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ScienceDirect
Procedia Environmental Sciences 2 (2010) 1032–1042
Procedia Environmental Sciences

International Society for Environmental Information Sciences 2010 Annual Conference (ISEIS)

Temporal and spatial distributions of soil nutrients in Hani terraced paddy fields, Southwestern China

Baoshan CUI[a,*], Hui ZHAO[a], Xia Li[a], Kejiang ZHANG[b], Huali Ren[a], Junhong Bai[a]

[a] *School of Environment, Beijing Normal University, Beijing 100875, China*

[b] *The Centre of Environmental Engineering Research and Education (CEERE),University of Calgary, Alberta T2N 1N4, Canada*

Abstract

Hani terraced paddy fields are one of the most important ways for agricultural products and greatly influence regional landscapes in mountainous areas of Southwestern China. However, the knowledge of soil nutrient conditions from Hani terraced paddy fields is limited. This paper investigates such soil nutrient parameters as organic matter (OM), total nitrogen (TN), total phosphorus (TP), available phosphorus (AP), total potassium (TK), available potassium (AK) of four sampling sites of paddy fields under special geographical environment and agricultural technology, and compares the differences of soil nutrients related to spatial patterns and temporal periods. Correlation analysis is performed to analyze the impact of environmental factors on soil nutrients, as well as the relationships between soil nutrient parameters and altitude, slope direction, gradient and distance from village. The results show that there were some differences separately in the content of soil nutrients such as OM, TN, TP, AP, TK and AK. The AK and AP levels are lower in the fallow period than that in the tillage period, only OM level in the fallow period is higher than that in the tillage period; TN, TK, TP levels are nearly similar in the tillage and the fallow period. Unlike great differences in two periods, soil nutrient content in the ridge of fields is identical basically with the content in the corresponding paddy fields. Correlation analysis shows that soil nutrients of AK, TP, TN and OM have distinctive negative correlations with distance from villages, while AP and TK display a slight fluctuation.

Keyways: Hani terraced paddy fields; soil nutrient parameters; temporal and spatial patterns; Southwestern China

1. Introduction

Terraced paddy fields dated from the prehistoric period distribute widely in many countries such as America, China, Japan, Peru, India, Philippines, Korea and so on [1, 2]. The most famous terraced paddy fields are Cordilleras's rice terraces of the Philippine, Machu Picchu terraces of Peru and Hani terraces of China. Terraced paddy fields are one of the most important land use systems for agricultural products and greatly influence regional landscapes in mountainous areas [3]. It is well known that the better terraced paddy wetlands can maintain biodiversity and resilience under the stresses of development. However, the gradient changes and vertical landforms

* Corresponding author. Tel.: +86-010-58802079; fax: +86-010-58802079.
E-mail address: cuibs@bnu.edu.cn.

doi:10.1016/j.proenv.2010.10.115

have intensively effected on habitat patches resulting from differences in management practice among farmers [4, 5]. The introduction of high value vegetable crops which do not require year round inundation and are very dependent on inorganic fertilizer and pesticide inputs have contributed to the collapse of some terraces due to the absence of water in the terraces. Absence of inundation promoted the growth of large earthworms (*Polypheretima elongata*) creating channels in the paddy horizon that perforate the formerly impervious layer and thereby weakening the terraces [6].

In the Philippines, the rice terraces of Cordilleras, specifically the Ifugao rice terraces, were registered as a World Heritage in 1995, but with diminishing interest of the Ifugao people in their culture and in maintaining the rice terraces, as a result, land use changed and biodiversity decreased. Erosion and siltation followed, so that the rice terraces of Cordilleras were included in the list of 100 most endangered sites in the World Monument Watch List in 1999 [6, 7]. In Japan, as a result of the rapid decrease in the agricultural population and an increase of abandoned paddies, the terrace landscape had disappeared gradually. Given this serious situation, a number of individuals and organizations in Japan have sought to conserve and restore terraced paddy landscapes and their biodiversity [8-12], and pushed for conservation legislation [13, 14]. Many management measures were put forward for protecting terraced landscapes from the view of ecology and society [15]. A framework was developed for evaluating terraced paddies that the landscape should be used and managed as a rural park, rather than for agricultural purposes [16]. Moreover, some studies showed that the structure of paddy levees and ponds as well as management practices have strongly influenced the plant species [17-20]; the irrigation system influenced the pattern of change in land use [21].

