NUCLEAR TECHNIQUE OF SOIL MANAGEMENT FOR SUSTAINABLE AGRICULTURE

Sueo Machi, Fellow, Japan Atomic Energy Agency
Former DDG-NA, IAEA
Climate Change Threatening Mankind

"15,000 French died by heat wave in 2003"

The politics of heat waves • By Eric Klinenberg

Victims of a hot climate and a cold society

Dr. Lucien Abenhaim, France's director general for health, resigned this week after acknowledging that up to 5,000 French citizens died during the recent heat wave. The minister for the aged said Thursday the number of victims should prevent fatal symptoms. The morgues reached capacity and refrigerated trucks arrived to store the cadavers. Commentators noted that the victims had accessed the two forms of assistance that would have saved them, artificial cooling and medical attention, only after they

Reduction of CO2 emission by 50% from 1990 level before 2050 is essential to avoid destructive climate change (Global consensus)

IAEA FAO Syno. Soil, 23-26
July, 2012 S.Machi
Concern for Accelerated Global Warming by Increasing Fossil Fuel Burning under BAU Policy (Int. Energy Agency)

- Some 70% of world power supply is from fossil fuels causing increase CO2 emission (IEA)
- 70% of power in India and China with large population of 2.4 billion is produced by coal burning power station
- Nuclear power is still only 7% of primary energy
- Increasing nuclear power is essential for mitigation of climate change
Nuclear Techniques for Sustainable Agriculture and Food Security

- Improved soil management by using nuclear techniques
- Mutation breeding to develop crop varieties resistant to environmental stress
- SIT to protect crops and animals from insect pest with reduced application of pesticides
- Food irradiation to decrease post harvest loss
- Isotope hydrology for better fresh water resource management
Useful Nuclear Techniques to Improve Soil Management

• To study interaction of plant with soil, nutrient, and water using isotopes
• To study soil erosion and movement by isotope tracer
• To improve soil quality by extension of bio-fertilizer produced by radiation technology
• To improve soil quality by recycling sewage sludge to soil after sterilization by radiation
• To develop soil conditioner for agriculture in arid region using hydro-gel produce by radiation
Bio-Fertilizer of Rhizobium
Increasing Yield of Grain Legume
- To reduce chemical fertilizer -

**with Rhizobium**

**Mungbean**  
**Soybean**

**Environmentally friendly.**  
**Less expensive**
### Increase in Yield and Income by Application of *Rhizobium* Biofertilizer (Thailand, ‘07)

<table>
<thead>
<tr>
<th>Host plant</th>
<th>Season, Location</th>
<th>Increased yield (%)</th>
<th>Increased income (baht/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean</td>
<td>Rainy, 2534</td>
<td>49.4</td>
<td>4,056.25</td>
</tr>
<tr>
<td></td>
<td>10 plots</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peanut</td>
<td>Rainy, 2534</td>
<td>34.0</td>
<td>3,718.75</td>
</tr>
<tr>
<td></td>
<td>Ubonratchathani</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yard long bean</td>
<td>Dry, 2536</td>
<td>25.6</td>
<td>30,875</td>
</tr>
<tr>
<td></td>
<td>Udonthani</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweet pea</td>
<td>Dry, 2536</td>
<td>52.2</td>
<td>25,650</td>
</tr>
<tr>
<td></td>
<td>Chiang Rai</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Chirasak, 2000)
Biofertilizer Application to Improve Soil

- Biofertilizer benefits farmers by increasing crop yield and improving soil by reducing chemicals.
- In order to further extend bio-fertilizer application, QA/QC of inoculants should be improved.
- **Sterilization of carrier** by radiation instead of conventional high pressure steam can provide **quality assured and long shelf life bio-fertilizer inoculants**.
The application of radiation sterilization of carrier for commercial biofertilizer production will be expanded.
Radiation Sterilization of Carriers:
- Suitable for large production: Efficient/less labor
- Better quality assurance

Indonesia

Sterilization by irradiation

- Box Size: 30 x 30 x 58 cm
- Package Nos: 900 pcs
- 25kg for irradiation box
- 16 boxes (400kg) in one time

Sterilization by autoclave

- Container size: 3 kg in one time

<table>
<thead>
<tr>
<th>Size</th>
<th>Packages nos</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>20</td>
</tr>
</tbody>
</table>
The Bucillus population in the biofertilizer made from peat soil was decreased gradually in the γ-sterilized carrier, while it was decreased sharply in the carrier sterilized by high temperature steam in autoclave.
Growth and survival of *Azospirillum TS13* in radiation vs. heat sterilized carriers (Thailand)

