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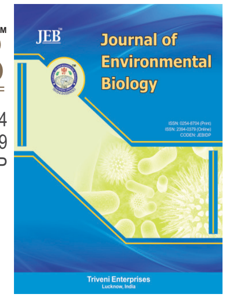

Study of soil nutrients, physical and biological characteristics of paddy fields after lifting measures : A case study of China's Ganjiang region

Authors Info

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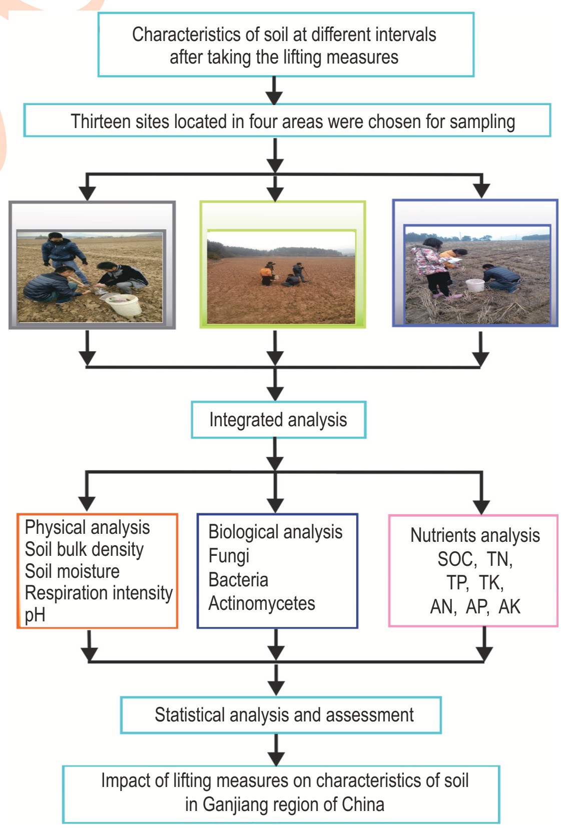
Abstract

Aim : Lifting measures combining stripping of soil surface with lifting of soil by stone and clay have been widely employed to solve land-flooding conflicts in water project construction. The aim of the present research was to demonstrate the physical, biological and nutrient characteristics of soil at different intervals after taking the lifting measures.

Methodology : Considering farm field cultivation, thirty nine sites of three different kinds were selected to reflect the effect of construction of the Xiajiang Water Control Project on soil characteristics. Soils were collected to test the physical, chemical, and nutrient properties. Soil quality indices were combined with statistical analyses to evaluate the effect of the lifting measures.

Results : After the lifting measures were employed, the quality of soil physical properties and nutrients, such as the level of soil moisture content, soil respiration intensity, soil organic carbon value and total nitrogen decreased significantly in the first year. Compared with non-lifted areas, both physical and chemical properties decreased to a certain degree. However, soil quality gradually recovered via continuous management and cultivation, and no significant difference between the lifted and non-lifted areas was observed after three years of cultivation based on the Integrated Fertility Index.



Interpretation : Lifting measures can destroy the soil structure in the early stage and thus degrade the soil quality and nutrient cycles. Through scientific management and cultivation, soil physical and chemical properties could be gradually

Introduction

Soil fertility is subject to the biological environment and presents individual differences in different places (Mandal et al., 2015). Nutrients and microorganisms in soil play an important role in improving soil quality (Sun *et al*., 2011). In the past several decades, the function of organic and microbial matter in soil has attracted extensive attention because of the positive effects on agricultural productiveness (Castilho *et al*., 2016). Biological properties of soil are closely related to biochemical properties that greatly contributed to decomposition processes (Hobara *et al*., 2014). Some studies have indicated that microorganisms can increase amino acid levels, whereas soil fungi can change the amount of macro aggregates and the structure of soil (Helfricha *et al*., 2015). Microorganisms are necessary for recycling within terrestrial ecosystems. In addition, soil organic matter (SOM) has been considered a complex compound of plant litters and microbial outputs in various stages of degradation (Masoom *et al*., 2016). It can be very effective in maintaining moisture in the soil, preventing soil salinization, and providing a medium environment for microorganisms (Mlih *et al*., 2016).