Hani terraced paddy fields in Yuanyang county of Southwest China, called the apotheosis of the terraces, which have been carved on the Mountain by the Hani people for centuries, are important man-made wetlands and agricultural ecosystems [22]. In order to protect the ecological structure, ethical culture, and landscape of wetlands, Hani terraced paddy fields have been applied to UNESCO to put them on the world heritage list. If the terraces are recognized as a World Heritage site, protecting the rice terraces leads to protecting the cultures of Hani ethnic minorities. In the early studies, most of these were folklore studies that placed more emphasis on the description of the Hani people's traditional culture, discussed the relationships between Hani terraced paddy fields and the social structure of Hani ethnic minority such as life styles, cultivation etiquette, philosophy and personal connection and so on [23, 24]. In the last decade, most scientists paid more attention to the origin and history, formation reasons, ecosystem structure, heavy metal distribution, production value and management of the terraced paddy fields [25-31]. However, Due to soil physical and chemical properties being changed by man-made management and cultivation, as a result, soil nutrient concentrations are different largely with the different farming and management ways. The objectives of the paper are to (1) investigate soil nutrient characteristics of Hani terraced paddy fields under special geographical environmental conditions and agricultural technology; (2) compare the differences of soil nutrients related to spatial patterns and cultivation periods, so as to support more efficient farming practices and maintenance of the sustainable development of terraced paddy fields.

2. Study site

Hani terrace paddy soils, which are distributed from 144 m to 2000 m above sea level in the Mountains of Yuanyang County (Fig. 1), evolved by a series of farmland construction, soil amelioration measures and long term rice cultivation [32]. There are 1.27×10^5 m^2 of terraced paddy fields distributed on slopes of 700 m - 1,800 m in altitude in Yuanyang County, with a particularly high concentration at 1,200 m - 1,800 m, where 28 km^2 of terraced paddy fields have been designated as terraced paddy cultural heritage reserve accounting for 12.8% of total area of Yuanyang County. The terraced paddy fields are situated in V-shaped valleys, which were deeply cut by Red River (Yuan River) and the Tengtiao River, developed a special topography. There is a difference of about 10°C in the yearly average temperature between the foot and the upper slopes of the mountains. Monthly mean temperatures range from 20.6 °C in July to 9.9 °C in January. The average annual precipitation is 1397.6 mm. The seasonal rainfall pattern shows the existence of two contrasting seasons: rainy season (May-October) with moist monsoon from the south and dry season (November-April) with dry monsoon from the north [30]. Rainfall amounts to 257.9 mm in June and to 34.1 mm in February. Rainfall in the wet season tends to increase with altitude. Annual Sunshine duration is 1770.2 h accounting for 40％of the astronomically possible sunshine hours [33].

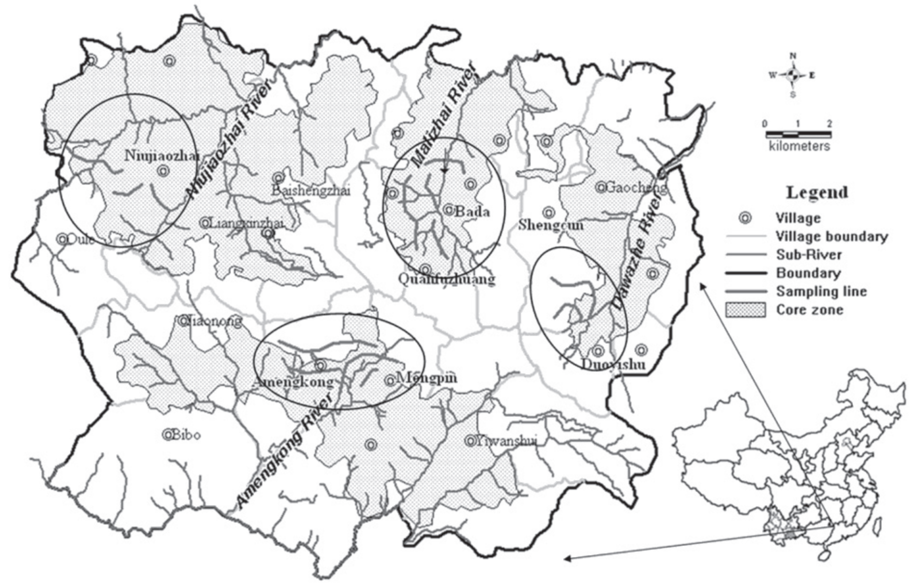

Fig. 1 Position of the study area and soil samples

3. Materials and methods

3.1. Sampling collecting and analysis

Study sites were set up in the drainage areas of Niujiaozhai River (NiRD), Amengkong River (AmRD), Dawazhe River (DaRD) and Malizhai River (MaRD), which are the core parts of Hani terraced paddy fields in Yuanyang County of Southwestern China (Fig. 1). We selected the terraced paddy fields around Niujiaozhai village in NiRD, Bada village in MaRD, Duoyishu villages in DaRD, and Mengpin villages in AmRD as sampling sites (Table 1). Based on special geomorphic features and distribution patterns of terraced paddy fields, the total of 168 sampling points were set up at altitudes from 1000 m to 1800 m with an interval of 30m - 50m in vertical direction (Fig. 2, Table 2).

