Soil genesis along a paddy soil chronosequence in a millennium scale

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Abstract

A paddy soil chronosequence consisting of five profiles derived from calcareous marine sediments ranging in paddy cultivation history from 0 to 1000 years was studied. The general soil physical and chemical properties, magnetic properties, clay mineral and major elements of the soil samples were measured, in order to investigate the dynamic change of different soil properties, and to understand the response rate of soil properties over different time scales. The results showed that soil properties including surface soil organic carbon, $CaCO_3$, MS(magnetic susceptibility), IRM_s(soft isothermal remanent magnetization), had notable changes within the initial stage (50 yrs) of paddy cultivation. Clay content, free iron oxides, and IRM_h (hard isothermal remanent magnetization), change notably when paddy cultivation history reach 700 years. However, clay mineralogy shows few changes even if the cultivation time reaches 1000 years. The results of gains and losses of major elements indicate Ca, Mg, and Na are strongly lost in the initial stage (50 yrs) of paddy cultivation and gradually depleted with increasing paddy cultivation time, Si and Al remain basically constant, while, Fe has large depth variation. In conclusion, our data demonstrate that different soil components and properties have quite different changing process and rate under paddy cultivation condition.

Key Words

Paddy soils, chronosequence, pedogenesis, mass balance, dynamic change, time scale.

Introduction

Soil chronosequences are valuable tools for investigating rates and directions of pedogenic evolution (Huggett 1998). Brantley (2008) indicated that different soil components have different response times that vary from hundreds of millions of years to minutes in regolith and suggested that learning how soils will change in the future will require observations and models that cross time scales. Paddy soils are an important soil resource for food production in Asia. Knowledge of rates and processes of geochemical and pedogenic changes under wet cultivation is useful for the improvement and sustainable use of these important soil resources. As anthropogenic soils, paddy soils provide a good basis for soil change study over a millennium scale. The objectives of this study are to investigate the dynamic change of various soil properties over a fairly well quantified time scales, using a well-dated paddy chronosequence under human cultivation condition.

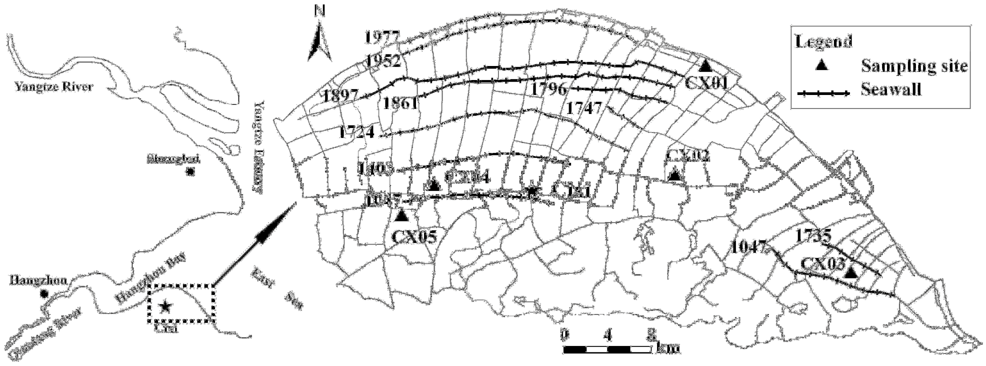

Figure 1. Location of study area and sampling sites. Numbers beside the dark line (seawall position) represent the calendar (AD) year when the seawall was built.

Materials and methods

Study area and soil chronosequence recognition

The studied area is located in Cixi, Zhejiang Province, facing the East China Sea (Figure 1). The region belongs to the southern fringe of northern subtropics and has a mean annual temperature of 16.3℃ and a mean annual rainfall of 1325 mm. The sampling area is a marine deposit plain. Parent materials are mainly marine sediments with some river alluvium derived from East Sea and Qiantang River. With sedimentation, the land becomes free from tides and followed by building seawall for paddy cultivation. Along the coastline extension, seawalls were built in different stages successively. Wang (2004) collected and compiled a series of Cixi County Annals that records chronologically the significant natural, social and economical events. The detailed records of seawall construction and rice cultivation history are available. A paddy soil chronosequence consisting of four profiles were sampled. The age data, i.e., approximately 300, 700, and 1000 years of paddy cultivation history, was determined based on the time of seawall constructions, while the profile with 50 years of paddy cultivation was determined by local farmers. In addition, we selected an uncultivated mud beach profile as the original soil (Gleyic Fluvisols) (time zero).

