Agro-pedological Assessment of the Traditional Yuanyang Rice Terraces of Yunnan Province, China

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\textbf{Abstract:} As a contribution to a long-term evaluation of the sustainability of agro-ecosystems in the Yuanyang rice terraces, this paper reviews the bio-physical environment of the terraced landscape in a small catchment around Qingkou village and assesses soil fertility in the village crop growing area. A soil-landscape organization pattern was developed using a geomorphopedological approach. Anthropogenic, climatic and topographic factors were identified as the main soil forming factors. Soil capability and associated edaphic constraints were assessed and the main soil types were identified and classified using FAO protocols. Spatial patterns of soil fertility appear quite homogeneous. Soils are acid and cation exchange capacity and nutrient reserves are generally low. The agro-ecosystem has largely been developed by the Hani population. This agro-ecosystem has succeeded in maintaining a relatively dynamic nutrient circulation system. Current research is focusing on: (i) the evaluation of the representativeness of the studied area compared to the whole terraced system in the Yuanyang terraced landscape; (ii) measurements of nutrients flows at the field scale; (iii) the effects of soil properties on crop yields; and (iv) up-scaling field levels results to larger spatial units.

\textbf{Key words:} terraced paddy fields; geomorphopedological approach; soil fertility diagnosis; Yuanyang rice terraces; sustainable agriculture

1 Introduction

They are “Magic Mountain Sculptors” for “building their ladders to Heaven” (commendation of the Hani people by an Emperor of the Ming Dynasty, 1368–1644).

“Better water comes from better trees, better paddies develop with better water, and better offspring prosper with better paddies” (traditional Ancient song of the Hani people).

Yuanyang County, in southern Yunnan, is famous for its rice terraces, which are claimed to form the world’s largest and most spectacular terraced landscape (covering ~11 000 ha). The Hani minority people began crafting the terraces an estimated 1300 years ago and the terraces remain in use today (Shimpei Adachi 2007; FAO 2010; Wan 2010). The Hani Rice Terraces System, including the Yuanyang rice terrace system in Honghe Autonomous Prefecture, was listed as one of the “Globally Important Agricultural Heritage Systems” (GIAHS) pilot sites by FAO in 2010 (FAO 2010). These are specific agricultural systems and landscapes that merit conservation. The state and future of the Yuanyang terraces was the focus of the “First World Conference on Terraced Landscapes” held in Honghe (Yunnan Province) in November 2010. Social, historical, cultural and agronomic aspects of the terraces and the main challenges for their conservation and future development have been summarized by Wan (2010). The remarkable nature of the Hani landscape relies largely on the sustainability of the agro-ecosystem (Na Guo 2010). Local records show that, in addition to the
terraces being in continuous cultivation for ~1300 years, the same group of ~30 traditional rice cultivars have been used around Qingkou village for the past ~200 years, without significant loss of crops yields or major crop disease problems. Moreover, villagers do not generally use synthetic pesticides or artificial fertilizers, suggesting that it is likely to be a highly sustainable system. However, the critical question for local farmers is whether a more intensive, but less sustainable, system would generate more income and improve their living standards. This question requires thorough investigation, not only to understand the basis for the apparent sustainability, but also to evaluate whether branding and higher profile marketing of products produced by this sustainable, environmentally-friendly system, linked to ecotourism, constitute more appropriate options for economic development, rather than agricultural intensification.

Although visited by many people with diverse interests, the terraces have received little scientific study to date. Therefore, an international consortium of academic partners (from Belgium, China and the UK) designed a multi-disciplinary research project to investigate all aspects of the sustainability of the traditional Hani rice production system. The purpose of the present study was to evaluate the potentialities and edaphic constraints of the bio-physical environment of the terraced landscape around Qingkou village. The specific goals of the research were: (i) to understand soil patterns within the landscape and (ii) to evaluate the fertility status of cultivated fields.

2 Materials and methods

2.1 Study site

The Yuanyang terraces are 326 km south of Kunming (22°49′–23°19′ N, 102°27′–103°13′ E, Fig. 1). They were built on the slopes of Ailao Mountain, which belongs to the longitudinal range-gorge landsystem, in which relief is characterized by the association of south-north orientated mountain chains, deep valleys and large rivers. Elevation ranges from 144–2940 m above sea-level and the region can be divided according to this criterion into lowlands (altitude <700 m) and uplands (>700 m).