Table 1 Basic status of four drainage areas from Hani terrace core reserve

Drainage	Drainage area (km^2)	District	Villages	Population	Sampling sites
MaRD	21.9	Xinjie Town, Shengcun Town	55	17,182	Bada
AmRD	34.3	Panzhihua Town	74	16,229	Mengpin
NiuRD	51.4	Niujiaozhai Town	89	26,773	Niujiaozhai
DaRD	24.3	Shengcun Town	47	25,297	Duoyishu

Soil samples were collected from 0 cm to 10 cm depth using a split core sampler with a diameter of 5 cm at each location, while recording environmental factors such as altitude, gradient, orientation of slope and the distance from village of sampling points.

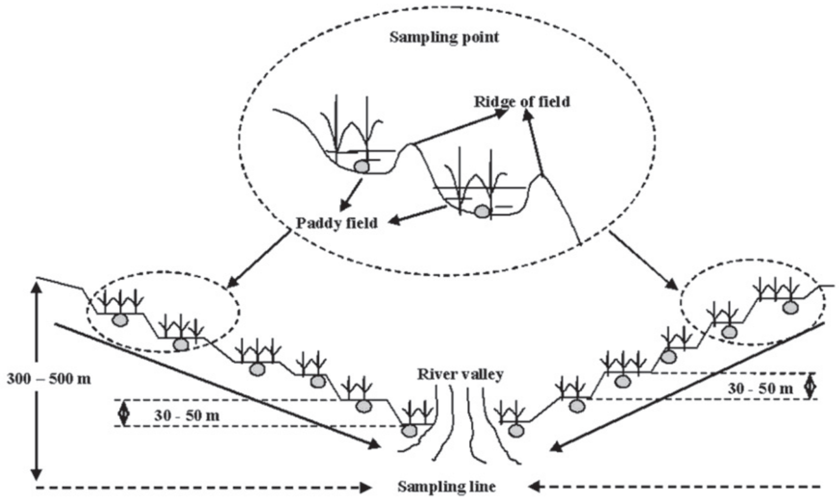

Fig. 2 Sketch for terraced paddy fields and sampling points

Table 2 Sampling sites and their base circumstances

Sampling time	Serial	Sampling sites	Longitude (E)	Latitude (N)	Altitude (m)	Slope (°)	Number of sampling lines	Number of sampling point
2004.12	1	Bada	102°45′~102°46′	23°06′~23°07′	1510~1848	10~25	2	12
	2	Mengpin	102°43′~102°45′	23°03′~23°05′	1069~1397	10~30	2	12
	3	Niujiaozhai	102°38′~102°41′	23°07′~23°08′	1095~1337	8~30	2	12
2005.10	1	Bada	102°45′~102°46′	23°06′~23°07′	1510~1848	10~25	2	12
	2	Mengpin	102°43′~102°45′	23°03′~23°05′	1069~1397	10~30	2	12
	3	Duoyishu	102°47′~102°49′	23°05′~23°06′	1553~1801	15~30	2	12
2006.08	1	Bada	102°45′~102°46′	23°06′~23°07′	1510~1848	10~25	4	24
	2	Mengpin	102°43′~102°45′	23°03′~23°05′	1069~1397	10~30	4	24
	3	Niujiaozhai	102°38′~102°41′	23°07′~23°08′	1103~1340	8~30	4	24
	4	Duoyishu	102°47′~102°49′	23°05′~23°06′	1553~1801	15~30	4	24

All soil samples were sealed and brought back to the laboratory. Soil nutrient status was determined for these parameters, i.e. OM, TN, TP, AP, TK and AK associated with pH. Recognizable plant litters, coarse root materials, and the stone were removed. Soil samples were oven-dried to constant weight at 75°C, mixed well, ground to a fine power using muller, sieved with 80-mesh size, and then stored in covered cardboard containers before analysis. OM was determined wet oxidation with $K_2Cr_2O_7$, TN was determined by the semi-micro Kjeldahl method, and TP was determined by colorimetrical method after wet digestion with H_2SO_4 + $HClO_4$. TK was measured with an atomic absorption spectrophotometer with NaOH fusion. AK was extracted with 1 mol/ l NH_4Ac, and then measured by an atomic absorption spectrometer. AP was extracted with 0.5 mol /l $NaHCO_3$ at pH 8.5. Soil pH was measured using a glass electrode in a 1:5 soil/water suspension [34-35].

3.2. Statistical analysis

Paired-samples T test was used to detect the difference of soil nutrients in paddy fields and ridge of fields, and independent-samples T test was used to test the differences of soil nutrients between tillage period and fallow period. Pearson's correlation coefficient was compared to determine the relationships among soil nutrients (OM, TN, TP, TK, AP, and AK) and environmental factors in the four sampling sites. Analyses were conducted using SPSS 15.0 statistical package and Sigmaplot 9.0 software.

