Environmental and economic performance of paddy rice and upland crop rotation in Japan: a comparison between organic and conventional systems

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Kiyotada Hayashi

National Agriculture and Food Research Organization, Japan
An overview of organic farming in Japan

### Cultivation area (ha) (year: 2010)

<table>
<thead>
<tr>
<th></th>
<th>Paddy</th>
<th>Upland</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>2,496,000</td>
<td>2,097,000</td>
<td>4,593,000</td>
</tr>
<tr>
<td>Organic</td>
<td>6,981 (0.28%)</td>
<td>9,276 (0.44%)</td>
<td>16,417 (0.36%)</td>
</tr>
</tbody>
</table>

### Amount of production (t)

<table>
<thead>
<tr>
<th></th>
<th>Rice</th>
<th>Soya bean</th>
<th>Wheat, Barley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>8,474,000</td>
<td>230,000</td>
<td>853,000</td>
</tr>
<tr>
<td>Organic</td>
<td>25,565 (0.30%)</td>
<td>1,169 (0.51%)</td>
<td>1,042 (0.12%)</td>
</tr>
</tbody>
</table>

MOA natural farming and culture foundation (2011)

### Certified abroad (t)

<table>
<thead>
<tr>
<th></th>
<th>Rice</th>
<th>Soya bean</th>
<th>Wheat, Barley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic (Imported)</td>
<td>14,558</td>
<td>103,784</td>
<td>8,185</td>
</tr>
</tbody>
</table>

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Variety of organic rice farming in Japan

Mechanical weeding

Paper mulching

Rice bran application

Rice-duck
Paddy rice and upland crop rotation

• “Paddy rice and upland crop rotation” is widely practiced in Japan because rice is always in surplus.
• Crop rotation has various benefits.
  – Technically
    Suppression of weeds
    Reduction of plant disease risk
    Symbiotic N$_2$ fixation by planting beans
    Decrease environmental impacts
  – Economically
    Increasing rice yields following soya beans
    Higher direct payment for upland crops than for rice
    Increase agricultural profitability
Outline of the study

• Objectives
  – To evaluate the environmental and economic effects of introducing crop rotation in organic paddy fields
  – To confirm whether tradeoffs exist between them

• Comparisons
  – Organic farming vs. Conventional farming
  – Continuous rice cropping vs. Crop rotation

• Indicators
  – Environmental impact
    (Global warming, Acidification, Eutrophication, Non-renewable energy consumption)
  – Annual income (and yield for reference)
Data collection for paddy rotation

Tochigi Prefecture

Cultivated paddy (lowland) area
- Rice: 67,600 ha
- Wheat: 2,270 ha
- Two-row barley: 9,700 ha
- Six-row barley: 1,610 ha
- Soya beans: 3,240 ha

Crops for the evaluation
- Rice
- Two-row barley
- Soya bean

Farm scale
- Organic: 5.0ha
- Conventional: 10.5ha (managed by a household)
Organic rice farming method

- **Fertilising**
  - Compost (rice bran, rice husk, and bean curd refuse) (2200kg/ha)
  - Guano (400kg/ha)

- **Disease treatment**
  - Hot water treatment of rice seed

- **Weed control**
  - Puddling twice before transplanting
  - Transplanting pot type nursery seedlings
  - Rice bran and irregular soya bean application (600kg/ha)
  - Waterlogging with constant depth in crop season
## Grain yield and unit price for each crop

<table>
<thead>
<tr>
<th>Preceding crop</th>
<th>Grain yield (kg ha(^{-1}))</th>
<th>Unit price (yen kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice</td>
<td>5,300</td>
<td>4,650</td>
</tr>
<tr>
<td>Barley</td>
<td>4,350</td>
<td>4,350</td>
</tr>
<tr>
<td>Soya bean</td>
<td>5,830</td>
<td>6,000</td>
</tr>
<tr>
<td>Barley</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice</td>
<td>3,864</td>
<td>2,500</td>
</tr>
<tr>
<td>Barley</td>
<td>4,250</td>
<td>2,750</td>
</tr>
<tr>
<td>Soya bean</td>
<td>2,400</td>
<td>1,800</td>
</tr>
</tbody>
</table>

