On-farm assessment of long term effects of organic matter management on soil characteristics of paddy fields threatened by salinity in Northeast Thailand

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Keywords: Organic matter management, paddy, fertilizer, farmer management

Abstract

In Southeast Asia, the long-term effects of organic matter management (OMM) on the soil’s attributes have seldom been studied in on-farm situations. Most studies are carried out in experimental plots where, except for OMM, all practices are kept similar. Therefore, their results need to be validated in the various crop management, soil and climatic conditions prevailing in the region. This paper develops an on-farm approach to diagnose some impacts of farmers’ OMM practiced during the last five years at least, in Northeastern Thailand. Surveys and field measurements were carried out on a network of 53 rainfed paddy fields belonging to 50 farmers. The network was designed to be representative of three OMM (straw burned; straw buried; and straw buried + animal manure) whose effects on soil characteristics can be more or less variable depending on the interactions between two rice establishment methods, (transplanting and broadcasting), various levels of N fertilizer (N<20 kg ha-1 and 20<N<100 kg ha-1) and two topographic positions of the fields (170 m<altitude<190 m and 190 m<alt<210 m). Whatever the method of sowing, the level of N fertilization and the field’s elevation, straw incorporation was not associated with higher soil organic carbon, pH, exchangeable cations, or with lower bulk density or electrical conductivity (EC) as compared with straw burning. Applications of animal manure were usually less than 1 t ha-1 and had no significant effect on these soil parameters. So far, there is little evidence that the various OMM currently practiced by farmers of this region will make any difference regarding the soil fertility evolution.

Keywords: Organic matter management (OMM); On-farm research; interactions; total C; salinity; sandy soils

Introduction

The possibility of rapidly forecasting long-term effects of cropping systems on soil fertility is one of the main concerns of sustainable agriculture (Hansen, 1996). In the rainfed paddy systems of Northeastern Thailand, this question is very important since many farmers, in order to reduce the cost of land preparation, burn the rice straw remaining on the fields after harvest. Conversely, others go to much trouble to incorporate it, or even to add animal compost, being convinced that these practices will improve the fertility and prevent salinization of the soil (Grunberger, and Hartmann, 2004). A decrease in organic matter content of soils in the longterm could be very harmful since many farmers of this region are too poor to invest in mineral fertilizers. Hence, they often rely on the indigenous soil N supply to satisfy most of the rice crop’s demand (Olk et al., 2000; Powlson and Olk, 2000).

One of the difficulties of the assessment of these OMM in Northeast Thailand is the need to take into account the interactions of various cropping practices existing over the region (Olk et al., 2000; Powlson and Olk, 2000). Indeed, due to the higher yields associated with the transplanting method of establishing rice compared to direct seeding (Pandey et al., 2002), a higher input of carbon to soils via the residues can be expected. Therefore, effects of burning the straw on soil carbon evolution might be greater in fields where transplanting is practiced than in direct-seeded fields. Likewise, the use of inorganic fertilizer could interact with OMM effects, not only via the increase of residue inputs to soils but also through the rate of carbon mineralization (Whitbread et al., 2003, Shirato et al., 2005). As different fields elevation could be associated with varied water dynamics and salinity levels (Arunin,
1984, Bolomey 2002, Grunberger and Hartmann, 2004), the effects of this factor on inputs of carbon as well as loss of carbon by erosion and mineralization could also be expected. Considering all these interactions, and the lack of a carbon turnover model validated for these tropical cropping systems (Parton and Stanford, 1989), the assessment of OMM over the region could be investigated using an on-farm approach rather than by a long term “in station” experiment. This on-farm approach, based on comparison of fertility criteria over a network of farmers’ fields, requires that the current cropping systems have been practiced for at least five years, so that differences in the soil fertility components can be attributed to differences in the current cropping systems (Hasewaga et al., 2005). With such a network of fields, derivation of the parameters of a generic model of organic matter evolution could be carried out. However, as many fields have to be explored, basic or summary models using few parameters could be more successful than complex models.

Few data are available on the long-term effects of the OMM practiced by the farmers in Northeast Thailand. Experimental data sets exist for the cassava system developed in the uplands of the region, but not for the paddy system (Shirato et al., 2005). Tangtrakarnpong and Vityakon (2002), regarding the paddy system as relatively homogenous in comparison with other land use types existing in the region (forests, cassava, sugarcane), showed that carbon pools (labile and stable) of the paddy system ranked second behind forest systems, as total soil organic matter decreased from 5.5 in the forest to 4.2 g kg$^{-1}$ in the paddy system, and microbial biomass, which corresponds to the pools of higher turnover rate, decreased from 116 in the forest to 78 mg kg$^{-1}$ in the paddy system. Whitbread et al. (2003) examined the effects of the removal or otherwise of straw, and of leaf litter application on soil carbon in experimental plots. However, because it was mainly focused on the testing of new organic matter management, this study did not consider the possible interactions of the various current cropping practices and topography of fields at the level of the region. Moreover, the burning of straw was not assessed. Other studies pointed out the possible positive effect of organic matter on soil pH, due to increase of Fe reduction in the flooded soils (Maegth, 2003; Quantin et al., submitted). In accordance with this hypothesis, Enet (2003), by comparing two fields annually receiving (or not) animal compost amendments, showed positive effects of organic matter application on soil pH, measured during the cropping period. It was however likely that this effect of organic matter could be a short term effect, not noticeable during the following dry period.

The purpose of this paper was to assess briefly, using surveys and observations over a network of farmers’ fields, long-term effects on soil carbon, nutrient content, soil pH, salinity and bulk density of various OMM strategies encountered in the paddy systems of Northeast Thailand. Comparison of annual inputs of carbon as crop residues and manure with the measured post-harvest carbon content of soils was used to formulate hypotheses for the carbon dynamics of these sandy soils threatened by salinity.

