Distribution of fresh carbon in different particle-size aggregates of different soil type

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Abstract. In order to study the effects of application of fresh carbon on distribution in soil aggregate fractions of red soil and lime concretion black soil, the stable carbon isotope (δ¹³C) technique was used, and explore the dynamic variation and distribution of soil organic carbon (SOC) in soil aggregates during ¹³C-labelled rice straw decomposition by an indoor incubation experiment. This experiment was put under incubation at 28 °C for 120 days, which included two treatments: CK (no straw) and Str (added with 1% straw), all samples were separated into four aggregate-size classes (>2000, 2000~250, 250~53, <53 μm) by wet sieving in the different incubation period, while soil aggregates in different size fraction and organic carbon in soil aggregates were determined. The results showed that the δ¹³C value of organic carbon in different particle-size water-stable aggregates of Str treatment was significantly higher than that of CK treatment, the δ¹³C value varied greatly both in red soil and lime concretion black soil, but the turnover rate of native SOC was slow and the degradation degree was relatively close. The quantity of new organic carbon supplied by rice straw found in different levels of aggregates followed a same increasing order of 2000~250 μm < (<2000 μm) < (53 μm) < 250~53 μm in red soil and lime concretion black soil at 120 days, which further indicates that the added fresh carbon was mainly accumulated in small-sized soil aggregates. The result shows that the addition of rice straw could increase soil organic carbon content in all sizes of aggregates, which provide theory basis for soil quality improvement and organic carbon recycle.

1. Introduction
Soil organic carbon (SOC) plays an important role in cycling plant nutrients, increasing grain yield and improving the physical, chemical properties of soils. Application of organic materials such as crop residues, compost and poultry manure are well known environmental practices in soil restoration, maintaining soil organic matter and reclaiming degraded soils[1-2]. Residue C is mineralized to CO₂ or transformed to soluble or stable organic matter by soil micro-organisms[3], soil organic matter is mainly derived from plant tissues that have a specific isotopic signature arising from differences in
their photosynthetic carbon assimilation pathways. The importance of the relationship between aggregate and SOC dynamics has been elucidated[6], the application of crop residues could influence soil physical properties and soil structure because they could change SOC content.

Regulate C and plant nutrient cycling through SOC and litter decomposition. Several studies have used $^{13}$C isotopic technology to trace the C movement from $^{13}$C-labeled substrates into aggregates in surface soils[5,8]. Soils developed under C3 or C4 vegetation contain SOC with a $^{13}$C signature reflecting the source of their plant inputs, the preservation of $^{13}$C-enriched compounds, such as cellulose, sugars and amino acids in rice straw, is unlikely in soil, these labile compounds may be converted into microbial compounds – hypothesis[7]. There is little information on the distribution and dynamics of residue C after incorporation of residue into soil with the stable carbon isotope ($^{13}$C) technique, which is important to sequester SOC. This information is critical for understanding the carbon cycle, increasing soil fertility, and developing sustainable agricultural management practices. Thus, we took advantage of an indoor incubation experiment with $^{13}$C labelled rice straw which was cultivated in greenhouse for up to 115 days, via measurement of the $^{13}$C label, we were able to analyse changes over time in aggregates by solid-state $^{13}$C nuclear magnetic resonance spectroscopy.

2. Materials and methods

2.1. Site description
The research site of red soil is located at the ecological experiment station, in Yingtan County, Jiangxi Province, China ($28^\circ 15'N, 116^\circ 55'E$). The red soil was developed from Quaternary red clay, its mineral types of the parent rocks were mainly Fe-Al oxides and clay minerals. The research site of lime concretion black soil is located at the ecological experiment station, in Suixi County, Huaibei City, Anhui Province, China ($33^\circ 62'N, 116^\circ 77'E$), its main mineral types were montmorillonite.

2.2. Treatments and sampling
Soil samples were taken after the summer maize was reaped in 2014, and divided into two layers of 0–15 and 15–30 cm. Each plot has three replicates. Soil samples were air-dried at the Experimental Station. The experiment included two treatments: CK (no straw) and Str (added with 1% straw), all samples were separated into four aggregate-size classes (>2000, 2000–250, 250–53, <53 μm) by wet sieving in the different incubation period, while soil aggregates in different size fraction and organic carbon in soil aggregates were determined[8]. Soil organic matter was determined by wet oxidation (potassium dichromate oxidation with external heating), the content of $^{13}$C in soil water-stable aggregates was determined by solid-state $^{13}$C nuclear magnetic resonance spectroscopy[9]. The properties of soil were showed in table 1.

