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Article

Stocks and stoichiometry of soil organic carbon, total nitrogen, and total phosphorus after vegetation restoration in the Loess Hilly Region, China

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Abstract: The Loess Plateau is an important region for vegetation restoration in China, however, changes in soil organic carbon (SOC), soil nutrients, and stoichiometry after restoration in this vulnerable ecoregion are not well understood. Typical restoration types, including orchardland (OL), grassland (GL), shrubland (SL), and forestland (FL) were chosen to examine changes in the stocks and stoichiometry of SOC, soil total nitrogen (TN), and soil total phosphorus (TP) at different soil depths and recovery times. Results showed that SOC stocks first increased and then stabilized in OL, GL, and SL at 0–30 cm depth, while in FL, stocks gradually increased. Soil TN stocks first increased and then decreased in OL, SL, and FL with vegetation age at 0–30 cm depth, while soil TP stocks showed little variation between restoration types. In the later stages of restoration, the stocks of SOC and soil TN at 0–30 cm soil depth were still lower than those in natural grassland (NG) and natural forest (NF). The overall C:N, C:P, and N:P ratios increased with vegetation age. Additionally, the SOC, soil TN and soil TP stocks, and C:N, C:P, and N:P ratios decreased with soil depth. The FL had the highest rate of change in SOC and soil TN stocks, at 0-10 cm soil depth. These results indicate a complex response of SOC, soil TN, and soil TP stocks and stoichiometry to vegetation restoration, which could have important implications for understanding C, N, and P changes and nutrient limitations after vegetation restoration.

Keywords: soil stoichiometry; soil nutrient; nutrient limitations; natural grassland; natural forest

1. Introduction

Soil is an important component of terrestrial ecosystems and the main source of the nutrients required for plant growth and development. Soil organic carbon (SOC), soil total nitrogen (TN) and soil total phosphorus (TP) are the main structural and nutritional components of soil, and are also the main limiting factors in terrestrial ecosystems [1]. Soil organic C, soil TN, and soil TP stocks reflect the potential of the soil to provide nutrients to vegetation. These elements continuously circulate between the layers of the earth (the biogeochemical cycles of C, N, and P), which ensures a smooth flow of energy and maintains the stability of ecosystems [2]. The availability of soil TN and soil TP are major factors regulating the carbon balance of the ecosystem. Elemental stoichiometry is an important indicator reflecting the C, N, and P cycles in soil and the accumulation and balance of nutrients in ecosystems, which can help to determine the responses of ecological processes to global changes [3].

Vegetation restoration has received intensive interest because of its potential influence on global C and N cycling, soil quality improvement, land management, and regional economic development [4]. Land-use change in the form of vegetation restoration plays an important role in

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improving the ecological environment and function of ecosystems, and can also improve soil quality and soil nutrient cycling. Improved soil quality will, in turn, affect plant production and ecosystem function.

A large number of related studies have shown that stocks and stoichiometry of SOC, soil TN, and soil TP are closely related to land-use type [5, 6], and nutrient inputs and outputs are considered to be the main factors affecting soil nutrient content [7-9]. Some studies have found that vegetation restoration can promote photosynthesis, soil nutrient accumulation, and microbial activity [10-12], and increase the stoichiometry of SOC, soil TN, and soil TP [9]. However, other studies have indicated that land-use change can lead to decreases in soil nutrient contents [13]. Studies estimating the impact of land use on stocks and stoichiometry of SOC, TN, and TP, have mainly focused on the topsoil (0-20 cm), as this is considered to be the most active soil layer in terms of natural and man-made disturbances [14]. Recent studies have shown that the nutrient content of deep soils may also vary greatly with land use [14, 15]. Therefore, understanding how C, N, and P stocks and stoichiometry change in soil with land-use changes, can clarify soil nutrient availability, and nutrient cycling and balance mechanisms, and is of great significance for regional ecosystem health assessments.