**Materials and Methods**

**Study area**

The study was carried out during the dry season of December to April 2005 in Khon Kaen Province (16°N 102°E) in the Northeast of Thailand. The study area was chosen as representative of the natural conditions of the region. The landscape is a gently undulating plateau containing the villages of Ban Daeng, Ban Non Bo, Ban Kraduang and Ban Non Klong (Figure 1). The soils are classified according to the USDA Soil Taxonomy mostly as Paleaquults, and sometimes Paleustult in the central area (Craig and Pisone, 1988). They are sandy loams with a low clay fraction, mostly kaolinitic, and a low pH due to considerable leaching. Because of the presence of shallow, saline groundwater, some parts of the area can have an electrical conductivity of the saturated extract in the soil surface as high as 7 mS cm$^{-1}$. The mean annual rainfall in this region in the 1990s was around 1,000 mm, with 90% of this falling between May and the end of October. Daily mean temperatures vary from 20 to 28°C during the year. Temperature and rainfall recorded at the experimental site of IRD at Ban Daeng during the 2004 cropping season are representative of the region’s annual mean (Figure 2).

A preliminary study in this region showed that the farmers mainly grow rice. The rice is transplanted once a year during the rainy season, with nothing grown in the dry season. The soil preparation, consist of two plowings to 15 cm depth using a powered cultivator. The rice is either transplanted as month-old seedlings or directly sown by broadcasting just before the second plow. Direct seeding is not associated with the adoption of zero tillage in this region, probably because herbicides are not used. It is likely that the main difference between soil preparation for direct seeding and transplanting is the soil moisture during the second plow. In case of transplanting, soil moisture...
should be very high so that the soil structure will look like a uniform mud after plowing. The most common rice variety (RD6) is glutinous, photoperiodic sensitive with a flowering period in mid-October and harvest in November. The sowing date depends on the rainfall and on the method of planting. Whereas transplanting has to be done into flooded soils, direct seeding can be done at the beginning of the rainy season when the rainfall is still light. Whatever the method of sowing, the rates of chemical fertilizers used are often less than 60, 25, 25 kg ha\(^{-1}\) of N P and K, respectively. Three main methods of organic matter management can be distinguished: 1) straw burning (SB), 2) straw incorporation (SI) or 3) straw incorporation and animal compost application (SI+C) before soil preparation. Application of animal compost is generally less than 1 t ha\(^{-1}\). Potential yields in this area, estimated at 4 t ha\(^{-1}\) (Suzuki et al., 2003), are often not reached.

**Surveys**

A network of 53 plots, annually cropped with rice, were selected to represent the three main OMM methods, which were factorially combined with 2 topographic positions (lowlands, corresponding to altitudes from 170 m to 190 m, and uplands – altitudes between 191 m and 210 m), two methods of sowing (transplanting and direct seeding) and two fertilizer levels (low for applications of less than 20 kg N ha\(^{-1}\), and high for applications from 20 to 60 kg N ha\(^{-1}\)). Applications of P and K are often combined with those of N. The structure of the network is presented.
The role of organic matter and biological activity

in Table 1. Each plot corresponded to a set of practices stable over the last five years. The soil total N, C, cations content, pH and salinity level were considered in this study as output variables whose variations within the network could be explained by the various OMM methods interacting with various cropping practices. Within each plot, the following measurements and observations were made:

1) Soil analyses at the end of February (post-harvest period). At this time, the rice straw was still standing, as only the panicles were harvested by hand. No organic matter application or straw burning had yet been done. This period is probably the most appropriate to bring out long term effects of practices, as the short term effects of the crop management interventions are the least likely. Soil samples were made up of 5 cores collected from the 0-15 cm layer. Total organic carbon (C) was determined by the wet digestion method of Walkley and Black. Total N was determined by the Kjeldahl method. pH was determined in distilled water using 1:1 soil:solution ratio. Cation exchange capacity (CEC) was determined after a first exchange with 1M ammonium acetate at pH = 7, and a second exchange with 1 M NH4Cl. Exchangeable (exch) Ca, Mg and K extracted with 1 M ammonium acetate at pH7 were determined by atomic absorption spectrophotometry and flame photometry. Available P was analysed using the Bray P n°2 method. Electrical conductivity (EC) was measured using a 1/5 soil water ratio.

2) Measurements of the amount of rice straw remaining on the fields after harvest (three replicates of 4 m²).

3) Measurements of the amount of animal compost spread on the plots during the dry season, and records of farmers’ estimates of the amount spread during the last five years

4) Bulk density of the 0-15 cm ploughed soil layer (three replications using a 100 cm³ cylinder).

Data Analysis

Effects of position of the field in the landscape, OMM, method of sowing and N fertilizer level on soil contents of C, exchangeable cations and on soil pH, EC and bulk density were analysed by four-way analysis of variance using the GLM procedure and type III sum of squares of SAS 9.1 (2003). Interactions between cropping practices were also analysed statistically. The Student-Newman-Keuls test was used to compare the average values of the recorded variables.

The mineralization rate of the organic matter (K2), which is supposed to be very variable according to soil and climatic conditions and cropping systems (Mary and Guerif, 1994; Olk et al., 2000), was deduced according to the basic equation of Jenny (1941), which considers the soil carbon content as homogenous as regards its decomposition rate:

\[ C_1 = C_0 e^{-K_2 t} + m \, c_r \frac{K_1 (1 - e^{-K_2 t})}{K_2} \]

Assuming the soil carbon content was at equilibrium:

\[ K_2 = \frac{m \, c_r \, K_1}{C_1} \]

where m is the amount of annual organic dry matter supplied (mainly as straw residues), c_r the carbon content of the residues, and K1 the iso-humic coefficient which generally varies according to the composition of the amendment (Mary and Guerif, 1994). C_0 is the soil C content in the first year of the OMM application. C_1 is the total C content given by the soil analysis at the end of February 2004. As it has to be expressed in t ha⁻¹ rather than mass (kg kg⁻¹), the data recorded for soil bulk density are used. The annual C supplied by straw residue humification (m* c_r *K1) was calculated assuming values of 15% for water content. K1 of rice straw was fixed at 0.15 (Mary and Guerif, 1994), and carbon content of the humus at 50%. According to the observation that the most lignin rich parts of the residues are not affected by the burning, this practice was assumed to reduce the annual C input of straw by only 50%. A specific contribution of the rice roots to the total input of carbon to soils was ignored. Carbon supplied by the

