

DOES BURNING OF HARVESTING RESIDUES INCREASE SOIL CARBON STORAGE?

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¿La quema de residuos de cosecha aumenta el almacenaje de carbono en el suelo?

Keywords: Black carbon, stubble burning, soil organic C.

ABSTRACT

The influence of 31 years of stubble burning on the carbon storage as well of chemical composition of soil organic matter (SOM) was studied in agricultural soil of a long-term field experiment. Additionally, the potential of black carbon (BC) produced by burning of harvesting residues, to be lost by horizontal as well as vertical transport was quantified during a rainfall simulation experiment. Our results show that 31 years of stubble burning as a regular agricultural practice did not change carbon storage or the chemical composition of SOM. This is most likely due to a small quantitative input of highly stable aromatic carbon into the soil. A significant portion of BC deposited on the soil surface by the fire may have been exported from the site as shown during the rainfall simulation experiment.

Palabras claves: Carbono condensado (BC), quema de residuos agrícolas, carbono orgánico del suelo, simulación de lluvia.

RESUMEN

La influencia de 31 años de quema de residuos sobre el almacenaje de carbono y también la composición de la materia orgánica (SOM) fue estudiada en un suelo agrícola de un experimento de largo plazo. Además el potencial de pérdida del carbono condensado (BC) que se produce por la quema de los residuos de cosecha por el transporte horizontal y vertical fue cuantificado durante un experimento de simulación de lluvia. Nuestros resultados muestran que 31 años de quema de residuos, como una práctica regular de la agricultura, no cambió el almacenaje de C o la composición química de la SOM. Esto es muy probable que se deba a que una pequeña cantidad de carbono altamente aromático entra al suelo. Una porción significativa de BC depositado en la superficie del suelo por el fuego puede haber sido exportada desde el sitio como fue demostrado durante el experimento de simulación de lluvia.

INTRODUCTION

Burning of harvesting residues in agricultural systems has two main consequences for the soils carbon cycle. In the short term, much of the aboveground carbon, otherwise returned to the soil after harvesting is lost as CO₂. On the other hand, carbon formed by fire, the so called black carbon (BC), may be added to the soil. BC is generally aromatic in nature and was therefore thought to be stable towards microbial decay (Knicker, 2007). The effect of burning of harvesting residues (stubble burning) on the soil's carbon stock has rarely been examined. During a long-term field experiment, little change of the soils carbon stocks were noticed (Chang and Heenan, 2005). Studies on the chemical composition of the organic matter left in the soil after stubble burning are lacking.

In addition to microbial decomposition, organic matter may be lost from the soil by horizontal as well as vertical transport processes. Erosion processes may affect BC more than other organic matter types (Rumpel *et al.*, 2006a). Export of BC from the site as a result of water erosion may occur right after the fire, when BC is deposited at the soils surface. Once

incorporated into the soil matrix, BC could be protected from erosion as well as stabilised against microbial decay by interaction with the mineral phase (Czimzik and Masiello, 2007).

In this paper we examine the long-term effect of burning of harvesting residues on the organic matter of an agricultural soil and quantify the potential of BC to be lost from soil by water erosion. The objective of the study was to evaluate the impact of BC additions to soil on SOM stocks as well as SOM composition.

MATERIAL AND METHODS

Study sites

The long-term influence of burning of harvesting residues was analysed at a longterm field experiment of Issoudun in the Champagne region (France). In this region intensive wheat cultivation is practiced. The longterm field experiment consisted of burning of harvesting residues site for 31 years between 1963 and 1994 (ThOvenet *et al.*, 2002). Soil type is a shallow calcareous soil developed from limestone.

Three samples were taken at four occasions from burned plots and unburned control sites, where harvesting residues were incorporated into the soil by ploughing. Sampling dates were 1962, 1970, 1983 and 1994. In addition wheat litter and black material after burning was sampled.

To assess the importance of water erosion on the fate of BC after burning of harvesting residues, a rainfall simulation was designed and carried out by O. Planchon (IRD). Harvesting residues were gathered and burned. After the burning, six plots (1 m²) were installed. Out of these plots, three were covered by mosquito nets to prevent splash erosion due to impact of raindrops. At these three plots the only process allowed was runoff erosion. A rainfall of 60–70 mm h⁻¹ was applied during 76 minutes. During this time the sediments eroded from the plots were collected. The soil was sampled before and after the experiment from the 0–5 mm and 5–10 mm layers.

