Thinking from the Dark Earth in a Buried Ancient Paddy Soil

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Background

Global warming & GHGs

IPCC AR4 FAQ
China becomes the highest CO$_2$ emission country in the earth
Big challenges for the Chinese government to realize the carbon reduction target

To 2020, CO₂ emissions per unit of GDP will be reduced by 40-45% in China on the basis of 2005.
Carbon reduction technologies

1) Carbon Capture and Sequestration (CCS) technology
   - Forestry measures
   - Ocean sequestration
   - …

2) Carbon reduction
   - Agricultural Sources
   - Industrial Sources
   - Domestic Sources
   - …
Contribution of agriculture/paddy soil on the global GHGs emission

(Khalil, et al. 2006)
**Chemical fertilizer**

The chemical fertilizer was increased from $8 \times 10^6$ t in 1978 to $4.3 \times 10^7$ t in 2003, and increased by 4 times.

1) Massive production results in serious energy input (carbon emission) and environmental pollution.

2) Low utilization rate of chemical fertilizer lead to nutrient losses from agriculture land, and become a main contributor to water eutrophication.

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- **Large amount of fertilizer**

  - Energy input
  - Air pollution
  - Serious nutrient run-off
Current situation of soil quality in China

- Low organic matter content: average 1% in China
- Large area of middle and low yield arable land
- Lack of nutrients

![Pie chart showing arable land of different yield in China (1996)]

(Xu Minggang, 2008)
How to achieve the target for carbon reduction in agriculture!

On the basis of decreasing GHGs emission, maintaining high yield of food, declining amount of chemical fertilizer use, improving soil quality……
Terra Preta-Amazonian Dark Earth

- Terra Preta soil has high content of charcoal/biochar, the carbon content is up to 15%, compared with 2-3% in adjacent soils.
- Radiocarbon dating revealed charcoal ages of up to 7000 years (Neves et al., 2001)
Biochar:

**Characteristics**

- High content of C
- Great porosity
- Large surface area
- High charge density
- Great negative surface charge
Biochar: High stability

- High aromaticity makes it lack of (bio)chemical reactivity and strongly resist decomposition.
- Present for several hundred to thousand years.

(Glaser, 2007)

(Lehnman, 2006)
What about the stability of biochar in paddy soil?

Can straw charcoal be sequestrated in soil?

…
Recent discovery of a Chinese Ancient Paddy Soil

Archaeological site
The collected soil sample
Large amount of straw charcoal in the black layer of ancient paddy soil can be obviously identified.
Quantification of TOC and BC contents

TOC of current paddy soils in China is 10-20 g/kg.
**NMR spectra of charcoal in ancient paddy soil**

Table **Quantitative NMR spectral analysis** of charcoal from ancient paddy soil

<table>
<thead>
<tr>
<th>Moieties</th>
<th>carbonyls</th>
<th>aromatics</th>
<th>alkyls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (ppm)</td>
<td>210-165</td>
<td>165-90</td>
<td>45-0</td>
</tr>
<tr>
<td>charcoal</td>
<td>14.57</td>
<td>83.3</td>
<td>2.13</td>
</tr>
</tbody>
</table>
FTIR spectra of charcoal

- FTIR spectra of char in ancient paddy soil is similar to straw char.
- Compared with 500 ℃ 3h, aliphatic C-H stretching was declined in the others.
- Greater aromatic C=C (double bond) stretching vibrations (1600 cm⁻¹) in char from ancient paddy.
- C-O-C stretching (1100 cm⁻¹) was the smallest amount in char from the ancient paddy soil.

500 ℃ 3h: fresh produced rice straw char
SC: rice straw char collected after burying into field 1 year.
All samples have analogous diffractogram patterns.

Sharp peaks indicate miscellaneous inorganic components, and is consistent with the high percentage of ash. Compare to PDF card, most of them are $\text{SiO}_2$, $\text{CaCO}_3$, KCl.

The broad (002) peaks indicate the structural differences between chars and graphite.

Fig. XRD spectra of charcoal
SEM-EDX analysis of the straw charcoal

The ancient straw charcoal has great porosity. O/C was higher in the exterior than that of interior.

Fig. SEM-EDX spectra of charcoal from ancient paddy soil
Burying biochar into soil could be a possible way for CCS.
Potential CO₂ reduction from straw-char in China

- Straw yield in China was approximately 700 Mt/yr
- Potential CO₂ reduction: ~73 Mt/yr

In terms of 20% of straw converted to biochar, 30% rate of production, 50% carbon content, and 5% mineralized
Effect of biochar amendment on GHGs emission from paddy soil
**Results from upland studies**

In greenhouse experiments, NO$_x$ emissions were reduced by 80% and CH$_4$ emissions were completely suppressed with biochar additions of 20 g kg$^{-1}$ to a forage grass stand. *(Rondon et al. 2005)*

Charcoal: made from municipal biowaste

*(Spokas et al. 2009)* *(Yanai et al. 2007)*
**Our research**

**Effect of biochar amendment on CH₄ emission from paddy soil**

- Amendment of both kinds of biochar could significantly reduce CH₄ emission from paddy soil.

- CH₄ emission from the paddy soil amended with 2.5% BC and SC reduced by 51.1% and 91.2%, respectively as compared with non-amendment control soil.

- CH₄ reduction with biochar amendment could also be observed with straw addition.
Effect of biochar amendment on CO₂ emission from paddy soil

- Lower amount of CO₂ emission from the waterlogged paddy soil with the addition of biochar was observed during the incubation. But there were no significant differences among CK, BC and SC.

- Addition of rice straw could significantly increase CO₂ emission from paddy soil. But only high biochar amendment rate would result in significantly CO₂ emission reduction on day 49.
Effect of biochar amendment on methanogenic activity in paddy soil

- Addition of both kinds of biochar resulted in the significant decrease of methanogenic activity in soil over the whole incubation period.

- In corresponding to the pattern of CH$_4$ emission, inhibition was more significant in soil with SC amendment as compared with BC amendment.

- Under straw addition, inhibition of CH$_4$ emission was only observed on day 7 and 14.
**Effect of biochar amendment on methanogenic diversity in paddy soil**

DGGE profiles of methanogen were quite similar to each other, with no apparently visible differences between the patterns for all treatments. It indicated that compositions of the methanogenic bacteria have no significant changes after the addition of biochar in 49 days.
Effect of biochar amendment on the rice production
Influence on rice height and yield

CK: control
BC: bamboo char
SC: rice straw char
CKU: urea
BCU: bamboo char + urea
SCU: rice straw char + urea
SRU: slow released fertilizer
Reducing chemical fertilizer application rate

general amount of fertilizer

rice straw charcoal + less amount of fertilizer
Charcoal coated slow released fertilizer

SRF1: charcoal coated slow released fertilizer1
SRF2: charcoal coated slow released fertilizer2
Influence on concentration of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^\text{-N}$ in surface water

CK: general amount of fertilizer
BC: bamboo char + CK
SC: straw char + CK
SCL: straw char + less CK
RS: rice straw + CK
SRF1: charcoal coated slow released fertilizer1
SRF2: charcoal coated slow released fertilizer2
**Perspectives**

- Put straw into field???

- Put straw biochar into field

- C sequestration
- Decline GHGs emission
- Increase crop yield
- Decrease amount of chemical fertilizer use
- Reduce nutrient run-off
- Improve soil quality
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