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ORIGINAL ARTICLE

Soil organic carbon dynamics study bias deduced from isotopic fractionation in corn plant

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Abstract Carbon stable isotope techniques were extensively employed to trace the dynamics of soil organic carbon (SOC) across a land-use change involving a shift to vegetation with different photosynthetic pathways. Based on the isotopic mass balance equation, relative contributions of new versus old SOC, and SOC turnover rate in corn fields were evaluated world-wide. However, most previous research had not analyzed corn debris left in the field, instead using an average corn plant δ^{13}C value or a measured value to calculate the proportion of corn-derived SOC, either of which could bias results. This paper carried out a detailed analysis of isotopic fractionation in corn plants and deduced the maximum possible bias of SOC dynamics study. The results show approximately 3‰ isotopic fractionation from top to bottom of the corn leaf. The ^{13}C enrichment sequence in corn plant was tassel > stalk or cob > root > leaves. Individual parts accounting for the total dry mass of corn returned distinct values. Consequently, the average δ^{13}C value of corn does not represent the actual isotopic composition of corn debris. Furthermore, we deduced that the greater the fractionation in corn plant, the greater the possible bias. To alleviate bias of SOC dynamics study, we suggest two measures: analyze isotopic compositions and proportions of each part of the corn and determine which parts of the corn plant are left in the field and incorporated into SOC.

Keywords Bias of SOC dynamics study · Isotopic fractionation in corn · Isotope mass balance equation · Bias range

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1 Introduction

As rising population has increased demand for agricultural products, the conversion of natural ecosystems to crop land and pasture has been extensive. To date, evidence increasingly shows that land-use change (LUC) can affect soil organic carbon (SOC) dynamics by influencing the rate of mineralization. LUC is a major controlling factor for the balance of SOC stocks and for the global carbon cycle (Sun et al. 2013).

In any report on the dynamics of SOC, the loss of old carbon and accumulation of new carbon are key data for assessing land-use impacts on SOC dynamics. Spatial and temporal trends in the carbon isotopic composition of SOC are valuable in understanding the component processes of the terrestrial carbon cycle, especially when a change between C-3 and C-4 vegetation occurs. Plants that use C-3 photosynthesis have δ^{13}C values ranging from approximately −32‰ to −22‰ (mean ca. −27‰), while C-4 plants' values range from about −17‰ to 9‰ (mean ca.−13‰) (Griffiths 1992). These natural isotopic differences allow C-3 and C-4 carbon to be traced through aboveground and belowground food webs, and ultimately into the soil organic matter (SOM). This method has regularly been applied to understand the fate of fresh organic carbon from corn, a globally-grown crop species with a C-4 photosynthetic pathway.

However, few researchers have considered isotopic fractionation in corn, and most have ignored which components of corn debris were left in the field and incorporated into SOC. These omissions result in bias in SOC dynamics study. We therefore undertook a study of isotopic fractionation in corn plant to properly deduce the bias of SOC dynamics study.

2 Materials and methods

Several corn plants were collected from northeastern China. Each leaf and root was separated as an individual sample. Organic carbon and nitrogen were quantified by combustion of ground samples in an elemental analyzer with an analytical precision of 0.1%. The natural abundance of heavy isotopes (δ^{13}C) was measured with a Finnigan MAT253 isotope ratio mass spectrometer, and expressed as parts per thousand relative to the international standard PDB (Peedee belemnite) using delta units (δ). δ^{13}C was calculated according to Eq. 1:

$$\delta^{13}\mathrm{C}(‰) = \left[\left(R_{\mathrm{Sample}}/R_{\mathrm{Standard}}\right) - 1\right] \times 10^3 \quad (1)$$

where R_{Sample} is the ^{13}C/^{12}C ratio of the sample, and R_{Standard} is the ^{13}C/^{12}C ratio of PDB.

