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Land-Use Conversion Altered Topsoil Properties and Stoichiometry in a Reclaimed Coastal Agroforestry System

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Abstract: Reclaimed coastal areas were mostly used for agricultural purposes in the past, while land-use conversion was initiated in recent decades in eastern China. Elucidation of the effects of land-use conversion on soil properties and stoichiometry is essential for addressing climate change and ecological conservation. In this study, five land-use types in a reclaimed area were chosen to compare the differences of soil properties and stoichiometry, which comprised paddy, upland, upland-forest, forest, and vegetable garden, with a soil age of about 100 years. The results indicated that these land-use types significantly differed in soil water concentration, pH, bulk density, soil salt concentration, soil organic carbon content, total nitrogen content, and total phosphorus, as well as C:N, C:P, and N:P ratios. Positive correlations were found among soil organic carbon, total nitrogen, and total phosphorus; and among pH, bulk density, and soil salt concentration. Total phosphorus and soil organic carbon contents were the main factors shaping the topsoil among the land-use types. Contents of soil organic carbon, total nitrogen, and total phosphorus in paddy and vegetable garden soils were higher than that in upland and upland-forest soils, while bulk density, pH, and soil salt concentration showed the opposite trends. Forest soil demonstrated intermediate values for most properties. And the highest C:N occurred in the upland and vegetable garden, the highest C:P in paddy and vegetable garden, while the lowest C:N and C:P occurred in upland-forest. The highest and lowest N:P occurred in paddy and upland, respectively. The stoichiometric characteristics presented a narrow range of the ratio, and the C:N:P averaged 48:3:1 similar to the stoichiometry of average Chinese cropland soils. Rotations including legume, the use of organic fertilizers, and appropriate fertilization strategies were suggested for improving cropland management.

Keywords: cultivation history; forestation; management practice; soil organic carbon; soil development

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1. Introduction

Coastal areas and small islands exhibit a high human population density, and humans living in coastal areas have benefited from land reclamation from the coastal wetlands [1]. However, the loss and degradation of coastal wetlands caused by land reclamation have been a global concern during the past decades [2]. For instance, about 1.19×10^6 ha of new land had been created between the 1950s and 1980s on the Chinese mainland, and the area had exceeded 2.60×10^6 ha between the 1950s and 2000s [3,4]. The newly created lands, such as the reclaimed coastal area of the Yellow Sea in eastern China, were mainly used for agriculture [5,6]. Assessment of the reclaimed coastal wetlands has indicated that their soil process has some distinguishing features compared to other soils [2]. The soil and the nutrient status can be modified by human activities, and the distribution and supply of nutrients in soils under different land uses are the key factors to understand the global biogeochemical cycles. The carbon (C), nitrogen (N), and phosphorus (P) pools in soils can be altered by the input and export of nutrients (fertilization, crop harvest), the variation in land cover (plant communities), and the modification of soil structures (tillage methods, cultivation history) [7]. In coastal areas, the soil development is complex and related to the land-use, hydrology, climatic conditions, plant cover, and fertilization after reclamation [8]. The soil characteristics of newly created lands from reclaimed coasts are usually determined by the reclamation history, land-use, and development intensity [9]. At the landscape level, the main factors affecting soil properties in the reclaimed area are soil salinity, pH, and carbon concentration, which are greatly affected by soil age [4,10]. Many studies have indicated that long-term cultivation can regulate the soil organic carbon (SOC), N, and P; the contents of the nutrients, which tended to increase with the reclamation history [2]. Especially, the topsoil is one of the most essential components of our food systems, as it provides 95% of the food worldwide. And it is also the most sensitive component in the food system due to human activities [5,11].

In the biosphere, ecosystem processes and functions largely depend on C, N, and P cycling because these are the major macroelements required to sustain life [12,13]. There is a strong equilibrium among C, N, and P, which are essential factors in soil stoichiometry [14]. The relative concentrations of C, N, and P in the soils are often presented as the ratios of C:N, C:P, N:P, and C:N:P to indicate soil quality and to describe the quantitative characteristics. On a global scale, the average atomic C:N:P stoichiometry has been estimated at 287:17:1 for topsoil elements, but large variations in the ratios were found because of spatial heterogeneity, biome characteristics, and climatic conditions [11]. C:N:P stoichiometry is a powerful tool to indicate nutrient limitations, understand crucial ecological processes, and explore the relationships and feedback among different parts of ecosystems [15–17]. For example, the concentrations of C, N, and P were shown to be lowest in the desert, while the highest C content in soils was found in natural wetlands and tundra soils, the highest N content in natural wetlands, and the highest P content in tundra soils [11]. And soil C:N:P ratio varied greatly with plantations and management practices [18–20]. However, it remained unclear how human activities impact the stoichiometry of reclaimed coastal areas [11,21].