The study area is located in the Ailao Shan metamorphic belt, a geological structure between the two major tectonic blocks of South China and Indochina. As a result of the collision between India and Asia during Cainozoic time, Indochina was extruded to the south-east along the Ailao shear zone, with a minimum offset of 300 km. This left-lateral displacement occurred between 35–17 Ma BP and was followed by a right-lateral shear along the Red River fault during the late Miocene (~4.5 Ma BP) and Quaternary times. Mylonitic gneisses with amphibolites and anatectic granites constitute the Ailao metamorphic belt in the Yuanyang region (Tapponnier et al. 1986, 1990; Leloup and Kienast 1993; Leloup et al. 1993, 1995; Li et al. 2008) and belong to the ‘A’long Formation (Pta)’ and ‘Xiaoyangjie Formation (Ptx)’ (Second National Soil Survey Offices of Honghe Hani and Yi Nationality Autonomous Prefecture and Yuanyang County 1986).

Fig. 1 Location of Yuanyang County in Yunnan Province, China.
According to field surveys, gneiss and amphibolite are the most regularly outcropping rocks. Hydrogeology plays an important role, with upslope rocks acting as aquitards and encouraging runoff from mid-slopes. Mid- to lower slopes present a multitude of springs, which are important water sources for lower paddy fields.

Climatic conditions in the Yunnan uplands are suitable for rice cultivation, with a mean annual sunshine of 1670 hours and mean annual temperature of 15.4°C (Wang 1999). Average annual precipitation ranges between 1200–1500 mm on lower slopes and 1500–2000 mm on upper slopes. Most precipitation falls as summer monsoon rains between May and October and is enhanced by orographic effects. Fogs are frequent and differential late afternoon solar heating of mountain sides induces slight pressure differences, which cause upslope (anabatic) winds to transport moist airstreams from the valley base upslope (Vogel et al. 1995a, 1995b).

Hilltops are generally afforested, predominantly with Yunnan pine (*Pinus yunnanensis*), but many other species are present (such as *Alnus nepalensis* and *Neolitsea aurata*). Upland forests are very effective in conserving soil and water and release high quality water from upper to lower slopes (Liang 2010). Forest covers ~27% of Yuanyang County. The location of Hani villages indicate their environmental understanding, as they are usually located on middle and sunny mountain slopes. At the mid-part of the mountain, temperatures are mild, with less risk of disease and pest damage than at lower elevations. A typical Hani village is comprised of 20–50 households and the distance between two adjacent villages is ~2 km. With such small villages in close proximity, people can efficiently manage their lands without long walks to the fields. The Hani cultivation system consists of mixed farming, associating pond-field rice cultivation and dry crops (such as maize and beans), multiple cropping of domesticated plants and raising livestock (Bouchery 2010). Rice is the dominant crop and is managed with few additions of artificial fertilizers or pesticides. Complex fertigation systems provide most nutrients, especially nitrogen (N). Mixes of cattle manure and organic wastes are placed adjacent to channels. When needed, irrigation waters are diverted into paddy fields, inputting a N flush, especially in the early growing season. Grains and straw are exported from the fields, while ploughing-in of stubble returns nutrients to the soil. Aquaculture is a frequent practice within the flooded paddy fields, adding valuable supplements to the diet and increasing nutrient loads within paddy fields.

A 560 ha pilot research catchment (referred to as the Qingkou sub-catchment) was chosen in the uplands of Yuanyang County, in order to concentrate research efforts in a representative area, prior to extrapolation to the larger terraced landscape. The Qingkou study site is located on the east-facing slope within the Malizhai River basin, a southern tributary of the Red River. Slope characteristics have been determined from topographic maps (1:25 000) and ground-truthed in the field. Hani terraces have been cut in long moderate (<10°) slopes, separated by shorter steeper (20–25°) sections. Elevation ranges from 1400 to >2000 m and the landscape is organized according to topography (Fig. 2). The summit is mainly covered by low vegetation such as shrubs and bushes, and recent tree plantations (*Alnus sp.*). This area (5% of the total) is used for grazing. Tea fields (~80 ha) and pine forests (>150 ha) are located below this area. Six villages were built by the Hani people between the forests and the paddy fields, of which Qingkou is the largest in Yuanyang County (Fig. 2). Some terraces near the villages are reserved for dry crops, mainly multiple cropings of beans and maize (<5%). The terraced paddy fields are located on the mountain slopes ≤1800 m, with more plots concentrated at lower elevations within the catchment. These benefit from higher temperatures and are naturally protected from the potentially damaging upper mountain winds. Paddy fields cover almost half of the 560 ha.