All data were presented as means of three replicates with standard error. Mean comparisons were performed by Duncan’s multiple range test ($P < 0.05$). All analyses were operated using SPSS 19.0.

| soil type                          | Sand (%) | Silt (%) | Clay (%) | Organic carbon (g kg$^{-1}$) | pH          |
|------------------------------------|----------|----------|----------|-----------------------------|-------------|
| Red Soil                           | 36       | 20       | 44       | 9.86±0.23                   | 4.62±0.01   |
| Lime concretion black soil         | 30       | 33       | 37       | 10.45±0.33                  | 6.34±0.02   |

3. Results and analysis

3.1. Dynamics of $^{13}$C value in different soil aggregate fractions of lime concretion black soil with rice straw treatment
The $^{13}$C value of soil organic carbon (SOC) was affected by the types of organic materials entering the soil. The $^{13}$C method can not only investigate the turnover of the original SOC, but also trace the changes of fresh carbon in the soil. The $^{13}$C value of organic carbon in the four-different particle-size
aggregates in the CK treatment was between -22.08 ‰ and -23.52 ‰, while the δ^{13}C value of organic carbon in different particle-size aggregates of the Str treatment was significantly higher than that of the CK treatment, the δ^{13}C value varied greatly (figure 1). The results showed that the turnover of fresh carbon into the soil was very fast. From 15 d to 120 d, the δ^{13}C values of the four different particle-size aggregates in the CK treatment showed little dynamic change, indicating that the turnover rate of native soil organic carbon was slow and the degradation degree was relatively close.

**Figure 1.** Dynamics of δ^{13}C value in different soil aggregate fractions of lime concretion black soil with rice straw treatment.

The δ^{13}C values of different size aggregates in the Str treatment followed a decreasing order of 250–53, <53, >2000, 2000–250 μm at 15 days. With the extension of incubation time, the δ^{13}C of the four different particle-size aggregates decreased greatly at 60 days, decreasing by 27.8%, 24.6%, 30.9% and 73.8% than that of 15 days. In general, the δ^{13}C values of macroaggregates decline faster than microaggregates. After 60 days, the overall trend of δ^{13}C value of 250–53, <53 μm microaggregates was still decreasing, while the trend of δ^{13}C values of >2000, 2000–250 μm macroaggregates increased slightly. The main reason was that the Str treatment added the straw which was shredded into 0.25 mm, the microaggregates contained more fresh straw in the early stage, δ^{13}C value was relatively large, but with the extension of incubation time, the amount of decomposed residues of rice straw in the 250-53 and <53 μm microaggregates decreased gradually, and the organic matter containing ^{13}C was continuously decomposed, so that the δ^{13}C value of the 250–53 and <53 μm aggregates decreased. The microaggregates were continuously aggregated into >2000 and 2000–250 μm particle size aggregates, as a result, the δ^{13}C value of 2000 and 2000–250 μm aggregates showed a slight increase trend after 60 days.

3.2. Dynamics of δ^{13}C value in different soil aggregate fractions of red soil with rice straw treatment

Similar to happened in lime concretion black soil, the δ^{13}C value of organic carbon in the four-different particle-size aggregates of red soil in the Str treatment was significantly higher than that of the CK treatment (P<0.05), meanwhile the δ^{13}C values of four-different particle-size aggregates of red soil in the CK treatment showed little dynamic change (figure 2). The δ^{13}C values of different size aggregates of red soil in the Str treatment followed a decreasing order of 250–53, >2000, <53, 2000–250 μm at 15 days. With the extension of incubation time, the trend of δ^{13}C values of >2000 and 250–53 μm aggregates was decreasing, and the trend of δ^{13}C values of <2000 and <53 μm aggregates decreased firstly then increased. Finally, the δ^{13}C values of the microaggregate was higher than that of the macroaggregate, this showed the same trend as what happened in lime concretion black soil.
3.3. Distribution of fresh carbon in different particle-size aggregates

