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Vertical Distribution of pH and Nutrients in Forest Soil on Water-eroded Area of Southern China

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Abstract

The analysis of soil physical and chemical properties in typical water erosion area is helpful to understand the mechanism of soil and water conservation. Vertical soil samples were collected from topsoil to 50cm depth in southern China under coniferous forests, coniferous and broad-leaved mixed forests, and broad-leaved forests. The distribution characteristics of soil pH and nutrients were then analyzed. The nutrients include organic matter (OM), total nitrogen (TN), available nitrogen (AN), total phosphorus (TP) available phosphorus (AP) total potassium (TK), and available potassium (AK). Results showed that, with the increase of soil depth, the average pH increased, OM, TN, an, AK decreased, while TK, TP, AP changed not significantly. The soil nutrients were mostly the greatest in broad leaved forests, and the least in the coniferous forests. All the soil nutrients were the greatest in the Light soil erosion grade, the least in the Moderate grade, and the middle in the Intense grade. These results indicated that ground litter contributed mainly to the vertical change of soil properties, broad leaved forests had a stronger capacity to gather nutrients and could increase the contents of soil nutrients in vertical profiles, and the soil erosion resulted in the loss of soil nutrients, but the degree of the loss was affected by the forest communities. This study provided valuable references for vegetation restoration and ecological reconstruction in water-eroded areas.

INTRODUCTION

Soil degradation caused by water erosion has been a key factor plagued regional or national development [1]. The red soil area in southern China, with the special soil parent materials, vegetation and climatic environments, had become one of the areas with the most severe soil erosion (2,3). Soil pH and nutrients are the main factors affecting vegetation reconstruction, and play an important role in the ecological restoration of water-eroded areas in southern China (4). The research on the spatial distribution pattern of soil pH and nutrients in the areas will help understand the mechanism of water and soil conservation and provide scientific basis for water and soil conservation.

In recent years, many researchers have studied the vertical distribution characteristics of soil properties. Literatures reported that as soil depth increased, soil pH showed a slowly increasing trend (5,6) , while soil organic matter (OM), total nitrogen (TN), available nitrogen (AN), total phosphorus (TP) and available potassium (AP) were affected by litter and showed a decreasing trend (7, 8). There was no significant change in the content of total potassium (TK) (9), and the content was mainly affected by the soil parent material. Some studies have shown that the content of TK decreased gradually with the increase of soil depth (10). The content of TP reduced slightly (11 ; 12) while other studies showed no obvious change in the content of TP (13, 14). The content of AP generally decreased gradually (15, 16). It was also found that soil nutrients varied under different vegetation types (17)During the process of vegetation growth, vegetation absorbs soil nutrients, and litter returns to soil, thereby affecting the accumulation of soil nutrients. Besides, soil erosion led to the loss of soil nutrients and a decrease in the contents (18) obvious reduction of soil OM and TN (19), and a decrease in AP (20, 21).

Studies on the soil physical and chemical properties had achieved fruitful results, but there were few reports on the integrated analysis of the soil properties on water-eroded forest area, which restricts understanding of the mechanism and the effect of soil and water conservation. In this paper, soil pH and contents of main nutrients in different soil depths were measured, and their characteristics were analyzed with the variation of soil depth, forest type, and soil erosion grade, so as to provide scientific basis for vegetation restoration in the water-eroded area.

MATERIALS AND METHODS

Study area

The study area is situated in Changting County (25.18’40”-

26.02’05”N, 116.00’45”- 116.39’20” E) in the southwest of Fujian Province, China, with a total land area of 3 099 km^2 (Figure 1). It is located in the mid-subtropical monsoon region, with the annual average temperature of 17.5- 18.8 °C. The annual average precipitation is about 1 700 mm, which from March to June accounts for 60%. It is dominated by secondary vegetation such as Pinus massoniana Lamb. and shrubs. The humic Planosols (FAO-WRB) is distributed most widely, accounting for 79.8% of the total area, and the soil parent material is mainly the early Yanshanian biotite granite with strong weathering, and poor resistance to erosion (22). Because of its special lithology and characteristics of subtropical monsoon climate, it has become one of the most typical areas of soil erosion in southern China, and the loss of soil nutrients is serious (23).(Figure 1)