Field sampling and 1aboratory analyses

Within each identical paddy cultivation history area, three paddy fields are chosen based on historic information, specific location, fresh irrigation water availability and current land uses, and one representative profile is chosen for sampling. All soil samples were collected when the fields were drained after rice harvest. Soil profiles were described and sampled according to genetic horizons following standard field study methods. Figure 2 show the image of the five studied profiles. Soil samples were dried at room temperature and gently crushed using a wooden pestle and mortar, and then passed through a 2 mm nylon sieve. Soil organic carbon, $CaCO_3$, particle size distribution, free iron oxides, clay mineral, and major element concentrations were measured according to ISSAS (1978). Magnetic parameters were measured and calculated according to Evans and Heller (2003). Chen and Zhang (2009) indicated that no lithological discontinuities occur both within and among the studied soils, by using various indicators determining lithological discontinuities (LDs) (Schaetzl 1998).

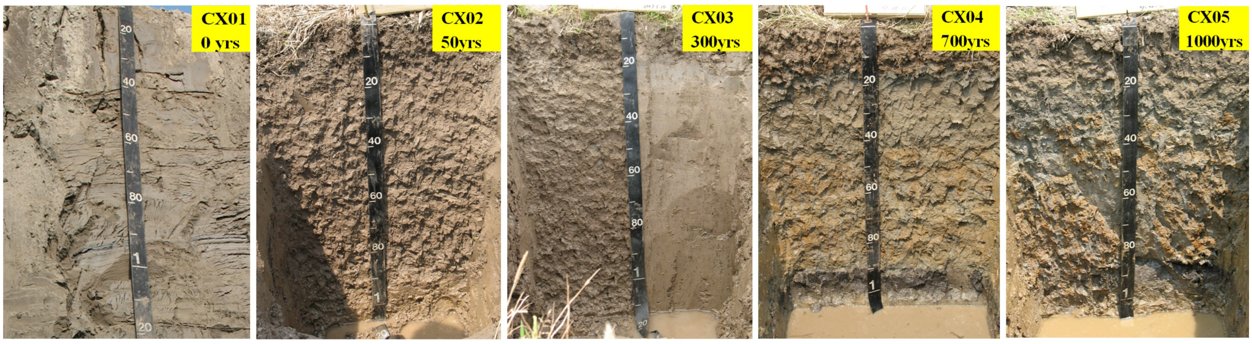

Figure 2. The studied pedons of the paddy soil chronosequence, with age varying from 0 to 1000 years of paddy cultivation history.

Results and discussion

Physical and chemical properties

The vertical distribution of soil organic carbon (SOC), $CaCO_3$, clay content and free iron oxides (Fe_d) in the uncultivated soil is relatively uniform over 0-120 cm soil depth, as compared with that in paddy soils (Figure 3), showing that no pedological changes occur. SOC value in A horizons (roughly 0-16 cm depth) in paddy soils (range from 14.2g/kg to 24.3g/kg) was consistently higher than that in uncultivated soil (4.0g/kg). Vertical distribution of SOC in the lower horizons is generally uniform and the contents in majority of horizons are around 4.0g/kg, except the Ahb horizon in 700yrs paddy profile (90-112cm) and 1000yrs paddy profile (85-100cm), which is a buried layer rich in humus and partially degraded plant debris. SOC in any horizons in paddy soil profiles does not show increasing or decreasing trend against paddy cultivation age. This indicates that paddy cultivation significantly increases the SOC in surface horizons, but SOC does increase constantly and would reach an equilibrium stage in a relatively short time span (around 50 years) under a given ecosystem conditions. The mean value of $CaCO_3$ content (averaged over 0-120cm depth) is 58.3g/kg in the uncultivated soil. $CaCO_3$ content decreases gradually with increasing paddy cultivation age within 300yrs. In the pedons of paddy cultivation age more than 300 yrs, i.e. 700yrs and 1000yrs no $CaCO_3$ is found over 0-120 cm soil depth. The leaching loss of $CaCO_3$ in the calcareous soil increases with increasing paddy cultivation age due to the artificial periodic irrigation and drainage in rice planting system. Clay content in overall depth in paddy soils is consistently higher than that in uncultivated soil. Clay content in the profiles with 50 and 300 years of cultivation history show slightly higher, however, in the 700 and 1000-year paddy profiles have obviously higher clay content, compared with uncultivated soil. The increased clay content is mainly found in depth within about 40 cm and 80cm of paddy profiles. The depth distribution of clay content in paddy soils suggest clear clay illuviation occurred in older paddy soils, i.e.700 and 1000 years paddy profiles in the depth about below 40cm for 700 years paddy pedons, 20cm for 1000 years one. Deposition of suspended material from irrigation water (generally fine particles) and mechanical leaching probably favors clay accumulations and differentiation.