The Loess Plateau, China, is located in a semi-arid/semi-humid climate zone, which has undergone serious soil erosion. It is an ecologically fragile area and a key area for soil and water conservation efforts in China. Before the 1950s, extreme weather such as droughts, heavy rain, hailstorms, strong winds, and dust storms occurred frequently in this area, resulting in serious soil erosion. In addition, as a result of long-term and unsustainable land use, vegetation has been destroyed over large areas due to grazing and farming. The large-scale cultivation of sloping cropland further aggravated the soil erosion. The amount of nitrogen, phosphorus, and potassium lost from slope farmland has been estimated at 12.7 million tons per year [16]. Vegetation restoration was implemented in the 1970s in this region. In order to control soil erosion and improve ecosystem function, ecological restoration and environmental reconstruction work has been carried out in which slope cropland (slope > 25°) is converted into orchardland (OL), grassland (GL), shrubland (SL) and forestland (FL). After decades of continuous efforts, vegetation coverage has increased and the ecological environment has been greatly improved [17]. The sequestration and stoichiometry of SOC, soil TN, and soil TP varies among different vegetation types and vegetation ages, and therefore its effect on soil physicochemical properties varies as well. It is important, therefore, to clarify annual and vertical variations in the SOC, soil TN and soil TP stocks and stoichiometry in soils with different vegetation types in the Loess Hilly Region, China.

In order to better understand the SOC processes, carbon budget of the soil, and soil fertility issues after afforestation, we addressed the following questions: (1) How have stocks of SOC, soil TN, and soil TP, and their ratios, changed across the Loess Hilly Region, China, after decades of vegetation restoration? (2) Are these changes associated with soil depth? (3) How do these changes vary with restoration type? We further hypothesized that (1) as litter inputs to the soil increase with vegetation age, stocks of SOC and soil TN increase, whereas soil TP stocks do not significantly change since P stocks are primarily affected by parent minerals. The change rate will be greatest for SOC, followed by soil TN, and then soil TP, causing an increase in the C:N, C:P, and N:P ratios with vegetation age; (2) vegetation restoration affects stocks of SOC, soil TN, and soil TP at the soil surface more than at greater soil depths; (3) due to differences in the litter produced by different vegetation, root secretions and soil microorganisms will also vary between restoration types, resulting in differences in stocks and ratios of SOC, soil TN, and soil TP.

2. Materials and Methods

2.1. Study area

The study area was located in Ansai County, Shanxi Province, China in the center of the Loess Plateau (Figure 1). This region has a warm temperate and semi-arid climate with an annual average temperature of 8.8°C. Annual precipitation is approximately 500 mm, 60% of which falls between

July and September, and the frost-free period is 157 d. The soil is mainly composed of Huangmian soil, developed on wind-deposited loessial parent material. This type of soil is characterized by weak cohesion, which has made it prone to severe soil erosion. The sand (2.00–0.05 mm grain size), silt (0.05–0.02 mm) and clay (<0.02 mm) contents are 65%, 24%, and 11%, respectively. The soil bulk density (BD) and soil pH of the tillage layer ranged from 1.15 to 1.35 g cm-3 and 8.4 to 8.6, respectively.

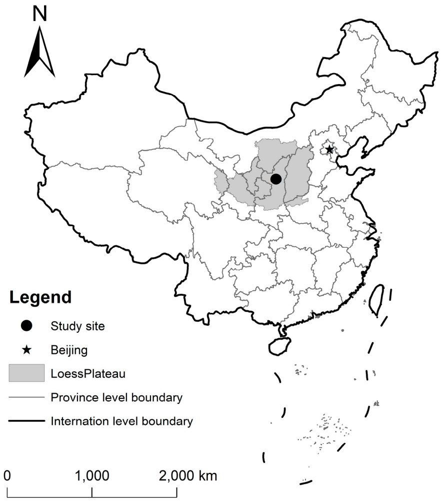

Figure 1. The locations of study sites in Ansai County, Shanxi Province, China

2.2. Soil sampling and laboratory analyses

This study adopted a “space for time” approach. A total of 82 sites representing four restoration types were selected based on vegetation type, topographic features, and vegetation age, including nine sites of OL (5, 10, and 20 years), thirty-four sites of GL (2, 5, 8, 11, 15, 18, 26, and 30 years), twenty-four SL (5, 10, 20, 30, 36, and 47 years), and fifteen FL (5, 10, 20, 37, and 56 years). In addition, we selected three slope cropland (CL) sites, which were studied at 0 years. Because the four restoration areas were transformed from croplands, four natural grassland (NG) sites (age > 50 years) and nine natural forest (NF) sites (age > 100 years) were selected as controls (Table S1). Three 10 × 10 m plots were chosen in each OL, three 2 × 2 m plots in each grassland (GL and NG), three 10 × 10 m plots in each SL, and three 20 × 20 m plots in each forestland type (FL and NF). Each plot was at least 50 m from the other plots. A total of 15 soil samples were collected from five soil depths (0–10, 10–20, 20–30, 30–50, and 50–100 cm) in a random sampling design using a soil drilling sampler (4 cm inner diameter). Soil samples from each plot from the same soil depth were mixed to form one sample. These soil samples were brought back to the laboratory and then divided into two parts. One part of the sample was naturally air-dried, plant roots and other impurities were removed, and then the SOC, soil TN, and soil TP were measured. The other part was stored in a refrigerator at 4°C until further analysis of other indicators, which are not presented in this paper.