### 2.2 Field and analytical methods

A reconnaissance soil survey was conducted, based on a geomorphopedological approach. In addition, soil fertility status was assessed, based on composite samples of the surface layer from representative fields. Soil organization within the landscape has been characterized along toposequences. The main soil types of the study area were identified and classified according to FAO World Reference Base (WRB) protocols (FAO 2006a).

After an initial scoping of relief features and lithological outcrops in the catchment environment, detailed observations of terrain and soil properties were made along sequences within the study area (Fig. 3). Some 69 augering points and eight profiles were described using standardized procedures (Delecour and Kindermans 1980; FAO 2006b). The WRB classification is defined in terms of diagnostic soil horizons and soil properties, which as...
far as possible should be observable and measurable in the field (FAO 2006a).

Some 25 composite samples of the plough layer (0–20 cm depth) from representative paddy fields (n = 16) and dry fields (n = 9) were sampled and analysed for evaluation of soil fertility. The determinations were: pH, exchangeable acidity and aluminium, Total Organic Carbon (TOC), total Nitrogen (NT) and available nutrients (Ca, Mg, K and P).

Soil samples were air-dried, gently crushed, and ground to ≤2.0 mm. A fraction was ground to 500 µm for TOC and NT determinations. Soil pH was measured both in water and 1N KCl (2:5 w:v ratio) by potentiometry, after two hours of end-over-end shaking and 10 min. of centrifugation. Exchangeable acidity and aluminium were measured, adopting the procedures of Yuan (1959) if pH water was <5.5. Aliquots of 200 ml 1N KCl were percolated through 5 g of soil in columns. Exchangeable acidity was measured by titration with 0.1N NaOH. Exchangeable Al was measured using flame atomic absorption. TOC determinations adopted the principles of the Springer-Klee method (Springer and Klee 1954). OC was oxidized by K$_2$Cr$_2$O$_7$ in acid conditions during a 10 min. boiling period and excess K$_2$Cr$_2$O$_7$ was measured by titration with Mohr’s salt. Total N was measured using the Keldahl method (Bremner and Mulvaney 1982). Organic N was transformed to ammonium under acid conditions and the evolved ammonium was trapped by H$_3$BO$_3$ after distillation under alkaline conditions. N-NH$_4^+$ was titrated with 0.1N HCl. Cation Exchange Capacity (CEC) and exchangeable bases were determined following the Metson method. Soil samples (5 g) were shaken with 100 ml 1N CH$_3$COONH$_4$ at pH 7. Ca, Mg, K and Na were measured by flame spectrometry in the extract. NH$_4^+$ was displaced from the complex exchange by hot water distillation with NaOH, trapped in H$_2$BO$_3$, and titrated with 0.1N HCl. Effective CEC (CEC$_{eff}$) is calculated as the sum of bases (S) and exchangeable acidity. The saturation ratio (V) is the ratio between S and CEC. Available Ca, Mg, K and P were measured after extraction from 10 g of soil in 50 ml CH$_3$COONH$_4$ at pH 4.65 + EDTA. The elements were measured using either flame spectrometry (Ca, Mg, K) or spectrophotometer (P). Soil properties were mapped using ArcGis 9.3 software.

3 Results
3.1 Soil characteristics
Soil observations in the field (augerings and profiles) included soil and horizon depths, texture, colour and the nature and properties of stones and mottles, which are summarized in Table 1. Soils on steep slopes are usually more influenced by slope processes than pedogenetic processes. In Yuanyang, relief has been strongly modified by the Hani people in order to facilitate agricultural activities. Soil thickness is usually >100 cm (Table 1), but thinner soils are also frequent (~1/3 of augerings). The thinner soils (<60 cm) are weakly developed in upper slopes or along stream banks. They present two to four distinctive horizons, while other soils present four to six. The dominant hue is 10YR in the summit area and upper slopes (Fig. 4). Paddy fields present a wide variation of colour, from reddish-brown (2.5YR) to typical blue and green related to reduction. The subsoil and topsoil horizon of a given soil usually have the same hue (except paddy soils and some dry crop soils with a weathering B horizon). Some soils of the upper part have light colours (high value), while paddy fields soils are darker. The latter also present wider chroma ranges in subsoil horizons.