Elemental analysis

Organic carbon and N contents were determined by the dry combustion method using a CHN auto-analyser (CHN NA 1500, Carlo Erba). Analytical precision was ± 0.1 mg g⁻¹ for OC and ± 0.05 mg g⁻¹ for N content.

¹³C - CPMAS NMR - spectroscopy

The chemical composition of burned and unburned samples was analysed by solid-state ¹³C NMR spectra of HF treated, mineral-free soil samples, plant litter and BC. The spectra were obtained on a Bruker DSX-200 NMR spectrometer.

Cross polarization with magic angle spinning (CPMAS) (Schaefer and Stejskal, 1976) was applied at 6.8 kHz. The ¹³C chemical shifts were referenced to tetramethylsilane. A contact time of 1 ms was used. The pulse delay was 2000 ms for wheat straw and 400 ms for burned wheat straw and soil. Solid-state ¹³C NMR signal was recorded as free induction decay (FID) and Fourier transformed to yield a NMR

spectrum. The spectra were integrated using the integration routine of the spectrometer. The chemical shift regions 0–45 ppm, 45–110 ppm, 110–140 ppm, 140–160 ppm and 160–220 ppm were referred to alkyl C, O-alkyl C, C substituted aryl C, O substituted aryl C and carboxylic C, respectively (Wilson, 1987). Tentative assignments of chemical structures to the chemical shift regions are presented in Table 1. The variation in integration due to the treatment of a well resolved FID (Fourier transformation, phasing and baseline correction) was less than 5 % (Knicker, 1993).

Black carbon

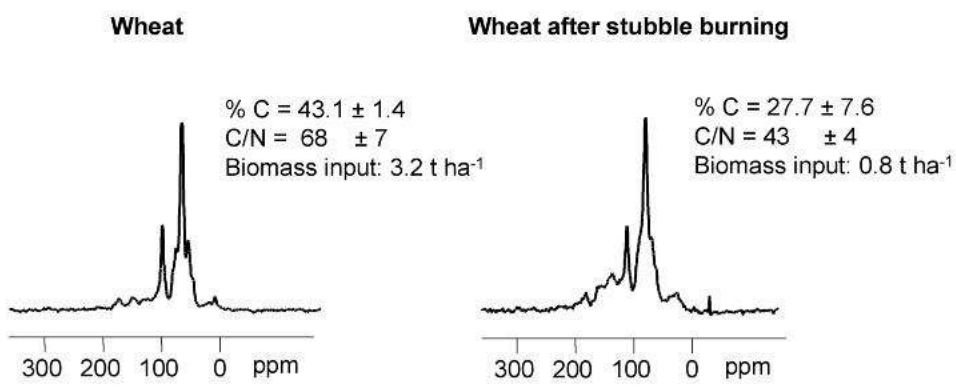
The BC contribution to total OC content was estimated as the oxidation resistant elemental carbon (OREC, Bird and Grbecke, 1997), and analysed on HF treated, mineral-free samples. Briefly, 150 mg of a HF treated sample was mixed with a potassium dichromate solution (0.1 M K₂Cr₂O₇ in 1L 2M H₂SO₄), and oxidised at 80°C in an ultrasonic bath. The solution was changed several times during the treatment. Thereafter the samples were washed 4 times with distilled H₂O before being freeze dried, weighed and analysed for elemental composition. The oxidation time needed to isolate OREC was 6 h.