The soil bulk density (BD) of each depth was measured using the cutting ring method. The SOC was determined using the H_2SO_4–$K_2Cr_2O_7$ method [18]. Soil TN was measured using the Kjeldahl method [19], and soil TP was determined colorimetrically using the ammonium molybdate method [20].

2.3. Calculation of SOC, soil TN and soil TP stocks

The SOC, soil TN and soil TP stocks (Mg ha^{-1}) were calculated as follows:

$$\text{SOC stock} = \text{SOC} \times \text{BD} \times \text{D}/10 \tag{1}$$

$$\text{Soil TN stock} = \text{soil TN} \times \text{BD} \times \text{D}/10 \tag{2}$$

$$\text{Soil TP stock} = \text{soil TP} \times \text{BD} \times \text{D}/10 \tag{3}$$

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SOC is soil organic carbon content (g kg^{-1}), soil TN is soil total N content (g kg^{-1}), soil TP is soil total P content (g kg^{-1}), BD is soil bulk density (g cm^{-3}), and D is the soil depth (cm).

2.4. Calculation of soil OC, soil TN and soil TP stocks

Two-way ANOVAs were used to determine the effects of vegetation age, soil depth, and their interaction on SOC, soil TN, and soil TP stocks and C:N, C:P, and N:P ratios. An independent samples T-test was used to compare the SOC, soil TN, and soil TP stocks, and C:N, C:P, and N:P ratios from sites GL30, NG, SL47, FL56, and NF ($p<0.05$). Before ANOVA analyses, we performed tests for normality and homogeneity of variance. In order to compare the effects of vegetation type, we selected SOC, soil TN, and soil TP contents and stoichiometry for the same or similar years from the four restoration types: OL (5 years, 10 years, 20 years), GL (5 years, 11 years as 10 years, 18 as 20 years), SL (5 years, 10 years), and FL (5 years, 10 years). In addition, we selected the SOC, soil TN, and soil TP contents from different soil depths as the rate of change with recovery years and compared SOC, soil TN, and soil TP sequestration rates between different restoration types. All statistical analyses were conducted using SPSS 21.0 (SPSS Inc., Chicago, IL, USA). Figures were drawn using Origin 9.0.

3. Results

3.1. SOC, soil TN and soil TP stocks in different restoration types

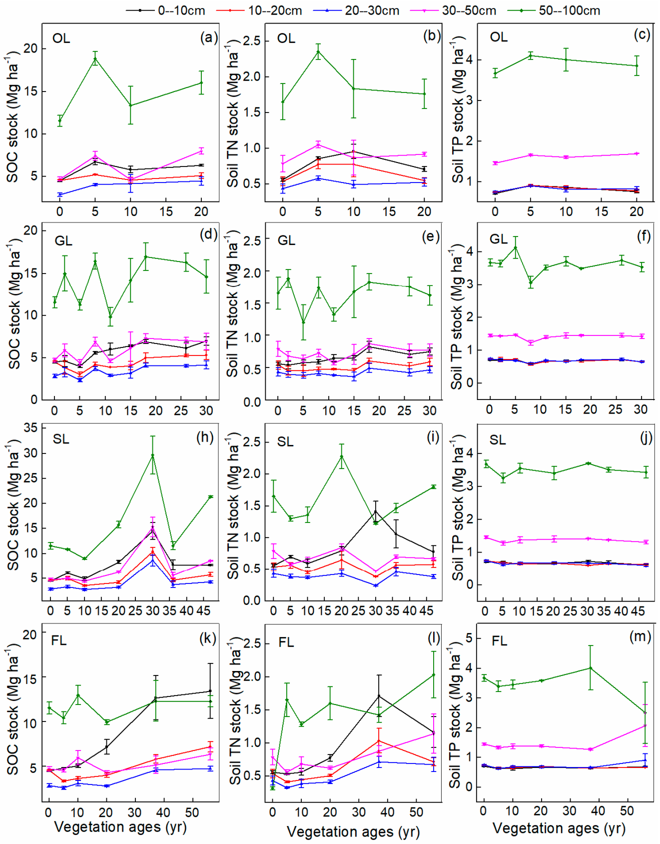

Figure 2 Changes in stocks of soil organic carbon (SOC), soil total nitrogen (TN), and soil total phosphorus (TP) with vegetation age. Note: Values are mean ± standard error. OL, orchardland, GL, grassland. SL, shrubland. FL, and forestland.