Many studies have revealed that rotational tillage can enhance the vertical distribution of total nitrogen (TN) and SOM stocks (Sutton and Sposito, 2006). Compared with conventional methods, rotational tillage decreases soil bulk density and positively influences biomass and productiveness (Hou *et al*., 2012). Some studies have also shown that effective management alleviates soil water deficit, increases crop productivity and improves soil physical properties (Lozano *et al*., 2016). Lifting measures are comparable to rotational tillage, both destroy the soil's original structure and greatly effect the soil quality. Since the 1970s, lifting measures have been used extensively in basins destroyed by Water Control Projects in China to resolve immigration and relocation issues at lower cost (Zhen, 2015). However, lifting measure application is usually limited to a small scale and does not cause obvious effects on the local environment. Nevertheless, few studies have been conducted to examine the effect on agricultural production caused by lifting.

The Xiajiang Water Control Project is the largest water conservancy program of the Ganjiang River, and aims in controlling flood, generating power and utilizing water resources for agricultural purposes. Its implementation can significantly enhance flood control capacity of cities located downstream of the project (Tang and Wang, 2003). However, this project faces a big challenge in terms of large areas of cultivable land that become submerged. Presently, these arable land areas are very important in guaranteeing food production for local residents. After wide discussion, lifting measures have been accepted as an alternative method for reducing the amount of submerged areas of arable lands. The objective of this study was to analyse the physical, chemical and biological properties of lifted soil, correlation between nutrients and properties, and soil quality at different stages using Integrated Fertility Index (IFI).

Materials and Methods

Study area : During the construction of Xiajiang Water Control Project, more than 1910.06 ha of farmland have been occupied. Among those occupied, approximatly 142.63 ha are reverting to forests and 1092.93 ha are undergoing lifting measure. Lifting measures involved three steps. First, the surface soil of original fields is stripped, collected and stored. Then, the original fields were lifted by adding stone layers and clay layers whose thickness was determined by hydrologic calculation. After compaction, the original surface soil was added back as a top layer for agricultural purposes. Based on the scientific field investigation, the surface arable layer was about 30 cm deep. Based on the recultivation period after lifting measures were applied, 13 sites located in four areas on the east side of the Reservoir Xiajiang, namely Shui Tian, Cha Tan, Liao Qiao, and Ge Shan, were selected for sampling. Of these sampling sites, 3 were in Shui Tian, 4 in Cha Tan, 4 in Liao Qiao and 2 in Ge Shan, respectvely.

Sample collection and preparation : Thirty nine samples were collected at the end of December 2014 from the four lifted areas using a Hydro-Bios stainless steel grab sampler and then wrapped in polyethylene plastic bags (Fig. 1). At each site, three samples, using a five-point sampling method with a 'W'-shaped distribution, were collected from the surface soil (0 to 20 cm). The soil samples were designated 3Y (3 years post-lifting), 1Y (1-year post-lifting), 0Y(0 years post-lifting), and BK (original field as blank) based on the cultivation period after lifting measures were applied. A portable Magellan GPS (Triton 300E) was used to record the global position information.

Sample analysis and processing : After gathering, the surface soil samples were well marked, immediately sent to the laboratory, and then air-dried. Stones, gravel, animal residues, plant roots and sticks were picked out. These samples were then ground with a mortar, passed through a 0.15 mm mesh sieve, and stored in a ziplock bag at -4 °C prior to laboratory analyses.

As mentioned in Masciandaro *et al*. (2013), the potassium dichromate external heating method, Kjeldahl method, molybdenum antimony colorimetric assay, flame photometry, alkaline hydrolysis diffusion method, flame photometry and sodium bicarbonate method were used to determine the levels of soil organic carbon (SOC), TN, total phosphorus (TP), total potassium (TK), alkaline hydrolysis nitrogen (AN), available potassium (AK) and available phosphorus (AP), respectively. After 20 min of sterilization, beef extract-peptone medium, improved Gause's No. 1 medium, and Martin agar medium were used to culture bacteria, actinomycetes and fungi, respectively. The improved Gause's No. 1 medium and Martin agar medium, 3% potassium dichromate (One ml per 300 ml) and 1% streptomycin (3.3 per ml 1000 ml) were added to inhibit the growth of bacteria and actinomycetes. Diluted samples were inoculated under sterile conditions and then moved into a constant temperature incubator. The cell counts for bacteria and actinomycetes were calculated after 10 d culture at 25°C and for the fungus after 5 d culture at 25°C.