<table>
<thead>
<tr>
<th></th>
<th>Straw burned</th>
<th>Straw incorporated</th>
<th>Straw incorporated + animal compost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowland</td>
<td>15 (60%)</td>
<td>14 (60%)</td>
<td>8 (66%)</td>
</tr>
<tr>
<td>(altitude &lt; 190 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upland</td>
<td>6 (14%)</td>
<td>5 (37%)</td>
<td>5 (40%)</td>
</tr>
<tr>
<td>(altitude = 190-210 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>19</td>
<td>13</td>
</tr>
</tbody>
</table>
compost was considered as negligible, as the fresh weights of these amendments were less than 1 t ha\(^{-1}\).

**Results**

**Relationships between different soil criteria**

The mean values and standard deviations of each of the studied variables and their mutual correlations are presented in Table 2. Carbon content was significantly positively correlated with soil CEC. As well as CEC, carbon content was significant correlated with exch. K, Ca, and Mg. Total C and N were highly correlated, with a C/N ratio of 11 that was quite stable among fields (not shown). No significant correlations between carbon content and pH, bulk density or EC were found. EC was significantly correlated with Na and Mg.

**Changes in soil characteristics according to practices**

Whereas altitude had a highly significant effect on soil exch. K and Na, EC and pH, OMM had no significant long-term effect on any of the measured variables. Significant effects of method of sowing appeared on available P and bulk density. Available P was lower in direct sowing as opposed to transplanting. Exch. K and bulk density were lower and soil pH higher in fertilized than in unfertilized fields (Table 3).

**Calculation of K\(2\) assuming organic matter equilibrium**

The dry weight of the straw incorporated in the SI and SI + C fields varied from 2 to 7 t ha\(^{-1}\). This variation is significantly associated with the method of sowing, but not to the elevation of the fields or to the use of fertilizer (not shown). The dry weight of residues in the direct-seeded fields was 0.70 t ha\(^{-1}\) less than in the transplanted ones. The mean value of K\(2\) allowing equality between annual incoming carbon and mineralized carbon was 3% in the SI fields. The same value might not apply to the SB fields under the equilibrium hypothesis: if it is assumed that about 50% of the carbon of the straw is lost due to burning, the mean K\(2\) value of these situations should not be more than 2% (Figure 3).

**Discussion**

This on-farm survey was conducted to compare long-term effects of the various OMM of paddy fields existing in a region. These OMM are developed on sandy soils with a very low carbon content of 0.5% on average (Table 2). The C/N ratio of 11 suggests that the organic matter mineralizes readily in all these situations. About 20% of the CEC is due to the humus. Exch. K and Ca were very low, consistent with the low CEC. EC values were, at the time of the study, mostly below the level considered to pose a salinity problem for rice production (Dobermann and Fairhurst, 2000); however, these EC are significantly correlated with the Na content of the soils, revealing that they are due to the upward movement of saline groundwater. Due to the effects of farmers’ practices, variations in soil bulk density and pH were not significantly related to EC levels.

This study revealed that the observed differences in OMM did not result in differences in the soil C content, nor in pH, EC, exch. cations or bulk density. This non-significant effect on total C is consistent with results of Whitbread et al. (2003) who

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Table 2. Average values, standard deviations of measured variables and correlations between them. Bold values mean that the correlation is significant at the 0.05 probability level

<table>
<thead>
<tr>
<th>Mean Root</th>
<th>CEC (cmol kg(^{-1}))</th>
<th>Total Carbon (%)</th>
<th>Exch K (cmol kg(^{-1}))</th>
<th>Exch Ca (cmol kg(^{-1}))</th>
<th>Exch Mg (cmol kg(^{-1}))</th>
<th>Exch Na (cmol kg(^{-1}))</th>
<th>EC (µS/cm)</th>
<th>pH H(_2)O</th>
<th>Bulk density (kg dcm(^{-3}))</th>
<th>P (Bray 2) (mg P kg sol(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC</td>
<td>4.067</td>
<td>2.009</td>
<td>–</td>
<td>0.61</td>
<td>0.44</td>
<td>0.81</td>
<td>0.67</td>
<td>0.05</td>
<td>0.12</td>
<td>0.02</td>
</tr>
<tr>
<td>Total Carbon (%)</td>
<td>0.47</td>
<td>0.12</td>
<td>–</td>
<td>0.48</td>
<td>0.68</td>
<td>0.45</td>
<td>0.07</td>
<td>0.00</td>
<td>0.14</td>
<td>-0.20</td>
</tr>
<tr>
<td>Exch K (cmol kg(^{-1}))</td>
<td>0.092</td>
<td>0.091</td>
<td>–</td>
<td>0.40</td>
<td>0.29</td>
<td>0.01</td>
<td>0.12</td>
<td>0.04</td>
<td>0.16</td>
<td>0.10</td>
</tr>
<tr>
<td>Exch Ca (cmol kg(^{-1}))</td>
<td>1.522</td>
<td>1.535</td>
<td>–</td>
<td>0.87</td>
<td>0.06</td>
<td>0.16</td>
<td>0.21</td>
<td>0.11</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Exch Mg (cmol kg(^{-1}))</td>
<td>0.343</td>
<td>0.326</td>
<td>–</td>
<td>0.31</td>
<td>0.32</td>
<td>0.14</td>
<td>0.06</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Exch Na (cmol kg(^{-1}))</td>
<td>1.341</td>
<td>1.414</td>
<td>–</td>
<td>–</td>
<td>0.66</td>
<td>0.17</td>
<td>0.06</td>
<td>0.04</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>EC 1:5 (µS/cm)</td>
<td>290</td>
<td>278</td>
<td>–</td>
<td>0.04</td>
<td>0.00</td>
<td>0.04</td>
<td>0.12</td>
<td>0.12</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>pH H(_2)O</td>
<td>5.770</td>
<td>0.835</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Bulk density (kg dcm(^{-3}))</td>
<td>1.557</td>
<td>0.065</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>P (Bray 2) (mg P kg sol(^{-1}))</td>
<td>7.930</td>
<td>10.515</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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</tr>
</tbody>
</table>
The role of organic matter and biological activity

redox status, as the process of increasing pH found by Quantin et al., (submitted) and Maeght, (2003), was related to the increase of soil carbon content and the reducing conditions of flooded soils.