Vegetation age had a significant effect on SOC and soil TN stocks ($p<0.01$) (Table S2). In OL, the SOC stocks of the soil at 0-30 cm depth first increased and then stabilized after 5 years; the soil TN

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stock at the same depth first increased and then decreased with vegetation age. The soil TP stocks at 0-100 cm depth showed no significant change with vegetation age (Figure 2a, b and c). In GL, the SOC and soil TN stocks at 0-30 cm depth first increased and then stabilized after 18 years, and the soil TP stocks at 0-100 cm depth showed no significant change with different vegetation ages (Figure 2d, e and f). In SL, the SOC stocks at 0-50 cm depth and soil TN at 0-10 cm increased at first, peaked after 5 years, and then stabilized after 30 years; the soil TP stocks at 0-100 cm depth showed no significant change (Figure 2h, i and j). In FL, the SOC at 0-50 cm gradually increased, and the soil TN stocks increased before peaking after 37 years, and then decreased with vegetation age; the soil TP stock at 0-100 cm depth showed no significant change (Figure 2k, l and m). In addition, SOC and soil TN stocks from the 0-30 cm soil layer of GL30 were significantly lower than those in NG (Figure 3a and b). SOC and soil TN stocks at 0-30 cm soil depth in SL47, and SOC stocks at 0-100 cm depth and soil TN stocks at 0-20 cm depth in FL56 were significantly lower than those in NF (Figure 3d and e). The soil TP stocks at all soil depths showed no significant differences between GL30 and NG, SL47 and NF, or FL56 and NF (Figure 3c and f).

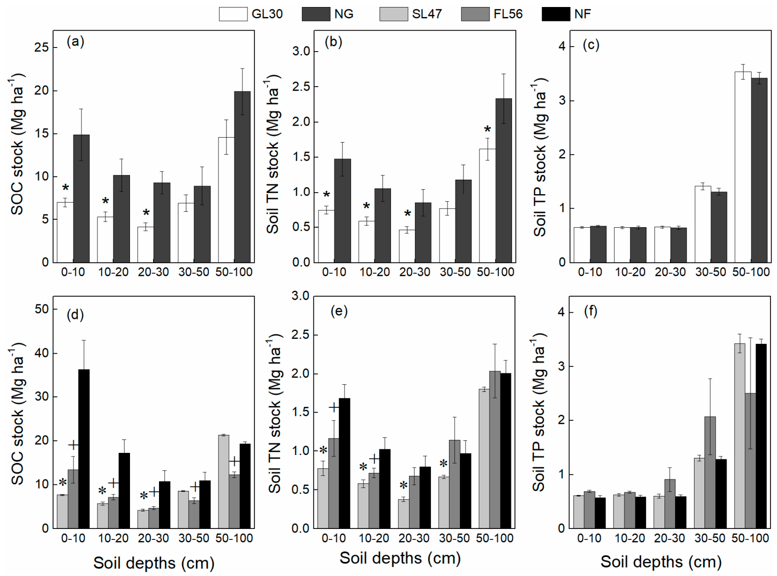

Figure 3 Stocks of soil organic carbon (SOC), soil total nitrogen (TN), and soil total phosphorus (TP) at different soil depths in grassland at 30 years (GL20) compared to that of natural grassland (NG), and shrubland at 47 years (SL47); and forestland at 56 years (FL56) compared to that of natural forestland (NF). Note: Values are mean ± standard error.

3.2. Changes in SOC, soil TN and soil TP stoichiometry

In OL, the C:N ratio at 0-100 cm depth showed no obvious changes with vegetation age, but there was an overall increasing trend (Figure 4a, Table S3). The C:P ratio at 0-30 cm increased, while the N:P ratio at 0-20 cm first increased and then decreased after 10 years of restoration (Figure 4b and c). In GL, the C:N ratio at 0-100 cm showed an overall increasing trend with vegetation age (Figure 4d, Appendix Table 3); the C:P and N:P ratios in soils of 0-30 cm depth gradually increased with vegetation age (Figure 4e and f). In SL, the C:N ratio at 0-100 cm showed little variation with vegetation age, but the overall trend was an increase (Figure 4h, Table S3); the C:P and N:P ratios at 0-10 cm depth first increased, then peaked at 30 years before decreasing again with vegetation age (Figure 4i and j). In FL, the C:N ratio at 0-100 cm depth showed little change with vegetation age, but the overall trend was an increase (Figure 4k, Table S3). The C:P ratio in soils of 0-100 cm depth gradually increased with vegetation age (Figure 4l) and the N:P ratio at 0-50 cm first increased then peaked at 37 years, before decreasing again with vegetation age (Figure 4m).