Distribution pattern of Fe_d was similar to that of clay contents. The Fe_d in paddy profiles showed obvious sequential trend with time. The differentiation of Fe_d between surface horizon and subsurface horizon is stronger with paddy cultivation time, especially in those older soils (700 and 1000 yrs paddy cultivation history) in which the Fe_d of surface horizon to Fe_d of subsurface horizon ratio is more than 2.0. The illuviation depth of maximum Fe_d content of 300, 700, and 1000 years paddy profiles over 0-120 cm depth occurs at 30 cm, 50 cm and 80 cm respectively. The amount of Fe_d in illuviation horizon increases gradually with increasing rice cultivation age. The results indicate that the illuviation of Fe_d increases in quantity and the depth of illuviation lower gradually with the increasing of paddy cultivation age.

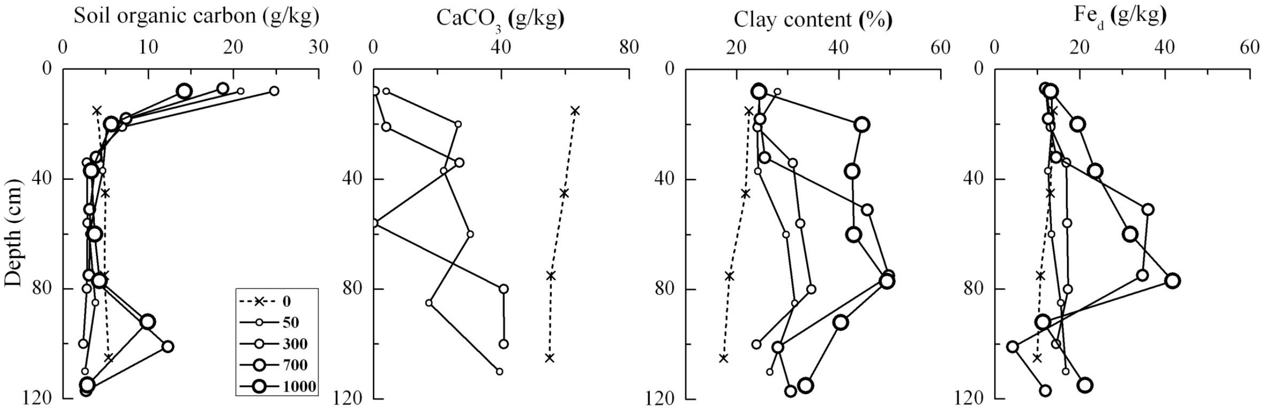

Figure 3. Depth distribution of soil organic carbon, $CaCO_3$, clay (<2μm) and Fe_d (free iron oxides) in the chronosequential soils.

Magnetic properties

The depth distribution of magnetic susceptibility (MS), soft and hard isothermal remanent magnetization (IRM_s and IRM_h) in all pedons is relatively uniform over 0-120cm soil depth, as compared with S_{-100mT} (Figure 4). Three stages could be divided for the changes of the magentic parameters with paddy cultivation age. The first stage (from uncultivated soil to 50 years paddy soil) is characterized by the remarkable decrease of MS and IRM_s resulting from reductive dissolution of ferrimagnetic minerals. The second stage (50~700 years) is characterized by the profile differentiation of $S_{-100mT.}$ The third stage (700~1000 years) is characterized by significant decrease of IRM_h and relatively stable MS, indicating that antiferromagnatic mineral (goethite) remarkably decreases and paramagnetic minerals (lepidocrocite) are formed in the illuviation horizon when the paddy cultivation age reach to 700yrs in which $CaCO_3$ have been leached out completely from the overall pedons. The results reveal that magnetic parameters can both respond to and reflect iron oxides minerals change in paddy soils and have a quite different change pattern in submerged environment compared with that in non-paddy soils (Singer *et al.* 1996).