Results and Discussion

Appropriate physical and biological properties have positive effects on nutrient cycling and water transportation, transfer and storage. Several studies have revealed that the physical and biological properties of soil are closely related to the soil fertility level (Smebye *et al*., 2015). As shown in Fig. 2, the soil bulk densities of four soil types ranged from 1.09 to 1.87 $g \cdot cm^{-3}$ and their average values were in the following order: 0Y> 1Y> 3Y> BK.The soil moisture contents ranged from 6.96% to 31.27%, and their average values ranked as follows: BK >3Y>1Y>0Y.The trend for soil respiration intensity was same as that for soil moisture: BK >3Y>1Y>0Y. The pH varied from 6.91 to 4.61, with a mean value of 5.49. The pH values of 0Y areas were higher compared with those of BK and 3Y areas.

It is well acknowledged that microorganisms play an important role during the recycling process of soil nutrients. The quantity of organisms is determined by type of soil, soil layer thickness, type of vegetation, geographical climate and other factors. Therefore, the number of microorganisms could directly reflect the status of soil fertility (Mahanta *et al*., 2014). In soil, bacteria had the highest abundance, followed by actinomycetes and fungi. When compared with BK, no significant differences were found among the abundances of all the selected microorganisms of 1Y and 3Y (Fig. 3); which indicate that soil quality in 1Y and 3Y gradually increased after several years of cultivation and management. However, the abundance of fungi and bacteria in 0Y were still lower than those in BK.