4. Results

4.1. Statistics analysis of soil nutrient

The mean, SD, minimum and maximum values for each soil parameter did not show significant differences among the four sampling sites (Table 3). The mean contents of all soil nutrients were the highest in Niujiaozhai, except TK. The concentrations showed a considerable variability between soil nutrients and among individual soil nutrients, as evidenced by relatively large SD. The soil nutrients from samples in paddy fields and field ridges were compared using paired-samples T test, and the results showed that no significant difference (p>0.05) was found for any of the soil nutrients. The differences between soil nutrient contents in paddy fields with corresponding ridges were little.

Table 3 Statistics results of chemical properties of the soils

Sampling sites	Statistical value	OM（g/kg）	TN （g/kg）	TP （g/kg）	AP (mg/kg)	TK （g/kg）	AK (mg/kg)
Niujiao zhai	Maximum	57.27	3.49	1.75	88.74	14.57	593.23
	Minimum	23.28	0.49	0.21	7.38	1.20	94.96
	Mean	36.71 ^{N}	1.66 ^{N}	0.72 ^{N}	27.58 ^{N}	7.36 ^{N}	278.66 ^{N}
	SD	11.20	0.89	0.37	20.99	3.91	150.79
Bada	Maximum	49.14	3.32	0.41	19.59	24.49	345.99
	Minimum	14.12	0.93	0.13	6.62	2.91	83.68
	Mean	34.50 ^{N}	1.39 ^{N}	0.29 ^{N}	12.01 ^{N}	12.64 ^{N}	178.85 ^{N}
	SD	8.99	0.72	0.10	3.53	5.50	76.33
Mengpin	Maximum	48.41	3.34	1.64	41.36	21.82	435.62
	Minimum	17.35	0.68	0.09	5.44	7.08	91.76
	Mean	29.37 ^{N}	1.50 ^{N}	0.46 ^{N}	18.45 ^{N}	14.90 ^{N}	253.05 ^{N}
	SD	9.20	0.88	0.41	12.27	4.60	136.18
Duoyishu	Maximum	57.04	3.88	0.64	25.40	34.84	348.44
	Minimum	9.47	0.96	0.16	8.55	3.85	130.47
	Mean	32.10 ^{N}	1.51 ^{N}	0.37 ^{N}	13.11 ^{N}	16.55 ^{N}	226.11 ^{N}
	SD	14.42	0.93	0.17	4.94	8.98	69.39

N: P>0.05; paired-samples T test, comparing soil nutrients in paddy fields with those in ridge of fields.

4.2. Comparison of soil nutrient during the tillage and fallow period

Six kinds of soil nutrients in the tillage and fallow period were significantly different using independent-samples T test (Table 4). The AK and AP levels were extremely lower in the fallow period than that in the tillage period, only OM level in the fallow period was higher than that in the tillage period; TN, TK, TP levels were little even nearly similar in the tillage and the fallow period.

Table 4 Comparisons of soil nutrients during the tillage and fallow period

Period	OM (g/kg)	TN (g/kg)	TP (g/kg)	AP (mg/kg)	TK (g/kg)	AK (mg/kg)
Fallow	34.05	1.64	0.65	1.37	19.55	181.39
Tillage	29.37	3.33	0.46	18.45	14.9	253.05
P	***	***	**	***	**	***

**, P<0.01; ***, P<0.001; independent-samples T test.

Based on the correlation analysis between AK, TK, AP, TP, TN and OM (Table 5), TN and OM (0.652, p<0.01), AK and TN (0.444, p<0.01), and TP and AP (0.717, p<0.01) had significant correlations. Moreover, we found that AP, TP, TN and OM had a distinctive negative correlation to the distance from village with 0.315 ($p < 0.01$), 0.396 ($p < 0.01$), 0.283 ($p < 0.05$) and 0.578 ($p < 0.01$) of correlation coefficient, respectively (Table 6).

Soil nutrients of AK, TP, TN, OM had distinctive negative correlations with distance from villages, and an obvious declination trend along distance from villages (Fig. 3), while AP and TK had a slight fluctuation. Generally, the longer the distance from villages was, and the lower the contents of soil nutrients were.

Table 5 Correlation analysis for soil nutrients during the tillage and fallow period

	AK	TK	AP	TP	TN	OM
AK	1					
TK	-0.096	1				
AP	0.396*	-0.181	1			
TP	0.396*	-0.287*	0.717**	1		
TN	0.444**	-0.095	0.236	0.398*	1	
OM	0.332*	-0.180	0.331*	0.396*	0.652**	1

$p < 0.05$, ** $p < 0.01$

Table 6 Correlation analysis between soil nutrients and some environmental factors during the tillage and fallow period

Soil nutrients	Soil pH	Altitude	Gradient	Slope direction	Distance from village
AK	0.203	-0.138	0.111	-0.118	-0.093
TK	-0.030	0.202	0.245	0.068	0.083
AP	0.125	-0.231	0.076	0.078	-0.315*
TP	-0.133	-0.205	0.129	-0.028	-0.396**
TN	0.124	0.096	-0.182	0.146	-0.283*
OM	-0.589	-0.009	-0.042	0.101	-.0.297*