Forestation has been promoted in China as an essential and effective way to reduce greenhouse gas emissions and promote C fixation during the past decades [22]. The changes in plantations also significantly changed the coastal environment [23]. For ecological and political reasons, some newly created coastal lands that were used solely for agricultural purposes have subsequently been modified into agroforestry systems [6,23]. A better knowledge of the resulting soil properties and stoichiometric characteristics would lay solid foundations for policymaking and ecosystem management, while the stoichiometry of saline soils has rarely been studied. In this study, the variations of the soil properties and stoichiometry characteristics were analyzed from an agroforestry ecosystem in a reclaimed coastal area. The area was subjected to different land uses formed in the same period and shared the same reclamation history [6,23]. In the agroforestry ecosystem, five land-use types varying in cultivation history were selected at a reclaimed coast in the east of China with a soil age of about 100 years. This study aimed to address the following two questions: (1) How did the topsoil properties and stoichiometry characteristics change under the converted land uses? (2) What was the relationship between topsoil properties and stoichiometry characteristics?

2. Materials and Methods

2.1. Study Area

The study area (33.507–33.528° N, 120.456–120.477° E) was located on the reclaimed coast of Yancheng, Jiangsu Province, China (Figure 1). The area has a subtropical monsoon climate, and the mean annual temperature and precipitation are 13.7 °C and 1051 mm, respectively. According to IUSS Working Group WRB [24], the soil type is Gleyic Cambisol (Eutric, Siltic) [25]. A traditional cultivation history has been recorded for the area dating back to the 19th century [26]. In the first ten years after reclamation, the area was not used for croplands due to high soil salinity, so the lands were either abandoned or used as aquaculture ponds. Later, croplands became common with a rotation system of paddy rice and dryland fields (wheat and rapeseed), and some of the reclaimed lands were also used as coastal forests in the past decades [6,23].

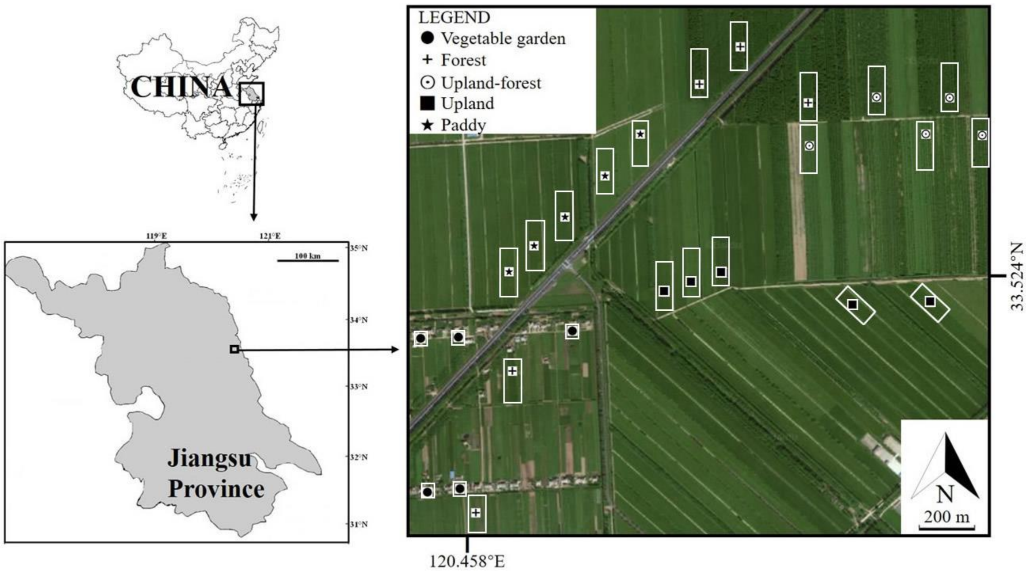

Figure 1. Sampling sites and land-use delimitation (white box) in the study area.

In this study, a reclaimed coast with a soil age of about 100 years was distinguished from lands created by intermittent reclamation with soil ages ranging from 35 to 500 years [6]. Soil ages were determined based on the reclamation time recorded in literature [27–29], which were also verified by local inhabitants, yet there may be an error in the cultivation history because of the war years (1938–1945), which was treated as a systemic error.