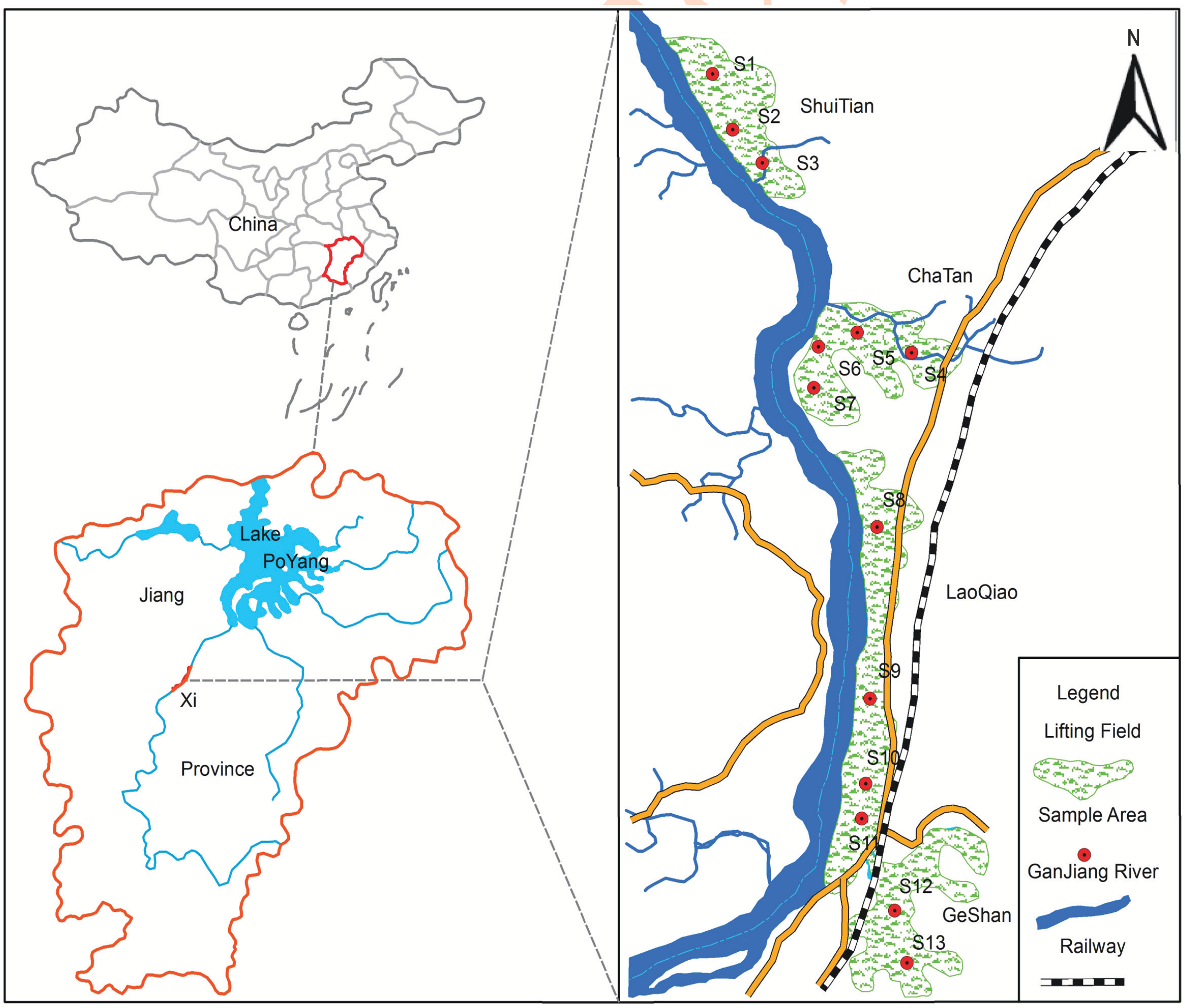


Fig.1 : Map showing the geographical location of sampling sites in Ganjiang region of China

The function of soil physical and biological properties lies in maintaining soil fertility level and guaranteeing productivity (Mahanta *et al*., 2014). The results conclude that lifting measures decrease soil quality during the initial stage by reducing vegetation coverage and cultivation layer thickness, weakening the soil aggregate permeability and lowering the soil water holding capacity. Research has indicated that soil environment deterioration and poor plant growth may increase from soil hardening (Hamza *et al*., 2005). The critical role of long-term fertilization regimes in enhancing soil water moisture and regulating pH values and soil respiration intensity has been demonstrated (Yang *et al*., 2011). The current research indicated that the tillage layer soil at the initial stage was inappropriate for microorganisms and nutrient cycles. However, soil physical and biological properties were gradually ameliorated after 1–3 years of cultivation. Similar results were reported by Moffat and Mcneill (1994).

Several studies have indicated that SOC is directly influenced by land management pattern and soil physical properties (Zhang *et al*., 2012). In red soil, the content and distribution of SOC was significantly related with soil usage. As shown in Fig. 4, SOC contents ranged from 2.4 to 25.3 g kg^{-1}, with an average of 13.29 g kg^{-1}. The values of SOC in BK ranged from