The paddy field topsoils are deep (typically 0.6–1.2 m) and black and are a direct result of human activities. They are characterized by a plough pan (which is difficult to penetrate with an auger), increased subsoil clay, gravel (>2.0 mm) contents of 15%–50% and large surface cracks. Below the puddled layer, various colour sequences may be observed in the subsurface horizons: black-yellow-orange in the northern part and black-yellow in the southern part. However, we cannot exclude the possibility that the orange horizon exists at greater depth. These colour differences could be linked to differences in Fe-minerals (goethite and hematite) and may result from different former weathering
regimes or from differences in the mineralogical composition of soil parent materials. This question merits further research.

The dominant texture is clay loam (~40% of described horizons). The various sandy, loamy and clayey textures represent <5, >75 and ~20% of samples, respectively. Two trends may be observed; clay content increases from higher to lower areas and from topsoil to subsoil (argic horizons).

Topsoils present no or few (<15%) mottles, resulting mainly from weathering processes, except paddy field soils which often exhibit many redox mottles. In dry fields, mottle abundance usually increases in subsoil horizons compared to topsoil. In paddy fields, there is no clear trend with depth. Soils in the upper catchment are less affected by mottles than lower slopes.

Table 1 Synthesis of morphological properties of topsoil and subsoil horizons in Yuanyang County (part 1 of 2): thickness and colour.

<table>
<thead>
<tr>
<th>Relief division Sector</th>
<th>Soils</th>
<th>No.</th>
<th>Thickness (cm)</th>
<th>Hue Value Topsoil</th>
<th>Chroma Topsoil</th>
<th>Chroma Subsoil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summit</td>
<td>Umbrisol</td>
<td>3</td>
<td>90–100</td>
<td>10YR 10YR</td>
<td>3</td>
<td>3–5</td>
</tr>
<tr>
<td></td>
<td>Regosol</td>
<td>3</td>
<td>75–90</td>
<td>10YR</td>
<td>4</td>
<td>5–7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper slopes</td>
<td>Umbrisol</td>
<td>10</td>
<td>65–&gt;100</td>
<td>10YR 7.5YR–10YR</td>
<td>3–4</td>
<td>3–4</td>
</tr>
<tr>
<td></td>
<td>Regosol</td>
<td>2</td>
<td>30–75</td>
<td>10YR</td>
<td>3–5</td>
<td>2–5</td>
</tr>
<tr>
<td></td>
<td>Cambisol</td>
<td>1</td>
<td>75–90</td>
<td>10YR</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Acrisol</td>
<td>1</td>
<td>75–90</td>
<td>10YR</td>
<td>4</td>
<td>2–4</td>
</tr>
</tbody>
</table>

Table 1 Synthesis of morphological properties of topsoil and subsoil horizons in Yuanyang County (part 2 of 2): texture, mottle abundance andstoniness.