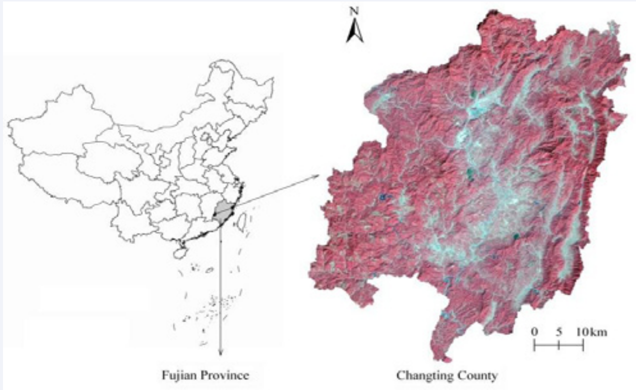

Figure 1 Geographic location of the study area.

Collection and measurement of soil samples

According to the distribution of typical forest stands, 14 field plots (10 m × 10 m) were selected for different soil erosion grade, which was in situ evaluated according to soil bareness, slope, and vegetation coverage. In the plots, there were different types of vegetation, such as coniferous forests (CF) (Pinus. massoniana Lamb., Dicranopteris dichotoma (Thunb.) Berhn. and Baeckea frutescens L.), coniferous and broad-leaved mixed forests (CB) (P. massoniana Lamb., Cunninghamia lanceolata (Lamb.) Hook. and broad-leaved trees), and broad-leaved forests (BF) (Castanopsis nigrescens). The general situation of the plots is shown in (Table 1). Two quadrats (1m × 1m) were set as repetitions in each plot, and soil profiles were cut in each plot, to collect soil samples at a depth of 0-10, 10-20, 20-30, 30-40 and 40-50 cm respectively. A total of 128 soil samples collected from each sampling point in each quadrat were dried by air in a ventilated, dry and dark room, from which plant roots and residue and stones were removed. The samples were then sieved through a sieve with 60 meshes. The measurement methods of soil pH and nutrients are shown in (Table 2).

Table 1: General situation of the plots.

Quadrat	Vegetation	Forest type	Soil erosion
1	*Pinus. massoniana* Lamb., *Dicranopteris dichotoma* (Thunb.) Berhn *Baeckea frutescens* L.	CF	Moderate
2	broad-leaved trees *Pinus. massoniana* Lamb.	CB	intense
3	broad-leaved trees Cunninghamia lanceolata	CB	intense
4	broad-leaved trees	CB	intense
5	*Pinus. massoniana* Lamb., *Dicranopteris dichotoma* (Thunb.) Berhn	CF	Moderate
6	*Pinus. massoniana* Lamb., *Dicranopteris dichotoma* (Thunb.) Berhn	CF	Moderate
7	*Pinus. massoniana* Lamb., *Dicranopteris dichotoma* (Thunb.) Berhn	CF	Moderate
8	broad-leaved trees	CB	slight
9	*Castanopsis nigrescens Chun et C. C.* Huang	CB	slight
10	*Castanopsis nigrescens Chun et C. C.* Huang	BF	slight
11	*Castanopsis nigrescens Chun et C. C.* Huang	BF	slight
12	*Castanopsis nigrescens Chun et C. C.* Huang	BF	slight
13	*Castanopsis nigrescens Chun et C. C.* Huang	BF	slight
14	*Castanopsis nigrescens Chun et C. C.* Huang	BF	slight

CF: coniferous forests. CB: coniferous and broad-leaved mixed forests. BF:broad-leaved forests.

Data processing and analysis

The two values of the same soil depth of two measurement points were averaged as the pH or nutrient content value of the sample in each soil depth. In the analysis of soil pH and nutrient content with the change of soil depth, forest type and soil erosion grade, the other two factors were ignored, and the mean and standard deviation of soil pH and nutrient content with each of the factors were calculated. For example, when analyzing the soil pH and nutrient content with the change of the soil depth, the mean and standard deviation of pH and nutrient content of all soil samples in each soil depth were calculated respectively, while the differences of forest type and soil erosion grade were not considered. When the soil pH and nutrient content with the change of forest type (or soil erosion grade) were analyzed, the soil depth and soil erosion grade (or soil depth and forest type) were not concerned. All analyses were conducted using SPSS 19.0 statistical analysis software (SPSS Inc., USA).