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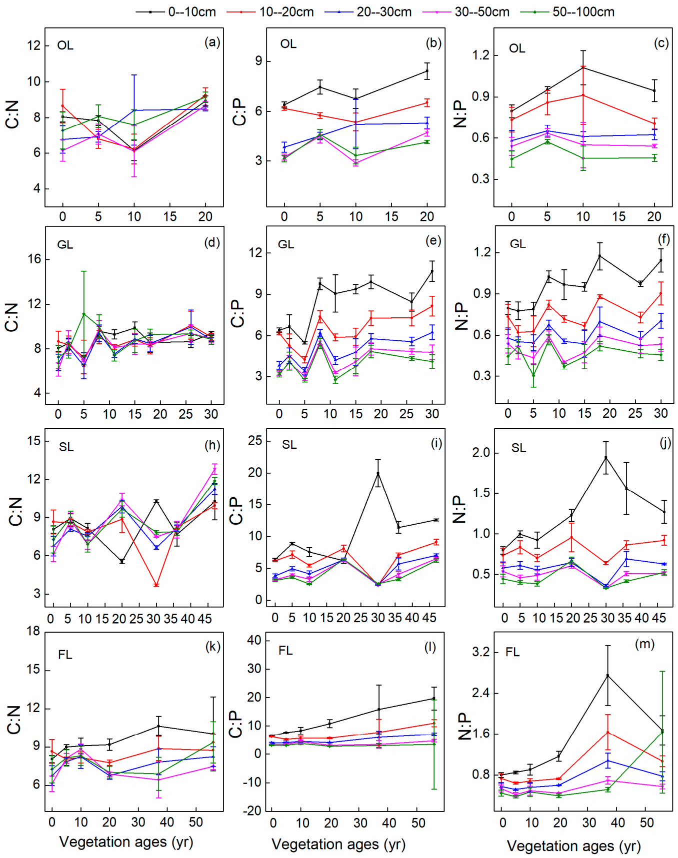

Figure 4 Stoichiometric characteristics of soil organic carbon (SOC), soil total nitrogen (TN), and soil total phosphorus (TP) with vegetation age. Note: Values are mean ± standard error. OL, orchardland, GL, grassland. SL, shrubland. FL, and forestland.

The C:P and N:P ratios at 0-30 cm in GL30 were significantly lower than those in NG (Figure 5b and c) and the C:P and N:P ratios at 0-30 cm depth in SL47 and FL56 were significantly lower than those in NF (Figure 5e and f). In addition, the C:N ratio decreased with soil depth in FL (Figure 4k). Overall the C:P and N:P ratios gradually decreased with soil depth in the three types (Figure 4b, c, e, f, I, j, l and m).

4. Discussion

4.1 Vegetation ages altered SOC, soil TN, and soil TP the stocks and stoichiometry

Our results showed that the SOC stocks at 0-30 cm soil depth in OL, GL, and SL first increased and then stabilized with vegetation age, while the SOC stocks at 0-50 cm in FL gradually increased with vegetation age. SOC is mainly derived from surface litter, root secretions, and animal residues [21, 22]. After vegetation restoration, a large input of litter and organic matter can enhance the accumulation of SOC [23] and with an improvement in soil structure, surface runoff, soil erosion, and soil nutrient loss may be reduced [24]. In addition, soil microbial activity is strengthened as vegetation age increases [25], and soil nutrient conversion and storage are further enhanced. But vegetation restoration involves the coordinated development of the plant community and soil environment, and the plant community structure, soil structure, and microbial diversity reach a stable level as vegetation age increases [26-28]. However, in FL, SOC stocks had not reached a steady level at 57 years and understanding when these stocks may stabilize needs to be evaluated. In our study, the soil TN stocks at 0-30 cm depth decreased in the later stages of OL, SL, and FL restoration. Plants may enter a senescence phase and the soil nitrogen nutrients absorbed during the plant growth process are then fed back to the soil by litter, so that the nitrogen absorption rate is lower