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## Evaluated cropping systems

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Cropping pattern</th>
<th>Digestible energy yield (MJ ha(^{-1}) a(^{-1}))</th>
<th>Con.</th>
<th>Org.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous cropping</td>
<td>Rice</td>
<td>77,592</td>
<td>68,076</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td>54,876</td>
<td>35,450</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soya bean</td>
<td>41,880</td>
<td>31,410</td>
<td></td>
</tr>
<tr>
<td>Crop rotation</td>
<td>1-year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R – wB</td>
<td>132,378</td>
<td>99,134</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S – wB</td>
<td>102,145</td>
<td>70,405</td>
<td></td>
</tr>
<tr>
<td>2-year</td>
<td>R – S</td>
<td>63,616</td>
<td>59,625</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R – wB – S</td>
<td>91,009</td>
<td>77,350</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R – wB – S – wB</td>
<td>121,000</td>
<td>84,800</td>
<td></td>
</tr>
<tr>
<td>3-year</td>
<td>R – R – S</td>
<td>68,274</td>
<td>62,442</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R – R – wB – S</td>
<td>86,537</td>
<td>74,259</td>
<td></td>
</tr>
</tbody>
</table>

\(R = \text{rice}, \ wB = \text{winter barley}, \ S = \text{soya bean}\)
Life cycle assessment (LCA) of cropping system

**Foreground processes**

**Background processes**
- Seed
- Fertilizer
- Compost
- Pesticide
- Herbicide
- Fuel
- Machinery
- Greenhouse
- Nursery box

**Direct field emission**
- \( \text{CH}_4 \)
- \( \text{NH}_3 \)
- \( \text{N}_2\text{O} \)

**Emissions to air and water**
- Total N
- Total P

**Products**
- Brown rice
- Barley
- Soya bean
- Irregular soya bean
- Rice bran
- White rice
Evaluation of economic performance

• Each crop: Subtract total cost from total value of sales
  – Total cost: material costs and depreciation of machinery and implements

• Crop rotation: Combine the incomes of each crop together with subsidies.
  (calculate as annual incomes)

Income Support Direct Payment Program 2011

– Rice: $150,000$ yen ha$^{-1}$
– Barley, Soya bean: $350,000$ yen ha$^{-1}$ (only 1 crop per year)
– Double cropping: $150,000$ yen ha$^{-1}$
– Yield-proportional adding: $188.5$ yen kg$^{-1}$ (only for Soya)
  (Adding for organic farming: $80,000$ yen ha$^{-1}$)
Results: Global warming (kg CO$_2$ eq. MJ$^{-1}$)

- **Rice**
- **Barley**
- **Soya bean**

<table>
<thead>
<tr>
<th>Crop Rotation</th>
<th>Rice</th>
<th>Barley</th>
<th>Soya bean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous</td>
<td><img src="chart" alt="Barley" /></td>
<td><img src="chart" alt="Rice" /></td>
<td><img src="chart" alt="Soya bean" /></td>
</tr>
<tr>
<td>Crop rotation</td>
<td><img src="chart" alt="Soya bean" /></td>
<td><img src="chart" alt="Rice" /></td>
<td><img src="chart" alt="Barley" /></td>
</tr>
</tbody>
</table>

**Legend:**
- **R:** rice
- **wB:** winter barley
- **S:** soya bean

**Source:** National Agriculture and Food Research Organization
Results: Acidification (kg SO₂ eq. MJ⁻¹)

- **Rice** (Con)
  - (Org)

- **Barley** (Con)
  - (Org)

- **Soya bean** (Con)
  - (Org)

- **R-wB** (Con)
  - (Org)

- **S-wB** (Con)
  - (Org)

- **R-S** (Con)
  - (Org)

- **R-wB-S** (Con)
  - (Org)

- **R-wB-S-wB** (Con)
  - (Org)