RESULTS AND DISCUSSION

Carbon content of the agricultural soils of the Issoudoun field trial ranged between 13.9 and 16.3 g kg⁻¹, the control soil showed slightly higher initial carbon contents (B. Mary, unpublished data). The burned plot showed carbon stocks of 43 Gg ha⁻¹ after 31 years of stubble burning. These values were not significantly different from those measured before burning (Table 1). Stubble burning did not significantly influence the carbon stocks of this soil. This is surprising because of the biomass input was greatly reduced from 3.2 to 0.8 t ha⁻¹ (Fig. 1) (B. Mary, unpublished data). Reduction of the carbon

Table 1: Carbon content and stock in the burned and control soil at the first and the last sampling date (Data from B. Mary, unpublished)**Cuadro 1:** Contenido de carbono y acumulación en el suelo quemado y el control en el primer y último dTa de muestreo (Datos de B. Mary, no publicado)

	C content	C stock
	g kg ⁻¹	Gg ha ⁻¹
Burned (1962)	14.9 ± 0.5	45.7 ± 1.5
Burned (1994)	13.9 ± 0.2	43.8 ± 1.6
Unburned (1962)	16.3 ± 0.4	45.7 ± 1.1
Unburned (1994)	16.3 ± 0.6	46.6 ± 1.8

**Figure 1:** Characterisation of input material into burned and unburned soil (elemental content and biomass input from B. Mary, unpublished)**Figura 1:** Características del material de entrada al suelo quemado y no quemado (contenido de carbono elemental y biomasa de entrada de B. Mary, no publicado)

input over time usually leads to lower soil carbon stocks.

The chemical composition of SOM in the burned and unburned soil (Fig. 2) is characterised by a dominant signal in the O-alkyl region of the spectra (45-110 ppm). The dominant peak in this region at 72 ppm together with the peak at 105 ppm is generally assigned to polysaccharides (Kögel-Knabner, 1997). The contribution of methoxyl C derived from lignins and α -C of proteins gives rise to the signal at 53 ppm (Skjemstad *et al.*, 1983). Alkyl C in the chemical shift region between 0-45 ppm may be assigned to lipids, waxes and other plant or microbial derived aliphatic biomolecules (Golchin *et al.*, 1997). In the aryl C region of the spectra, the peaks at 140 to 160 ppm are assigned to O-substituted aromatic C. Signals from unsubstituted and for substituted aromatic C are found between 110 and 140 ppm. Lignin C contributes to both types of aryl C (Knicker and Lüdemann, 1995). The chemical composition of SOM in both soil samples is characteristic of soils rich in clay content (Wattel-Koekkoek *et al.*, 2001; Goncalves *et al.*, 2003; Krull and Skjemstad, 2003). Stubble burning had very little impact on the bulk SOM composition. Small

differences could be noted in the shape of the aromatic signal at 110-160 ppm (Fig. 2). The peak became sharper after 30 years of stubble burning, whereas the relative contribution of the signal remained unchanged.

The small changes of chemical composition due to repeated stubble burning may be explained by the nature of the input material. Characterisation of the chemical composition of wheat straw before burning and the black material collected after burning showed very little increase of the aromatic carbon contribution despite the substantial carbon loss (Fig. 1). The C/N ratio of the material decreased after burning, suggesting that the material is more easily decomposed.

The black carbon content of the soils could be assessed thanks to the control soil. BC values obtained with dichromate oxidation have to be corrected for oxidation resistant aliphatic material. Therefore, BC values of the control soil were subtracted from those obtained for the burned soil. The BC values obtained after this correction were similar in all soil samples (Fig. 3). Thirty years of stubble burning did thus not lead to an increase in neither the aromatic carbon contribution nor the contribution of chemically recalcitrant BC.

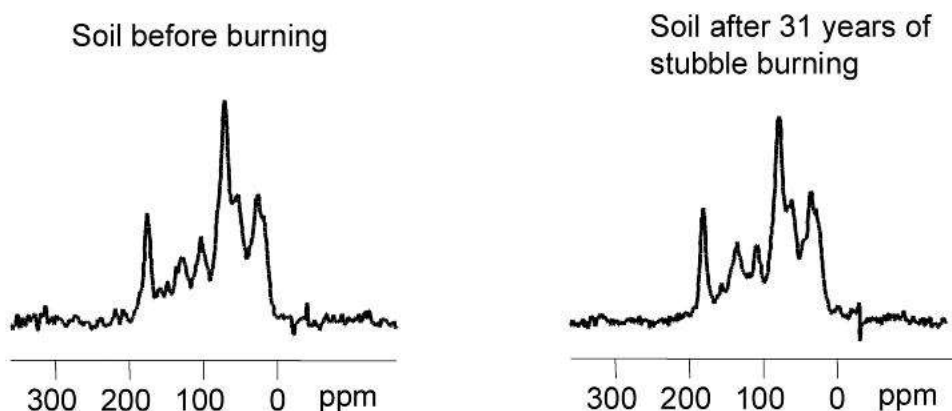


Figure 2: Chemical composition of SOM before and after 31 years of stubble burning

