Effects of Soil Microbial Fertility by Charcoal in Soil

Charcoal!

Effects on microorganism propagation and plant growth, and future prospect to sequester CO2

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The amounts of consumed and imported charcoal in Japan
Marketing of new-use charcoal except for fuel in Japan (Charcoal Asoc.1999)

- Activate charcoal, briquette charcoal, charcoal powder
- Charcoal powder for Soil conditioner
  - Soil properties: acid soil, water holding
  - Soil microorganisms

Materials for construction
- Conditioner of humidity in house, - Thermal conditioner in wall,

- Water purification 0.5%
  - Cleaning bath water 1.1%
- Greening/gardening 3.6%
- Golf course 4.0%
- Conditioning of humidity 17.9%
- Agriculture 30.6%
- Live stock industries 22.3%
- Others 20.0%
- Total 50,835 ton

- Under floor in house
- Deodorizer
1. Characteristics of Charcoal and It’s Functions
Characteristics and Functions of Charcoal

1. Porous substance with high water and air holding capacity; Suitable habitat for some microbes and plant growth, good material for soil amendment, absorption of chemicals and humidity control

2. High alkalinity; Neutralization of acidic soil and improvement of chemical components of soil and selection of microorganisms

3. Non organic matter; Exclusion of saprophytes and propagation of autotrophic and symbiotic microorganisms, free living nitrogen fixing bacteria, root nodule bacteria, Frankia and some mycorrhizal fungi

4. Low mineral content; “Charcoal has no roles as a fertilizer”

Composition of bark charcoal %
 Carbon: 77.58, Volatile Substances: 12.92, Ash: 9.50

Mineral contents of ash %
 SiO$_2$: 36.5, Al$_2$O$_3$: 10.9, CaO: 19.2, K$_2$O: 1.1, Na$_2$O$_3$: 5.35, Fe$_2$O$_3$: 7.5, MgO: 10.3, P$_2$O$_5$: 1.7

# Air supply by charcoal induces the activation of soil microbes and CO$_2$ emission temporarily. Small amount of chemical fertilizers or organic matters should be mixed with charcoal in agricultural use.
Improvement of soil physical properties by charcoal application.

\[ Y = 17.37 + 0.31X \]

\[ R^2 = 0.918 \]

Change of Available Water by charcoal application.

Change of Water Permeability by charcoal application.
2. Effects on Ectomycorrhiza and Tree Growth

Trees, Mycorrhizae, Mushrooms and Charcoal
Application of charcoal to rehabilitation of declined pine tree (Ito 1998)
Recovering of Pine Tree from Wilting by Charcoal Treatment after a year

The growth of pine root and mycorrhiza formation started at 5 to 6 months after treatment.

Inoculation Effect of ectomycorrhizal fungi to Dipterocarps in Indonesia (Ogawa 1989)

Fruitbody of Scleroderma

No-inoculation                 Inoculated seedling
Stimulation of Ectomycorrhiza Formation on Dipterocarps root by Charcoal Application in Pot Soil
3. Effects on Root Nodule Formation and Soy bean Yield

+Char coal

-Control +phosphate

-Char coal

+Phosphate
Yield of Soy Bean Cultivated by Charcoal with Fertilizers

The amount of fertilizer was adjusted 1% of charcoal in weight. The yield was estimated in average of 30 plants.

(M. Ogawa 1983)