* $p < 0.05$, ** $p < 0.01$

5. Discussion

5.1. Spatial distribution characteristics of soil nutrients

According to the assessment standard of Yuanyang County Soil Survey, 5.00 g/kg, 1.00 g/kg, 0.60 g/kg, 10 mg/kg, 15 g/kg and 100 mg/kg for OM, TN, TP, AP, TK and AK respectively, are the values under which the plant growth is limited. Our study results show at least 90% of values for OM and TN are higher than the critical values and both of them display similar pattern tendency. This similarity may be related to OM influencing N retention and supply [36]. About 75% of values for TP and TK are lower than the critical values. In the tillage period, 26.7% for AP and 8.3% for AK of the sites are lower than the values, while in the fallow period the percentages go up to 56.3% for AP and 35.4% for AK. The result of lacking of P and K is still identical to soil survey in 1986, although soil quality has had a great improvement under farmers' efforts in the last years. The lack of P and K is closely related to parent materials and acidity soil which limit the supply of soil nutrients for rice [32]. In addition, AP and AK are not soluble and easily washed away by water especially in terraced paddy fields with frequent irrigation and drainage under acidic conditions [37]. As a result, farmers would apply much manure and mineral fertilizer to increase the contents of AP and AK in the tillage period. However, once fertilizer input from farmers stopped, the contents of AP and AK would decrease dramatically.

Within the physical structure of terraced paddy fields, the ridges of fields occupy a substantial portion of the total farmland area and play an important role in water and soil retention. As a result, utilization of the ridges of fields has been highly developed in Yuanyang terraced paddy fields [30]. Most of the ridges of fields are made of soil where stones are used for some dikes in order to reinforce the structure [17, 20, 25, 38], thus the ridges with stone dikes usually are massive and thick. The ridges of fields not only have the function of physical structure protection, but also have the function of farm production. In order to fully utilize the land resource, local people usually plant some economic crops such as soybean, capsicum, taro and others on the ridges of fields (Fig. 4(a)-(d)).

Our results show that the soil nutrient content in the ridges of fields is almost similar to that of paddy fields. This similarity of soil nutrient status for ridges and paddy fields might have resulted from repairing the ridges of fields twice one year. When the soil of the paddy fields are plowed using a buffalo after the harvest, the ridges of fields are fixed at this time. Mud on the field surface is shoveled up and covered on the ridges (Fig. 4(b)), and this process could make the ridges become unbreakable. This cultivation practice of terraced paddy fields not only prevents from crack and leakage, but also balances the soil nutrient status between the ridges and paddy fields [23, 39]. In addition, unlike paddy fields the ridges are usually not irrigated frequently and there is little leaching of nutrients resulting in rather stable nutrient contents [40].

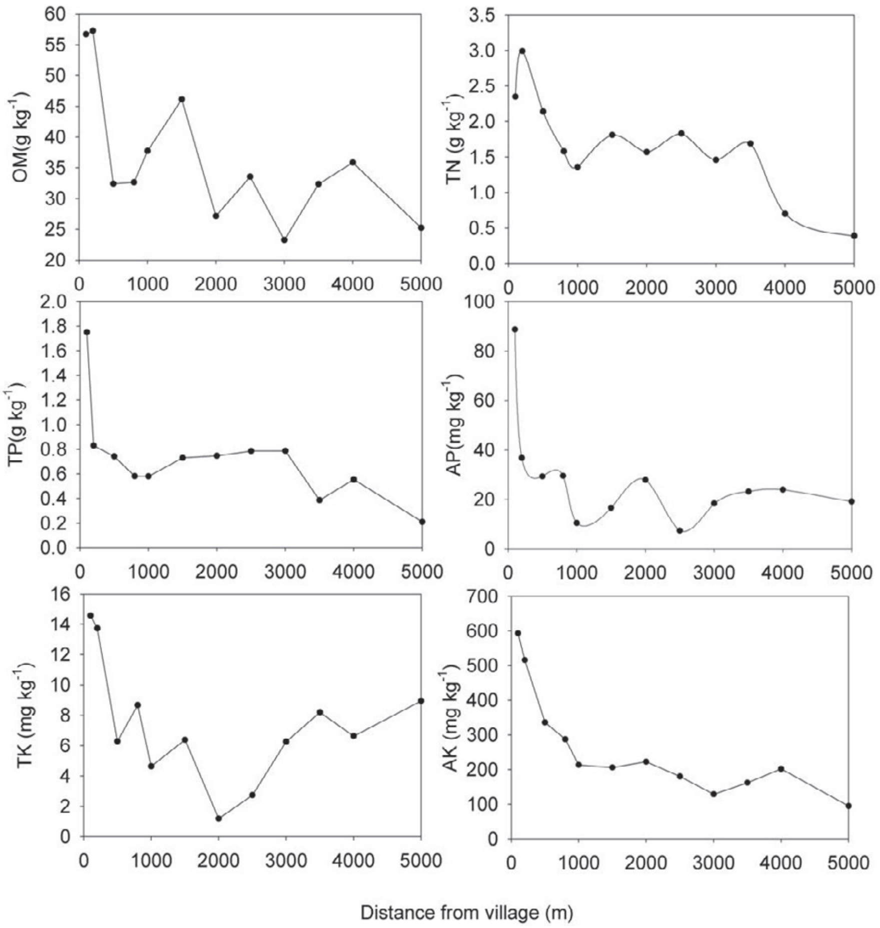

Fig. 3. Distributions of OM, TN, TP, TK, AP, and AK with the distance from village during the tillage and fallow period