<table>
<thead>
<tr>
<th>Storage period (days)</th>
<th>Autoclave 110°C 45 min (x10^6 cells/g)</th>
<th>Gamma-rays 14.4 kGy. Keep 10°C (x10^6 cells/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell number before mixing</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td>0</td>
<td>3.3</td>
<td>160</td>
</tr>
<tr>
<td>30</td>
<td>7.9</td>
<td>140</td>
</tr>
<tr>
<td>90</td>
<td>13</td>
<td>130</td>
</tr>
<tr>
<td>180</td>
<td>0.35</td>
<td>3.3</td>
</tr>
<tr>
<td>360</td>
<td>0.23</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Mycorrhiza fungi living in the plant root
Recycle of Sewage Sludge in Soil

- Sewage sludge contains nutrient and organic matters to be recycled in soil for better management
- Sewage sludge should be sterilized before application to soil to remove pathogenic microorganism
- Radiation is the most effective way to sterilize sewage sludge
- In India this technology is commercially used
Success Story of Commercial Application of Irradiated Sewage Sludge for Agriculture in India
Radiation Sterilization of Sludge for Fertilizer -Commercial Application in India-
Radiation Treatment of Sewage Sludge in India

- Radiation source: Co-60 500 Ci
- Sludge treatment capacity: 110 cu.m./day of liquid sludge
- Radiation dose: 3 – 4 kGy
- Pathogen reduction factor: 6 – 7 log cycles
- Plant area: 400 sq.m.
Drying Irradiated Sludge by Solar Energy
Irradiated Sludge: Good Carrier of Rhizobium Biofertilizer

<table>
<thead>
<tr>
<th></th>
<th>CFU*/ML (unirradiated)</th>
<th>CFU*/ML (irradiated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total bacterial count</td>
<td>2x10^6</td>
<td>8x10^2</td>
</tr>
<tr>
<td>Fecal coliform count</td>
<td>1x10^5</td>
<td>38</td>
</tr>
<tr>
<td>Rhizobium count</td>
<td>4x10^7</td>
<td>9x10^9</td>
</tr>
</tbody>
</table>

CFU = Colony forming units

Water Environment Research 77 (2005)
Testing of irradiated sludge as a fertilizer under the supervision of agriculture experts in Vadodara, India

- Soil condition improves considerably after application of hygienised sludge
- The hygienised sludge is an ideal medium for nitrogen fixing bacteria like Rhizobium to produce bio-fertilizer.
Super Water Absorbent (SWA) for Soil Conditioner in Semiarid /Arid Region

- Hydrogel SWA is effectively produced from natural polymers, such as cassava starch by radiation cross-linking or radiation grafting
- 1 gram of the SWA absorbs 400 – 500 gram of water
- Soil mixed with small amount of SWA can retain longer the scarce rain or irrigated water

Field tests in Vietnam showed crop yield increase by 10-30% by the use of SWA
1 g of SWA absorbs 400-500 g water

Swollen by water

Before swelling
Yield Increase of Crops by SWA Soil Conditioner (Vietnam)

<table>
<thead>
<tr>
<th>Crops</th>
<th>SWA kg/ha</th>
<th>Yield increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>40</td>
<td>28.8 %</td>
</tr>
<tr>
<td>Cabbage</td>
<td>40</td>
<td>15.4</td>
</tr>
<tr>
<td>Peanuts</td>
<td>30</td>
<td>16.3</td>
</tr>
<tr>
<td>Peanuts</td>
<td>40</td>
<td>21.1</td>
</tr>
<tr>
<td>Cotton</td>
<td>30</td>
<td>31.1</td>
</tr>
<tr>
<td>Grape</td>
<td>50</td>
<td>29.8</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>60</td>
<td>19.8</td>
</tr>
<tr>
<td>Cassava</td>
<td>60</td>
<td>22.8</td>
</tr>
</tbody>
</table>
Field Test of SWA for Lily Plant: Vietnam

With SWA

With SWA

Without SWA

1 week

2 weeks

S.Machi
Field Test of SWA for Lily Plant: Vietnam

12 weeks
SWA Production in Vietnam

- Scarce rain water and irrigated water in arid and semi-arid region can be saved by using SWA from **natural polymers** as soil conditioner
- The Ministry of Agriculture and Rural Development in Vietnam permits the production of SWA by **radiation grafting of AAc on starch** as a soil conditioner in Vietnam in 2006
Plant Growth Promoter (PGP) Produced by Radiation Increasing Crop Yield

- Raw material is natural polymers such as chitosan from crab & shrimp shells, and seaweeds (carageenan, alginate)
- Radiation degrades chitosan and carageenan to lower molecular weight oligo-chitosan and oligo-carageenan, which promote plant growth and give plant disease resistance
Chitosan and Alginate/Carageenan:

Chitosan

Alginate
Oligo-chitosan produced by radiation degradation: Used for red chili, rice, tomato, potato, carrot:
Yield increase of 5-50% (Vietnam, Japan, Indonesia, Malaysia: Semi Commercial appl.)