Comparison of the carbon inputs with the calculated outputs using the basic equation of Jenny (1941) at equilibrium (Figure 3), suggested that the non-significant effect of burning straw is due to a very low mineralization rate (K2) of the organic matter remaining in the soil after burning. Hence, the quality of this organic matter could be different from that of fields where the straw is incorporated every year. The average K2 of 3% is deduced for these situations, whereas the highest values mentioned in the literature for sandy soils in temperate zones reach 2% (Boiffin et al., 1986). Using the Jenny equation, this K2 value refers to the total organic matter content of the soils, with no distinction between more or less recalcitrant, or old or fresh organic materials. Therefore, it is certainly much lower than the mineralization rate that would be expected in such a tropical area for the incoming residues only (Shirato et al., 2005). It’s clear that it would have been more accurate to distinguish two different pools in the total C amount: labile carbon, and less quickly mineralized carbon. The pool of labile carbon could be approached either by the microbial biomass (Alvarez et al., 1998), or following Blair et al.

Table 3. Soil chemical properties of 52 rainfed paddy fields of Khon Kaen as affected by altitude, organic matter management, crop establishment method and N fertilizer level

<table>
<thead>
<tr>
<th>Factor</th>
<th>n</th>
<th>Organic C</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>Bray-2 P</th>
<th>pH</th>
<th>EC 1:5</th>
<th>Bulk density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(g 100 g⁻¹)</td>
<td>(cmol kg⁻¹)</td>
<td>(cmol kg⁻¹)</td>
<td>(cmol kg⁻¹)</td>
<td>(mg kg⁻¹)</td>
<td>(µs/cm)</td>
<td>(kg dcm⁻³)</td>
<td>(kg dcm⁻³)</td>
<td></td>
</tr>
<tr>
<td>Elevation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowland (&lt;190 m)</td>
<td>37</td>
<td>0.46</td>
<td>0.10 a</td>
<td>1.59</td>
<td>0.38</td>
<td>1.69 a</td>
<td>9.76</td>
<td>5.59 b</td>
<td>374 a</td>
<td>1.57</td>
</tr>
<tr>
<td>Upland (≥190 m)</td>
<td>16</td>
<td>0.48</td>
<td>0.06 b</td>
<td>1.36</td>
<td>0.25</td>
<td>0.53 b</td>
<td>3.68</td>
<td>6.18 a</td>
<td>96 b</td>
<td>1.53</td>
</tr>
<tr>
<td>Organic management</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straw burned</td>
<td>21</td>
<td>0.46</td>
<td>0.09</td>
<td>1.77</td>
<td>0.41</td>
<td>1.36</td>
<td>7.43</td>
<td>5.82</td>
<td>283</td>
<td>1.56</td>
</tr>
<tr>
<td>Straw incorporated</td>
<td>19</td>
<td>0.49</td>
<td>0.10</td>
<td>1.47</td>
<td>0.32</td>
<td>1.66</td>
<td>8.79</td>
<td>5.90</td>
<td>364</td>
<td>1.55</td>
</tr>
<tr>
<td>Straw incorporated + OM</td>
<td>13</td>
<td>0.44</td>
<td>0.06</td>
<td>1.19</td>
<td>0.26</td>
<td>0.84</td>
<td>7.25</td>
<td>5.48</td>
<td>194</td>
<td>1.56</td>
</tr>
<tr>
<td>Crop establishment</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>method</td>
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</tr>
<tr>
<td>Transplanting</td>
<td>31</td>
<td>0.49</td>
<td>0.09</td>
<td>1.67</td>
<td>1.37</td>
<td>1.59</td>
<td>10.71a</td>
<td>5.70</td>
<td>379</td>
<td>1.55b</td>
</tr>
<tr>
<td>Direct seeding</td>
<td>22</td>
<td>0.44</td>
<td>0.08</td>
<td>1.31</td>
<td>1.29</td>
<td>0.98</td>
<td>4.01b</td>
<td>5.86</td>
<td>165</td>
<td>1.57a</td>
</tr>
<tr>
<td>N fertilizer level</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low (&lt;20 kg ha⁻¹)</td>
<td>26</td>
<td>0.47</td>
<td>0.10 a</td>
<td>1.49</td>
<td>0.31</td>
<td>0.98</td>
<td>7.83</td>
<td>5.66b</td>
<td>212</td>
<td>1.58a</td>
</tr>
<tr>
<td>High (&gt;20 kg ha⁻¹)</td>
<td>27</td>
<td>0.46</td>
<td>0.08 b</td>
<td>1.55</td>
<td>0.37</td>
<td>1.68</td>
<td>8.02</td>
<td>5.87a</td>
<td>365</td>
<td>1.53b</td>
</tr>
<tr>
<td>Mean square</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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Table Asterisks (*, **, ****) mean significant at the 0.05, 0.01 and 0.001 probability level respectively. Numerals with different letters are significantly different at the 0.05 probability level using the Student-Newman-Keuls Test of SAS.

