Organic carbon content in the particulate matter emitted by rural soils. A laboratory assessment.

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Abstract

The aim of this study was to assess the organic carbon (OC) content in the PM10 emitted by agricultural soils and rural roads under controlled conditions. Samples were collected from agricultural soils and rural roads. The PM10 was generated and collected using an electrostatic precipitator coupled with the Easy Dust Generator (EDG). This procedure ensures that the PM10 collected come specifically from soil. OC contents were measured in both the soil and PM10. The enrichment ratio (ER) was calculated as the ratio between OC content in the PM10 and OC content in the soil. The results showed that OC content in the PM10 ranged from 2.7 to 3.5 % in agricultural soils and from 1.4 to 2.9 % in rural roads. These values were comparable to the OC contents observed in fine particles transported by the wind, but lower than OC contents observed in PM10 samples collected in rural areas using active samplers and filters. A quadratic function described the association between OC in PM10 and OC in the soil. A negative potential function described the association between ERs and OC in the soil. Both associations suggested a saturation of OC in PM10 when the OC content in the soil was high. This information is crucial for a better comprehending of the dust emission role in the redistribution of OC within terrestrial ecosystems and to the atmosphere and oceans.

Organic carbon content in the particulate matter emitted by rural soils. A laboratory assessment.

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Keywords

Soil organic carbon; PM10; Dust; Unpaved rural roads; Agricultural soil

Introduction

Dust-borne carbon plays a significant role in the carbon cycle and is closely linked to global warming and climate change (Wang and Jia, 2013). Soils are the main terrestrial reservoir of organic carbon (OC), which accumulates in the first layer of the soil. Lands used for agriculture and livestock are a large source of suspended dust containing OC. Particles with an aerodynamic diameter less than 10 µm (PM10, respirable dust) are emitted from topsoil layer by wind erosion, tillage and traffic. Quantifying the OC content in PM10 emitted by rural soils provides valuable insights for dust models to estimate the redistribution of OC within terrestrial ecosystems and to the atmosphere and oceans.

The precise determination of the OC content in PM10 emitted by rural soils remains limited. Field studies on wind erosion have reported OC content for particles larger than 10 microns (Li et al., 2009). Environmental monitoring in rural areas has provided information on OC in PM10 (Borlaza et al., 2022). However, PM10 collected with active samplers represents a mixture of PM10 from primary biogenic aerosols, dispersal units, plant residues and biomass burning among other (Huffman et al., 2020). Only a limited number of studies have investigated the OC content in PM10 specifically emitted by rural soil (Mendez et al., 2017; Iturri et al., 2017). However, these studies have focused on a narrow range of soils, and there is currently a lack of research examining different rural soils.

In the central semiarid Pampas of Argentina, agricultural soils and rural roads occupy the rural areas. Recent estimates suggest that the actual PM10 emission from rural roads is 409 times higher than that from agricultural soils (Ramirez Haberkon et al., 2021). Despite the significant contribution of rural roads to PM10 discharge into the atmosphere, the OC content in the PM10 specifically emitted by them remain unknown. The aim of this study was to assess the OC content in the PM10 emitted by agricultural soils and rural roads under controlled conditions.

Materials and methods

Three agricultural soils for grain production (AG), three agricultural soils for forage and grain production (AFG), three unpaved rural roads inside farm field (RRI) and three unpaved rural roads outside farm field (RRO) were sampled in the eastern region of La Pampa province, Argentina (see supplementary material Table 1). From each soil, three subsamples of 2.5 cm depth were collected, and the following determinations were performed: texture, OC content and erodible fraction (see supplementary material Table 2).

For each subsample, PM10 was generated using the Easy Dust Generation (EDG) and the PM10 was collected using an electrostatic precipitator as described by Mendez et al. (2017). The collection procedure consisted in introducing 40 g of soil in the rotating chamber of the EDG for 30 minutes. In the rotation chamber aggregates broke up for collision generating dust, which was collected, by electrostatic differences, on an aluminum plate located inside an electrostatic precipitator. The collected dust was carefully separated from the aluminum plate using a brush, weighed, and stored in a plastic tube (Polistor 45 PST). This procedure was repeated until approximately 0.5 g of PM10 was obtained. Additional technical specifications, photographs, and detailed procedural information can be found in Mendez et al. (2017).