3 Results and discussion

3.1 Isotope fractionation of corn plant

The δ^{13}C values of corn leaves from top to bottom generally became more negative and show reverse correlation with carbon–nitrogen ratios ($p < 0.05$). Leaf δ^{13}C values range from −13.62‰ to −10.99‰. Similar to earlier reports (Table 1), leaves showed the least enriched ^{13}C. The tassel had the highest δ^{13}C values in the plant. The seed and stalk had similar δ^{13}C, with values of −10.81‰ and −10.88‰, respectively. The average δ^{13}C value of corn root was −11.06‰. Combined with previous reports on isotopic fractionation in corn, our data established the isotopic enrichment sequence in corn as: tassel > stalk or cob > root > leaves (Fig. 1), but without detailed documentation of isotopic fractionation in other studies, we were unable to determine whether the fractionation of corn plant is similar globally.

3.2 Bias of soil organic carbon dynamics study deduced from isotopic fractionation in corn plant

δ^{13}C values can be used to estimate the distribution of SOC in soils cultivated with C-4 crops following deforestation of C-3 plants; the proportion of C-3 and C-4 carbon in the soil can be estimated according to the following isotopic dilution equation (Bernoux et al. 1998; Dungait et al. 2013):

$$f(\mathrm{C\text{-}4}) = (\delta_{\mathrm{t}} - \delta_{\mathrm{A}})/(\delta_{\mathrm{B}} - \delta_{\mathrm{A}}) \quad (2)$$

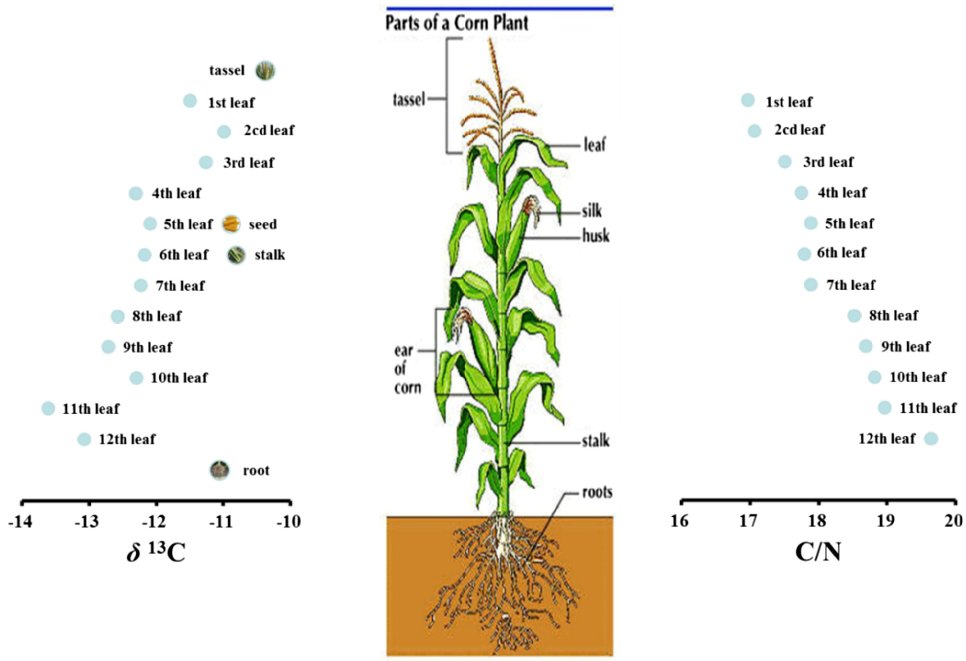
where f(C-4) is the proportion of C-4 carbon, δ_{t} is the carbon isotopic composition of the SOC; δ_{A} is the value of SOC from original (C-3) plants and δ_{B} is the value of SOC from corn (C-4). Furthermore, SOC turnover can be estimated by dividing the above formula by cultivated years.