Asterisks (*, **, ****) mean significant at the 0.05, 0.01 and 0.001 probability level respectively. Numerals with different letters are significantly different at the 0.05 probability level using the Student-Newman-Keuls Test of SAS.

a Degrees of freedom (d.f).

Figure 3. Values of annual output of carbon assuming mineralization rate of K2 = 3% for total soil C content

Field with straw incorporated (SI)
Field with straw burned (SB)

Comparison of the carbon inputs with the calculated outputs using the basic equation of Jenny (1941) at equilibrium (Figure 3), suggested that the non-significant effect of burning straw is due to a very low mineralization rate (K2) of the organic matter remaining in the soil after burning. Hence, the quality of this organic matter could be different from that of fields where the straw is incorporated every year. The average K2 of 3% is deduced for these situations, whereas the highest values mentioned in the literature for sandy soils in temperate zones reach 2% (Boiffin et al., 1986). Using the Jenny equation, this K2 value refers to the total organic matter content of the soils, with no distinction between more or less recalcitrant, or old or fresh organic materials. Therefore, it is certainly much lower than the mineralization rate that would be expected in such a tropical area for the incoming residues only (Shirato et al., 2005). It’s clear that it would have been more accurate to distinguish two different pools in the total C amount: labile carbon, and less quickly mineralized carbon. The pool of labile carbon could be approached either by the microbial biomass (Alvarez et al., 1998), or following Blair et al.
Besides the effects of farmers’ fields were mainly related to the position of the fields in the landscape. The higher values recorded for these variables in the lower lands were due to the proximity of the saline water table. The non-significant effect of topographic position on soil C content could mean that carbon movement by erosion is negligible. The effect of the method of sowing on available P (Table 3) could be due to a higher uptake of P by the recently harvested rice in the direct seeding method, whereas with transplanting most of the P would be fixed by the ferrous iron concentrated in the submerged soils during the cropping period. The lower soil bulk density in transplanted fields with fertilizer application could be due to the higher root volume developed by the recently harvested rice, or perhaps to a higher level of labile carbon in these soils. The lower exch. K in fertilized plots (Table 3) suggests that greater uptake of the initial soil K was possible by the rice crop. The higher pH recorded in fields receiving the higher fertilizer should be confirmed as acidification effect of urea application is more often observed.

Conclusion

Using a survey approach over a network of fields, it has been possible, within a short time, to examine some long-term effects of practices developed in paddy fields of Northeastern Thailand. More detailed data are in many cases still needed to draw definite conclusions. Future research should include assessment of labile carbon, as a more sensitive and early indicator of a change in the organic status of soils. Input of carbon by the roots, and leaching by drainage should be assessed for more accurate estimation of carbon budgets. Loss of carbon by the light burning practiced by the farmers should be measured. Estimation of nutrient uptake and root density of the rice with the various practices would allow our hypothesis to be used to explain variation in P and K availability and bulk density over the network. Besides the effects of farmers’ practices on the soil chemical and physical attributes, changes in incidence of weeds, diseases and insects on the rice crop should be studied. The present preliminary results call into question farmers’ assertions about the decrease in the extent of saline patches in their fields over time due to straw incorporation. Although the practice of burning straw should be avoided owing to air pollution, as regards soil fertility it does not seem to differ from the incorporation of straw. Therefore, positive short-term effects of straw incorporation on rice grain yield need to be large enough to persuade the farmer to accept its higher cost compared with burning.

Bibliography


Nitrogen mineralization capacity of coastal sandy soils of the Thua Thien Hue Province, Central Vietnam

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Keywords: sandy soils, Central Vietnam, nitrogen mineralization, cropping pattern

Abstract

Coastal sandy soils of Thua Thien Hue Province in Central Vietnam represent an important soil order that increasingly contributes to regional economic growth. However these soils have generally low productivity because of chemical and physical constraints associated with low pH values and coarse texture; sand contents exceeding 70%, are common for those soils. Obviously, organic matter management represents a key factor for crop productivity improvement on these soils. However, before considering the possible contributions of various organic amendments, it is important to evaluate the actual contribution of the initial soil organic matter, through its N-mineralization, considered as a prime source of N for plants. Therefore, 14 soil samples (0-20 cm) representing different cropping patterns on coastal sandy soils were collected before the spring season to determine their N-mineralization capacity. After air drying and grinding to pass 2 mm sieve, the samples were incubated under waterlogged conditions for 7, 14, 28, and 42 days; in addition, these soil samples were analysed for chemical and physical characteristics. Because of significant differences between major physical and chemical characteristics, the soils were grouped in two classes: soils under rice cultivation and soils with other crops. The rice soils had, on average, lower sand content, higher clay content, higher organic carbon content, higher cation exchange capacity and lower pH water. The release of NH₄⁺ was, on average, higher in rice soils, but no statistically significant differences were found between the two groups of soils. Fitting the results with a first order kinetic equation led to the calculation of potentially mineralizable nitrogen. As expected, the values were much smaller than the total soil-N content, which indicates different soil-N pools. The N-pool identified in this study can be considered as very labile N which might be available to crops within few weeks. Therefore, the total N-content of soils cannot be considered as a reliable indicator of short term N-availability, though some limited correlation was observed between these characteristics.

Introduction

Careful management of soil nitrogen (soil-N) is crucial for plant production and environmental reasons. In ecological/traditional farming systems, N deficiency is often seen in early spring, partially due to low soil temperatures which limit microbial activity, and thus mineral-N production through N-mineralization. In a variety of ecosystems, rates of N-mineralization and the total soil-N are indicators of soil fertility (Nadelhoffer et al., 1983; Pastor et al., 1984; Vitousek and Matson, 1985). However, a large nitrification rate can reflect potential N losses, either through leaching, leading to groundwater pollution, or through gaseous emission, contributing to greenhouse effect (Likens et al., 1969; Vitousek and Melillo, 1979; Krause, 1982; Vitousek and Matson, 1985). One strategy to meet crop N demand in these farming systems is to maximize the stabilization of organic-N inputs to soils, and thereby, build up a soil organic matter pool, rich in organic-N. In such systems, N-mineralization from this organic pool determines the amount of available N for crops.