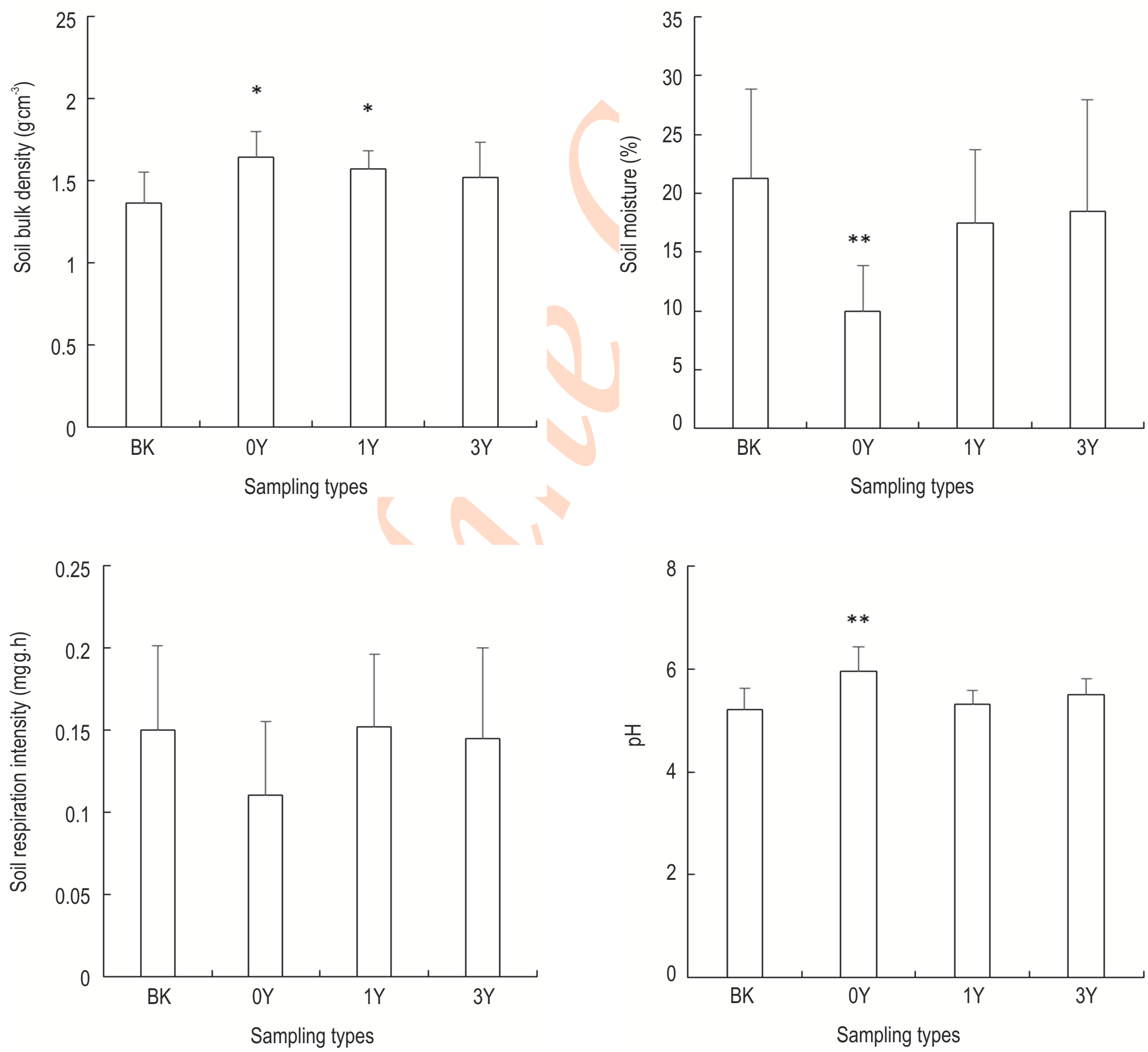


Fig. 2 : The characteristic values of soil density, moisture, respiration intensity and pH in Ganjiang region of China (asterisks indicate P<0.05; double asterisks indicate P < 0.01)

9.24 to 25.3 g kg^{-1}, with an average of 18.13 g kg^{-1}. The minimum average SOC value of 9.03 g kg^{-1} was recorded in 0Y, which was 0.43 times that of the average BK value. However, the average SOC values in 3Y reached to 16.27 g kg^{-1} after three years cultivating. After calculation, the average SOC values in the study area were in the following order: BK>3Y>1Y>0Y. Although SOC content decreased significantly after lifting measures, it gradually recovered via scientific management and cultivation.

Total nutrients in soil are the stock of available nutrients, which could reflect the state of soil resource quality (Mitsch and Gosselin, 2000). Previous studies have clarified that total nutrients in paddy soil are one of the important factors effecting rice growth and yield (Li *et al*., 2011). As shown in Fig. 4(B), 4(C) and 4(D), TN ranged from 0.09 to 1.67 g kg^{-1}, with an average of 0.58 g kg^{-1}. The lifting measures had a significant effect on TN by disturbing the soil physical characteristics and leading to a sharp decrease. However, TN accumulated gradually and was maintained at a certain level via scientific management and effective fertilization. TP content changes were in a range of 0.99-0.41 g kg^{-1}, with an average value of 0.65 g kg^{-1}. Similar to TP, TN decreased dramatically after lifting measures and increased gradually to a certain level after a period of cultivation and field management. TK content ranged from 2.4 to 20.7 g kg^{-1}, with a mean value of 10.3 g kg^{-1}.