2.2. Land-Use Types and Soil Samples Collection

In the study area, five land-use types were identified in the agroforestry ecosystem, which comprised paddy, upland, forest, upland-forest, and vegetable garden, forming mosaic patches. Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.)/oilseed rape (*Brassica campestris* L.) was a primarily planted rotation in the reclaimed lands, referred to as paddy. Some land was planted under upland-based crop rotations, such as wheat maize (*Zea mays* L.), wheat cotton (*Gossypium hirsutum* L.), and maize-oilseed rape. And poplar (*Populus euramericana*) was used for forestation. Upland rotations with lower intensity of land-use were also used in the young poplar forest, including oilseed rape, maize, pumpkin (*Cucurbita moschata* Duch. ex Poir.), and white gourd (*Benincasa hispida* Cong.), and this land-use type named upland-forest. The vegetable garden was planted with pakchoi (*Brassica chinensis* L.), chilli (*Capsicum annuum* L.), cowpea (*Vigna unguiculata* L. Walp.), potato (*Solanum tuberosum* L.), napa cabbage (*Brassica rapa var. glabra* Regel), and tomato (*Lycopersicon esculentum* Mill.), etc. The fertilizers applied to the five different lands were listed in Table 1.

Table 1. The description of the land-use types in the selected study area.

Land-Use	Cultivation History	Dominant Cover Plants in the Past Five Years	Fertilizers
Vegetable garden	About 60 years for paddy, and 30 years for a vegetable garden (providing daily vegetables for local residents)	Pakchoi, chilli, cowpea, potato, napa cabbage, tomato, etc.	Organic fertilizers (Green, pig and chicken mature, traditional usage)
Forest	About 70 years for paddy, and then 20 years for forest	Poplar	None
Upland-forest	About 70 years for paddy, 15 years for upland, and 5 years for planting young trees in the upland	Oilseed rape, maize, pumpkin, white gourd, and young poplar	Chemical fertilizers (Totally about 150 kg ha^{-1} a^{-1}, $N:P_2O_5:K_2O$ = 1:0.25:0.25)
Upland	About 70 years for paddy, and then about 20 years for upland	Wheat, oilseed rape, maize, cotton	Chemical fertilizers (Totally about 300 kg ha^{-1} a^{-1}, $N:P_2O_5:K_2O$ = 1:0.25:0.25)
Paddy	About 90 years for paddy	Rice, wheat, oilseed rape	Chemical fertilizers (Totally about 450 kg ha^{-1} a^{-1}, $N:P_2O_5:K_2O$ = 1:0.2:0.2)

Five separated patches (as replicates) were selected for each land-use type as the sampling sites, and patch size varied with land shape, normally > 50 × 100 m^2 except vegetable garden with a size of about 10 × 10 m^2. The distances between the patches under the same land-use were at least 50 m apart. All the sampling sites were distributed within an area with a radius of 1.6 km; such compact distribution of the sampling sites was conducive to reducing spatial variability, and the soils formed from the same sediment resources with the same reclamation history.

The fieldwork was conducted in June 2018, when the paddy fields were in the ending stage of dry farming after the wheat harvest. At each sampling site, a sampling plot with a size of 5 m × 5 m was established, except in the vegetable garden (2 m × 2 m). In each plot, three surface soil cores (100 cm^3, depth 5 cm) were obtained with a soil loop cutter, which was then mixed and immediately packed in polyethylene plastic bags. The cores were taken to the laboratory for water content (WC) and bulk density (BD) determination. Additionally, three top soil cores with a depth of 10 cm were collected in each plot with a steel corer and mixed, used for determination of soil properties except BD and WC. Twenty-five samples of both surface soil and topsoil were collected from the five land-use types.

2.3. Determination of Soil Properties

The WC and BD of the surface soil samples were determined after oven-drying the samples at 105 °C for 24 h. The moist topsoil samples were homogenized by sieving them through an 8-mm sieve, and then the air-drying method was used to process the topsoil samples: the soils were dried at room temperature for three weeks and then sieved through a 2-mm sieve to remove coarse debris and stones. Each of the processed air-dried soil samples was ground with a pestle and mortar until all particles passed a 0.149-mm nylon sieve. Afterward, the prepared soil samples were used for the determination of total phosphorous (TP), total nitrogen (TN), SOC, pH, and soil salt concentration (SSC) [5,6]. The soil samples were digested with a mineral acid mixture (HNO_3, $HClO_4$, and HF in the ratio of 4:5:2) in Teflon tubes for total phosphorous (TP) analysis through inductively coupled plasma atomic emission spectrometry (ICP-AES, Optima 8000DV, Perkin-Elmer Inc., Waltham, MA, USA). After soil carbonates were removed with 1 mol L^{-1} HCl, SOC and TN were determined with a Carbon Nitrogen Elemental Analyzer (Vario Macro Cube, Elementar Analysensysteme GmbH Inc., Hanau, Germany). Soil pH was measured using a pH meter (soil:water = 1:5) (FE 28, Mettler-Toledo Inc., Shanghai, China), and then the soil solution was used for the determination of SSC according to the gravimetric method. The stoichiometric characteristics (atomic C:N, N:P, and C:P ratios) were determined according to SOC, TN, and TP contents.

