# Long-term impact of organic amendments (compost, vermicompost and biochar) on soil organic matter quality

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## Abstract
The aims of our study were (1) to analyze the suitability of buffalo manure, compost and vermicompost and biochar alone or in combination for improving carbon stabilization and soil fertility and (2) to investigate their impacts on soil carbon storage capacity. The addition of biochar influenced the mineralization of other organic amendments. A mesocosm experiment under natural weather showed that compost and vermicompost had similar effects on soil carbon and nitrogen content, whereas the presence of biochar increased carbon and nitrogen sequestration. The association between vermicompost and biochar could constitute an interesting amendment for improving carbon storage and soil fertility in tropical soils.

## Introduction
Organic matter (OM) amendments may be used for the rehabilitation of degraded soils, often characterized by low carbon contents. In Vietnam, the utilization of compost and vermicompost produced from buffalo manure, and biochar made from bamboo residues are suggested as novel approaches for improving soil fertility, plant growth as well as sequestering carbon and reducing the flow of nutrients and microbes from the soil to the water system. The aims of this study were to: (1) characterize the chemical and biochemical nature of the three organic amendments (manure, compost and vermicompost) and biochar; (2) evaluate their biological stability, (3) to assess the effect of these substrates on soil C sequestration and soil organic matter quality in the long term (3 years).

## Material and Methods
*Substrates analyses*:
Composts and vermicomposts were produced from buffalo manure on a farm in north-east Vietnam, after 5 months of maturation in different and separate units. The earthworm species used to produce the vermicompost was *Eisenia Andrei*. The biochar used in this study was produced from the bamboo (*Dendrocalamus membranaceus Munro*).
The differences organic substrates have been characterized by the elemental (C, H, O, N) analysis. The chemical compositions of these substrates were analyzed by solid-state $^{13}C$ nuclear magnetic resonance ($^{13}C$ CPMAS NMR) spectroscopy and Van-soest extraction. The stability of buffalo manure, compost, vermicompost and biochar and their mixes were determined through an incubation experiment at 28°C during 7 months.

*Field experiment and soil analyses:*
An experiment was also carried out outdoor with lysimeters, where maize was cultivated for three years. Plants received four different kinds of fertilizations: only chemical nutrients (control) or the same amount of chemical nutrients plus organic fertilization (2 kg of buffalo dung, compost or vermicompost). The influence of the incorporation of biochar (700 g) was also tested for the control and vermicompost treatments. After 3 year, soils were collected for elemental (C, N) analysis.

## Results and discussion
*Elemental and functional group composition of*
*(i) Three organic substrates*
The carbon, nitrogen, oxygen and hydrogen content decreased significantly after composting and vermicomposting, but the effect was more important with vermicompost than compost with lower C

and O contents (Table 1). These results suggest a more important degradation of vermicompost compared to compost. The $^{13}C$ CPMAS NMR spectroscopy did not show any differences among the buffalo manure, compost and vermicompost (Fig. 1). However, biochemical composition analyzed by Van-soest fractionation showed an increase of the soluble fraction during the composting (Table 2). This increase is the result of a decrease in the fraction soluble in water and a strong increase of the fraction soluble in neutral detergent [1]. The cellulose/lignin ratio was 0.69 for vermicompost, lower than manure (0.9). However, no significant difference was observed between the compost and the initial materials. This could suggest that the vermicompost is more biologically stable than the two other organic substrates because of high contribution of the residual VanSoest fraction, which is most probably composed of lignin as well as other non soluble aromatic and aliphatic materials.