Available nutrients can be directly absorbed by plants, which have a close relation with soil fertility level (Li *et al*., 2011). Available soil nutrients have a close relationship with land use type geomorphic type and soil type (Yang *et al*., 2010). The maximum value for AN was 83.3 mg kg^{-1}, with an average value of 39.2 mg kg^{-1}. Lifting measures may have destroyed the stability of soil, which led to decrease of AN. The AP content varied between 1.7 and 42.1 mg kg^{-1}, with an average value of 15.12 mg kg^{-1}. Like AN, AP can be seriously affected by lifting measures, but continuously recovered through cultivation. The AK content was in the range of 31.1–132.0 mg kg^{-1}, with an average value of 71.4 mg kg^{-1}. Lifting measures led to a decrease by 44% for the initial stage but 89% recovery after three years of farming (Fig. 4E,F and G).

Physical properties influence the accumulation and recycling of soil nutrients (Steven *et al*., 2005). All soil nutrients studied showed negative correlations with bulk density and positive correlations with soil moisture. A positive correlation was

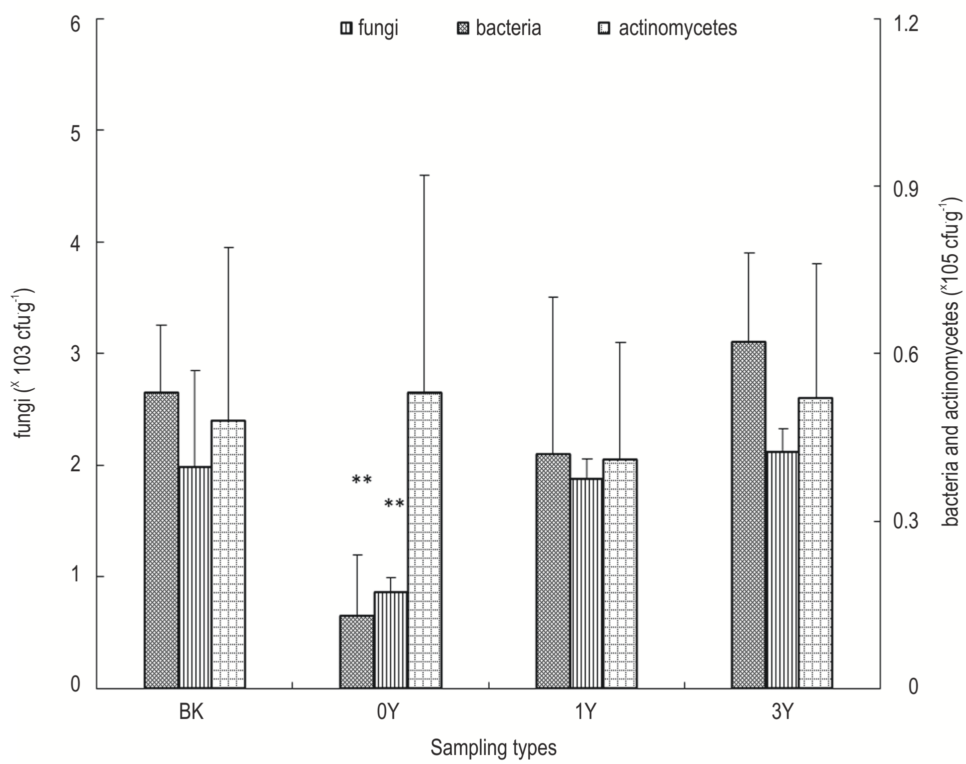


Fig. 3 : Comparison of microbial quantity with BK after different period of lifting measures in Ganjiang region of China (double asterisks indicates P<0.01)