The isotope mass balance equation makes it convenient to study SOC dynamics in situ. However, most researchers have not considered which parts of corn were incorporated into SOC, instead using an average δ^{13}C value of corn in the above formula (Table 1). Depending on agricultural practices, this could introduce significant bias into the dynamics analysis. Before the end of the last century, above-ground corn debris was burned or taken away in several parts of China. The parts returned to soil were mainly roots or burned corn residue. Roots account for 25%–35% of total dry mass of corn, but more than 60% of debris left in the field. Consequently, the average δ^{13}C value of corn does not represent the isotopic composition of corn debris left in the field and incorporated into SOC. In addition, turnover rates of plant parts vary significantly in the short time scale. Generally, leaves easily degrade and incorporate into SOC. Roots and stalks take more time to

Table 1 Carbon isotope values of corn used as reference

Part of corn plant	δ^{13}C (‰)	Region	References
Leaves	−13.4	South of Canada	Gregorich et al. (1995)
Surface root	−12.8		
Stalk	−13.1		
Cob	−13.0		
Kernel	−9.6	Middle of China	Lowdon (1969)
Leaves	−11.0		
Average value	−12.6	Middle of China	Fan-qiao et al. (2010)
	−12.5	France	Salome et al. (2010)

Fig. 1 Carbon isotopic compositions in corn plant, and ratios of carbon to nitrogen in corn leaves



decompose completely (Ninghui et al. 2016). Thus, the turnover rate of corn-derived C will be misestimated in short-term experiments if a mean or part-specific value is used. In addition, the distribution of corn debris in the soil profile is not uniform, and corn debris is very difficult to move to the deep soil layer (Müller et al. 2016).

To understand the maximum possible bias range that may be caused by isotopic fractionation in corn, we drew a schematic diagram of possible bias (Fig. 2). At a given δ value of SOC, the possible max bias was obtained by subtracting f_1 from f_2. The greater the fractionation in a plant, the greater the possible bias. As shown, the maximum possible bias increases with increasing δ value of SOC.

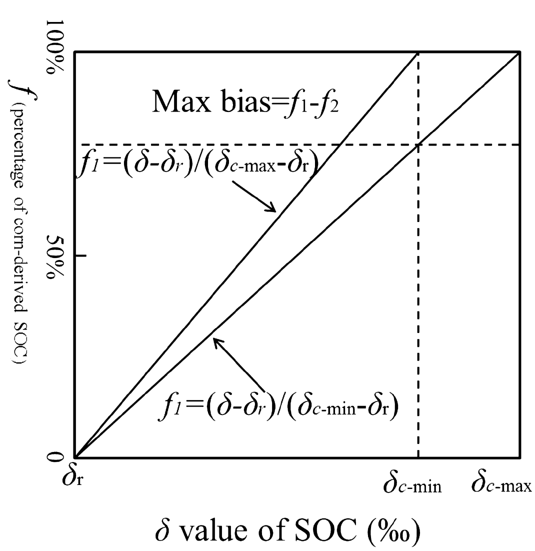


Fig. 2 Schematic diagram of maximum possible bias range. Both *lines* labeled f_1

In the diagram, δ is measured for SOC; δr is the value of SOC from original plants (C-3); $\delta_{\text{c-max}}$ and $\delta_{\text{c-min}}$ are the largest and smallest values in the corn plant, respectively; and f_1 and f_2 are percent of corn-derived SOC based on minimum and maximum δ values of the corn plant.

4 Conclusions

Based on carbon isotopic composition, this study found large fractionations in corn plant parts. The ^{13}C enrichment sequence was tassel > stalk or cob > root > leaves. The range of difference reached 4‰, with the tassel being 140% more enriched in ^{13}C compared to the bottom leaf.

Due to the difference in proportions of corn parts, the average δ^{13}C value of the corn plant does not represent the isotopic composition of corn debris incorporated back into the field, which is a crucial cause of bias of SOC dynamics study. The heterogeneity of both distribution of corn debris in the soil profile and turnover rates of corn parts also contribute.

The maximum possible bias will occur when the minimum δ^{13}C value of the corn plant is taken as the maximum in the isotope mass balance formula. The maximum possible bias gradually increases as the δ^{13}C value of SOC increases, and greater fractionation in the plant will lead to greater possible bias.

To alleviate bias of SOC dynamics study, two measures should be taken: analyze the isotopic composition of each corn part and investigate the proportions of corn parts left in the field and incorporated into SOC.

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