The Soils of the Xizhuang Watershed, Baoshan, China

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Abstract

Preliminary results from soil studies conducted in 1997 and 1998 show that the soils of the Xizhuang watershed, near Baoshan, are generally poor in available phosphorus, have a low pH range, and are deficient in exchangeable cations. Only the soils originating from limestone have adequate pH and cation concentrations. The organic carbon content is generally higher than in most other Himalayan watersheds; the presence of limestone and the effect of elevation are the key factors responsible for conserving soil carbon concentrations. A brief description of the biophysical setting is provided and the key factors that influence soil fertility—elevation, parent materials, and land use—are identified.

Introduction

Soils are one of the most valuable natural resources in the world but insufficient attention is being placed on them both globally and in China. Soils are under stress as a result of rapidly expanding populations, particularly in China where the arable soil resources are limited, population densities are high, the expansion of urban centres into the best agricultural land is rapid, and inputs and cropping intensities are often excessive. The unreasonable use of soils will quickly exhaust soil fertility.

Soil degradation is of concern in China because of agricultural intensification, agricultural expansion into marginal lands, deforestation, overgrazing, atmospheric pollution, and poor management. Mountain watersheds are particularly sensitive to degradation because of the steep topography, relatively young and poorly developed soils, and accelerated hydrological processes. Slope failures, soil erosion, deterioration of soil nutrients, and downstream effects such as flooding and sedimentation will increase rapidly under inappropriate land uses. Hence, if we hope to achieve sustainable management of resources overall, special attention should be paid to the management of soil resources in the mountains.

The overall goal of the People and Resource Dynamics Project (PARDYP) is to improve understanding of the environmental and socioeconomic processes that lead to soil degradation, to develop land use management practices that prevent degradation, and to promote rehabilitation techniques in those areas where degradation has already occurred. To be successful, techniques need to be adapted to the prevailing environmental conditions, and acceptable to the stakeholders in terms of productivity, profitability, time, labour, and input requirements.

PARDYP selected the Xizhuang watershed in Yunnan Province as a study site to gain a better understanding of the relationships between sustainable soil use, degradation, and socioeconomic impacts and constraints. A series of research projects was carried out between June 1997 and February 1998 to determine the soil fertility status in Xizhuang watershed, to identify the key issues that need to be addressed, to measure the rates of change in soil quality, to develop options to reduce degradation, and to promote techniques that restore soil productivity.

Methods

Data Collection

Socioeconomic, climatic, hydrological, geological, land use and vegetation, and socio-cultural data were collected in the watershed. Maps, aerial photographs, PRA surveys, field surveys, and laboratory analysis were used.

Survey and Sampling

Several transects were selected based on the land use, elevation, soil type, and parent material and a detailed soil survey carried out along each. Soil samples were collected at a depth of 0-20 cm at places representing each major combination of these factors. The locations of the sites were drawn on a topographic map for subsequent incorporation into a GIS system and the samples were analysed in the laboratory.

Soil Analysis

The following soil parameters were determined in the laboratory: pH; organic carbon; total nitrogen; available nitrogen; available phosphorus; exchangeable Ca, Mg, K, Na; exchangeable Al; cation exchange capacity; and base saturation. The methods used to determine these parameters are described in Liu *et al*. (1996).

Soil Mapping

A GPS (global positioning system) unit was used to generate the site co-ordinates in the field and the site information was transferred to an ARC/INFO GIS database for spatial analysis. Aerial photos, topographic maps, geological maps, and field observations served as the basis for selecting appropriate sampling sites and delineating land forms.

Results and Discussion

The Biophysical Setting of Xizhuang Watershed

Climate—Three distinct climatic zones were identified based on elevation, air temperature, and rainfall distribution: the north subtropical zone, the south temperate zone, and the temperate zone. These zones can also be identified in the watershed by vegetation zonations.

Geology—The geology is described in more detail in Yang, Liu and Xu in this volume. The dominant parent materials of the watershed soils are: Quaternary alluvial deposits; Ordovician sandstone, shale, quartzite, and sandy slate; and Cambrian carbonate rock, sandstone, and shale.

Water System—The Xizhuang River originates in the Yiwanshui mountians, the highest area of the Xizhuang watershed. The stream system runs in a north-easterly direction into the Baoshan Basin. The main tributaries are the Lijiahe and Qingshuihe rivers. As a result of the predominance of limestone rock, the stream channels disappear in many places to form underground rivers, thus many springs originate in the watershed.