2.4. Statistical Analysis

One-way analysis of variance (ANOVA) was performed to clarify the soil properties and stoichiometric characteristics among different land-use types. The Tukey test or Dunnett's T3 test was employed for multiple comparisons, based on whether or not Levene's test homogeneity of variances was successful [30].

Principal components analysis (PCA) on the measured soil properties and stoichiometric characteristics was conducted. Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy ($\geq$0.500) and Bartlett's test of sphericity ($\leq$0.050) was employed to detect the data suitability for PCA [31]. Based on the soil properties, a one-way analysis of similarities (ANOSIM) (with 9999 permutations) was performed to assess the statistical significance of the differences among soil samples with the Gower distance method [30]. Pearson's correlation analysis was conducted to evaluate relationships between the soil properties and stoichiometric characteristics.

In this study, no variable was transformed. Statistically significant differences were set at $p < 0.050$. SPSS 18.0 (SPSS Inc., Chicago, MI, USA) and PAST 3.2 were used for statistical processes [10,32].

3. Results

3.1. Variations of Soil Properties

All the measured topsoil properties varied significantly under different land-use types (Table 2). The WC was highest in vegetable garden, standing at 19.92%, and lowest in upland at 13.31% ($F_{4,20}$ = 17.811, $p < 0.001$). The highest value of pH occurred in upland-forest, and the lowest occurred in paddy and vegetable garden ($F_{4,20}$ = 23.769, $p < 0.001$). The highest SSC was found in forest and the lowest in vegetable garden ($F_{4,20}$ = 29.253, $p < 0.001$). The topsoil in the forest presented the highest BD of 1.38 g cm^{-3}, whereas the BD was approximately 1.15 g cm^{-3} in the vegetable garden ($F_{5,24}$ = 13.033, $p < 0.001$). Similar results were noted for SOC ($F_{4,20}$ = 143.638, $p < 0.001$), TN ($F_{4,20}$ = 45.940, $p < 0.001$), and TP ($F_{4,20}$ = 51.953, $p < 0.001$); and their highest values occurred in vegetable garden and the lowest in upland-forest.

Table 2. The determined topsoil properties (mean ± S.D.) under different land-use types (n = 5 for each land-use type, n = 25 for total, different letters mean significant difference occurred).

Soil Properties	Paddy	Upland	Upland-Forest	Forest	Vegetable Garden	Total
BD (g cm^{-3})	1.21 ± 0.05 a	1.31 ± 0.05 b	1.31 ± 0.06 b	1.38 ± 0.02 b	1.15 ± 0.05 a	1.27 ± 0.09
WC (%)	14.19 ± 1.31 a	13.31 ± 1.25 a	16.00 ± 1.16 ab	18.50 ± 1.47 bc	19.92 ± 2.06 c	16.38 ± 2.9
pH	8.22 ± 0.08 a	8.47 ± 0.05 bc	8.54 ± 0.06 c	8.38 ± 0.07 b	8.22 ± 0.07 a	8.37 ± 0.14
SSC (g kg^{-1})	0.37 ± 0.03 a	0.46 ± 0.04 b	0.50 ± 0.02 b	0.57 ± 0.04 c	0.35 ± 0.05 a	0.46 ± 0.10
SOC (g kg^{-1})	17.86 ± 0.06 c	12.84 ± 0.03 b	10.44 ± 0.05 a	12.24 ± 0.09 b	21.90 ± 0.15 d	15.05 ± 0.44
TN (g kg^{-1})	1.25 ± 0.04 c	0.80 ± 0.02 a	1.05 ± 0.10 b	1.05 ± 0.07 b	1.37 ± 0.09 c	1.11 ± 0.21
TP (g kg^{-1})	0.79 ± 0.04 b	0.73 ± 0.01 ab	0.71 ± 0.02 a	0.74 ± 0.03 ab	1.02 ± 0.07 c	0.80 ± 0.12

3.2. Variations of Soil Stoichiometric Characteristics

There were significant differences in soil C:N ($F_{4,20}$ = 79.318, $p < 0.001$), C:P ($F_{4,20}$ = 68.234, $p < 0.001$), and N:P ($F_{4,20}$ = 27.422, $p < 0.001$). The C:N, C:P and N:P averaged 15.86, 48.08, and 3.08, respectively. Soil C:N and C:P were lowest in upland-forest, standing at 11.76 and 38.23, while soil N:P was lowest in upland at 2.41. The upland and vegetable garden showed a higher C:N at 18.83 and 18.61, the paddy and vegetable garden showed a higher C:P at 58.51 and 55.39, and higher N:P occurred in paddy and upland at 3.52 and 3.30. And all the ratios in the forest were intermediate among the selected land-use types (Figure 2).