In conventional/modern farming systems, mineral-N fertilizers are applied in spring to meet crop N demand. However, even if mineral N-fertilizer is applied, N-mineralization from soil organic matter remains an important source for crop N-uptake. As pointed out by Macdonald et al. (1989), the leaching risk is mainly due to nitrate derived from soil organic matter mineralization after harvest, rather than from unused fertilizer-N applied in spring. Consequently, predicting N-mineralization from soil organic matter is important, both in ecological and in conventional systems.

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farming systems, to meet crop N demand and to reduce nitrate leaching during autumn and winter.

In coarse sandy soils (<5% clay), mineral-N is generally low (<10 kg N ha⁻¹) with very small variations between sites (Østergaard et al., 1985). Correlation between mineral-N in spring and nitrogen uptake in aerial plant parts is low, indicating that mineral-N provides little information about the mineralization potential of sandy soils.

Environmental impact of excessive fertilizer use has increased the demand for valid and accurate methods leading to optimum nitrogen supply to agricultural crops. Due to added and native soil organic matter, complex turnover processes, this optimum N-fertilizer supply, aiming to maximize profits and minimize nitrate leaching risks, represents a great challenge, both for scientists and for farmers. However, before considering the possible contribution of organic amendments, it is important to evaluate the actual contribution of the native soil organic matter, through its N-mineralization considered as a prime source of N for plant. Therefore, a study was carried out to estimate the N-mineralization capacity of coastal sandy soils in Thua Thien Hue Province, with different cropping patterns. In this province, the crop-lands cover some 84,000 ha with 66,000 ha on sandy soils.

Materials and methods

Study area, soils sampling and characterization

The research was conducted in 4 communes of the coastal area of Thua Thien Hue Province: Phong Hoa, Quang Loi, Vinh Xuan, and Vinh Phu. The sandy soils used in this study were selected from a previous survey including 300 cultivated plots. The selection aimed at gathering a collection of samples representing the main differences of soil characteristics and cropping patterns encountered in the general survey. The total number of soil samples was fixed by laboratory constraints.

Fourteen composite soil samples were collected from the top horizon (0-20 cm) of cultivated plots before spring season. The samples references as well as the land uses are presented in Table 1. The cropping patterns include the following annual rotations: two rice crops, one rice crop, one rice crop followed by another crop (cassava, peanuts, sweet potatoes) referred as cash crop, one or two cash crops. All the soil samples were air dried and ground to pass 2 mm sieve. They were analysed by standard techniques for particle size distribution (pipette method), pH in water and in 1 M KCl (1:5 soil-solution ratio), electrical conductivity (EC, 1:5 soil-water ratio), organic carbon

![Table 1. Characteristics of the 14 soils used in this study. The reference codes denote the origin of the samples: PH-Phong Hoa, QL-Quang Loi, VX-Vinh Xuan, and VP-Vinh Phu. Last line of table: statistical test for significant differences between rice soils and other soils.](image)
content (OC, Walkley and Black method), total nitrogen content (Kjeldahl method), cation exchange capacity (CEC, leaching with 1 M NH₄-acetate pH 7, desorption with 1 M KCl, and measurement of NH₄⁺ by distillation).

**Incubation experiments**

The air-dried soils were incubated in waterlogged conditions at optimum temperature for biological activity following a technique recommended for characterizing the mineralization capacity of soil organic matter (e.g., Waring and Bremner, 1964; Keeney, 1982; Bundy and Meisinger, 1994; Drinkwater et al., 1996). From each soil sample, subsamples of 5 g were transferred to screw caped test tubes, 16 mm in diameter, and 12.5 mL of deionized water were added. Closed tightly to prevent air exchange, the tubes, 3 for each sample, were then stored at constant temperature (37°C), and incubated for periods of 7, 14, 28, and 42 days. Another subsample of each soil (5 g) was used for extraction of the initial NH₄⁺-N content by 2 M KCl, based on a method described by Bundy and Meisinger (1994). The same procedure of extraction was applied to the incubated samples at the end of incubation times. All incubation and extraction procedures were followed by three blanks treated exactly the same way. The NH₄⁺-N concentration was determined using a micro-Kjeldahl distillation method.

**Results and discussion**

**Soils characteristics**

Selected characteristics of the 14 soils are presented in Table 1. The soils were grouped in two classes according to two main different cropping patterns: soils with at least one rice season, and soils without rice cultivation, i.e., with cash crops only. Indeed, significant differences were found between these two groups for the following major physical and chemical properties: sand and clay content, pH H₂O, organic carbon, and CEC.

Rice soils were on average less sandy and contain more clay than the other soils. This might be due to the fact that farmers empirically chose these soils for rice cultivation because they were less permeable than the others. Organic carbon (OC), though being generally low, was higher in rice soils, which may result from their higher clay content which stabilizes humus compounds and from smaller mineralization rate in waterlogged conditions, i.e., higher humus content at steady state. The CEC values were low for all soils because of low clay and organic matter content; good correlation was observed between CEC and OC with the following equation: CEC (cmolc.kg⁻¹) = 0.05 + 1.78 OC (%); this means that the CEC of soil organic matter was some 178 cmolc.kg⁻¹ OC, which stresses on the need of maintaining a high soil OC pool by careful management of organic matter in farming systems, more especially in soils with naturally low clay content. The soil pH (measured in water suspension) varied from 4.7 to 6.1, and rice soils appeared on average more acid than the others. This can result, among other reasons, from oxidation reactions when waterlogged soils are re-aerated or dried after sampling.