**Table 1: Carbon (OC), nitrogen (N), oxygen (O), hydrogen (H), C/N mass ratio, O/C and H/C atomic ratios of the buffalo manure (M), compost (C), vermicompost (V) and bamboo biochar (B). Different letters within the same column are related to significant differences (n = 4).**

| Sample | N(%) | C(%) | C/N | O (%) | H (%) | H/C | O/C |
|---|---|---|---|---|---|---|---|
| M | $1.99^a$ | $30.14^b$ | $15,0^b$ | $29.34^a$ | $4.55^a$ | $1,81^a$ | $0,73^a$ |
| C | $1.63^b$ | $24.80^c$ | $14,6^b$ | $25,78^b$ | $3.52^b$ | $1,80^a$ | $0,83^a$ |
| V | $1.54^b$ | $21.56^d$ | $14,0^b$ | $23.55^c$ | $3.12^b$ | $1,77^a$ | $0,84^a$ |
| B | $0.87^c$ | $74.16^a$ | $84,6^a$ | $9.48^d$ | $2.42^c$ | $0.39^b$ | $0.10^c$ |

**Table 2: Biochemical fractions of the buffalo manure (M), compost (C), vermicompost (V) and bamboo biochar (B): soluble (SOL), cellulose (CEL), hemicellulose (HEM), lingnin and cutin (LIC), LIC/CEL ratio. Different letters within the same column are related to significant differences (n = 3).**

| Substrates | Hot water soluble C (%TOC) | Fraction (% MS) | | | | |
|---|---|---|---|---|---|---|
| | | SOL | HEM | CEL | LIC | CEL/LIC |
| M | $17.47^a$ | $51.3^c$ | $14.3^b$ | $16.0^a$ | $15.4^b$ | $1.0^a$ |
| C | $13.50^b$ | $57.7^b$ | $16.2^a$ | $13.0^b$ | $13.1^c$ | $1.0^a$ |
| V | $13.40^b$ | $61.4^a$ | $13.2^c$ | $10.4^c$ | $15.0^b$ | $0.69^b$ |
| B | $1.75^c$ | $17.8^d$ | $0.5^d$ | $12.0^{ab}$ | $69.7^a$ | $0.17^c$ |

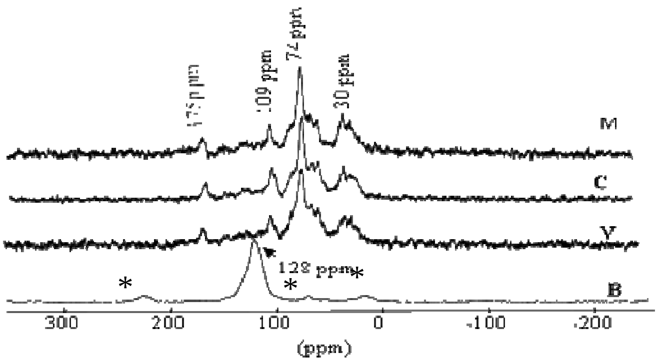


**Figure 1: representative NMR spectra of buffalo manure (M), compost (C), vermicompost (V) and Bamboo biochar (B). Spinning sidebands are indicated by ***

*(ii) Biochar*

Our biochar had very high carbon content (74.2%) but very low nitrogen content (0.87%) due to the dehydration during the carbonization process. As shown several times before ([2], [3], [4]), biochar is characterized by high C/N ratios and far lower H/C and O/C ratios (0.4 and 0.1 respectively) than the other organic substrates due to its very low hydrogen (2.42%) and oxygen (9.48%) contents and its enrichment in carbon. The $^{13}C$ CPMAS spectra of biochar shows one broad signal spanning centered at about 128 ppm that can be assigned to aromatic C. In addition, its CEL/LIC ratio (0.17) obtained after Van Soest-fractionation was lowest and confirms the high recalcitrant nature of this material.

*Stability of manure, compost, vermicompost and biochar*

Figure 2 presents the percentage of carbon mineralized after 7 months of incubation. The strongest mineralization was observed for manure and the lowest was recorded for the biochar. Total C mineralized ranged from 0.25 to 15.87 % of TOC. Mineralized C decreased in the order manure (15.9% of TOC after 217 days) > compost (13.4% of TOC) > vermicompost (10.9% of TOC). This result may be explained by a higher content of water soluble carbon content, and cellulose fraction that was highlighted by Van Soest extraction. It is in the same order with the results of hot water extractable organic carbon. According to [1] and [5], hot water extractable carbon has frequently been used to estimate potentially bioavailable organic carbon. The mineralization of substrates is generally controlled by its content of SOM soluble in hot water.