<table>
<thead>
<tr>
<th>Relief division Sector</th>
<th>Soils</th>
<th>No.</th>
<th>Texture (FAO)*</th>
<th>Mottle Abundance Topsoil</th>
<th>Stoniness (% Topsoil Subsoil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summit</td>
<td>Umbrisol</td>
<td>3</td>
<td>SL C-CL-SCL</td>
<td>0</td>
<td>&lt;15</td>
</tr>
<tr>
<td></td>
<td>Regosol</td>
<td>3</td>
<td>SL-L</td>
<td>0</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Upper slopes</td>
<td>Umbrisol</td>
<td>10</td>
<td>L-SL CL-L-C-SL</td>
<td>0</td>
<td>&lt;50</td>
</tr>
<tr>
<td></td>
<td>Regosol</td>
<td>2</td>
<td>SL-L</td>
<td>0</td>
<td>&lt;15</td>
</tr>
<tr>
<td></td>
<td>Cambisol</td>
<td>1</td>
<td>CL C</td>
<td>&lt;50</td>
<td>&gt;15</td>
</tr>
<tr>
<td></td>
<td>Acrisol</td>
<td>1</td>
<td>L CL</td>
<td>&lt;15</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Middle slopes</td>
<td>Anthrosol</td>
<td>7</td>
<td>L-CL L-CL-SCL</td>
<td>&gt;5</td>
<td>&lt;15</td>
</tr>
<tr>
<td></td>
<td>Acrisol</td>
<td>2</td>
<td>SCL SCL-C-SC</td>
<td>&lt;15</td>
<td>&lt;15</td>
</tr>
<tr>
<td></td>
<td>Umbrisol</td>
<td>1</td>
<td>CL C-SC-SL</td>
<td>0</td>
<td>&gt;15</td>
</tr>
<tr>
<td>Lower slopes</td>
<td>Anthrosol</td>
<td>10</td>
<td>SL-CL CL-SL-SCL</td>
<td>All classes</td>
<td>&lt;15</td>
</tr>
<tr>
<td></td>
<td>Acrisol</td>
<td>1</td>
<td>L L-CL</td>
<td>0</td>
<td>15–50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;15</td>
</tr>
<tr>
<td>Mid</td>
<td>Anthrosol</td>
<td>18</td>
<td>CL-L-SL CL-SL-SC</td>
<td>All classes</td>
<td>&lt;15</td>
</tr>
<tr>
<td></td>
<td>Umbrisol</td>
<td>4</td>
<td>CL C-CL</td>
<td>&lt;50</td>
<td>&gt;5</td>
</tr>
<tr>
<td></td>
<td>Cambisol</td>
<td>2</td>
<td>C-SCL CL-C</td>
<td>&lt;15</td>
<td>&lt;15</td>
</tr>
<tr>
<td></td>
<td>Acrisol</td>
<td>1</td>
<td>CL SC</td>
<td>0</td>
<td>&gt;15</td>
</tr>
<tr>
<td></td>
<td>Arenosol</td>
<td>1</td>
<td>SL</td>
<td>15–50</td>
<td>0</td>
</tr>
<tr>
<td>Down</td>
<td>Anthrosol</td>
<td>6</td>
<td>CL-SC-L CL-SC</td>
<td>&lt;50</td>
<td>&lt;15</td>
</tr>
<tr>
<td></td>
<td>Cambisol</td>
<td>1</td>
<td>SC</td>
<td>&lt;15</td>
<td>15–50</td>
</tr>
<tr>
<td></td>
<td>Arenosol</td>
<td>1</td>
<td>L S-CL</td>
<td>&lt;15</td>
<td>15–50</td>
</tr>
</tbody>
</table>

Topsoil stoniness is generally low (<15%) and usually increases with depth. A mean index has been calculated, assigning stoniness into classes (1 = 0%, 2 ≤ 15%, 3 = 15% – <50%, 4 ≥ 50% stones; >2.0 mm diameter). Soils of the Qinkou sub-catchment were grouped according to their stoniness characteristics (Fig. 5). Three situations were observed: a continuous increase with depth, a marked increase between 80–100 cm and an increase from the surface to 50 cm depth and either constant or decreasing contents deeper in the profile.

3.2 Soil classification according to WRB

The escalic characteristics (synonymous with terracing) is a general feature and was therefore not used to differentiate soils. Various other diagnostic horizons and properties were observed in the soils of Qinkou sub-catchment. According to the sequence given by the WRB key, the first point to notice is the occurrence of both an anthraquic (puddled) layer and a plough pan (hydragric) horizons as distinctive criteria of Hydragric Anthrosols, which are characteristic of paddy soils. Coarse materials, consisting of sandy or gravelly alluvial deposits, were found in some observation points near permanent streams. Argic horizons (characterized by subsoil increases in clay content) were frequently identified, leading to the diagnosis of Acrisols or Alisols, if no other Reference Soil Groups (RSG) had been previously attributed to the soil. The distinction between Acrisol and Alisol relies upon clay activity (CEC threshold = 24 cmolc kg⁻¹ of clay). Clay content is undergoing laboratory analysis, but field observations suggest clay contents are quite high. It was therefore decided to retain the Acrisol option, given the relatively low levels of exchangeable Al (see below). Umbric (thick, dark, base-deficient) horizons were found either in the surface (strict definition) or subsurface horizons, due to terrace crafting. Cambic horizons were also identified, indicative of weathering in some profiles. Cambic horizons were either associated with umbric horizons or as the only diagnostic horizon. Regosols is the last RSG in the key, and is used to designate soils without clear diagnostic horizons.