RESULTS AND DISCUSSIONS

Changes of soil pH and nutrients with soil depth

With the increasing of soil depth (for all forest type and soil erosion grade), the average value of pH increased, OM, TN, an, AK decreased, while TK, TP, AP changed not significantly (Figure 2). That is to say, the topsoil in the study area was acid, the deeper the soil layer was, the weaker the acid was, and most of the nutrients tended to decrease with the soil depth. This is consistent with the conclusions of other studies (24, 17). Because the topsoil is rich in dry branches, leaves, litter, plant roots and

Table 2: Determination meathod of soil pH and nutrients.

pH and nutrients	Determination method	Literature cited
pH	potentiometry	Allen et al.,1986
OM	potassium dichromate-sulfuric acid digestion method	Nelson et al., 1996
TN	semimicro-kjeldahl method	Bremner et al., 1996
AN	alkaline hydrolysis diffusion method	Bremner et al., 1996
TP	sodium hydroxide alkali fusion-molybdenum antimony colorimetric method	Olson et al.,1990
AP	ammonia fluoride and hydrochloric acid extraction-molybdic acid colorimetric method	Olson et al.,1990
TK	sodium hydroxide alkali fusion-flame photometry	Page et al.,1982
AK	ammonium acetate extraction-flame photometry	Page et al.,1982

OM:organic matter, TN:total nitrogen, AN:available nitrogen, TP:total phosphorus, AP:available phosphorus, TK:total potassium, AK:available potassium

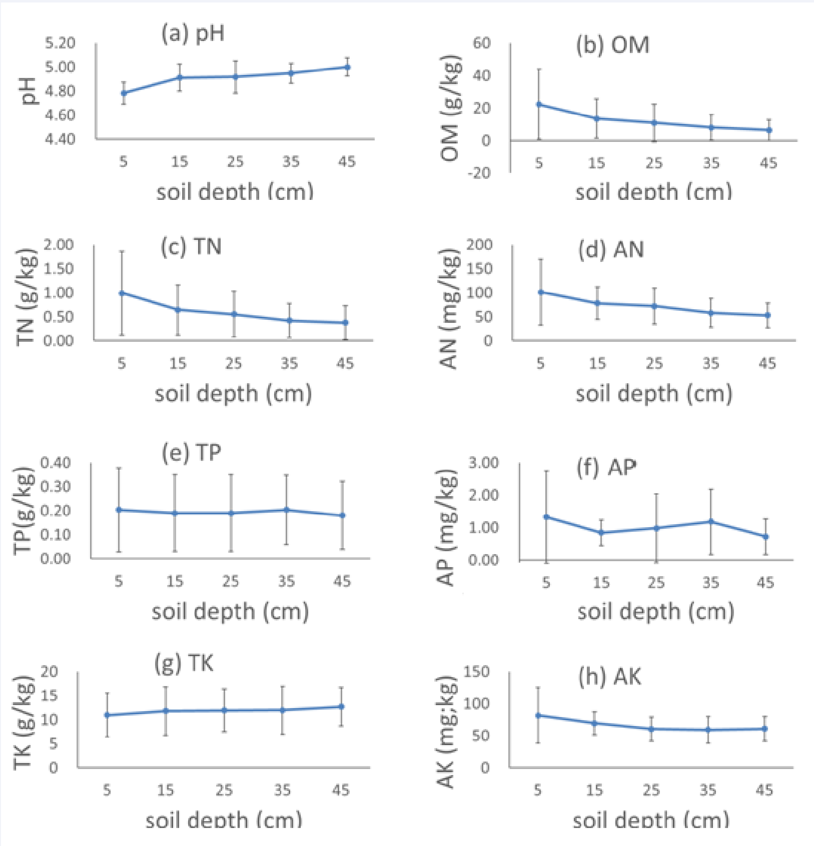

Figure 2 Distribution of soil pH and nutrients in vertical profiles.

various biological humus, which will release various organic acids under the decomposition of microorganisms. The air subsidence will also input more H^+ to the topsoil to replace alkali metal ions, and then enter the deeper soil, which further enlarge the vertical distribution of the pH value (25). Nutrients first accumulate in the topsoil and then infiltrate down through water or other media. With the increase of soil depth, the bulk density of soil increases, the permeability of soil becomes poor, and the decomposition activity of microorganisms also weakens (26), which leads to the decrease of nutrients in the soil from surface to the bottom. The TK content had no significant change with the increase of soil depth, indicating that TK content was mainly related to soil parent material (27, 28) TP is mainly affected by soil parent material and litter, where the litter decomposition is the source of rapid phosphorus supplement in the soil (29, 30).