The mineralization of biochar was very slow and its combination with organic substrates led to a reduction in carbon mineralization. Although the amount of mineralized carbon was significantly different for compost and vermicompost, it was similar when these two substrates were incubated in the presence of biochar.

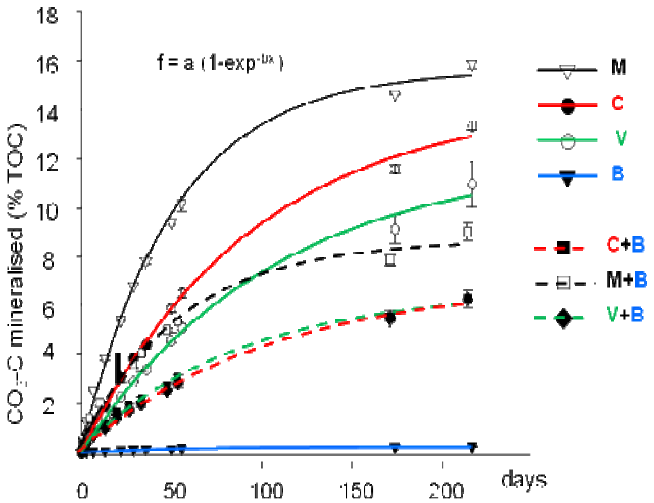


**Figure 2. Organic carbon mineralised during the soil incubation of bamboo biochar (B), buffalo manure (M), compost (C), vermicompost (V) and their mixtures with biochar**

*Effect of these substrates on soil organic matter in the long term*

After 3-years of experiment, the utilization of organic amendments increased the amount of SOM compared with the control soil. This is in agreement with several studies ([6], [7]). We did not find any significant difference between compost and vermicompost treatments. Our results show finally that the presence of biochar had a positive effect on soil carbon and nitrogen content. The highest soil carbon content (52.8 mg/g) and nitrogen content (3.2 mg/g) was observed for the vermicompost plus biochar treatment. The association between vermicompost and biochar appears as a good amendment for improving carbon storage in tropical soils.

**Table 3. Teneur en carbone total (mg/g) et azote total (mg/g), and C/N ratio of soil with mineral fertiliser (N:P:K) (F), compost (C), vermicompost (V), mineral fertiliser with biochar (F+B) and vermicompost with biochar (V+B) after 3 years. Different letters within the same column are related to significant differences (n = 4).**

| | N (mg/g) | C (mg/g) | C/N |
|---|---|---|---|
| M | $2{,}12^{b}$ | $21{,}87^{c}$ | $10{,}34^{c}$ |
| C | $2{,}33^{b}$ | $24{,}57^{c}$ | $10{,}53^{c}$ |
| V | $2{,}50^{b}$ | $25{,}36^{c}$ | $10{,}05^{c}$ |
| V+B | $3{,}22^{b}$ | $52{,}75^{a}$ | $17{,}08^{b}$ |
| F | $0{,}94^{d}$ | $9{,}41^{d}$ | $10{,}00^{c}$ |
| F+B | $1{,}40^{c}$ | $39{,}43^{b}$ | $28{,}25^{a}$ |

## Conclusion

Biochars were found enriched in aromatic carbon and high recalcitrance biologically and chemically. Composting in the presence of earthworms (vermicompost) led to a more important transformation of buffalo manure than regular composting process. The chemical composition shows little difference among organic amendments (manure, compost or vermicompost) but there was a difference in particular with regard to the contribution of biochemical Van Soest fractions. Short-term mineralization was significantly different for these substrates. The addition of biochar influenced the mineralization of the other organic amendments. Finally, our study suggest that mixing vermicompost and biochar improve carbon stabilization in tropical soils.

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