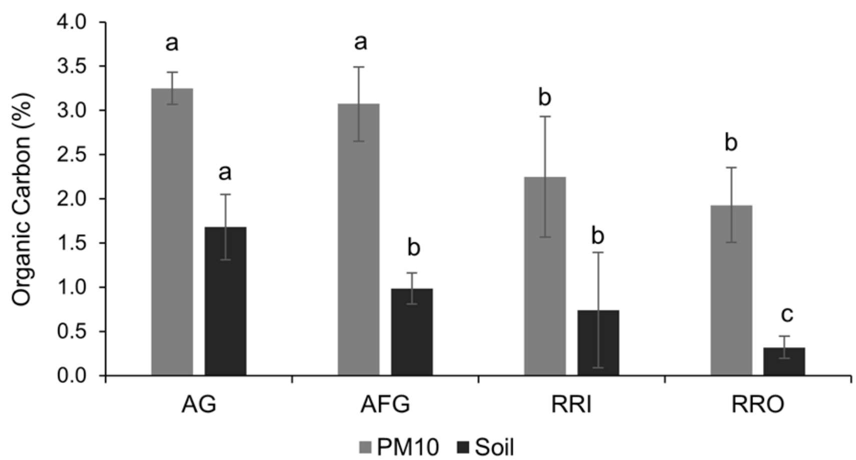
The OC enrichment ratio (ER) was calculated as the quotient between OC content in the PM10 and OC content in the soil. An ER higher than 1 meaning that the OC content in PM10 is greater than OC content in the soil. An ER lower than 1 meaning that the OC content in PM10 is smaller than OC content in the soil.

To assess the differences among means, ANOVA and LSD Fisher test comparisons were performed using the Infostat program (See supplementary material 1*) at a significance level of 0.05. Furthermore, for describing the relationships between OC in the PM10, OC content in the soil, and OC enrichment ratio, regression analysis in Microsoft Excel was employed.

Results and discussion

The OC content in the PM10 ranged from 1.9 to 3.3 % and the OC content in the soil ranges from 0.3 to 1.6 % (Fig. 1). In all rural soils analyzed the OC content in the PM10 was higher than the OC content in the soil. The same results were found in two agricultural soils of the same region (Mendez et al., 2017; Iturri et al., 2017). It is well known that OC tends to accumulate in clays and fine silts, which are two particle fractions within the size range of PM10 (Jagadamma and Lal, 2010).

Environmental monitoring in rural areas reported OC content in the PM10 from 4 to 8 times higher than OC content in the PM10 found in this study (Borlaza et al., 2022). Environmental monitoring used active samplers which probably collected PM10 from multiple sources. Primary biogenic aerosols, dispersal units, plant residues, vehicle emissions (tillage operations) and biomass burning are sources of PM10 with high OC content in rural areas (Huffman et al., 2020). This could explain the high OC content in PM10 found in environmental monitoring of rural areas.



The OC in AG soils was higher than in AFG, but the OC in the PM10 was similar (between 3 and 3.3 %) (Fig. 1). The OC in RRI was higher than in RRO, but the OC in the PM10 was similar (between 1.9 and 2.2 %) (Fig. 1). The OC content in PM10 emitted by agricultural soils (AG and AFG) was between 1.3 and 1.7 higher than that emitted by rural roads (RRI and RRO). To our knowledge, this is the first report of the OC content in the PM10 emitted by rural roads. The OC contents in the PM10 emitted by rural roads is valuable information to quantify the OC losses from the soil and the OC discharges into the atmosphere by dust emission. In semiarid pampas, actual PM10 emission per unit of area of rural roads was 400 times higher than PM10 emission of agricultural soils (Ramirez Haberkon et al., 2021).

Figure 1. Contents of organic carbon (OC) in soil and in PM10. AG: agricultural soils for grain production (n=9); AFG: agricultural soils for forage and grain production (n=9); RRI: rural roads inside farm fields (n=9); RRO: rural roads outside farm fields (n=9). Different lowercase letters indicate statistical differences between land management systems ($p<0.05$). Bars represent standard deviations.

The OC in the PM10 was associated to the OC in the soil. This relationship was described by a quadratic function (Fig. 2), suggesting that OC was accumulated in PM10 until reaches a maximum. The maximum

OC in the PM10 was 3.5 % and it was reached in soils with more than 1.3 % OC. This relationship has not been explored in previous studies for PM10, but it was explored for other soil fractions. In the clay fraction (particles <2 µm) a maximum OC content was reached when the OC in the soil was high than 3 % (Jagadamma and Lal, 2010). A limit of accumulation of OC also was found for particles fraction <20 µm (Hassink, 1997). Our results and those of previous studies suggest that the OC can be accumulated in the PM10 until a limit (saturation).

