than the added amount of C. However, as our experimental design did not allow us to separate soil CO_2 release from litter CO_2 release, we cannot discern the relevance of the possible priming effect on the low-dose litter treatment. In other words, litter quantity and the probability of encounter between microorganisms and substrate would regulate not only organic C mineralization but also the possibility of priming effect occurrence (Dungait et al., 2012; Don et al., 2013).

4. Conclusions

We conclude that the amount of litter input (regardless of its quality) would be the fundamental determinant of CO_2 release in degraded soils like those of the Chaco shrublands. Accordingly, in these soils, changes in plant litter input would have the potential to impact SOC dynamics, with positive feedback to the atmospheric C pool.

CRediT authorship contribution statement

María Betania Naldini: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Natalia Pérez Harguindeguy:** Conceptualization, Methodology, Writing - review & editing, Supervision, Project administration. **Esteban Kowaljow:** Conceptualization, Methodology, Writing - review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are grateful to land dwellers, owners and managers for allowing us to work on their properties, and to the Secretaría de Ambiente de Córdoba and staff of the Reserva Natural Chancaní. This study was supported by FonCyT (PICT-2013 n° 0554) and CONICET (PIP n° 1122015-0100387CO).

References

Blagodatskaya, E., Kuzyakov, Y., 2008. Mechanisms of real and apparent priming effects and their dependence on soil microbial biomass and community structure: critical review. Biol. Fertil. Soils 45 (2), 115–131. https://doi.org/10.1007/s00374-008-0334-y.

Chao, L., Liu, Y., Freschet, G.T., Zhang, W., Yu, X., Zheng, W., et al., 2019. Litter carbon and nutrient chemistry control the magnitude of soil priming effect. Funct. Ecol. 33 (5), 876–888. https://doi.org/10.1111/1365-2435.13278.

Conti, G., Pérez-Harguindeguy, N., Quètier, F., Gorné, L.D., Jaureguiberry, P., Bertone, G.A., et al., 2014. Large changes in carbon storage under different land-use regimes in subtropical seasonally dry forests of southern South America. Agric. Ecosyst. Environ. 197, 68–76. https://doi.org/10.1016/j.agee.2014.07.025.

Conti, G., Kowaljow, E., Baptist, F., Rumpel, C., Cuchietti, A., Harguindeguy, N.P., Díaz, S., 2016. Altered soil carbon dynamics under different land-use regimes in subtropical seasonally-dry forests of central Argentina. Plant Soil 403 (1–2), 375–387. https://doi.org/10.1007/s11104-016-2816-2.

Córdova, S.C., Olk, D.C., Dietzel, R.N., Mueller, K.E., Archontouilis, S.V., Castellano, M. J., 2018. Plant litter quality affects the accumulation rate, composition, and stability of mineral-associated soil organic matter. Soil Biol. Biochem. 125, 115–124. https://doi.org/10.1016/j.soilbio.2018.07.010.

Cuchietti, A., 2016. Efectos del uso de la tierra y la biodiversidad funcional sobre el ciclado de la materia orgánica en el centro-oeste de Argentina. Universidad Nacional de Córdoba, Córdoba, Argentina. Ph.D.

Di Rienzo, J.A., Casanoves, F., Balzarini, M.G., Gonzalez, L., Tablada, M., Robledo, C.W., 2017. InfoStat. Grupo Infoestat, FCA, Universidad Nacional de Córdoba, Argentina [WWW Document].

Don, A., Rödenbeck, C., Gleixner, G., 2013. Unexpected control of soil carbon turnover by soil carbon concentration. Environ. Chem. Lett. 11 (4), 407–413. https://doi.org/10.1007/s10311-013-0433-3.

Don, A., Schumacher, J., Freibauer, A., 2011. Impact of tropical land-use change on soil organic carbon stocks–a meta-analysis. Global Change Biol. 17 (4), 1658–1670. https://doi.org/10.1111/j.1365-2486.2010.02336.x.

Dungait, J.A., Hopkins, D.W., Gregory, A.S., Whitmore, A.P., 2012. Soil organic matter turnover is governed by accessibility not recalcitrance. Global Change Biol. 18 (6), 1781–1796. https://doi.org/10.1111/j.1365-2486.2012.02665.x.

Fekete, I., Lajtha, K., Kotroczó, Z., Várbíró, G., Varga, C., Tóth, J.A., et al., 2017. Long-term effects of climate change on carbon storage and tree species composition in a dry deciduous forest. Global Change Biol. 23 (8), 3154–3168. https://doi.org/10.1111/gcb.13669.

Fontaine, S., Mariotti, A., Abbadie, L., 2003. The priming effect of organic matter: a question of microbial competition? Soil Biol. Biochem. 35 (6), 837–843. https://doi.org/10.1016/S0038-0717(03)00123-8.

Guo, L.B., Gifford, R.M., 2002. Soil carbon stocks and land use change: a meta analysis. Global Change Biol. 8 (4), 345–360. https://doi.org/10.1046/j.1354-1013.2002.00486.x.

Kögel-Knabner, I., 2017. The macromolecular organic composition of plant and microbial residues as inputs to soil organic matter: fourteen years on. Soil Biol. Biochem. 105, A3–A8. https://doi.org/10.1016/j.soilbio.2016.08.011.

Kuzyakov, Y., 2010. Priming effects: interactions between living and dead organic matter. Soil Biol. Biochem. 42 (9), 1363–1371. https://doi.org/10.1016/j.soilbio.2010.04.003.

Lajtha, K., Bowden, R.D., Crow, S., Fekete, I., Kotroczó, Z., Plante, A., et al., 2018. The detrital input and removal treatment (DIRT) network: insights into soil carbon stabilization. Sci. Total Environ. 640, 1112–1120. https://doi.org/10.1016/j.scitotenv.2018.05.388.

Lerch, R.N., Barbarick, K.A., Sommers, L.E., Westfall, D.G., 1992. Sewage sludge proteins as labile carbon and nitrogen sources. Soil Sci. Soc. Am. J. 56 (5), 1470–1476. https://doi.org/10.2136/sssaj1992.03615995005600050022x.

Lützow, M.V., Kögel-Knabner, I., Ekschmitt, K., Matzner, E., Guggenberger, G., Marschner, B., Flessa, H., 2006. Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions–a review. Eur. J. Soil Sci. 57 (4), 426–445. https://doi.org/10.1111/j.1365-2389.2006.00809.x.

Núñez, S., Martínez-Yrízar, A., Búrquez, A., García-Oliva, F., 2001. Carbon mineralization in the southern sonoran desert. Acta Oecol. 22 (5–6), 269–276. https://doi.org/10.1016/S1146-609X(01)01122-5.

Prescott, C.E., 2010. Litter decomposition: what controls it and how can we alter it to sequester more carbon in forest soils? Biogeochemistry 101 (1–3), 133–149. https://doi.org/10.1007/s10533-010-9439-0.

Six, J., Conant, R.T., Paul, E.A., Paustian, K., 2002. Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. Plant Soil 241 (2), 155–176. https://doi.org/10.1023/A:1016125726789.

Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., 1996. Methods of soil analysis, part 3. Chemical methods 1085–1121.

Wiesmeier, M., Urbanski, L., Hobley, E., Lang, B., von Lützow, M., Marin-Spiotta, E., et al., 2019. Soil organic carbon storage as a key function of soils-a review of drivers and indicators at various scales. Geoderma 333, 149–162. https://doi.org/10.1016/j.geoderma.2018.07.026.