We find that AK, TP, TN, OM have a distinctive negative correlation to the distance from village with 0.578 ($p < 0.01$) of correlation coefficient. Because of high and steep mountainous area, the paths from village to farmland are generally narrow and bumpy; it is difficult to send manure into terraced paddy fields especially the further paddy fields for peasants. So the local peasants usually manure the farmlands nearer to the villages or close to irrigation channels, along which water can carry and wash the fertilizer into the fields, this practice is named as "water washing fertilizer". After having made use of all the water resources available near the villages, the water of the upper part of the watershed is exploited to enable further expansion of terraced fields by the construction of a longer irrigation channel (Fig. 5).

There were only insignificant effects of altitude, slope direction and gradient on soil nutrients. Compared with the soils eroded intensively in dry land areas of mountainous region, where fertilizers are easily washed away by surface water and suspended sediment, terraced paddy fields prevent from soil erosion. In order to sustain agricultural activities on the steep mountain slopes as well as to maintain the productivity of the land, farmers improve soil fertility by plowing, fertilization (manure and chemical fertilizer) and irrigation. This strongly effects the soil nutrient concentrations and their spatial distribution. As a result, soil nutrients keep a relevant stability and are evidently not limited by environmental patterns.

5.2. Temporal distribution characteristics of soil nutrients

Comparing soil nutrient contents between in the fallow period and tillage period helps to understand the temporal patterns of soil nutrients in the terraced paddy fields; further it helps to explain the impact of farming manners, and improve agricultural management decisions. The fallow period of Hani terraced paddy fields where there are no crops for nearly five months is much longer than those paddy fields in the plains, during which land preparation and maintenance are important for the rice cultivation in the next year [24, 28, 30]. Soil nutrient situation in the fallow period plays an important role in crop growth and yield in the next year. One of the most significant features in terraced rice cultivation is the practice of year-round irrigation in Yuanyang County. Terraced fields are irrigated and kept inundated throughout the year, even in the fallow period when no crops are grown (Fig. 4c). After the rice harvest, the soils of the paddy fields are plowed (Fig. 4d), and then irrigated completely.

Fig. 4 Intercrop on the ridges of paddy fields (a); smearing dike (b); inundated paddy fields (c) and plowed paddy fields soil (d)

In the fallow period, the AK and AP levels are extremely low, even below the levels considered to be critical for paddy soils [32]. There is a medium-term fertilization for improving AK and AP to enhance rice yields by farmers in the tillage period. Unlike AK and AP, OM level is higher in the fallow period than in the tillage period. We can find the reason for these differences in the maintenance practices for terraced paddy fields. When the soils are plowed, rice stubbles remain in the fields and weed from the ridges of paddy fields is shaved off into the fields. Mineralization and humification start and the plants are soon decomposed. They become one of the most important nutrient sources. Nutrients are taken up by the rice plants during the growth period, which is associated with a decline of OM content. As the result of this agricultural practice and cultivation process, OM content is usually higher in the fallow period than in the tillage period. TN, TK, TP levels of the soils are little higher in the tillage period than in the fallow period, but the difference is not remarkable due to the efficiency of soil retention in fields mentioned in above.

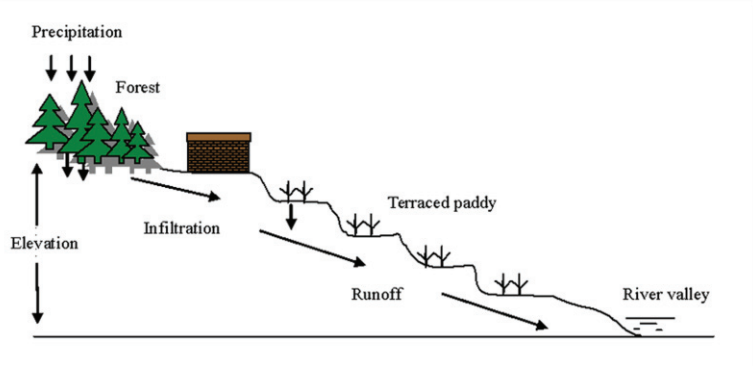

Fig. 5 Sketch of water flow with elevation in terraced paddy field

6. Conclusions

This paper showed that most of soil nutrients in Hani terraced paddy fields were characterized by spatial patterns and cultivation periods. Nevertheless it is obvious that many environmental factors such as precipitation and runoff due to absence of local data, were not considered in understanding soil nutrient characteristics. Especially, if our study was scaled up to the whole Yuanyang terraced paddy fields, it is likely to have some differences compared to studied sampling sites. Further works need focus on connecting soil nutrient to other factors and more examining temporal and spatial variability in favor of sustainability of Hani farming systems.