Success story in Indonesia (BATAN)
Radiation produced oligochitosan enhances growth rate of seedling of rice (Malaysia)

Malaysia
2011

Yield increase:
24%

Treated with commercial product Treated with oligochitosan

Philippines:
Rice: 25% yield increase by irradiated Carageenan (‘11)
Nuclear Analytical Technique for Studying Interaction of Plant with Soil, Nutrient and Water

- New technique: Positron-Emitting Tracer Imaging System (PETIS)
  - C-11: CO2,
  - N-13,
  - Na-22: NaCl
  - Cd-107
Positron Imaging Experiment in JAEA

Takasaki Ion Accelerators for Advanced Radiation Application (TIARA)

AVF cyclotron

Produce radionuclide using ion beam

Purification & labeling

PETIS imaging

Monitor radiation from tracer

Positron-emitting tracers

<table>
<thead>
<tr>
<th></th>
<th>$^{11}$CO$_2$, $^{13}$N$_2$, $^{13}$NH$_4^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>nutrient</td>
<td><strong>52</strong>Mn, <strong>52</strong>Fe, <strong>62</strong>Zn</td>
</tr>
<tr>
<td>toxic substance</td>
<td><strong>107</strong>Cd</td>
</tr>
</tbody>
</table>
PETIS (positron-emitting tracer imaging system) provides **non-invasive, time-course and quantitative** visualization of **radiotracers** in intact plant bodies, like video camera.

- **(ex.) Carbon translocation in an intact hemp plant**

A pair of detector heads are installed in a growth chamber for plants.

The test plant is placed in the mid-plane of them.

- **Pixel size** 1.1 mm × 1.1 mm
- **Field of view** 12.0 cm × 18.7 cm
Objective: Behavior of Toxic Metal, Cd, in Rice Plant

Cd contamination of irrigated rice is one of the most major agricultural problems in the world.

- How fast Cd travels in rice?
- Where is the site of xylem-to-phloem transfer?

Cd accumulated strongly in shoot base

(Vegetative stage)

(IAEA FAO Syno, Soil, 23-26 July, 2012)
Results

Nodes are sites where xylem-to-phloem transfer of Cd occurs.

Cd reached panicles at 7 h after feeding and accumulate at 0.5 % of total fed Cd/day.

Conclusions

- Isolation of xylem-to-phloem transporter gene
- Genetic regulation of xylem-to-phloem transporter
- Selection of variety possessing this genetic background

Strategies
Elucidation of salt-tolerance mechanism in plants

**22**Na (half-life: 2.60 years): commercially available

Salinity: The major problems facing agriculture in arid and semiarid regions.

- Common reed (Salt-tolerant)
- Rice (Salt-sensitive)

Different from rice, common reed has a mechanism that does not transport salt from roots to shoots.

Feed **22**Na to roots
Sustainable food production to reduce the load for an environment

13N (half-life: 9.97 min): CO₂ gas was irradiated with proton beams

[13N] N₂ was isolated by gas chromatography (<15 min)

Symbiotic nitrogen fixation

Soybean with nodules (Left), or without nodules (right)

Symbiotic nitrogen fixation in intact soybean plants is visualized non-invasively using PETIS for the first time!

Nitrogen fixation rate: 7 μg N₂ h⁻¹

Soybean with nodules

Nitrogen fixation rate: 7 μg N₂ h⁻¹

Symbiotic nitrogen fixation in intact soybean plants is visualized non-invasively using PETIS for the first time!

Sustainable food production to reduce the load for an environment

Challenges for Application of New Nuclear Techniques for Improving Soil Management

- Nuclear research organizations in MSs which is developing nuclear techniques should have **good linkage with agriculture sectors, end-user of the techniques**
- IAEA /FAO can support MSs to enhance linkage between nuclear sector and agriculture sector for promoting extension of nuclear technique in end-users including farmers through CRP and TC project
Thank you for your attention!
machi.sueo@jaea.go.jp