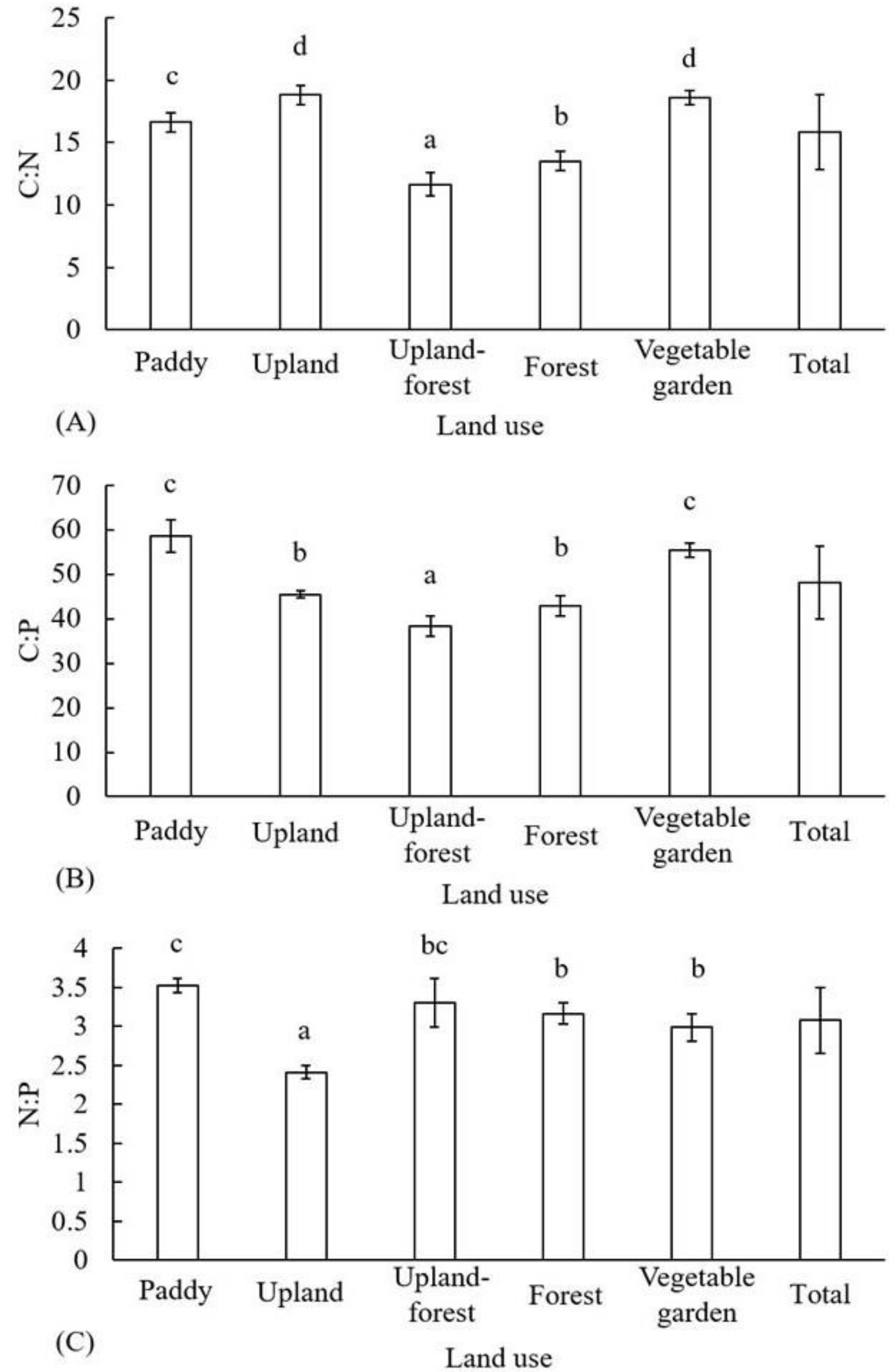

Figure 2. Topsoil stoichiometric characteristics (mean ± S.D.) of C:N (**A**), C:P (**B**), and N:P (**C**) under different land-use types (n = 5 for each land-use type, n = 25 for total, different letters mean significant difference occurred).