Acknowledgments

We thank Honghe Autonomous Prefecture of Yunnan province, Yuanyang County government for their supply on correlative materials. Thanks are also extended to program members for their work on soil sample collection and location mapping. We express the appreciation to the local people for their guide and help during the investigation of terraced paddy fields. This work was funded by the National Natural Science Foundation (U0833002; 50939001) and National Key Basic Research Project of People's Republic of China (2003CB415104).

References

[1] Gao RL. *History for Terraced Paddy Fields (in Chinese)*, Beijing: Chinese Water Conservancy Press; 1983, p. 1-20

[2] Schmitter P, Dercon G, Hilger T, Thi Le Ha T, Huu Thanh N, Lam N, et al. Sediment induced soil spatial variation in paddy fields of Northwest Vietnam. *Geoderma* 2010;**155(3-4)**: 298-307.

[3] Maltby E, Holdgate M, Aceman MC, Weir A. Ecosystem Management: Questions for Science and Society. *Sibthorp Trust*; 1999.

[4] Ichinose T, Kataoka M. Water quality and fluctuation pattern in water level of small irrigation ponds in the rural area in Hokudan-cho, Hyogo Prefecture (in Japanese with English abstract). *Journal of the Rural Planning Association Special* 2003;**22**: 1-6.

[5] Wang HJ, Shi XZ, Yu DS, Weindorf David C, Huang B, Sun WX. Factors determining soil nutrient distribution in a small-scaled watershed in the purple soil region of Sichuan Province, China. *Soil and Tillage Research* 2009;**105(2)**: 300-6.

[6] Peñafiel SR. *Ifugao rice terraces agricultural heritage systems: Dynamic conservation and practices.* The International Forum on Globally Important Agricultural Heritage Systems: A Heritage for the Future held in FAO, Rome, Italy; 2006.

[7] PLGU-Ifugao. *Ifugao Rice Terraces Master Plan, 2003-2012.* Office of the Provincial Planning and Development Coordinator and Ifugao Rice Terraces and Cultural Heritage Office, Provincial Local Government Unit of Ifugao, Lagawe, Ifugao; 2004.

[8] Asami K, Nakao M, Akamatsu H, Tamura K. A case study of vegetation management of abandoned rice fields for the conservation of water and wetland wildlife (in Japanese with English abstract). *Journal of the Japanese Institute of Landscape Architecture* 2001;**64**: 571-6.

[9] Morita T, Yamano K, Yamamoto Y, Ichinose T. Dragonfly fauna of the rainwater storage ponds in a rural landscape in Hokudan-cho, Awaji Island, Hyogo Prefecture (in Japanese with English abstract). *Landscape Planning and Horticulture* 2001;2: 51-4.

[10] Ichinose T, Morita T. Factors influencing the distribution of dragonflys (Odonata) in the agricultural landscape in Hokudancho, Hyogo Prefecture (in Japanese with English abstract). *Journal of the Japanese Institute of Landscape Architecture* 2002;**65**: 501-6.

[11] Yamano K, Kataoka M, Ichinose T, Mino N, Hirata F. Relationship between distribution of dragonfly and environmental factors in small irrigation ponds in Hokudan-cho, Hyogo Prefecture (in Japanese with English abstract). *Journal of the Rural Planning Association Special* 2002;**4**: 25-30.

[12] Katoh K, Zhang D, Ichinose T. Factors controlling diatom species composition in agricultural reservoirs in Awajishima Island, Japan (in Japanese with English abstract). *Journal of the Japanese Institute of Landscape Architecture* 2004;**67**: 511-4.

[13] Nakajima M. Sustainability of rice terraces. *Journal of Geography* 1996;**105**: 547-68.

[14] Susumu Y, Satoru O, Yoshiko K, Kazuhiko T. Restoration of weed communities in abandoned rice paddy fields in the Tama Hills, central Japan. *Agriculture, Ecosystems and Environment*, 2007;**119**: 88-102.

[15] Yamanaka H, Sawada T, Kozuki Y, Kamada M, Ishida K, Yamaguchi Y, et al. An analysis of rice-terrace conservation strategy based on the Project-Cycle-Management method. *Environment System Research* 2000;**28**: 255-66.

[16] Naoki I, Mahito K, Nobukazu N. Ecological and social evaluation of landscape in a rural area with terraced paddies in southwestern Japan. *Landscape Urban Plan* 2005;**70**:301-13.