- **R-R-S** (Con)
  - (Org)

- **R-R-wB-S** (Con)
  - (Org)

R: rice
wB: winter barley
S: soya bean

Continuous cropping
Crop rotation

Rice Barley Soya bean
Results: Eutrophication (kg PO$_4^{3-}$ eq. MJ$^{-1}$)

Rice (Con)  (Org)
Barley (Con)  (Org)
Soya bean (Con)  (Org)
R-wB (Con)  (Org)
S-wB (Con)  (Org)
R-S (Con)  (Org)
R-wB-S (Con)  (Org)
R-wB-S-wB (Con)  (Org)
R-R-S (Con)  (Org)
R-R-wB-S (Con)  (Org)

R: rice
wB: winter barley
S: soya bean

Continuous cropping
Crop rotation
Results: Energy consumption (MJ MJ⁻¹)

Continuous cropping

Crop rotation

R: rice
wB: winter barley
S: soya bean

Rice (Con) (Org)
Barley (Con) (Org)
Soya bean (Con) (Org)
R-wB (Con) (Org)
S-wB (Con) (Org)
R-S (Con) (Org)
R-wB-S (Con) (Org)
R-wB-S-wB (Con) (Org)
R-R-S (Con) (Org)
R-R-wB-S (Con) (Org)

Rice Barley Soya bean

0 0.05 0.1 0.15 0.2 0.25 0.3 0.35

National Agriculture and Food Research Organization
Results: Income (1000 yen ha\(^{-1}\) a\(^{-1}\))
Impact–yield relation

(a) Global Warming

(b) Acidification

(c) Eutrophication

(d) Non-renewable energy

1 (R-wB), 2 (S-wB), 3 (R-S), 4 (R-wB-S), 5 (R-wB-S-wB), 6 (R-R-S), 7 (R-R-wB-S)
Impact–income relation

(a) Global Warming

(b) Acidification

(c) Eutrophication

(d) Non-renewable energy

1 (R-wB), 2 (S-wB), 3 (R-S), 4 (R-wB-S), 5 (R-wB-S-wB), 6 (R-R-S), 7 (R-R-wB-S)
Conclusions

• Organic farming vs. Conventional farming
  – The environmental impacts of organic farming were lower than those of conventional farming, except for eutrophication potential in continuous rice cropping.
  – Despite the lower productivity, organic farming earned higher incomes per hectare than conventional farming.
  – Results depend on units. (product, work time, household…)

• Continuous rice cropping vs. Crop rotation
  – Crop rotations mostly outperformed continuous rice cropping in terms of both environmental and economic performance.
  – Organic crop rotations including both barley and soya beans were able to achieve higher profitability while reducing environmental burdens.

No tradeoffs in the impact–income relation for organic rotation
Thank you for your attention!
Appendix: Work time and Net income (Income – Labour cost)

<table>
<thead>
<tr>
<th>Crop Rotation</th>
<th>Work Time (hours ha(^{-1}) a(^{-1}))</th>
<th>Net Income (1000 yen ha(^{-1}) a(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice (Con)</td>
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<tr>
<td>Rice (Org)</td>
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</tr>
<tr>
<td>Barley (Con)</td>
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<tr>
<td>Barley (Org)</td>
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<tr>
<td>Soya bean (Con)</td>
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<tr>
<td>Soya bean (Org)</td>
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<tr>
<td>R-wB (Con)</td>
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<td></td>
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<tr>
<td>R-wB (Org)</td>
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<tr>
<td>S-wB (Con)</td>
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<tr>
<td>S-wB (Org)</td>
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<tr>
<td>R-S (Con)</td>
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<td>R-S (Org)</td>
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<tr>
<td>R-wB-S (Con)</td>
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<td>R-wB-S (Org)</td>
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<td></td>
</tr>
<tr>
<td>R-wB-S-wB (Con)</td>
<td></td>
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<tr>
<td>R-wB-S-wB (Org)</td>
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R: rice  
wB: winter barley  
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