<table>
<thead>
<tr>
<th>Materials used</th>
<th>Pod number</th>
<th>Grain weight g./plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical fertilizer (NPK 8:8:8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100g/m²</td>
<td>85</td>
<td>9.0</td>
</tr>
<tr>
<td>200g/m²</td>
<td>106</td>
<td>13.6</td>
</tr>
<tr>
<td>Charcoal only 500 g/m²</td>
<td>28</td>
<td>1.7</td>
</tr>
<tr>
<td>1500 g/m²</td>
<td>15</td>
<td>1.2</td>
</tr>
<tr>
<td>Charcoal with super phosphate 500</td>
<td>113</td>
<td>14.6</td>
</tr>
<tr>
<td>Charcoal with super phosphate 1500</td>
<td>66</td>
<td>10.1</td>
</tr>
<tr>
<td>Charcoal with Ammonium sulphate 500</td>
<td>97</td>
<td>11.1</td>
</tr>
<tr>
<td>Charcoal with Ammonium sulphate 1500</td>
<td>102</td>
<td>10.5</td>
</tr>
<tr>
<td>Charcoal with Urea 500</td>
<td>96</td>
<td>11.1</td>
</tr>
<tr>
<td>Charcoal with Urea 1500</td>
<td>89</td>
<td>7.6</td>
</tr>
<tr>
<td>Charcoal with NPK fertilizer 500</td>
<td>115</td>
<td>10.9</td>
</tr>
<tr>
<td>Charcoal with NPK fertilizer 1500</td>
<td>80</td>
<td>9.6</td>
</tr>
<tr>
<td>Charcoal with oil cake 500</td>
<td>96</td>
<td>10.9</td>
</tr>
<tr>
<td>Charcoal with oil cake 1500</td>
<td>106</td>
<td>12.6</td>
</tr>
<tr>
<td>Control (non treatment)</td>
<td>39</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Effects of rice husk charcoal on the growth of soybean and Maize in Indonesia (Igarasi 1996)
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Basical application</th>
<th>Additional application</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N-P$_2$O$_5$-K$_2$O</td>
<td>Lime</td>
</tr>
<tr>
<td></td>
<td>Kg/ha</td>
<td>t/ha</td>
</tr>
<tr>
<td>A No</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B No + C</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C F</td>
<td>25 - 60 - 30</td>
<td>0</td>
</tr>
<tr>
<td>D F + C</td>
<td>25 - 60 - 30</td>
<td>0</td>
</tr>
<tr>
<td>E L</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>F L + C</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>G L + F</td>
<td>25 - 60 - 30</td>
<td>5</td>
</tr>
<tr>
<td>H L + F + C</td>
<td>25 - 60 - 30</td>
<td>5</td>
</tr>
</tbody>
</table>

Soil amendment plan by rice husk charcoal, lime and fertilizer.

Three kinds of materials were mixed with top soil before the experiment. C: charcoal, F: fertilizer, L: lime. Chemical fertilizer was supplied at 6th crop and charcoal at 5th and 6th.
Effect of rice husk charcoal on the yields of soybean and peanut under different soil condition (Igarasi 1996)

Soybean, peanut and corn were cultivated alternately in the same field. The yield in the plots with charcoal, lime and fertilizer showed the highest yield in any crop.
Maize was planted after soy bean without fertilizer

- Chemical fertilizer
- Fertilizer + Charcoal
- Control
- Charcoal only
Effect of charcoal on the root growth and nodule formation of Acacia mangium in Indonesia (Okimori, Yamato 2000)

Forest floor of Acacia plantation was covered by rice husk charcoal 5 cm in depth. Earthworm population increased soon after the treatment because of neutralization of top soil.
Acacia’s root growth started after three months and root biomass increased.

Root nodule formation was stimulated in charcoal, but the growth response was not so clear after 3 years.
4. Charcoal as a material for immobilization of useful microorganisms (Spores of bacteria, root nodule bacteria, mycorrhizal fungi, Frankia etc)

Cross section of the root nodules formed by *Frankia* sp.

Root nodules of *Myrica rubra*
Isolated colony of *Frankia* sp. using of Frankia medium

Cultivation of *Frankia* sp. using of modified Q-mod liquid medium

*Frankia* and other nitrogen fixing bacteria can be immobilized in charcoal.
Charcoal compost is produced being mixed with live stock excretes and fermented. Some thermophilic bacteria which have high productivity of antibiotics propagate in charcoal.

Effect of Charcoal Compost on Soil Disease Control

Bacterial disease was controlled by the charcoal compost.
5. Effect of Charcoal on VA mycorrhizal Fungi and Plant Growth

Spore of VA mycorrhizal fungi, Gigaspora margarita

VA mycorrhiza is essential for phosphate and mineral absorption of many plants

Vesicle

Arbuscule

VA mycorrhiza formed on soy bean root
Charcoal is good habitat for some VA mycorrhizal fungi. The germination rate of G. margarita was higher than that on soil (Ogawa 1991).