Vegetation—Natural forests have almost all disappeared in the watershed and many have been replaced in recent decades by pine plantations, mainly dominated by *Pinus armandi* and *Pinus yunnanensis*. *Cunninghamia lanceolata* and *Alnus nepalensis* have also been planted in a number of places since the 1950s. Deforestation has been extensive in the past leading to soil erosion, landslides, and degraded areas.

Land Use—In the low and flat areas along streams, especially where irrigation is available, the lands are used primarily for rice, wheat, maize, and potato production. The staple crops (like maize) and tea are mainly grown in areas below 2,200m. Only potatoes and buckwheat are grown above 2,200m. Forests cover almost all the areas above 2,200m, and grazing land has almost totally disappeared from the watershed.

Soil Type—The soils in the Xizhuang watershed were classified into five types according to the Soil Classification System of Yunnan Province (Soil Survey Office of Yunnan Province 1980, 1996) (Table 90). These were:

- paddy soils, which are located in the lowest portion of the watershed;
- soils developed on recently accumulated alluvium, which are distributed along the rivers and streams (irrigation is available in most of these areas and the dominant land use is arable crop production—wheat, maize, potatoes, and vegetables);
- red soils, which occur below 2200 masl (these are the most widely distributed soils in the watershed and are mainly used for agriculture with commercial crops like tea and pine plantations dominating);
- yellow-brown soils, which are mainly found between 2200-2600 masl (forests cover most of these areas but some potato and buckwheat are also grown); and
- brown soils, which are located above 2600m and are almost exclusively under forest cover.

Table 90: **Soil Types and Their Area in the Xizhuang Watershed**

Soil Type	Area (ha)	Per Cent
Paddy soils	6	0.2
Recently accumulated soils	113	3.3
Red soils	1425	41.2
Yellow-brown soils	1353	39.1
Brown soils	559	16.2

Soil Fertility

Table 91 summarises the basic soil fertility parameters for the whole watershed. The soils are generally very acidic and lack basic nutrients such as available phosphorus and exchangeable cations. The nutrient status is highly variable within the watershed, but generally the soil organic carbon content and the base saturation values are quite high compared to those in other watersheds in the Himalayan region. The presence of limestone rock clearly plays a significant role in this.

Table 91: **Soil Fertility Status in the Xizhuang Watershed**

Characteristic	Range	Mean	Standard Deviation
pH	3.67 - 6.77	4.42	0.53
Organic C (%)	0.595 - 11.396	3.435	2.140
Total N (%)	0.071 - 0.786	0.271	0.147
Available N (mg/kg)	37.8 – 651.7	239.0	130.4
Available P (mg/kg)	0.4 - 97.1	4.6	13.3
Exch. Ca (cmol/kg)	0.042 - 16.411	2.194	2.606
Exch. Mg (cmol/kg)	0.115 - 1.667	0.557	0.405
CEC (cmol/kg)	3.063 - 17.475	6.583	2.761
Base saturation (%)	4.15 - 99.44	49.95	30.00

<u>Differences in Soil Fertility by Soil Type, Elevation, and Parent Material</u>

As paddy soils occupied only a very small area of the watershed, they are not discussed further in this paper. Table 92 shows the soil fertility parameters for the different soil types (apart from paddy soils). There were significant differences in fertility between the soil types. The yellow-brown and brown soils were more acidic and had higher organic C, total N, and available N values than the other two types of soil. The parent material and the elevation effects are considered to be the main reasons for these differences.

The relationship between certain soil fertility parameters and elevation and aspect are shown in Table 93. The soil organic carbon increased with elevation, which indicates that in the higher elevation soils the accumulation of litter was greater than the decomposition of organic matter. This is the result of the cooler conditions at higher elevations. Carbon influences the cation exchange capacity (CEC) so the CEC values also increased with elevation

Table 92: **Fertility of Different Soils**

Characteristic	Recently Accumulated Soil	Red Soil	Yellow-brown Soil	Brown Soil
pH	4.86	4.44	4.33	4.00
Organic C (%)	2.324	2.687	4.956	7.509
Total N (%)	0.208	0.221	0.370	0.538
Available N (mg/kg)	223.3	191.7	324.7	479.7
Available P (mg/kg)	21.7	2.1	1.4	2.2
Exch. Ca (cmol/kg)	4.054	2.371	0.625	1.827
Exch. Mg (cmol/kg)	0.840	0.571	0.250	0.707
CEC (cmol/kg)	6.495	5.966	6.103	11.847
Base saturation (%)	80.93	53.3	30.2	30.4

(Table 93). The soil acidity increased with elevation as a result of the higher precipitation, which results in higher leaching rates for base cations such as Mg, and a lower percentage base saturation.

