An Assessment of Paddy Soil Degradation and Its Impact on Sustainable Rice Production

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ABSTRACT

The degradation of paddy soils is due to both physical and chemical processes. A study was conducted in Kelantan, Malaysia where the top- and subsoils of two soil series (Tok Yong and Kg. Cempaka) planted with paddy and fruit trees were statistically compared. In this study, a field experiment was established to measure nutrient and sediment inputs/outputs in the paddy plots. The Tok Yong series under paddy and orchards differs significantly in its clay, pH and P values. In both the soil series, paddy cultivation has resulted in the depletion of clay and lowering of pH in the topsoils. The net sediment loss under paddy was about 3 to 4 t/ha/season. Sediment removal by surface water was the highest during the second rotation and lowering markedly 90 minutes thereafter. There was an increase of K and Cu, but N and Zn decreased. Soil degradation was not easily visible in this study as its effects were compounded by the various yield improvement measures undertaken. Using farmer’s practices and subsidized fertilizer, the rice yield was about 3.5 t/ha, and this was increased to 6.5 t/ha when MARDI’s technology was applied. Using FERTO technology, which incorporates organic manure, the yield was further increased to 8.1 t/ha.

Key words: Soil degradation, paddy soil, clay removal, nutrient loss

INTRODUCTION

Wetland rice accounts for more than 80% of rice production in Malaysia, covering an area of about 390,000 hectares. Soil ability to sustain intensive wet-rice monoculture cultivation for high rice production is questionable. Experiences overseas such as in Bangladesh where rice has been continuously grown for a long period of time indicate that there has been soil degradation, leading to yield stagnation or reduction (Saheed 1994).

The degradation of paddy soils occurs due to both physical and chemical factors. Repeated seasonal land preparation under flooded conditions could expedite clay removal through lateral suspension (Aminuddin et al. 1994). As a result, the
topsoil would acquire a coarser texture. Such a process is aggravated under direct seeding where soil is intermittently drained. The alternate wet and dry conditions of paddy soils leads to acidification and disintegration of clay minerals or ferrolysis (Brinkman 1970). Both of the above processes will result in less fertile topsoils, with a lower CEC value and lower macro- and micronutrients (Samy et al. 1992).

Soil degradation is further accelerated by mono-cropping, intensive rice cultivation, and the use of high yielding rice varieties that continuously and effectively mine the soils. It can also be caused by the continuous usage of inorganic fertilisers, which increase soil acidity. Inappropriate farm infrastructure development also results in soil degradation. This includes construction of farm roads and canals using laterite, leading to release of iron to toxic levels. Scraping of paddy soils during land levelling, if not properly carried out, may result in yield reduction (Ismail and Abdul Razak 1995); it may also expose the infertile subsoil layer such as sulfidic or sandy subsoils. The use of inappropriate machines has degraded paddy soils somewhat, such as the destruction of the plough pan, which aggravates water loss through seepage.

The negative effect of soil degradation is less visible because it has been compounded by numerous yield improvement measures that have been undertaken. Long-term yield trend in Peninsular Malaysia indicates that rice yield fluctuated around 3.30 t/ha in 1980, 3.06 t/ha in 1985, 3.16 t/ha in 1990, 3.70 t/ha in 1995 and 3.49 t/ha in 1999 (Anon. 1980-1999). The yield is rather stable although the fertilizer subsidy during the period increased from around 63 kg N/ha in early 1980s to 80 kg N/ha in late 1980s, and further increased to 110 kg N/ha in the 1990s. In addition, paddy varieties grown during that period were also consistently improved due to better water, crop and pest and diseases practices. The current study was aimed at: (a) quantifying the differences between properties of top- and subsoil both under paddy and orchards; (b) measuring clay and nutrient removal from the paddy farms; and (c) improving the production of degraded paddy soils through better fertilizer recommendation.

MATERIALS AND METHODS

The study was carried out in Kemubu Irrigation Scheme in KADA, Kelantan through three approaches: (i) quantifying soil degradation by statistically comparing the properties of top- and subsoils; (ii) measurement of clay and nutrient removal at plot and small catchment levels; and (iii) measuring the yield of rice under different management conditions.

Quantification of Soil Degradation Status
Soil samples were collected from two distinct soil layers from representative profiles of Tok Yong and Kg. Cempaka Series i.e. the plough layer (0-20 cm) and the upper subsoil (20-40 cm). The plough layer reflects the soil that is most degraded, while the upper subsoil layer is less affected. Samples from 19 profiles of the Tok Yong (10 under paddy and 9 under orchards) and 12 profiles of the Cempaka
Series (6 under paddy and 6 under orchards) were collected from various locations in KADA. The soils were analysed for texture, pH, organic carbon, EC, CEC, macro- and micronutrients. The two soil layers were compared statistically to determine their relative degradation status.