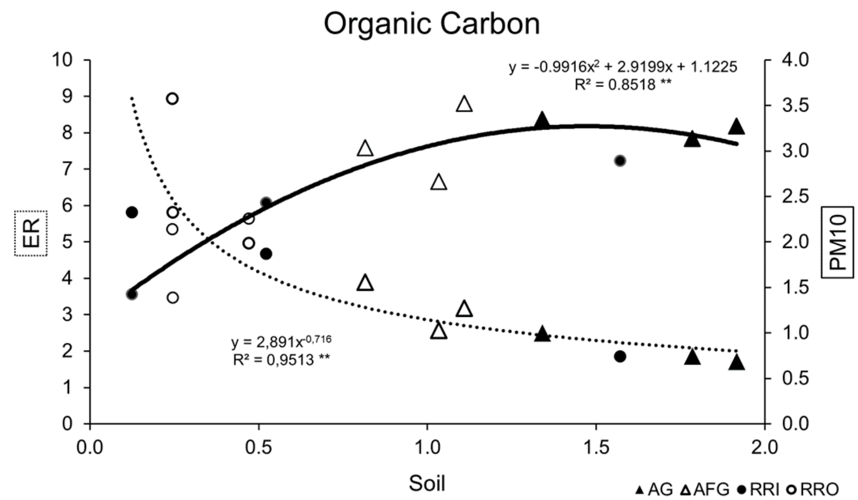


Figure 2. Organic carbon (OC) content (%) in PM10 and OC enrichment ratio (ER) as a function of OC content in the soil. AG: agricultural soils for grain production; AFG: agricultural soils for forage and grain production; RRI: rural roads inside farm fields; RRO: rural roads outside farm fields. **Statistically significant ($p<0.01$)

The OC ER was positive in all rural soils studied (Fig. 2). Other studies also found positive OC ER in the PM10 and in the fine fractions transported by the wind (Iturri et al., 2017; Mendez et al., 2017; Webb et al., 2012). The OC ER was associated to the OC in the soil, and it was described by a negative potential function (Fig. 2). Soils with low OC contents (rural roads) showed high ERs and soils with high OC contents (agricultural soils) showed low ERs. OC content in soils of rural roads was low (Fig. 1) and most of the OC was associated to the PM10 (Fig. 2). The low OC content in soils of rural roads can be attributed to the absence of a continuous supply of labile OC (due to lack of vegetation) and high rates of wind erosion (Ramirez Haberkon et al., 2021). In rural roads, OC tends to accumulate in PM10, which represents the stable fraction of OC that is protected chemically and physically (Hassink, 1997). The stable fraction of OC is less sensitive to soil management and wind erosion (Webb et al., 2012). Vegetal coverage in agricultural soils played a crucial role in preventing the loss of labile OC through wind erosion, while also facilitating the accumulation of labile OC in the soil.

Conclusions

Our study revealed important findings regarding the OC content in PM10 emitted by agricultural soils and rural roads. This study provides the first report on the OC content in the PM10 emitted by rural roads in the region. The OC content in the PM10 was consistently higher than that in the soil across all soils analyzed, indicating an enrichment of OC in the PM10. This finding aligns with previous studies demonstrating the accumulation of OC in fine particles.

This study reveals an association between organic carbon (OC) content in PM10 and OC content in the soil. An association between OC ER and OC content in the soil was also found. Both associations indicate that OC accumulates in PM10 until it reaches a maximum (Saturation), which was found to be 3.5% for the analyzed soils. These findings enhance our understanding of the dynamics of OC in PM10 and its association with the OC content in the soil. Our study highlights the importance of considering the OC content in the PM10 emitted by rural soils for quantifying OC losses from the soil and OC discharges into the atmosphere through dust emissions. Further investigations should examine the OC content in PM10 emitted by rural soils across diverse soil textures and geographical regions.

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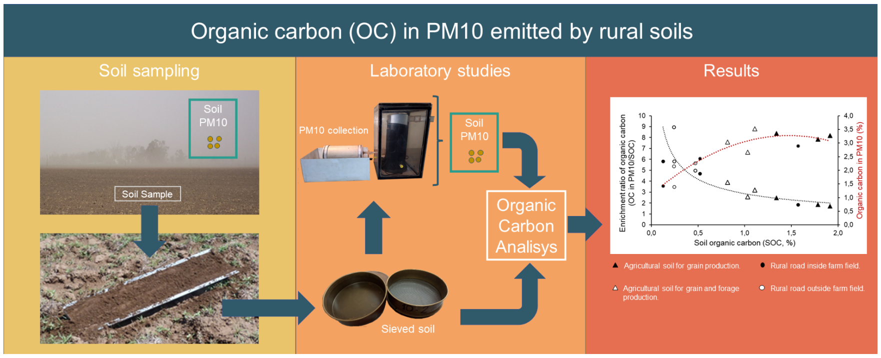

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