The 8 profiles and 69 augering points (total 77 observations) can thus be attached to six RSG: Anthrosols (n = 42), Umbrisols (18), Acrisols (6), Regosols (5), Cambisols (4) and Arenosols (2). Their spatial distribution is presented in Fig. 6. Anthrosols are clearly linked to the paddy fields below the main catchment road. Regosols and Umbrisols are associated with forested and dryland crops. Cambisols and Acrisols are associated with Anthrosols in middle and lower elevations. However, Umbrisols often present cambic properties. Arenosols are located along the largest streams. In the lowest part, alluvial material frequently includes rounded stones.

The most frequently used qualifiers for soils of the sub-catchment were: Colluvic (Hyper-) Dystric, Escalic, Hydragric, Gleyic, Stagnic, Cambic, Humic, Leptic, Endoclayic, Rhodic, Pachic, Chromic or Haplic (FAO 2006a). As reported by Kawaguchi and Kyuma (1977) for paddy fields in South-East Asia, Anthrosols are formed from diverse natural soils and agronomic practises tend to homogenize surface horizon properties.

3.3 Soil fertility diagnosis

The Hani farmers have practised sustainable agriculture and land conservation based on ecological principles centuries before those concepts were globally accepted (Kawaguchi and Kyuma 1977; FAO 2010). The crafting of the terrace walls and design of the irrigation systems not only prevented soil erosion inputting sediments into rivers (Kawaguchi and Kyuma 1977), but also raised the potential agricultural surface. An initial survey of the fertility status of the fields is summarized in Table 2.

Soils are acid or slightly acid (Vogel et al. 1995a, 1995b). Most pH_water values are between 5–6. Kawaguchi and Kyuma (1977) found similar levels for soils from 410 paddy fields in South-East Asia. However, exchangeable
acidity is relatively low. When soil is water-saturated, pH tends to increase. The situation should not therefore be considered as a major edaphic constraint. The organic status appears rather low compared to the data of Kawaguchi and Kyuma (1977). TOC contents ≥2% or C:N ratios between 12–14 were found only for one-third of studied fields in South-East Asia. This indicates that the transformation of organic matter is probably decreased by the redox conditions and local climate. According to Chinese standards (Zhang et al. 1995a, 1995b; Li 2004), Kawaguchi and Kyuma (1977) or Li (2004). However, they do not seem to be in ionic disequilibrium (Landon 2004). Kawaguchi and Kyuma 1977; Landon 1991). The low variability of base status is probably related to the relative homogeneity of soil parent materials. Both CEC and Al saturation are relatively low (Kawaguchi and Kyuma 1977; Landon 1991). Initial observations suggest that Al toxicity does not pose a major problem.

Available P was <1 mg 100g⁻¹ of soil in every sampled field (data not presented), although farmers regularly apply superphosphate fertilizers (Koulos 2010). P availability tends to be higher in waterlogged soils, due to the reduction of Fe-oxides. However, our results show very low concentrations, compared to standards and previous studies (Vogel et al. 1995a, 1995b; Li 2004). Kawaguchi and Kyuma (1977) also found most paddy fields had available P contents (Bray Kurtz 2 method) <1.5 mg 100g⁻¹. The question of the relevance of this protocol is being investigated, along with comparative analysis of available and total reserves.

Comparative analysis of wet rice fields with dry terraces devoted to bean and maize leads to the observation that soil fertility status is generally higher in dry terraces than in paddy fields. Dry soils are less acid and are richer in N and base cations. These findings will be validated by a broader survey, but it is possible that either the farmers have fertilized the vegetable plots, or the difference is partly due to the N-fixing activity of leguminous vegetables. Dry fields are typically closer to the village than wet fields and so require less effort to fertilize. The crops grown in these fields would be more responsive to applied fertilizer than traditional rice cultivars.

Despite the relatively poor soil nutrient status, rice crop yields are maintained from year-to-year. This suggests that, in addition to an effective nutrient cycling system within each of the paddy fields, which are perennially flooded, there are additional inputs from irrigation water (Fullen et al. 1995). This is supplemented by animal slurries (fertigation) flowing into the terraced fields. Some farmers may also carry solid animal manure directly to their individual fields every two or three years and there are anecdotal reports from villagers that this practise is undertaken. These input fluxes have not yet been quantified and this is currently under study within the catchment.