Table 93: **The Relationship between Soil Fertility and Elevation and Aspect**

Characteristic	<2200m South (n=31)	<2200m North (n=26)	>2200m South (n=8)	>2200m North (n=13)
Org. C (%)	3.863	3.991	7.447	5.761
Exch. Mg (cmol/kg)	0.484	0.621	0.423	0.573
CEC (cmol/kg)	6.898	6.603	10.536	7.843
Base saturation (%)	44.5	43.8	25.7	38.2

Figure 106 shows the relationship between parent material and soil fertility. The parent material had a significant effect, particularly when comparing the soils formed on limestone rocks with those originating from quartzite and sandstone. Soils on limestone had higher pH, higher available P, and higher exchangeable Ca than did those on sandstone.

The cation exchange capacity was particularly low in soils at lower elevations and in the red and yellow brown soils. The CEC could be improved by increasing the application rates of organic matter to these soils.

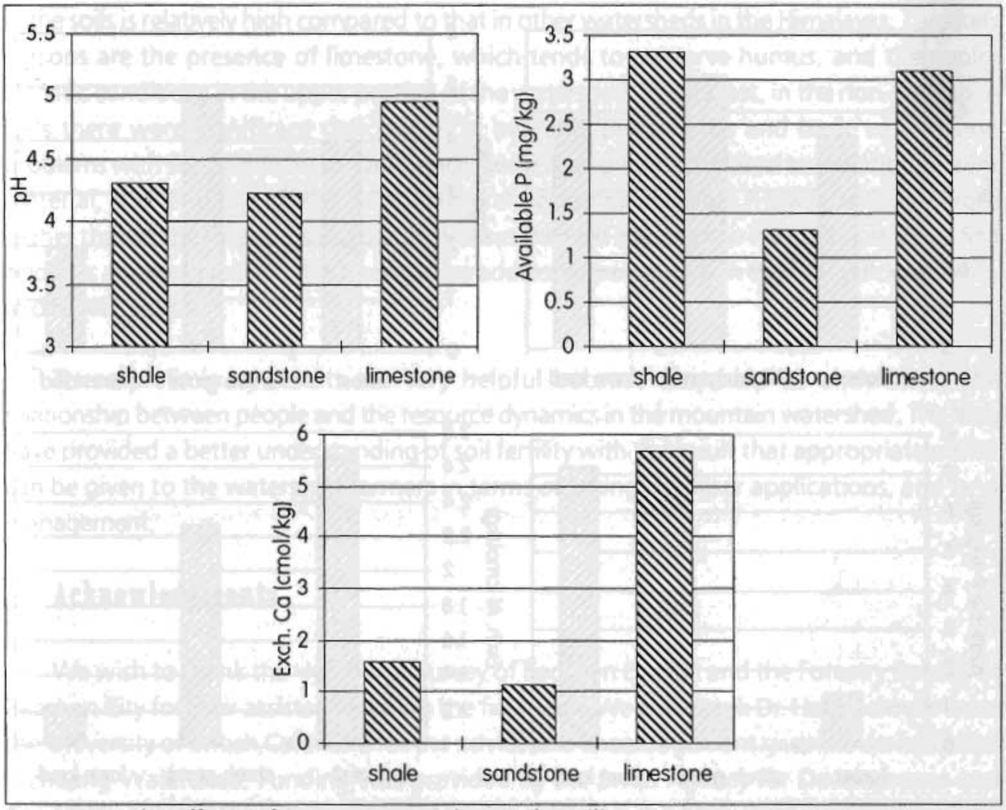

Figure 106: **The Effects of Parent Material on Soil Fertility**

Land Use Effects on Soil Fertility

The effect of land use on soil fertility is shown in Figure 107. Soils under forest and shrub grass vegetation generally had higher organic C and exchangeable Al than those in cultivated farmland. The available P was generally higher in farmland than in forest or shrub land. This may be due to a combination of factors: the difference in acidity, the lower exchangeable Al content (caused by the reduction in acidity), and the higher inputs of manure and fertiliser into the agricultural areas.

Human activities have both positive and negative effects on soil fertility. Agricultural intensification through multiple crop rotations and intercropping enables farmers to increase biomass production but also requires significantly higher inputs. As long as organic matter and chemical fertiliser inputs are maintained at the same level as removal by the crop and losses due to leaching and erosion, such systems can be sustained. The maintenance of organic carbon through applications of both animal manure and composted vegetation is of particular importance because of its influence on the physical properties of the soil (soil structure and hydrological properties) and its importance for microbial activity.