3.3. Ordination and Similarity

The overall KMO value of 0.697 (>0.500) demonstrated the sampling adequacy of the present study. The sphericity of Bartlett's test for PCA revealed that these approximately multivariate normal data were acceptable (χ^2 = 498.132, df = 45, $p < 0.001$). The PCA results indicated that the topsoil samples could be divided in terms of land-use, and 59.46% and 19.54% of the variance among habitats was explained by the eigenvectors of PC 1 and

PC 2 (Figure 3). TP, SOC, TN, C:P, WC, C:N, and N:P were positively correlated with PC 1, whereas SSS, pH, and BD were negatively correlated. N:P, WC, TN, SSC, BD, and TP were positively correlated with PC 2; however, C:N, pH, C:P, and SOC were negatively correlated. The PCA biplot illustrated that the vectors of SOC and TP had the smallest angles with Axis 1. Therefore, SOC and TP were strongly related to the soil differentiation with the land-use conversion.

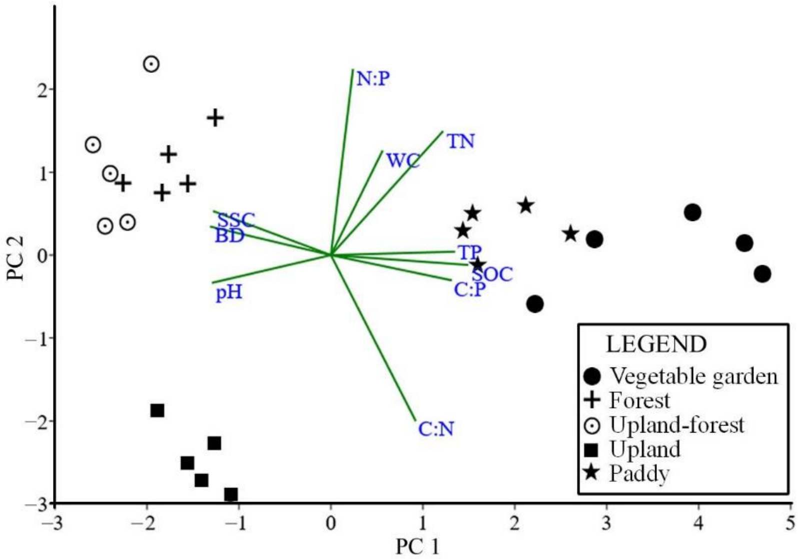

Figure 3. The PCA biplot on the determined topsoil properties.

Based on the soil properties, significant differences among topsoil samples under different land-use types were detected by one-way ANOSIM (R = 0.905, $p < 0.001$). In all of the comparisons, significant differences were found by the pairwise method ($p < 0.050$) (Table 3). The results indicated that there was significant differentiation after the land-use conversion.

Table 3. One-way ANOSIM analysis of topsoil properties based on Gower distance ($n = 5$ for each land-use type).

Land-Use	Paddy	Upland	Upland-Forest	Forest	Vegetable Garden
Paddy		$p = 0.008$	$p = 0.008$	$p = 0.007$	$p = 0.010$
Upland	R = 0.996		$p = 0.007$	$p = 0.008$	$p = 0.008$
Upland-forest	R = 1.000	R = 0.860		$p = 0.007$	$p = 0.009$
Forest	R = 1.000	R = 0.944	R = 0.712		$p = 0.009$
Vegetable garden	R = 0.700	R = 1.000	R = 1.000	R = 0.996	

3.4. Correlations between Soil Properties and Stoichiometric Characteristics

The relationship between soil properties and stoichiometric characteristics was explored by Pearson's correlation analysis based on the measured data of the topsoil under different land-use types (Figure 4). Significantly positive correlations existed among the contents of the nutrients (SOC, TN, and TP), and also among pH, SSC, and BD. However, these two classes of parameters had significantly negative correlations. Moreover, C:N and C:P showed positive correlations with nutrient contents (except for the relationship between C:N and TN), but negative correlations with pH, SCC, and BD. Furthermore, WC had significantly positive correlations with TN and TP, while N:P had significantly positive and negative correlations with TN and C:N, respectively, but no significant correlation with other parameters.