The hyphae growing from spore base invade into the charcoal pore with larger size.
Effect of inoculation of VA mycorrhizal fungi and charcoal use (Ogawa 1985)

Cucumber

Control Spore inoculated with charcoal

Apple tree seedling

Control Three species were inoculated with charcoal
The frequency of free living nitrogen fixing bacteria in subtropical soil is generally higher than those in temperate zone (Asou et al. in 1924). Bacterial population including aerobic nitrogen fixing bacteria (Beijerinckia) increased when charcoal powder was mixed with top soil in Indonesia. Nitrogen fixation seems to be promoted by charcoal application or shifting cultivation in tropical region. (Ogawa 1992)
Effect of bark charcoal and fertilizer on the plant growth and soil properties in south Sumatra (Yamato 2004 unpublished)
Effect of charcoal application on *Vigna sequipedalis*

Total weight (f.w.) of harvested seed pod (g/m²)

Site 1
- **First**: Control, Fertilizer, Fertilizer & Charcoal
- **Second**: Control, Fertilizer, Fertilizer & Charcoal

Site 2
- **First**: Control, Fertilizer, Fertilizer & Charcoal
- **Second**: Control, Fertilizer, Fertilizer & Charcoal

Average ± S.D.
Effect of charcoal application on *Zea mays* L

Total weight (f.w.) of harvested corn (g/m²)

**Site 1**

**First**

- Control
- Fertilizer
- Fertilizer & Charcoal

**Second**

- Control
- Fertilizer
- Fertilizer & Charcoal

**Site 2**

**First**

- Control
- Fertilizer
- Fertilizer & Charcoal

**Second**

- Control
- Fertilizer
- Fertilizer & Charcoal

Average ± S.D.
## Soil analysis

### Site 1 (First experiment)

<table>
<thead>
<tr>
<th></th>
<th>pH (H₂O)</th>
<th>pH (KCl)</th>
<th>Total C (%)</th>
<th>Total-N (%)</th>
<th>P₂O₅ (ppm)</th>
<th>K₂O (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Exp.</td>
<td>3.9</td>
<td>3.9</td>
<td>1.63</td>
<td>0.17</td>
<td>47.8</td>
<td>75</td>
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<tr>
<td>After harvest of first experiment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>V. sequipedalis</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>con</td>
<td>4.2</td>
<td>3.9</td>
<td>2.00</td>
<td>0.12</td>
<td>25.4</td>
<td>40</td>
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<tr>
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<td>4.1</td>
<td>3.9</td>
<td>1.85</td>
<td>0.18</td>
<td>44.0</td>
<td>59</td>
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<tr>
<td>charcoal</td>
<td>5.3</td>
<td>4.8</td>
<td>1.62</td>
<td>0.16</td>
<td>91.8</td>
<td>140</td>
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<tr>
<td><em>Z. mays</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>con</td>
<td>4.0</td>
<td>3.8</td>
<td>1.44</td>
<td>0.17</td>
<td>22.0</td>
<td>40</td>
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<tr>
<td>fertilizer</td>
<td>4.0</td>
<td>3.8</td>
<td>1.62</td>
<td>0.19</td>
<td>44.5</td>
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<tr>
<td>charcoal</td>
<td>5.1</td>
<td>4.5</td>
<td>2.44</td>
<td>0.24</td>
<td>80.2</td>
<td>90</td>
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<td><em>A. hypogaea</em></td>
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<tr>
<td>con</td>
<td>4.2</td>
<td>3.9</td>
<td>1.85</td>
<td>0.19</td>
<td>55.3</td>
<td>60</td>
</tr>
<tr>
<td>fertilizer</td>
<td>4.0</td>
<td>3.9</td>
<td>1.85</td>
<td>0.18</td>
<td>137.5</td>
<td>60</td>
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<tr>
<td>charcoal</td>
<td>5.1</td>
<td>4.6</td>
<td>2.53</td>
<td>0.25</td>
<td>176.0</td>
<td>120</td>
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</tbody>
</table>
## Soil analysis cont.