Soil aggregates were of great significance to soil carbon sequestration. The quantity of new organic carbon supplied by rice straw found in different levels of aggregates followed a same increasing order of 2000~250 μm < (>2000 μm) < (<53 μm) < 250~53 μm in red soil (table 2), accounting for 33.63%~37.40%, 29.27%~31.40%, 22.44%~22.79% and 10.89%~12.18% (table 3). This was consistent with the findings of Yin Yunfeng [10]. Yin Yunfeng et al found the fresh carbon supplied by rice straw was mainly found in the 53-250 μm fraction of water-stable aggregates after 112 days of incubation, making up 70.3%~75.3% of the total. In this study, the difference in the distribution of fresh carbon among different particle size aggregates was not significant for the two types of soil, the fresh carbon supplied by rice straw was mainly in the microaggregate in all these soils, making up 62.9%~68.8% of the total.

Table 2. Fresh carbon contents in different soil aggregate fractions (g·kg⁻¹).

| Incubation period/d | Soil type            | Different fractions of aggregates/μm | >2000 | 2000~250 | 250~53 | <53 |
|---------------------|----------------------|--------------------------------------|-------|----------|--------|-----|
| 15                  | red soil             | 3.43±0.26abA                        | 0.96±0.03cB | 3.77±0.47aA | 3.04±0.34bA |
|                     | lime concretion      | 2.13±0.15cA                        | 1.68±0.07cA | 4.26±0.76aA | 3.15±0.63bA |
|                     | black soil           |                                     |       |          |        |     |
| 60                  | red soil             | 2.69±0.13bB                        | 0.83±0.07cC | 3.37±0.68aAB | 2.63±0.17bB |
|                     | lime concretion      | 1.46±0.20cB                        | 0.66±0.02dB | 3.05±0.39aB | 2.00±0.21bAB |
|                     | black soil           |                                     |       |          |        |     |
| 120                 | red soil             | 2.04±0.32bC                        | 1.09±0.02cA | 3.01±0.54aB | 2.81±0.17aAB |
|                     | lime concretion      | 1.38±0.12cB                        | 0.67±0.02dB | 2.30±0.20aC | 1.80±0.14bA |
|                     | black soil           |                                     |       |          |        |     |

Note: Different lowercase letters indicate difference of significance at P<0.05 at the same treatments under the organic carbon in bulk soil and soil aggregates different in size fraction in the same incubation period, and different capital letters indicate difference of significance at P<0.05 at the same treatments under the soil aggregates same in size fraction in different incubation period. The same as below.

Table 3. Percentage of fresh carbon in different aggregate fractions to total fresh carbon in whole soil.

| Incubation period/d | Soil type            | Percentage of fresh carbon in different aggregate fractions (%) |
|---------------------|----------------------|---------------------------------------------------------------|
| 15                  | red soil             |                                                               |
|                     | lime concretion      |                                                               |
|                     | black soil           |                                                               |
| 60                  | red soil             |                                                               |
|                     | lime concretion      |                                                               |
|                     | black soil           |                                                               |
| 120                 | red soil             |                                                               |
|                     | lime concretion      |                                                               |
|                     | black soil           |                                                               |
4. Conclusion
Soil aggregates have a physical protective effect on organic carbon, which is the key to SOC stability. Through the comparison and analysis, we can find that the $\delta^{13}C$ value of organic carbon in different particle-size aggregates of the Str treatment was significantly higher than that of the CK treatment, the $\delta^{13}C$ value varied greatly both in red soil and lime concretion black soil, but the turnover rate of native soil organic carbon was slow and the degradation degree was relatively close. The quantity of new organic carbon supplied by rice straw found in different levels of aggregates followed a same increasing order of 2000–250 μm < (250–53 μm) < (53 μm) in red soil, the fresh carbon supplied by rice straw was mainly in the microaggregate in all these soils, making up 62.9%–68.8% of the total.

Acknowledgments
This work was supported by the Shaanxi focus on science and technology innovation team (2016KCT-23) and the Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Land and Resources of China. The author gratefully acknowledges the Institute of Land Engineering and Technology, Shanxi Provincial Land Engineering Construction Group, Xi’an, China.

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