**Measurement of Lateral Movement of Clay and Nutrients**

A series of 9 paddy plots, measuring 0.763 ha in Tok Akil, Keterih were selected for this study (*Fig. 1*). The water, sediment and nutrient inputs and outputs within each plot were determined. The volume of water flow was measured at the inlet (K1), between plots (K2, K3 and K4) and outlet (K5) using Parshall flumes as shown in *Fig. 1*. The water samples were taken at these points during land preparation, broadcasting, fertilizer application and crop maturing stages. The water samples were analysed for turbidity, conductivity, total dissolved solids (TDS) and pH using portable water quality meter, while the suspended load was measured by gravimetric method in the laboratory. Detail suspended load measurements were also taken during land preparation. At the catchment level, a small catchment at Alor Bakat, consisting of about 70 paddy plots was selected. Water samples
were collected throughout the cropping season from 10 inlets and 10 outlets chosen at random. Each set of samples was bulked and analysed as previously.

**Determination of Yield Performance with Improved Soil Management**

Rice plants were grown in two seasons (2001 and 2001/02). In the first season, the rice was grown in three plots, totaling 0.2 ha using farmers’ practice. In the second season, one experimental plot was managed by MARDI, while two more plots were managed by the farmer but under MARDI’s supervision. Fertilizer application in the farmer’s plots was based on the government’s subsidy recommendation (N:P₂O₅:K₂O amounting to 120, 80, 60 kg/ha, respectively), whereas that of MARDI’s plot was based on Fertilizer Recommendation Tool’s rate (FERTO) of Abd. Razak (2003) (N:P₂O₅:K₂O:Cu:B:Chicken manure amounting to 137:49:129:10:5:3400 kg/ha, respectively). Similar agronomic practice was adopted in all experimental plots, and crop yields were determined.

**RESULTS AND DISCUSSION**

**Soil Degradation Due to Paddy Cultivation**

The soils cultivated with paddy acquire characteristic morphology and properties, different from similar soil series under orchards (Aminuddin and FitzPatrick 1991). In this study, the soil in the surface plough layer cultivated with paddy and under orchards (0-20 cm) were compared with their subsoils (20-40 cm). The subsoil under paddy was used for comparison as it is less affected by paddy cultivation, whereas the surface soil under orchards resembles the original soil and was used as a reference. The result of the analysis is shown in Table 1, and the comparison between soil layers is shown in Table 2 and Fig. 2. Some findings are described in the following section.

**Differences in soils under paddy and orchards.** The contrast in the properties of soils due to differences in land use type (paddy and orchards) is reflected in the statistical analysis shown in Table 2. For Tok Yong series, the soils under different types of land use differ significantly in their pH, clay and P values. However, for Cempaka Series, no difference was observed except for a coarser sand content. This could be due to the fact that the latter soil is located at the mid-slope position, thus it is somewhat hydromorphic in nature, and does not differ drastically from the wet paddy soils.

**Changes in the surface soil.** Rice cultivation has caused some degree of soil degradation in its topsoils (0-20 cm), as a consequence of its peculiar cultivation practices under flooded condition. Over time, the Ap layer would be more degraded than the underlying layer (20-40 cm). Landuse type-depth interaction shows that C, N and P were significantly different between the two layers in both soils, while pH and CEC were significantly different in one of the soils (Table 2). For paddy soils, this is illustrated in Fig. 2. The result indicated that paddy cultivation has degraded several soil properties due to lower clay, N and pH in the surface layer.
### TABLE 1
Mean values of soil parameters in different soil layers under paddy and orchards