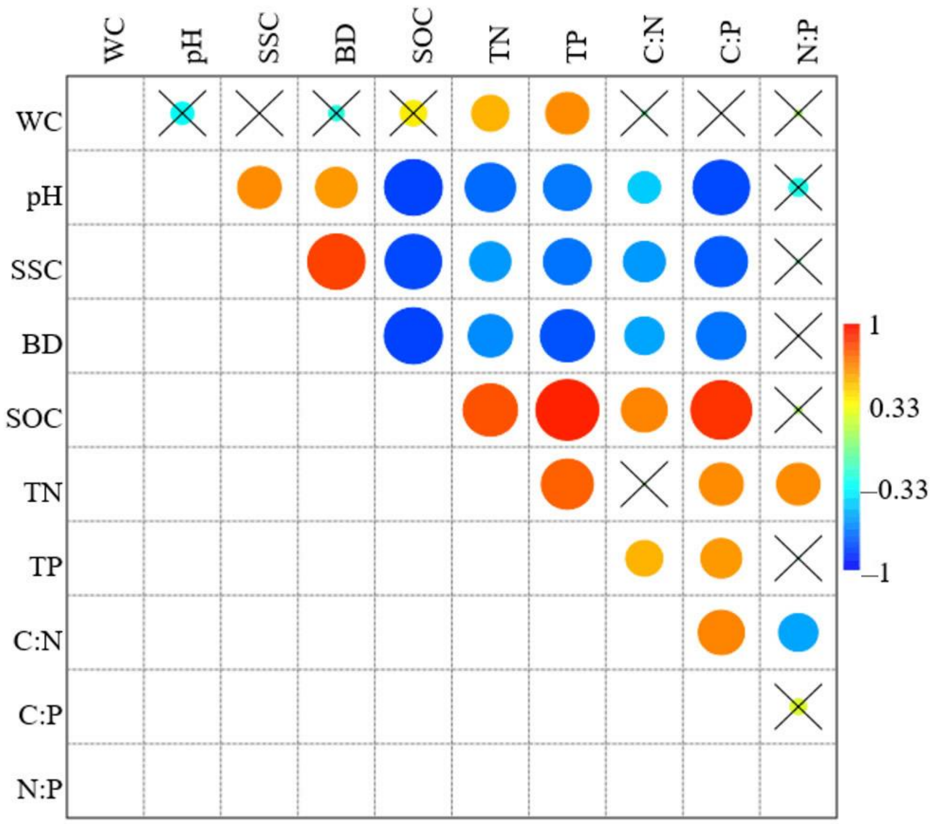

Figure 4. Pearson's correlations among the topsoil properties and stoichiometric characteristics. The size of the circle is proportional to the r value, and the coefficient of correlation was marked in the color gradient. The "×" mark indicates no significant Pearson correlation ($p \geq 0.050$).

4. Discussion

4.1. Differentiation of Soil Properties under Different Land-Use Types

In the reclaimed coastal area, most of the created lands were used for agricultural purposes before the end of the last century [2]. Up to now, the balance of coastal ecosystem and biodiversity has attracted much attention because of the salience of environmental problems faced by human society [6,33,34]. Land-use conversion offered an opportunity to run down the greenhouse gas emissions by adding more forests and grasslands to replace agricultural lands, which helped to reverse the trend of deforestation in the world [35]. In our study, the soils under different land-use types have been influenced by the same ecological conditions over long-term time scales because they were distributed in a relatively limited area [6,23]. Normally, salinity was the limiting factor for crop production because a high Na^+ concentration can inhibit plant growth and development, especially for the agricultural plant species [2,36]. Soil properties can be improved by reclamation, with SSC and pH decreasing and nutrient contents increasing on a long-term time scale, which has been demonstrated in Chongming Island, Shanghai [5], and the north coast of Jiangsu [6,8].

Consistently our study indicated that land-use and land cover conversion under different crop rotation systems also affected the soil properties [37]. SOC and TP were identified as the more important factors for distinguishing the soils under different land-use types (Figure 3); thus, these properties should receive more attention in future soil ecosystem research and management. Human activities may be responsible for the soil property variations, which were related to the plantations on the lands, including plowing, irrigation, and fertilization. The plantation was considered the main factor influencing WC as reported in the previous studies [38,39]. The increased proportions of macroaggregate and SOC are probably the main causes of the lowest BD value of 1.15 g cm^{-3} [2]. And the highest nutrient accumulation (SOC, TN, and TP) occurred in the topsoil of the vegetable garden

(Table 2); and the responses of nutrient elements to land-use conversion might also be due to variations of pH, SSC, and BD caused by the management and plantation as observed in previous studies [2,40]. Additionally, the soil properties in the forest presented intermediate values among land-use types except for SSC, while upland forest had the lowest values of SOC and TP, with similar TN levels to the forest. The highest TP (1.02‰) occurred in the vegetable garden, which may be due to the effect of management practice [2].

4.2. Comparison of Stoichiometric Characteristics

The reclaimed coastal saline soils were significantly modified by human activities, such as fertilization, cultivation, irrigation, and so on, which directly related to the soil properties and the stoichiometric characteristics [2,17]. It has been reported that all the soil elemental ratios of Chinese soils followed a normal distribution pattern, and most C:N, C:P and N:P ratios ranged from 6–12, 24–48, and 3–6, respectively [21]. The topsoils (0–10 cm in depth) in China had higher C:N and C:P ratios which averaged 14.4 and 9.3 because the topsoils were rich in organic matters [21]. The topsoils in the study area presented similar stoichiometric characteristics on average (C:N:P as 48:3:1) to Chinese croplands (C:N:P as 53:4:1). Compared with Chinese Entisol (C:N:P averaged 57:5:1) and global croplands (C:N:P averaged 64:5:1), the tops soils in the study area presented slightly lower relative C and N contents compared with P content [11,21]. The soil stoichiometric characteristics varied under different land-use types, which has been documented in the soils after the forests converted to agricultural lands [34].