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than the release rate, resulting in soil TN stock decreasing [29]. We also found that soil TP stocks did not significantly change with vegetation age, in contrast to some previous studies [30]. Soil TP is mainly influenced by parent material, land use, and biogeochemical processes in the soil [31, 32]. As the parent material and climate were similar for all vegetation types, the variability and migration rate of TP were not as obvious as those of SOC and soil TN, and vegetation age had little effect on soil TP. Within the range of vegetation ages that we studied, the SOC and soil TN stocks in GL, SL, and FL at 0-30 cm soil depth failed to reach the stock levels found in NG or NF. Severe soil erosion and lack of water are typical characteristics of the Loess Plateau, which may lead to the loss of soil nutrients [24, 33]. Additionally, soil tillage can also cause soil nutrient loss by negatively affecting soil physical structure and microbial activity [34].

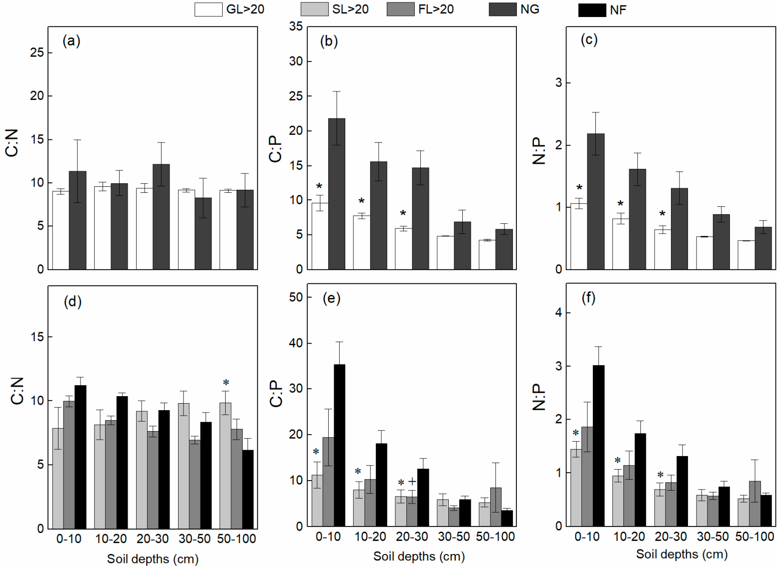

Figure 5 Stoichiometry of soil organic carbon (SOC), soil total nitrogen (TN), and soil total phosphorus (TP) at different soil depths in grassland at 30 years (GL30) compared to that of natural grassland (NG), and shrubland at 47 years (SL47), and forestland at 56 years (FL56) compared to that of natural forestland (NF). Note: Values are mean ± standard error.

Restoration age had a positive effect on the C:N ratio after vegetation restoration. The main factors affecting the C:N ratio are changes in the SOC and soil TN contents [35]. Both SOC and soil TN contents increased overall with vegetation age (Table S3), and the rate of increase of SOC was greater than that of soil TN; consequently the C:N ratio increased (Table S3). A previous study showed that the C:N ratio was negatively correlated with the rate of decomposition of organic matter [36], s so the decomposition rate of organic matter increases with vegetation age. The C:P ratio indicates the availability of soil TP in the soil [37], We found that the rate of increase of SOC was also greater than that of soil TP, resulting in an increase in the C:P ratio with vegetation age (Table S3). In addition, the rate of increase of soil TN was greater than that of soil TP, resulting in an increase in the N:P ratio with vegetation age (Table S3). The N:P ratio was reduced in the later stages of restoration, which may be related to the lower soil TN content (Figure S1). Soil N and soil TP are essential mineral nutrients for plant growth and common limiting elements in ecosystems, and the N:P ratio is a predictor of nutrient limitation [38]. In the GL, SL, and FL types, the N:P ratio at 0-30 cm soil depth in the later stages of recovery was lower than that of NG and NF, which may result from the more alkaline soil and lower soil TN content in the Loess Plateau Region; the soil TP content did not differ significantly between the restoration and control sites. In the GL, SL, and FL restoration types, the C:P ratio in the 0-30 cm soil layer was lower than that of NG and NF at the later stages of recovery, which may be related to the lower SOC content in restoration soils than in natural soils.