**N-mineralization**

The N-mineralization data, expressed as NH₄⁺-N extracted from soils after each period of incubation, are presented in Figure 1. For all soils, NH₄⁺ increased regularly from 0 to 42 days, and though starting from similar values at initial time, the rate of

![Figure 1. NH₄⁺-N extracted from soils as a function of incubation time. Left: rice soils; right: other soils.](image-url)
N-mineralization was, on average, higher in rice soils than in the others. However, the differences between the two groups of soils were not statistically significant at the 0.05 probability level.

The shape of NH$_4^+$ release vs time curves have a typical curvilinear shape, which indicates a decreasing mineralization rate with increasing time. It can be attempted to fit such type of curves with a first order kinetic equation for N-mineralization. If N$_{soil}$ is the soil-N pool which is susceptible to be released by mineralization at the time scale of our experiments (often called potentially mineralizable nitrogen), the variation of N$_{soil}$ with time, t, is given by:

$$\frac{dN_{soil}}{dt} = -k N_{soil}$$

By integrating from time 0 to t

$$N_{soil, t} = N_{soil, 0} e^{-kt}$$

If we consider that the amount of NH$_4^+$ released from time 0 to t is equal to the decrease of N$_{soil}$, then the balance equation is:

$$[\text{NH}_4^+]_t - [\text{NH}_4^+]_0 = N_{soil, 0} - N_{soil, t}$$

$$[\text{NH}_4^+]_t - [\text{NH}_4^+]_0 = N_{soil, 0} (1 - e^{-kt})$$

N$_{soil, 0}$ and k can be calculated by non linear regression of experimental values of extracted NH$_4^+$ vs time (Figure 1). The values of N$_{soil, 0}$ calculated from our data were in the range 22 to 132 mg N.kg$^{-1}$. The mean values of the regression parameters for the two groups of soils were: N$_{soil, 0}$ = 63 and 50 mg N.kg$^{-1}$, and k = 0.06 and 0.04 d$^{-1}$ for the rice soils and the other soils respectively, but these difference are not significant at the 0.05 probability level. As expected, the N$_{soil, 0}$ values were much smaller than the total N content of soils presented in Table 1, i.e. 580 and 430 mg N.kg$^{-1}$ for the two groups of soils respectively. Indeed, the N-pool revealed after some weeks of incubation can be qualified as labile organic-N and represents only a small fraction of total N. According to different authors (e.g. Dommergues and Mangenot, 1970; Wander et al., 1994), at least two other N-pools may be distinguished in soils, one pool of stable but still labile organic-N, and one pool of more stable organic-N which is involved in humification processes and only released at long term scale.

One question at the start of this study was to know whether short term N-mineralization might be related to any of the soil characteristics reported in Table 1. Correlations were calculated between these properties and NH$_4^+$ release at any given time. The best, though limited, correlation was found with total N content. These correlations are shown in Figure 2 with their respective r$^2$ values.
Conclusion

Through a short period of experimental observations, the sandy soils of the coastal area of Central Vietnam have been investigated for their N-fertility potential, generated by various soil characteristics and cropping patterns. The experimental approach focused on the initial soil organic matter contribution to the production of mineral-N, considered as a prime source of available N for plants.

Based on significant differences between major physical and chemical properties, two groups of soils were distinguished: soils with rice cultivation and soils with cash crops only. Mineralizable-N was usually higher for rice soils which had higher mean OC content, but the differences between the two groups of soils were not statistically different. More samples might be necessary to ascertain such conclusion. According to a first order kinetic equation, the soil N-pool participating in short term N-mineralization was much smaller than the total N content, which supports the general view of different soil N-pools with different potential availability to plants. Consequently, even if some correlation was observed between $\text{NH}_4^+$ release and total N content, this routine characteristic of soils cannot be considered as a reliable indicator of N-availability for crops cultivated in the coastal sandy area of Central Vietnam. This justifies further study to better assessment of native fertility of these soils and proper techniques for optimum management of organic matter in local farming systems. To that purpose, long term mineralization experiments, according for example to the leaching-incubation method proposed by Stanford and Smith (1972), are also necessary.

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References


Effects of salinity-tolerance cyanobacterium *Nostoc* sp. on soil characteristics and plant growth

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**Keywords:** cyanobacterium *Nostoc*, soil salinity reclamation, tolerance to salinity

**Abstract**

Soil degradation is a serious problem due to global population increase, with desert areas expanding at 6 millions ha per year. Terrestrial cyanobacterium *Nostoc*, a blue-green algae, forms a mat on soil surface and is dry- and heat-resistant. *Nostoc* is known as a pioneer organism, which can photosynthesize, fix atmospheric nitrogen, and secrete polysaccharides. Therefore the inoculation of *Nostoc* may have potentiality to reclaim degraded soil ecosystem, for example salt-affected sandy soil or alkaline soil. In order to explore the potential of *Nostoc* to be utilized for countermeasures to soil desertification, we examine salinity-tolerance of *Nostoc* which is found in temperate and tropical regions including Khon Kaen, Thailand. We also investigate the physicochemical soil properties suitable for cyanobacterial growth, effect of *Nostoc* on soil chemical and biological properties and plant growth both in a laboratory and an outdoor experiment.

Salinity-tolerance of *Nostoc* isolated from Khon Kaen soil was comparable or better than isolates from temperate region. *Nostoc* produced largest amounts of polysaccharides without saline condition, which may play important role in salinity-tolerance. Application of *Nostoc* increased soluble C and N soil content. In the outdoor experiment, *Nostoc* created a crust structure on the soil surface, reduced soil temperature fluctuations and delayed soil surface evaporation. These results indicate that the application of *Nostoc* to the soil surface presents a potential for organic matter production and could be a tool to reclaim degraded soil ecosystem.