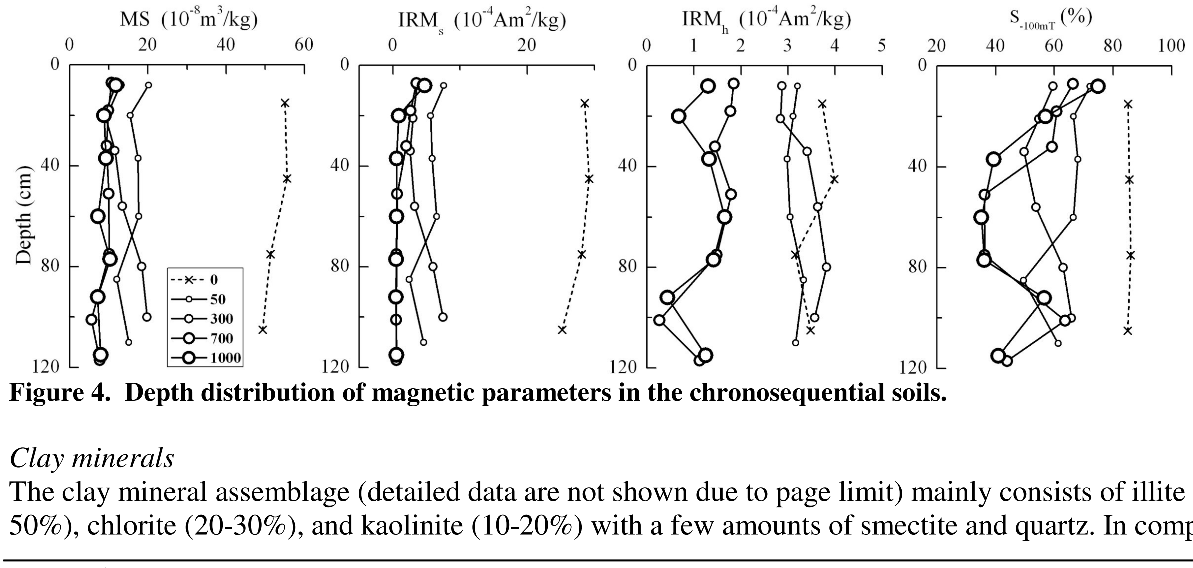

Figure 4. Depth distribution of magnetic parameters in the chronosequential soils.

Clay minerals

The clay mineral assemblage (detailed data are not shown due to page limit) mainly consists of illite (40-50%), chlorite (20-30%), and kaolinite (10-20%) with a few amounts of smectite and quartz. In comparison with the uncultivated soil and the paddy soils with different cultivation history, the clay mineralogy shows few change, even if the cultivation time reaches 1000 years.

Mass-balance calculations of major elements

Gains and losses of nine major elements (mean value in each paddy soil pedons over 0-120cm depth) in chronoseqnential paddy soils are calculated (using Ti as immobile element and using uncultivated soil as the original soil) and shown in Figure 5. Ca, Na, and Mg are characterized by the remarkable loss in the paddy cultivation initial stage (50 yrs) and gradually depleted with increasing paddy cultivation time. P and Mn are characterized by the slightly enriched in the paddy cultivation initial stage (50 yrs) and remarkable loss in the cultivation age more than 700 years. Comparatively, Si and Al have small migration rates. Fe and K are characterized by basically constant mean value in overall profiles and large depth variation with loss in the surface horizon and gain in the subsurface horizon (mainly between 40 cm and 80cm).

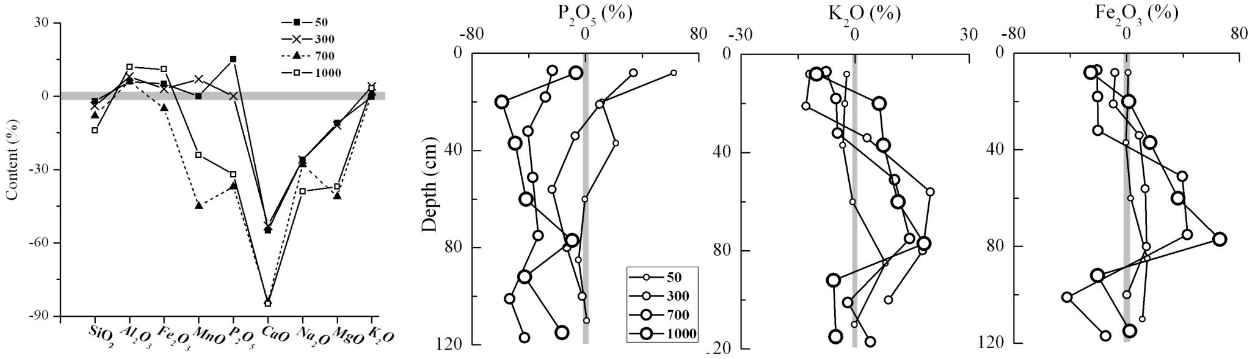

Figure 5. Gains and losses of major elements in paddy soils compared with uncultivated soil.

Conclusion

The studied paddy chronosequence developed on fairly uniform parent materials under nearly identical climate conditions and landscape provides a good opportunity to study the time-dependent changes in soil development. Soil properties including SOC, $CaCO_3$, MS, IRM_s, show notable changes within paddy cultivation initial stage (50 yrs). To clay content, free iron oxides, and IRM_h, notable changes occur when paddy cultivation history reach 700yrs. However, clay mineralogy shows few changes even if the cultivation time reaches to 1000 years. The mass balance of major elements indicate Ca, Mg, and Na are strongly lost in the paddy cultivation initial stage (50 yrs) and gradually depleted with increasing paddy cultivation time, Si and Al are basically constant, while, Fe has large depth variation. Although the total amount of iron has no dramatic change during paddy cultivation, it translocated to form an iron-rich layer with time and it transformed drastically as shown by the evolution of magnetic parameters.

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