Maintaining the soil pH within the optimum range of 5.5-6.5 is also critical for the availability of both macro and micro-nutrients. Application of lime is only needed in those

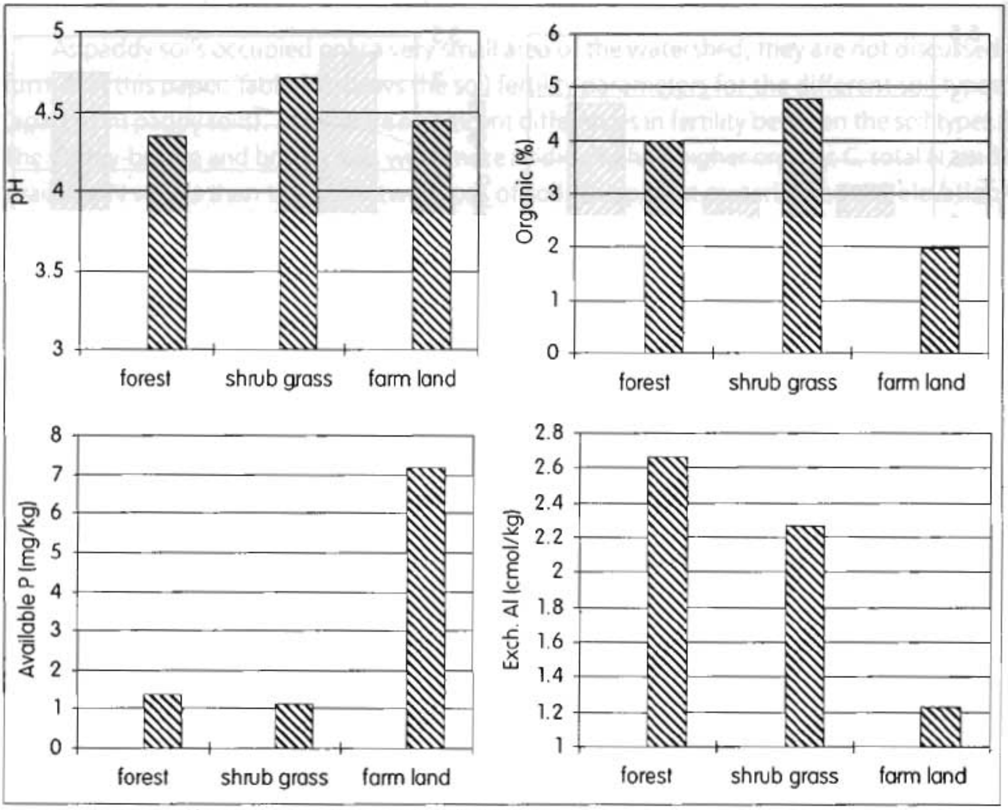

Figure 107: **The Effects of Land Use on Soil Fertility**

soils that have an undesirably acidic pH and that are deficient in base cations. Some of the red, yellow-brown, and brown soils fall into this category. The old and highly leached red soils which have very low pH and high Fe and Al content are particularly problematic because they usually have high P-sorption capacity and therefore restrict phosphorus availability to plants; in addition at a pH below 4.0 they often create Al toxicity.

Soil Stability and Erosion Prevention

Terrain instabilities lead to erosion, affect soil fertility, and influence flooding and sedimentation downstream. Soil stabilisation is an important part of the project and biological erosion control measures have been initiated using nitrogen fixing trees and grasses, as well as low nutrient demanding and drought resistant species. The following N-fixing species have been planted to stabilise the soils: *Acacia* sp., *Tephrosia* sp., *Albizzia* sp., *Maorotrilium macropurpureum*, *Crotalaria mucronata, Cajanus cajan,* and *Vicia villose.* At the same time *Juglans sigillata,* and *Morus alba* have been interplanted with corn and wheat as a soil protection measure.

Conclusions

The preliminary results of the research on soils indicate that the organic carbon content in the soils is relatively high compared to that in other watersheds in the Himalayas. The likely reasons are the presence of limestone, which tends to conserve humus, and the cooler climatic conditions in the upper portion of the watershed. In contrast, in the non-limestone soils there were significant deficiencies in available phosphorus and basic cations and problems with soil acidification. Differences were also identified related to elevation, parent material, and land use effects. In agricultural fields, the available P-levels were generally higher than in the forested soils, but in all cases they fell into the low P-fertility category. Soil acidity is another problem that needs to be addressed particularly in the red, yellow-brown, and brown soils.

These preliminary results are very helpful because they help us understand the relationship between people and the resource dynamics in the mountain watershed. The data have provided a better understanding of soil fertility with the result that appropriate advice can be given to the watershed farmers in terms of liming, fertiliser applications, and land management.

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