### Site 1 (First experiment) : continued

Below is a table showing the exchangeable cation content of soil samples after various treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>CEC (meq/100g)</th>
<th>1N CH₃COONH₄</th>
<th>1N KCl</th>
<th>Base saturation (%)</th>
<th>Al³⁺</th>
<th>H⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before Exp.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10.12</td>
<td>1.21</td>
<td>0.30</td>
<td>0.15</td>
<td>18.9</td>
<td>2.67</td>
</tr>
<tr>
<td><strong>After harvest of first experiment</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>V. sequipedalis</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>con</td>
<td>10.81</td>
<td>1.30</td>
<td>0.24</td>
<td>0.08</td>
<td>15.7</td>
<td>2.49</td>
</tr>
<tr>
<td>fertilizer</td>
<td>10.66</td>
<td>1.01</td>
<td>0.28</td>
<td>0.12</td>
<td>13.4</td>
<td>2.81</td>
</tr>
<tr>
<td>charcoal</td>
<td>16.42</td>
<td>7.80</td>
<td>0.43</td>
<td>0.29</td>
<td>52.7</td>
<td>0.02</td>
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<tr>
<td>Z. mays</td>
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<tr>
<td>con</td>
<td>9.87</td>
<td>0.80</td>
<td>0.20</td>
<td>0.12</td>
<td>13.6</td>
<td>2.93</td>
</tr>
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<td>10.23</td>
<td>0.79</td>
<td>0.18</td>
<td>0.12</td>
<td>11.3</td>
<td>2.97</td>
</tr>
<tr>
<td>charcoal</td>
<td>12.72</td>
<td>6.21</td>
<td>0.45</td>
<td>0.25</td>
<td>55.3</td>
<td>0.12</td>
</tr>
<tr>
<td>A. hypogoea</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>con</td>
<td>10.21</td>
<td>1.27</td>
<td>0.29</td>
<td>0.08</td>
<td>16.7</td>
<td>2.41</td>
</tr>
<tr>
<td>fertilizer</td>
<td>10.01</td>
<td>0.91</td>
<td>0.22</td>
<td>0.10</td>
<td>12.6</td>
<td>2.77</td>
</tr>
<tr>
<td>charcoal</td>
<td>12.66</td>
<td>5.98</td>
<td>0.37</td>
<td>0.18</td>
<td>52.1</td>
<td>0.15</td>
</tr>
</tbody>
</table>
7. Effective Sequestration of CO2 in Atmosphere and its Inactivation in Agriculture and Natural Environment

- Carbohydrates in wood (Cellulose, Hemicellulose, Lignin)
- CO2 in atmosphere
- Photosynthesis by green plants
- Harvesting and utilization for timber, pulp etc.
- Carbonization of wood wastes etc
- 25~70% of wood turns to charcoal by carbonization
- 80% of wood charcoal is pure carbon

Expansion of carbon-sink and carbon sequestration are a pair of wheels
Carbon sequestration project by charcoal utilization and forestation in South east Asia

CCF Scheme (Carbon Sequestration by Charcoal Utilization and Forestation) proposed by M. Ogawa in 1998

Logging & replantation of Acacia
- Harvesting
- 8-year Rotation
- Charcoal application in replanting

Dipterocarp plantation

Charscoal application

Logs
- Oilpalm, Coconut-palm, Rubber, Paddy
- Stems branches
- Chips
- Bark, chipdust

Carbonization
- Agriculture waste
- Flat kiln
- Charcoal wood & powder

Electric supply
- Power generation

Compost with charcoal
- Improving soil, Raising fertility

Agriculture, Agroforestry

Fuel
- Water purification
- Electrification in rural region
- Sewage
- Urban region

(KEPCO and Min.of Environment 2000~)
Recycling system of biomass waste for Carbon sequestration, a trial in Japan 2000

(Ogawa, RITE, METI, and EBARA 2001~2003)