<table>
<thead>
<tr>
<th>Soil series</th>
<th>Land use</th>
<th>Depth cm</th>
<th>pH</th>
<th>Cond. μS/cm</th>
<th>P μg/mL</th>
<th>C %</th>
<th>N %</th>
<th>CEC cmol c kg⁻¹</th>
<th>Clay %</th>
<th>Coarse sand %</th>
<th>Fine sand %</th>
<th>Silt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tok Yong</td>
<td>K</td>
<td>0-20</td>
<td>4.70</td>
<td>18.04</td>
<td>0.48</td>
<td>1.27</td>
<td>0.16</td>
<td>11.69</td>
<td>36.9</td>
<td>7.5</td>
<td>26.5</td>
<td>28.3</td>
</tr>
<tr>
<td>Tok Yong</td>
<td>S</td>
<td>0-20</td>
<td>5.13</td>
<td>19.64</td>
<td>1.04</td>
<td>1.33</td>
<td>0.20</td>
<td>12.41</td>
<td>32.0</td>
<td>8.5</td>
<td>28.2</td>
<td>30.3</td>
</tr>
<tr>
<td>Tok Yong</td>
<td>S</td>
<td>20-40</td>
<td>5.56</td>
<td>15.04</td>
<td>0.15</td>
<td>0.68</td>
<td>0.11</td>
<td>11.66</td>
<td>39.5</td>
<td>5.6</td>
<td>25.6</td>
<td>28.5</td>
</tr>
<tr>
<td>Cempaka</td>
<td>K</td>
<td>0-20</td>
<td>4.70</td>
<td>11.93</td>
<td>0.14</td>
<td>0.98</td>
<td>0.14</td>
<td>12.85</td>
<td>38.3</td>
<td>5.0</td>
<td>20.6</td>
<td>34.2</td>
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<tr>
<td>Cempaka</td>
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<td>0-20</td>
<td>4.96</td>
<td>14.29</td>
<td>0.42</td>
<td>1.11</td>
<td>0.18</td>
<td>10.53</td>
<td>41.3</td>
<td>2.2</td>
<td>20.4</td>
<td>35.4</td>
</tr>
<tr>
<td>Cempaka</td>
<td>S</td>
<td>20-40</td>
<td>4.91</td>
<td>12.94</td>
<td>0.07</td>
<td>0.60</td>
<td>0.11</td>
<td>10.10</td>
<td>47.5</td>
<td>2.7</td>
<td>17.7</td>
<td>30.8</td>
</tr>
</tbody>
</table>

Key: K = kampong/orchards;  S = Sawah/paddy
TABLE 2
Statistical comparison of soil samples (from two different series) from different land use (type) and depth

<table>
<thead>
<tr>
<th>Source</th>
<th>pH</th>
<th>Cond.</th>
<th>P</th>
<th>C</th>
<th>N</th>
<th>CEC cmol/</th>
<th>Clay sand (%)</th>
<th>Coarse sand (%)</th>
<th>Fine (%)</th>
<th>Silt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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<td></td>
<td>kg⁻¹</td>
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<tr>
<td>Type⁺</td>
<td>ns</td>
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<td>ns</td>
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<td>ns *</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
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</tr>
<tr>
<td>Depth⁺⁺</td>
<td>ns</td>
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<td>*</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Type*depth</td>
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<td>*</td>
<td>*</td>
<td>*</td>
<td>***</td>
<td>ns</td>
<td>ns</td>
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</table>

SOIL : Cempaka Series

<table>
<thead>
<tr>
<th>Source</th>
<th>pH</th>
<th>Cond.</th>
<th>P</th>
<th>C</th>
<th>N</th>
<th>CEC cmol/</th>
<th>Clay sand (%)</th>
<th>Coarse sand (%)</th>
<th>Fine (%)</th>
<th>Silt</th>
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<tr>
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<td></td>
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<td></td>
<td>kg⁻¹</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Type⁺</td>
<td>ns</td>
<td>ns</td>
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<td>ns</td>
</tr>
<tr>
<td>Depth⁺⁺</td>
<td>ns</td>
<td>ns</td>
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<td>ns</td>
</tr>
<tr>
<td>Type*depth</td>
<td>ns</td>
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<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

(⁺Type: paddy or orchards,  ⁺⁺Depth: 0-20cm and 20-40cm)
(****, ***, * = significant at 0.1%, 1% and 5% level respectively)

The loss of clay in surface soils could reduce its CEC value, hence its fertility status. Fortunately, the accumulation of organic carbon in the surface soils improved the CEC somewhat, and this conserves the soil fertility (Ahmad et al. 1997).

Sediment Removal by Surface Water

The water flow increased gradually from pre-saturation and peaked at 40-50 day after sowing (DAS), and decreased towards the draining stage. The incoming water at K1 is more than the outgoing water at K5 except when the water was allowed to pass to the adjacent plots during second rotovation (Table 3). The movement of suspended load follows the water flow (Fig. 3). The suspended load taken at K2, K3, K4 and K5 peaked during the second rotovation and then reduced markedly. This peak could have occurred due to massive soil disturbance during rotovation. A second minor peak occurred at the third fertilizer application. At other times during the crop season, the irrigation water and the outgoing water contained a low amount of suspended load. The amount of sediment lost ranged between 2.9 to 4.0 t/ha per season (Table 3). The variation of sediment concentration during and subsequent to rotovation period is shown in Fig. 4. It is evident from this figure that sediment concentration in the water was reduced to a low level 90 minutes after ploughing activity. This implies that sediment loss through suspension
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Fig. 2: Comparison of properties of the plough layer and the subsoil under paddy (note the 1:1 lines)

can be greatly minimized if lateral water flow is prevented during this critical period.