4.2. Vertical distribution of stocks and stoichiometry of SOC, soil TN and soil TP

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Soil depth is an important factor influencing SOC, soil TN, and soil TP distribution [39], Many studies have shown that increasing soil depth had negative effects on SOC, soil TN, and soil TP content [15, 40, 41]. In our study, the SOC and soil TN stocks decreased with soil depth at all vegetation ages in OL, GL, SL, and FL (Figure 6a, b, d, e, h, I, k and l), which is consistent with previous studies [42, 43]. Our study also revealed that the overall rate of SOC and soil TN content change decreased with soil depth in OL, GL, SL and FL (Table S3), which indicated that the SOC and soil TN sequestration rates gradually decreased with soil depth. Meanwhile, SOC, soil TN, and soil TP were most sensitive to change in the surface soil (0–30 cm). The SOC and soil TN content at 0-30 cm represented more than 65% of the total SOC and soil TN stocks from 0-100 cm depth for all restoration types; the soil TP content at 0-30 cm represented more than 60% of the total soil TP stocks from 0-100 cm (Figure S1). Such differences in SOC, soil TN, and soil TP profiles can be explained partly by root distribution. The surface soil is affected by external environmental factors, soil microorganisms, and the return of nutrients from surface litter, resulting in a concentration of nutrients in the surface soil [44], With increasing soil depth, the input of organic matter is limited by the permeability of the soil, microbial decomposition activity, and root absorption [21, 39]. Moreover, SOC and soil TN stocks are not only affected by soil parent material, but also by the decomposition of litter, and absorption and utilization by plants [42], resulting in large spatial variability. While the soil TP content of OL and FL decreased, it showed little variation with soil depth in GL and SL (Figure 6 c, f, j, and m). Soil TP is mainly affected by the soil parent material, which is a sedimentary mineral with low mobility in soil and, therefore, there was little vertical variation in soil TP [42].

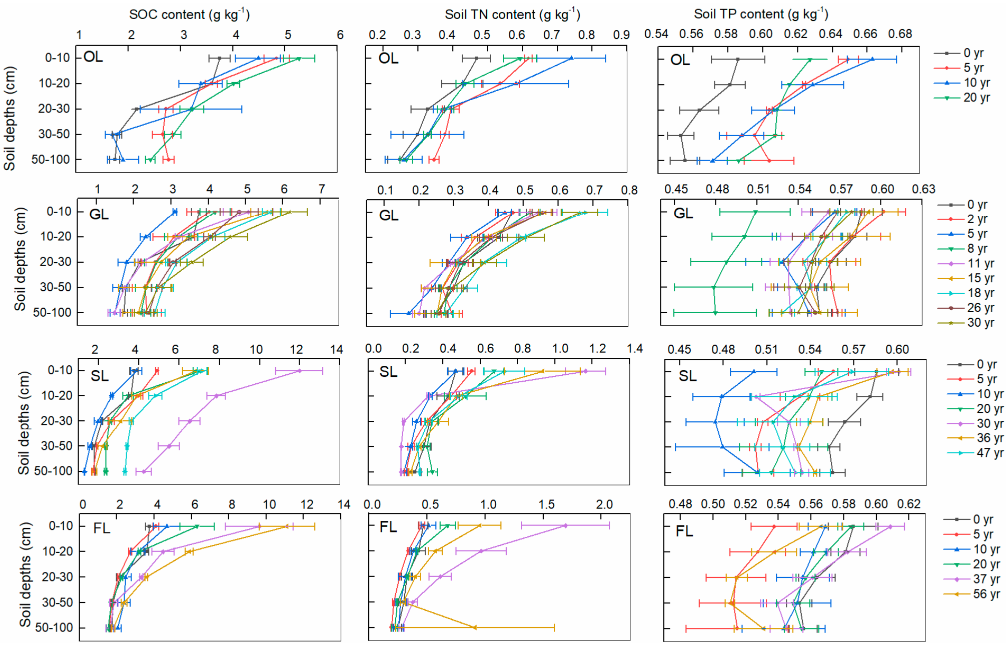

Figure 6 Vertical distributions of soil organic carbon (SOC), soil total nitrogen (TN), and soil total phosphorus (TP) contents for different vegetation types. Note: Values are mean ± standard error. OL, orchardland, GL, grassland. SL, shrubland. FL, and forestland.

Our study found that the overall C:N ratio gradually decreased with soil depth. It may be that the surface SOC and soil TN content were higher, but as the soil depth increased, the SOC content change was larger than that of the soil TN content. When the decomposition process occurs, easily decomposed material vanishes and soil TN is immobilized in decayed products, leaving behind more durable material with slower decomposition rates in the deeper layers [46], resulting in a relatively lower C:N ratio in the deep soil layers. There was a significant difference in the C:P and N:P ratios at different soil depths. It may be that the soil TP content is relatively stable at different

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soil depths, and the C:P ratio and N:P ratio are mainly affected by SOC and soil TN content, so they showed greater variation.