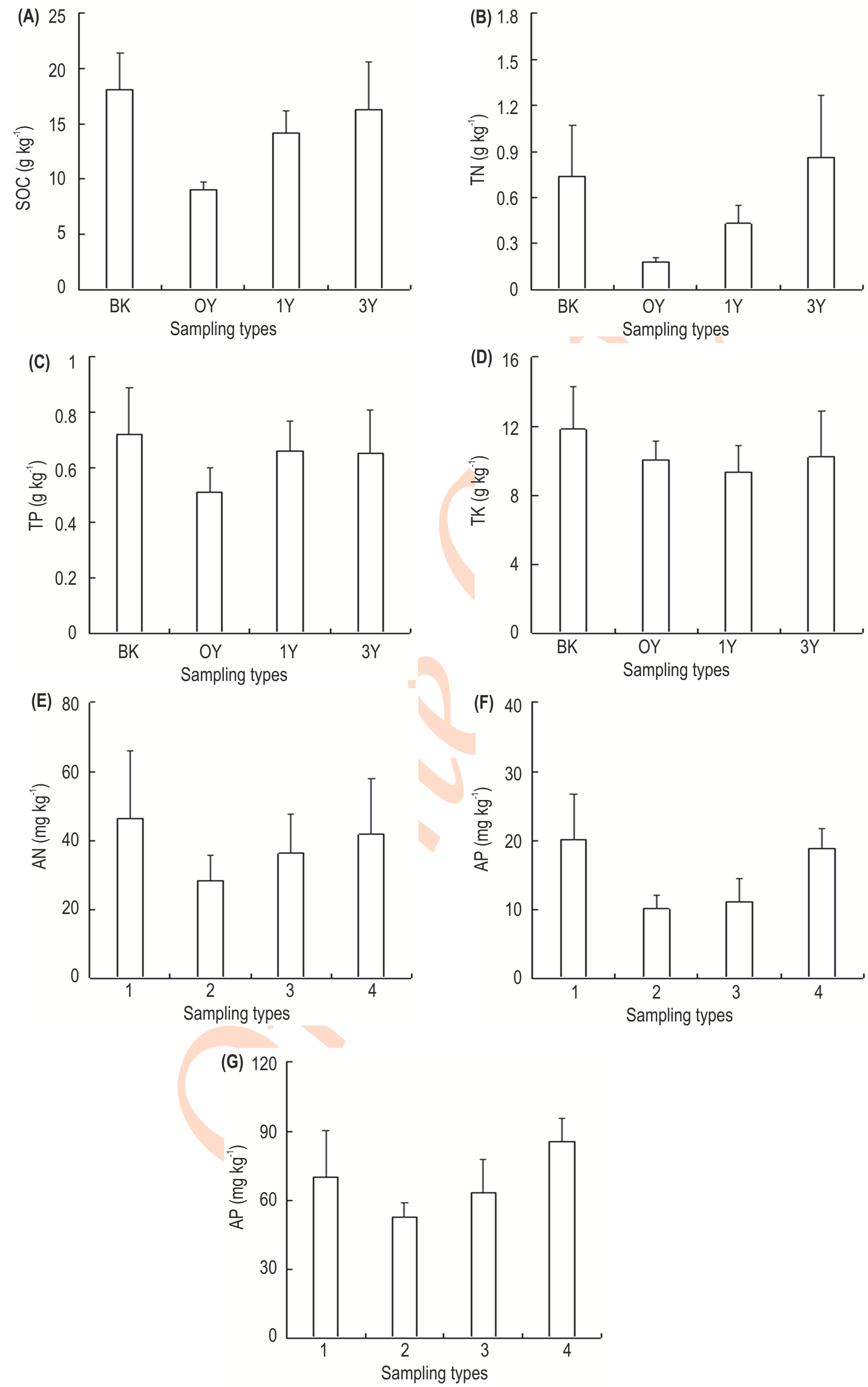


Fig. 4 : Distribution of nutrient and SOC in sediments in Ganjiang region of China (asterisks indicate P<0.05; double asterisks indicate P < 0.01)

also seen among respiration intensity and soil nutrients. There were no significant correlations among soil physical properties and TN, TK, or AK. It has been well reported that nutrient accumulation in soil is the result of complicated processes effected by multifactorial interactions (Manzoni *et al*., 2004). SOC and TP contents are easily affected by soil bulk density and moisture, and thus can achieve high levels via sufficient water supply and loose soil. The AN and AK were significantly affected by bulk density and respiration intensity (Stavi *et al*., 2008).