**Introduction**

Soil degradation is a serious problem in the context of global population increase, with desert areas expanding at the rate of 6 millions ha per year. Terrestrial cyanobacterium *Nostoc* is resistant to heat and dryness, and forms a mat on the soil surface. *Nostoc* is known as a pioneer organism that can photosynthesize, fix atmospheric nitrogen, and secrete polysaccharides. Polysaccharides contribute to soil structure, increase soil C and N, and promote plant growth. Through these characteristics, *Nostoc* has a potential to be used to reclaim degraded soil, for example salinized or alkalinized soil in semi-arid or arid areas. Carbon and nitrogen fixation by cyanobacteria in arid or boreal soil ecosystems is significant (Zaddy 1997; Okitsu et al. 2003). In the semi-arid regions of Southwest United States, primary production in soil crusts, mainly made of cyanobacteria, reached 6 to 23 kg C ha⁻¹ yr⁻¹ (Eldridge and Greene 1994), and the cyanobacterial mat prevented soil erosion, especially under dry conditions (Johansen 1993). Under such conditions soil salinity is often an issue, thus the use of salt-tolerant cyanobacteria may be an option.

Application of cyanobacteria mixed with gypsum and sulfur changed the soil pH from alkaline to neutral, reduced exchangeable Na and EC, and led to the development of soil aggregates in India (Kaushik and Mutri 1981; Kaushik 1989, Subhashini and Kaushik 1984). However these results were obtained with an application of a mixture of cyanobacteria together with a chemical. The quantitative evaluation of single species of cyanobacteria had not been conducted yet.

In our study, we evaluated the potential of single species of cyanobacteria *Nostoc* to prevent soil degradation. We investigated the effects of *Nostoc* application on the biochemical properties of the soil and on plant growth in outdoor and laboratory experiments.
Materials and methods

Three types of experiments were carried out. In the first and second the *Nostoc* species under study was isolated from the Chiba Prefecture Warm Horticulture Research Institute in Tateyama, Japan. This type of cyanobacteria is common on the soil surface, especially after rain. In the third type of experiment, four species of *Nostoc* were studied: the isolate from Tateyama, a strain from a dried-up paddy field in Ban Kham Pia, Khon Kaen, a strain from Morioka, Northern Japan, and the Himeji strain (HK strain), Western Japan.

**Experiment 1: Effects of *Nostoc* application on soil characteristics.**

**1-1 Outdoor experiment**

In this experiment, *Nostoc* was applied to the surface of soils in 30 l plastic containers (length: 41 cm, width: 31 cm) at the rate of 0.02 g cm$^{-2}$. *Nostoc* contained 340-430 mg C, 36-52 mg N and 46-50 mg polysaccharides g$^{-1}$ dry matter.

The soil used was a Brown Forest soil taken from the Chiba Prefecture Warm Horticulture Research Institute. Its main biochemical properties were: total C and N: 14.4 and 1.38 g kg$^{-1}$, respectively, pH (H$_2$O): 6.1, EC: 9.6 mS m$^{-1}$, and CEC: 28.4 cmol (+) kg$^{-1}$. The soil depth was 15 cm, and about 5 cm of gravel was added at the bottom. The sensors of an auto-thermo recorder (T&D, Ondotori TR-71) were installed at a depth of 1 cm to record soil temperature (Figure 1). Ceramic soil suction meters (Fujiwara Seisakusho, SPAD PF-33, sensing range pF 1.3 to 3.9) were also installed at 6 and 12 cm depth to record soil water potential. *Nostoc* was cultivated in outdoor plastic containers for 90 days from June 1 to September 1, 2002, without irrigation. *Nostoc* un-amended containers were set up as a control. Both treatments and control were replicated three times. After 90 days of cultivation, soil samples were taken for analysis at depths of 0-2.5, 2.5-5.0, 5.0-7.5 cm. Soluble soil organic C and N content were determined after extraction with 0.5 M K$_2$SO$_4$ solution (soil: solution 1:5 w/v) using a TOC meter (Shimadzu, TOC 5000) for C and the persulphate oxidation-hydrazine reduction method (Sakamoto et al. 1999) for N. Soil pH was measured using a soil:water or 1 M KCl ratio of 1:2.5 (w/w). Electrical conductivity (EC) was measured using a soil:water ratio of 1:5 (w/w). The number of soil microorganisms (fungi and bacteria) was measured by the dilution plate method (Soil Microbial Society, 1992). The cation exchange capacity (CEC) of the soil was measured by the Schorenberger’s method and exchangeable cations (Na, Mg, K, Ca, Mn) were measured in a 1.0 M ammonium acetate extract by ICP (Shimadzu, ICPS-1000IV) (Muramoto et al. 1992).

**1-2 Growth chamber experiment**

In this experiment *Nostoc* was applied at the rate of 1.0 g dry matter on the surface of 160 g of autoclaved Brown Forest soil or river sandy soil in 500 ml pots (diameter: 7.5 cm; height: 8.0 cm) either as dried ground powder or fresh minced mass after homogenisation. *Nostoc* un-amended pots were set up as a control. *Nostoc* was grown for 30 days at 30°C inside a growth chamber with a 16 h light (80 µmol m$^{-2}$ s$^{-1}$) and 8 h darkness cycle using irrigation to maintain moist conditions. Both treatments and control were replicated three times. At the end of the cultivation, the soil samples were analyzed for soluble organic C and N, CEC and exchangeable cations with the methods indicated in experiment 1-1.

**Experiment 2: Effects of *Nostoc* application on plant growth.**

**2-1 Sandy soil**

In this experiment, *Nostoc* (0.4 g dry matter) was applied on the soil surface or mixed with the autoclaved river sandy soil (100 g) placed in plastic seedling trays (5 cm × 5 cm × 5 cm). Weeping love grass (*Eragrostis curvula*) seeds (0.5 g) were planted and the trays were incubated in a growth chamber at 25°C for 30 days under similar illumination cycle and irrigation as in experiment 1-2. For comparison with *Nostoc* application, two more treatments, autoclaved river sandy soil that received only chemical fertilizer or not (control), were setup. Chemical fertilizer (N:P:K 8:8:8) was applied at a rate equivalent to 200 kg N ha$^{-1}$ (designated as fertilizer amended control). The soil not amended with *Nostoc* or fertilizer...