4.3. Effect of restorarion type on SOC, soil TN and soil TP stocks and stoichiometry

Our study demonstrated that the SOC and soil TN stocks in the 0-20 cm soil layer at 5 years were highest in OL, which may be related to the use of fertilizer. In other years, SOC, soil TN, and soil TP stocks showed no difference between OL, GL, SL, and FL (Figure S2). However, the rate of SOC and soil TN change at 0-10 cm soil depth was the highest in FL, while the rates of SOC and soil TN change at other depths varied among different restoration types (Table S3). The rapid increase in surface SOC and soil TN are closely related to the input of litter [47, 48], Guo et al.[48] showed that forest litter was 19 times higher than that of shrubs in the Loess Plateau Region. This also explains why the increase in SOC and soil TN in the topsoil of forests was higher than that of shrubs. As soil depth increases, root secretions and soil microorganisms are the main sources of soil nutrition [21, 22]. There are significant differences in the effects of different plant roots and litters on the community composition of microorganisms [49], which may explain the large differences in the rates of SOC and soil TN change between different restoration types.

The C:N ratios of OL5 and GL5 at 0-20 cm soil depth were lower than those of SL5 and FL5, and the C:N ratio of OL10 was significantly lower than that of GL10, SL10, and FL10 (Figure S2). The C:N ratio of OL was lower than that of GL, SL, and FL, which may be related to anthropogenic N deposition in OL (Figure S2). The lower C:N ratio in GL5 may occur because GL retains more organic matter content and greater nutrient absorption takes place through plant roots [41]. There were no significant differences in the C:N ratio at other soil depths of OL, GL, SL, and FL as there were no significant differences in the stocks of SOC and soil TN (Figure S2). This finding is related to the nutrient conditions of the soil in the study area and the feedbacks between plant and soil, so the soil stoichiometric changes in different restoration types showed the same characteristics in the same environmental context. In addition, the overall C:P and N:P ratios of OL5 and SL5 at 0-20 cm soil depth were higher than those of GL5 and FL5, which is related to the relatively higher SOC and soil TN content in OL5 and SL5 (Figure S2). However, there were no significant differences in the C:P and N:P ratios at 30-100 cm soil depth between the four restoration types because there were no significant differences in the SOC, soil TN, and soil TP stocks of OL, GL, SL, and FL (Figure S2).

5. Conclusions

We examined the changes in SOC, soil TN, and soil TP stocks and stoichiometry at depths of 0–100 cm following vegetation restoration in the Loess Hilly Region. Our results revealed that the SOC stocks appeared to increase and reach stable levels; the soil TN stocks first increased and then decreased with vegetation age but it is difficult for them to reach the levels seen in NG or NF in the Loess Hilly Region without appropriate management. At the same time, vegetation age had positive effects on C:N, C:P, and N:P ratios, while soil depth had negative effects on SOC, soil TN, and soil TP stocks, and C:N, C:P, and N:P ratios. Additionally, FL had the highest sequestration rate of SOC and N at 0-10 cm soil depth. The results of this study provide data for the assessment of the long-term SOC, soil TN, and soil TP stocks and stoichiometry after vegetation restoration under different restoration types in the Loess Hilly Region.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Figure S1: Changes in soil organic carbon (SOC), soil total nitrogen (TN), and soil total phosphorus (TP) content with vegetation age, Figure S2: Changes in content and stoichiometry of soil organic carbon (SOC), soil total nitrogen (TN), and soil total phosphorus (TP) for different vegetation types at 5, 10, and 20 years. Table S1: The details of the sample sites selected for the study, Table S2: F and p-values for independent factors [soil depth, vegetation age] and their interactions. Table S3: The slope parameters of the linear regression models for soil organic carbon (SOC), soil total nitrogen (TN), and soil total phosphorus (TP) contents, and C:N, C:P, and N:P ratios with recovery year at different soil depths under four restoration types.

Author Contributions: The research design was completed by Hongwei Xu and Sha Xue. The manuscript was written by Hongwei Xu and Qing Qu. The collection and analysis of soil samples were developed by Hongwei Xu, Peng Li, Qing Qu, Ziqi Guo and Entemake Wulan.

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Conflicts of Interest: All the authors declare no conflicts of interest.

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