Microorganisms were also positively correlated with soil physic-chemical characteristics (Parr and Papendick., 1997; Devi and Yadava., 2006). Several studies have shown correlation between microorganisms and soil nutrients (Devi and Yadava., 2006). In the present study, the bacteria, actinomycetes and fungi were positively correlated well with soil nutrients. The quantity of actinomycetes exhibited good positive relationship with SOC, TN, and AN. Similar results were also found for fungi, which correlated well with TN, TK and AN. The amount of bacteria had positive correlations with SOC, TN, TP, AN, and AP. Thus, it was concluded that SOC and nutrients significantly influence soil microbial biomass amounts, and bacteria are more sensitive than fungi and actinomycetes to the effects of SOC and nutrients.

It is well known that soil physical properties and microbial biomass can limit nutrient cycling processes (Compton *et al*., 2004). In this study, the correlation between nutrients were investigated using correlation analysis. All the nutrient elements correlated well each other. Based on one-way ANOVA, positive correlations existed between SOC and TN (R=0.338), SOC and TP (R=0.43) and SOC and AN (R=0.894). TN was also significantly correlated to SOC, AN, AP and AK. Similar results were found for TP, as it was correlated positively with AN and AP.

Principal component analysis (PCA) is a statistical method that is widely used to convert multiple indicators to fewer meaningful components by discarding some of the non-significant information (Xie *et al*., 2015). In this study, PCA was used to evaluate the degree to which the field lifting affected soil fertility. Four principal components were extracted from the original variables to represent all the information. In general, factor 1 represents all indices except that for TK. Factor 2 explains 20.57% of the variance with highly positive loading from rapidly AP. The scores of sampling sites added by these four factors were in the following order: 3Y > BK > 1Y > 0Y. Owing to effective management, nutrients approached their lowest levels in the early stage after lifting measurement. After that, the soil fertility index increased gradually to 4.53 after three years of management. This indicates that lifting measures cause soil quality to decrease significantly during the early stage and have significant impacts on soil nutrients (Edwards and Jefferies., 2013).

The Integrated Fertility Index (IFI) has been widely used to evaluate soil fertility (Li *et al*., 2011). In the present study, the correlation coefficients between different variables were used to determine weight (Lv *et al*., 2004), and the membership values were calculated via the standardized concentration of indices as listed in Li *et al*. (2011). Furthermore, data of the Second National Soil General Survey was used to determine the function threshold values. The lifting measures resulted in a wide range of IFI values, and the average IFI values of four types of soils were in the following order : 3Y > BK > 1Y > 0Y. Based on the statistical results and standards, 13 sampling sites in this study were divided into four levels: level I (IFI ≧ 0.75), level II (IFI: 0.75–0.5), level III (IFI: 0.5–0.25), and level IV (IFI ≦ 0.25). The IFI values of BK and 3Y were mainly focused in level II and III, with an average IFI value of 0.44 for BK and 0.47 for 3Y. The IFI values of 0Y and 1Y were lower than level IV, indicating that 0Y and 1Y were heavily affected by the lifting measures.

This study revealed that lifting measures can cause a significant quality decrease of paddy soil planted along the Gan River in Jiangxi province, which was mainly characterized by significant changes in physical and biological soil properties. Permeability and holding capacity of soil were largely destroyed during the early stage and were unsuitable for microorganisms and nutrient cycles. Nevertheless, soil physical and biological properties gradually ameliorated after several years' scientific management and cultivation. Hence, no significant difference was seen in nutrient levels between the original planting areas and areas after three years of cultivation.

Acknowledgments

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