Compared with the mean value, the standard deviation of soil pH and nutrients in each vertical layer was greater in TP and AP (except for AP in 10-20cm), which showed that the content of P in the soil vertical layer was affected by multiple factors. OM, TN, AN, and AK decreased with the soil depth, while pH and TK were close to each other, showing the different attenuation characteristics of the soil nutrients in the vertical distribution.

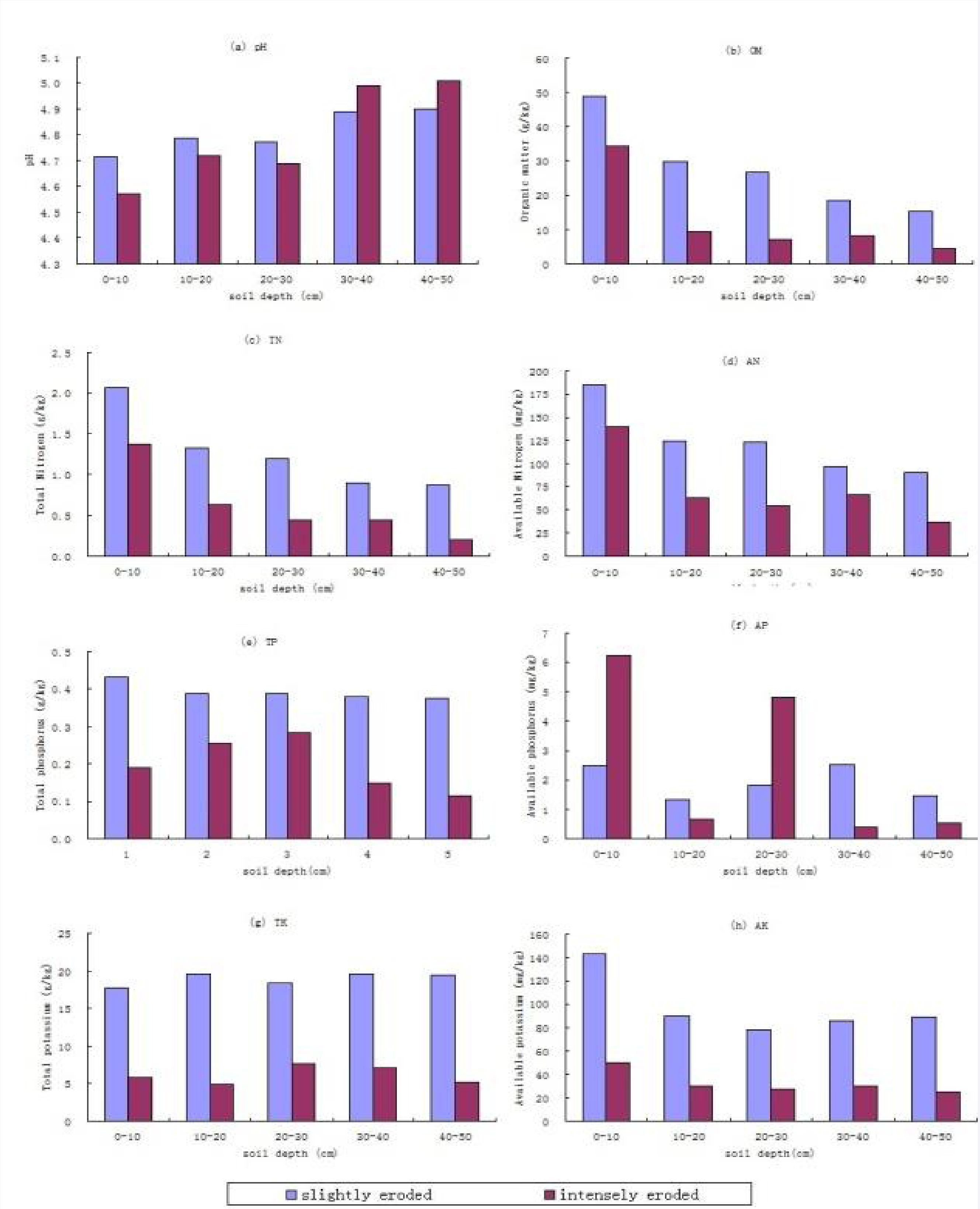

Figure 3 Comparison of contents of soil nutrients in the slightly eroded plots and strongly eroded plots with the broad-leaved forests.