In our study, significant positive correlations were found among C, N, and P contents, but correlations among C:N, C:P, and N:P ratios were much weaker (Figure 4). The C:N, C:P and N:P ratios of the topsoils were well-constrained with the relatively high correlation coefficients between C and N contents (r = 0.783, $p < 0.001$), between C and P contents (r = 0.906, $p < 0.001$), and between N and P contents (r = 0.748, $p < 0.001$). Consequently, a relatively constrained C:N:P ratio in the topsoil layer in the study area could be imaged as reported by Cleveland and Liptzin [41]. The significant differences in the ratios among different land-use types indicated that the stoichiometric characteristics responded to the land-use conversion in the past decades (Figure 1). Despite the variations of stoichiometric characteristics and N-limitation, relative narrow C:N, C:P, and N:P ratios were presented in the study area (Figure 2), which might be partly due to low C density and relatively abundant N and P inputs during the period of agricultural use in the past [11].

4.3. Application Suggestions

In the study area, SOC averaged 1.51%, higher than the average value of global cropland (1.39%) but lower than the average value of Chinese cropland (2.46%); TN averaged 1.11‰, lower than the average value of global cropland (1.32‰) and Chinese cropland (1.88‰); TP averaged 0.80‰ in the topsoils, higher than the average value of global cropland (0.46‰) and similar to that of Chinese cropland (0.78‰) [11,40]. The SOC and TN were relatively lower than the average Chinese cropland, which depended on the soil development conditions. The soil developed from the reclaimed coast in the study area, although SOC increased significantly because of fertilization, accumulation of organic residues, and field management after reclamation, the SOC was still not relatively abundant at the soil age of 100 years [2,6]. On the other hand, TP was relatively abundant compared with TN, suggesting that N was the limiting nutrient in the soil environment, as reported at the Yangtze River Estuary [42] and Minjiang River estuary [7]. The SOC content in the reclaimed soil decreased dramatically during and after reclamation for several years, but SOC and TN values continuously increased compared to soils reclaimed more than 16 years ago (and up to 500 years ago), and SOC displayed a higher increasing rate than TN, suggesting a route towards equilibrium in the stoichiometry [5]. A similar result has been reported in the soil after deforestation in Greece [35].

The land-use, cultivation history, and practice management should be comprehensively taken into account in ecosystem management. Although there were more fertilizer applications in the paddy, upland, and vegetable garden in the past decades, these land-use types did not diminish the C:N, which indicated that N is limited because more C fixation (crop yield and plant biomass) occurs in these lands that require more N supply [7,43]. Our study also indicated that the N-limited environment of cropland (including paddy and upland), as manifested by the C:N ratios in the study area higher than those of the global and national cropland. For improving crop yield and management practice, we recommend that crops should be planted in rotation with a legume, which normally helps to increase N_2 fixation, improve SOC and WC, promote belowground communities [29,44], and reduce greenhouse gas emissions [45]. Besides legumes, the use of organic fertilizers and appropriate fertilization strategies also deserve attention in the reclaimed coastal areas, which could improve soil fertility and reduce pH, consequently promoting the soil microorganisms with the SOC accumulation, which will help to balance the structure and function of the soil ecosystem [46].

5. Conclusions

Land-use conversion had a significant impact on the topsoil properties and stoichiometric characteristics in the reclaimed coastal area in eastern China. The plantation, cultivation history, and land-use type all impacted the topsoil properties and stoichiometric characteristics. Then, the management practices and environmental conditions of the agroforestry ecosystem determined soil properties. Among the five tested soil types in this study, the paddy and vegetable garden have the highest SOC and TN contents, probably resulting from a higher fertilizer application rate, application of organic fertilizers, and/or crop rotation practices. Significant positive correlations exist among the contents of different nutrients; and among BD, pH, and SSC as well. On the other hand, significant negative correlations exist between the two classes of the parameters. The results suggested that TP and SOC were the main properties distinguishing the topsoils under different land-use types. In the study area, topsoils had relatively narrow C:N, C:P, and N:P ratios, while the C:N:P ratio reached 48:3:1. And the results indicated that the forest had medium-level stoichiometric characteristics. Overall, the stoichiometric characteristics of the five soil types were similar to the averages of Chinese cropland soil but slightly different from those of global cropland and Chinese Entisol.

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Abbreviations

WC: water concentration; SSC: soil salt concentration; BD: bulk density; SOC: soil organic carbon; TN: total nitrogen; TP: total phosphorus.

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