The mini-catchment investigated consists of about 70 paddy plots with varied farm operation scheduling. The characteristics of the outlet water reflect the overall condition within the catchment. The concentration of suspended load in the water is highest during land preparation. During the rice growing period, the suspended load concentration of the inlet and outlet water is almost equal (Fig 5).
### TABLE 3
The removal of sediment and nutrients per hectare per season at plot level

<table>
<thead>
<tr>
<th>Water (m³)</th>
<th>Sediment (ton)</th>
<th>P (g)</th>
<th>N (kg)</th>
<th>K (kg)</th>
<th>Zn (g)</th>
<th>Cu (kg)</th>
<th>Fe (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet/ha</td>
<td>23,784</td>
<td>1.83</td>
<td>1.49</td>
<td>25</td>
<td>8</td>
<td>25.7</td>
<td>100</td>
</tr>
<tr>
<td>Outlet/ha</td>
<td>7,275</td>
<td>5.81</td>
<td>4.37</td>
<td>23</td>
<td>11</td>
<td>10.6</td>
<td>292</td>
</tr>
</tbody>
</table>

### TABLE 4
The yield of rice in experimental plots

<table>
<thead>
<tr>
<th>Cropping season</th>
<th>Gross weight (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Farmer A</td>
</tr>
<tr>
<td>Season I - 2001 (off season)</td>
<td>3.15</td>
</tr>
<tr>
<td>Season II - 2001/02 (main season)</td>
<td>6.45</td>
</tr>
</tbody>
</table>
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Fig. 3: Movement of suspended load in the study plots

Fig. 4: Variation of sediment concentration during ploughing activity

Nutrient Removal and Recharge by Surface Water
The amount of nutrient input and removal is shown in Table 3. Irrigation water provides a source of macro- and micronutrients to the paddy. The inputs of K and Cu are considerable. The K content of irrigation water was high as it flows through areas geologically high in K (MacDonald 1968). The amount of N in the irrigation water is inadequate for paddy production, and N fertilizer application is necessary. The nutrients removed in drained water are generally lower than their input from...
irrigation water. This could be due to the fact that the total volume of the drained water is only about 30% of the irrigation water supply. The concentration and pattern of dissolved nutrients in the inlet and outlet water during the cultivation
period at the plot level is reflected by the TDS values (Fig. 6). The TDS value in
the outlet water (K5) is higher after fertilizer application, indicating some nutrient
losses due to applied fertilizer. The nutrient losses could not be totally prevented
in paddy fields adopting plot-to-plot irrigation system. However, the outlet water
can be controlled in an improved rice farm, preventing the loss of both nutrient
and clay through lateral flow.

**Impact of Soil Degradation on Rice Production**
The results showed that under farmer’s practices, using the subsidized fertilizers,
the yields was between about 3 to 4 t/ha, depending on the season (Table 4). This
is consistent with the average yield obtained in KADA, which is 3.83 t/ha (1992),
stagnating yield is also observed for all of Asia where between 1981 and 1991 the
yield decreased by 1.5% per annum (De Datta 1994). However, under MARDI’s
supervision and similar fertilizer rate, the paddy yields under farmer’s practice
increased by between 50 to 100%. Using FERTO fertilizer rate (which incorporates
3.4 t/ha processed chicken manure), a further 30% increase in yield was obtained.
The results indicate that although paddy soils in the study area have degraded,
reasonable yield could still be obtained if good management and ameliorative
measures are undertaken. In the present case, the production on degraded soils
could be further improved with the use of organic fertilizer.

**CONCLUSION**

Our study shows some form of soil degradation does occur in paddy soils in the
KADA area. The most severe form of degradation is removal of clay from the
topsoils, amounting to about 3 to 4 t/ha/season. This clay loss can be greatly reduced
if drainage flow during land preparation is prevented. There is also some loss of
nutrients, specifically N and Zn. The net effect of soil degradation contributes to
the decline in soil fertility in the region which resulted in a lower yield of rice or
yield stagnation. It is, therefore, recommended that the extent of soil degradation
in other soil series under paddy be investigated. Rice production on the degraded
soils under study could be improved with the use of organic fertilizers, and a yield
level of about 8 t/ha/season could be achieved.

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