Changes of soil pH and nutrients with forest type

From CF, CB to BF, the average pH value (for all soil depth and soil erosion grade) gradually decreased, while the other nutrients increased (except AK first decreased and then increased). In other words, from CF, CB to BF, the soil acidity gradually increased, while the soil nutrients were mostly the greatest in BF, followed by CB and CF. These are mainly related to the differences of litter quantity and nature, vegetation absorption and accumulation of soil nutrients, and vegetation community structure among the three forests (31), especially the key role of the litter in the forest nutrient cycling process. Forest litters, including dead branches and leaves, fruits and animal excrement and debris living in the canopy layer, is generally positively correlated with the return of soil nutrients. The Pinus massoniana of the CF type are dominantly but sparsely distributed in the study area, with small leaf area and small litter biomass, which has non-degradable tannins, waxes, and resins, etc., resulting in the least soil nutrients among the three forests (31, 32).The ground litter of BF is relatively rich, and there are more acid substances, leading the pH value of soil slightly lower than that of other forests. In contrast, the BF litter has a high nutrient content and is easy to be decomposed and absorbed by the soil. Besides, higher canopy density of BF can effectively reduce soil nutrient loss and leaching, causing the greatest nutrient content among the three forests.

The standard deviation of soil pH and nutrients corresponding to each vegetation type was smaller in CF and CB, but greater in BF type, which further showed the complex coupling of soil-rain-vegetation in the BF type. The standard deviation of TP and TK was very small, which indicated that these two soil nutrients were slightly affected by vegetation types.

The impact of soil erosion on Soil pH and nutrients

The average pH value (for all soil depth and forest type) was the least in the Light soil erosion grade, the greatest in the Moderate grade, and the middle in the Intense grade. All the soil nutrients are on the contrary: the greatest in the Light soil erosion grade, the least in the Moderate grade, and the middle in the Intense grade (Figure.3). As for the standard deviation, among all soil erosion grades, TP, TK were very low, followed by pH. All other soil nutrients were low in Moderate soil erosion grade, and of the Slight grade a little bit higher than those of the Intense grade. Compared with other soil erosion grades, the standard deviation of soil pH and nutrients of the Moderate grade were all very low.

It is generally believed that there is a significant positive correlation between nutrient loss and soil loss (33, 34, 35).Soil erosion leads to the decrease of N, P, K and other soil available nutrients and organic matter. The decrease of organic matter will weaken the soil erosion resistance, which in turn favor the occurrence of soil erosion. In this study, the soil nutrient content of Moderate soil erosion grade was the lowest, not the Intense grade, mainly thanks to only the CF forest land of the Moderate grade, while the Intense grade was of the CB type (Table 1). Therefore, soil erosion leads to the loss of soil nutrients, thus reducing the productivity of soil and the ability to maintain life (36), but the degree of the loss is affected by the vegetation. Soil and water conservation measure like forestation is of great significance in the controlling of soil nutrient loss (37)

CONCLUSIONS

In this study, soil pH and contents of main nutrients in different soil depths under the forests were measured in a water-eroded area in southern China, and their change characteristics with soil depth, forest type, and soil erosion grade were analyzed. Some conclusions were drawn as follows.

(1)With the increasing of soil depth, the average value of pH increased, OM, TN, and AK decreased, TK, TP, AP changed not significantly. The standard deviations of TP and AP in each soil depth were greater, showing that the content of P in the soil vertical layer was affected by multiple factors.

(2)From CF, CB to BF, the soil acidity gradually increased, while the soil nutrients were mostly the greatest in BF, followed by CB and CF. The standard deviation of soil pH and nutrients corresponding to each forest type were smaller in CF and CB, but greater in BF.

(3)All the soil nutrient contents were the greatest in the Light soil erosion grade, the least in the Moderate grade, and the middle in the Intense grade, the soil pH was on the contrary. The standard deviations of most soil nutrients were low in the Moderate grade, and of the Slight grade a little bit higher than those of the Intense grade.

(4)Ground litter contributed mainly to the changes of soil properties. Broad leaved forests had a stronger capacity to gather nutrients in the topsoil and could increase the contents of soil nutrients in vertical profiles. Soil erosion resulted in the loss of soil nutrients, but the degree of the loss was affected by the forest communities.

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