[17] Matsumura T. The effect of construction on the slope vegetation of paddy levees (in Japanese with English abstract). *Journal of the Japanese Institute of Landscape Architecture* 2002;**65**:595-8.

[18] Iwasaki Y, Mitsui Y, Ichinose T. Photosynthetic characteristic of Pueraria lobata Ohwi growing in the surroundings of the irrigation pond (in Japanese with English abstract). *Landscape Planning and Horticulture* 2003;**4**:1-4.

[19] Mitsui Y, Iwasaki Y, Fijihara M, Ichinose T. Influences of environmental factors on flora at embankment of irrigation ponds (in Japanese with English abstract). *Journal of Japanese Society of Revegetation Technology* 2003;**1**:293-6.

[20] Katsue F, Hirokazu O, Aiko M. The relationships between the structure of paddy levees and the plant species diversity in cultural landscapes on the west side of Lake Biwa, Shiga, Japan. *Landscape and Ecological Engineering* 2005;**1**:191-9.

[21] Tomohiro I, Gusti AARA, Miwa K, Nurhayati HSA. Land-use change and irrigation systems in the agricultural landscape of terraced paddy fields in Awaji Island, central Japan. *Landscape and Ecological Engineering* 2007;**3**:171-7.

[22] Shi JC. The Hani Terrace field at Honghe: Typical Chinese wetland. *Journal of Yunnan Nationalities University (in Chinese with English abstract)* 2004;**21**:77-81.

[23] Lei B. *A Cultural History of the Hani Nationality (in Chinese)*. Kunming: Yunnan National Press; 2002, p. 2-34

[24] Wang QH. *On the Culture of the Terraced Field (in Chinese)*. Kunming: Yunnan University Press; 1999, p. 334-63

[25] Jiao YM, Zhang JY. The formation of steep terraced fields in South-western China-a case study on the terraced fields in the southern bank of Red River (in Chinese with English abstract). *Economic Geography* 2000;**20**:94-6.

[26] Jiao YM. The feature of Hani cultural region – the cultural landscape of Hani's terrace (in Chinese with English abstract). *Yunnan Geographic Environment Research* 2002;**21**:734-43.

[27] Jiao YM, Xiao DN, Cheng GD. Study on the coordinating development of ethnic culture and natural environment in subtropical mountain areas-a case of cultural landscape of Hani terrace in Yuanyang County (in Chinese with English abstract). *Journal of Mountain Science* 2002;**20**:265-70.

[28] Jiao YM, Cheng GD, Xiao DN. A study on the cultural landscape of Hani's terrace and its protection (in Chinese with English abstract). *Geographical Research* 2003;**15**:51-6.

[29] Yao M, Cui BS. The vertical characteristics of ecosystem of Hani's terrace paddy field in Yunnan, China (in Chinese with English abstract). *Acta Ecologica Sinica* 2006;**26**:2115-24.

[30] Shimpei A. Agricultural technologies of terraced rice cultivation in the Ailao Mountains, Yunnan, China. *Asian and African Area Studies* 2007;**6**:173-96.

[31] Ren HL, Cui BS, Bai JH, Dong SK, Hu B, Zhao H. Distribution of heavy metals in paddy soil of Hani terrace core zone and assessment on its potential ecological risk (in Chinese with English abstract). *Acta Ecological Sinca* 2008;**4**:56-78.

[32] Honghe Autonomous Prefecture Soil Survey Office. *Yuanyang Soil (in Chinese)*. Second Soil Survey of Yunnan Province ; 1986.

[33] Yuanyang Statistic Bureau. *Statistical Summary of National Economy and Social Development of Yuanyang County (in Chinese)*; 1986, p. 56-70

[34] Bao SD. *Soil and Agricultural Chemistry Analysis (in Chinese)*. Beijing: China Agriculture Press; 1986, p. 14-144

[35] Parkinson JA, Allen SE. A wet oxidation procedure suitable for determination of nitrogen and mineral nutrients in biological material. *Commun Soil Sci Plan*;1975;**6**:1-11.

[36] Brubaker SC, Jones AJ, Lewis DT, Frank K. Soil properties associated with landscape positions. *Soil Sci Soc Am J* 1993;**57**:235-9.

[37] Walker C, Lin HS. Soil property changes after four decades of wastewater irrigation: A landscape perspective. *Catena* 2008;**73**:63-74.

[38] Huang HC, Liu CW, Chen SK, Chen JS. Analysis of percolation and seepage through paddy bunds. *J Hydrol* 2003;**284**:13-25.

[39] Li QB. *Hani Terraced Paddy Fields Cultural Analects (in Chinese)*. Kunming: Yunnan Nationalities Press; 2000, p. 113-24

[40] Ramos MC, Martý´nez-Casasnovas JA. Erosion rates and nutrient losses affected by composted cattle manure application in vineyard soils of NE Spain. *Catena* 2006;**68**:177-85.