Figura 2: Composición química de SOM antes y después de 31 años de quema de residuos

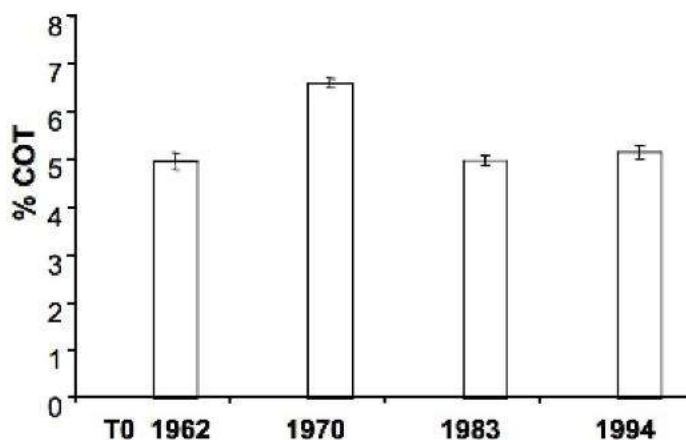


Figure 3: Evolution of the BC content during 31 years of stubble burning

Figura 3: Evolución del contenido de BC durante 31 años de quema de residuos

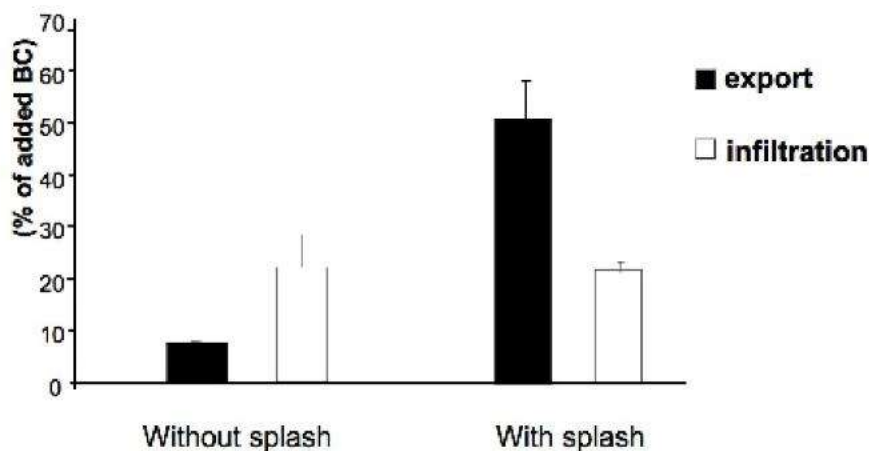


Figure 4: Percentage of BC transported horizontally and vertically under different rainfall regimes

Figura 4: Porcentaje de BC transportado horizontalmente y verticalmente bajo distintos regímenes de lluvia

This result is in contrast to sites under slash and burn agriculture in a tropical climate (Rumpel *et al.*, 2006b) and may be explained by export of BC from the site. BC, which is light material deposited at the soil surface with no mineral interactions is prone to erosion from the site (Rumpel *et al.*, 2006a).

Analysis of BC erosion during the rainfall simulation experiment confirmed that it may be eroded in high proportions from the site. Our data indicate that up to 50 % of the BC added to the soil by burning of harvesting residues is exported from the plots versus only 20 % infiltrating vertically (Fig. 4). However, whether BC is exported from the sites depends upon the rainfall regime. Little BC export was occurring under light rainfall condition, which do not lead to splash erosion.

CONCLUSION

Even after 30 years of stubble burning, carbon stocks and chemical composition of SOM remained unchanged. Our data show that the fire occurring during stubble burning is not intense enough to create high input of aromatic carbon. BC, the most recalcitrant carbon form produced by fire is highly susceptible to be eroded from the site. However, less intensive rainfall may lead to BC incorporation into the mineral soil, thus increasing the soil's potential for longterm carbon sequestration.

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