### 3.4 Soil and land use organization in relation to topography

There are logical linkages between soil organization and topography. As lithology is dominated by gneiss, amphibolites and granites (the spatial distribution appears random at the studied scale) the redistribution processes of weathering products in relation to slope and land use are the main factors explaining soil diversity. Morphological and physico-chemical properties determine the constraints
to agricultural use. The detailed soil profile data are not presented, but they can be summarized as follows.

From upslope to downslope:
- Regosols are located on the catchment summit. They are generally shallow (<50 cm depth), acid (pH <5.0), with very low base saturation (V <5%) and do not exhibit diagnostic horizons. They are used as cattle pasture.
- Umbrisols are located on upper slopes. They are characterized by: anthropization, acidity (pH <5.0) and very low base saturation (V <2%). Their agronomic potential is ensured by at least moderate reserves of SOM (4% TOC in surface horizons and 2% in subsoils). Woods and tea or bean fields cover this area.
- Hydragric Anthrosols were identified on lower slopes, which are used for rice cultivation. These soils are acid (but can present higher pH when waterlogged). Base-saturation is higher (V = 12%–25%) than in the other catchment zones.
- Acrisols are mainly found in the middle and lower areas. They are acid and weakly base saturated, with low agronomic potential.
- Arenosols line catchment streams and their cover is restricted to a few metres, mainly at the catchment outlet. They consist mainly of mixes of sandy sediments and rounded stones.

4 Conclusions

This study categorized the bio-physical environment of the terraced landscape around Qingkou village in Yuanyang County and reported a preliminary assessment of the agro-environmental sustainability of the rice cultivation system. A geomorphopedological approach enabled the characterization of landscape-based soil organization patterns. Human activities, geology and topography were identified as the dominant soil forming factors. The main soil types were identified and classified according to the FAO World Reference Base. Their potentiality and edaphic constraints were assessed. Further soil fertility diagnosis has been achieved by the measurement of ecological, organic and nutritional parameters. Composite samples were taken in rice and bean parcels across the terraced area. Analyses reveal fairly homogeneous fertility levels. Although soils were acid and cation exchange capacity was relatively low, the agro-ecosystem developed by the local population has succeeded in maintaining a relatively efficient and dynamic element circulation system. Future investigations will focus on: (i) the evaluation of the representativeness of the studied area compared to the whole terraced system, (ii) measurements of nutrient flows at the field scale. The main questions are related to the geochemical environment, organic matter turnover and understanding water circulation systems. Physico-chemical budgets are needed of inputs (natural and fertilization) and outputs (such as crop exports). These are essential to evaluate long-term sustainability, (iii) the effects of soil properties on crop yields, and finally (iv) the up-scaling of field levels results to broader spatial units (such as groups of land parcels, sub-catchments and the entire catchment). Research already in progress will also report on the impact of seed exchange/cultivar rotations and associated agronomic practices on the sustainability of this remarkable cropping system.

References


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云南省元阳县传统水稻梯田的农业土壤评价

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摘要: 作为元阳水稻梯田农业生态系统可持续性评价的一部分, 本文调查了箐口流域梯地的自然生物环境, 评价了农业土壤的土壤肥力, 采用地质—地貌—土壤信息相结合的方法建立了土壤—景观之间的组合模式。研究确定了人为、气候、地形因素为影响土壤形成的主要因素, 评价了土壤潜在生产力以及相关的限制因子, 并根据FAO体系, 确定并划分了主要的土壤类型。研究结果表明: 土壤肥力的空间分布相当均一; 土壤属酸性, 阳离子代换量和养分储量总体较低; 农业生态系统在较大程度上受哈尼群众人为活动的影响, 成功维持了相对活跃的养分循环系统。目前的研究集中在: (1) 本研究区域在整个哈尼梯田系统中的代表性评价; (2) 田间水平上的养分循环研究; (3) 土壤特性对作物产量的影响; (4) 将田间水平的研究结果应用于更大的空间单元。

关键词: 水稻梯田; 地质—地貌—土壤方法; 土壤肥力诊断; 元阳水稻梯田; 可持续农业