Effects of Grassland Conversion in the Chinese Chernozem Region on Soil Carbon, Nitrogen, and Phosphorus

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Abstract: Converting natural vegetation to other types of land utilization is presently the most common land use change around the world. Conversion of grassland plays an important role in estimating the regional nutrients budget and assessing ecological effects. However, few studies have estimated the impacts of grassland conversion on soil nutrients under different soil pedogenic horizons. This study selected three sites, which were covered by grassland, shelterbelt, and cropland. The study evaluated the effects of grassland conversion and soil pedogenic horizon (to a depth of 100 cm) on the soil organic carbon (SOC), soil total nitrogen (STN), and soil total phosphorus (STP) concentrations and stocks in the Chinese Chernozem region. The results revealed that significant \( p < 0.05 \) differences were seen after grassland conversion for concentrations and stocks of SOC, STN, and STP. The transformation from grassland to shelterbelt and cropland plantations caused soil carbon and soil nitrogen losses but caused soil phosphorus accumulations. Moreover, conversion of grassland made SOC, STN, and STP all drop below the B \( \text{K} \)-horizon. Changes in the SOC and STP on an area basis were the greatest after conversion of grassland to cropland, for concentrations of \(-16\%\) and \(+26\%\) and for stocks of \(-15\%\) and \(+32\%\), respectively. Land use change and soil pedogenic horizon primarily influenced the distribution patterns of nutrients concentrations and stocks. However, grassland conversion effects on nutrients were mainly at surface horizons. Soil properties, such as calcium carbonate (\( \text{CaCO}_3 \)) and soil texture, affected the nutrients from the B \( \text{K} \)-horizon to the C-horizon. This study indicates that land use management policies should protect natural grasslands to minimize losses of SOC, STN, and STP.

Keywords: soil nutrient; grassland conversion; land use change; soil pedogenic horizon; calcium carbonate

1. Introduction

Grasslands, which occupy approximately 20% of the terrestrial land surface and store 34% of the total terrestrial carbon, have stored about 89% of the sequestration carbon in the soil [1,2]. The conversion of grassland to other land uses is vital from the perspective of soil fertility and sustainable management and for their effects on atmospheric CO\(_2\) concentration and global warming. Such conversion has many negative influences on soil organic carbon (SOC), soil total nitrogen (STN), and soil total phosphorus (STP) circulation by altering soil C, N, and P accumulation and turnover [3–6]. Nonetheless, the change patterns of SOC, STN, and STP are not fully understood, and knowledge of the driving factors remains unclear.

The effects of grassland conversion on SOC, STN, and STP have received more and more attention all over the world because the massive emission of the oxides of C and N has worsened the earth’s climate. Conversion from grassland to shelterbelt and cropland resulted in great soil SOC and STN loss [7,8]. However, there is a lack of comprehensive understanding of the changes of SOC, STN, and STP after conversion of grassland to other land use types. Knowing the distribution of SOC, STN, and STP concentrations and stocks...
in the context of land use change is essential for evaluating soil quality, effects of land use change, and sustainable land uses.

The negative effects of grassland conversion on SOC, STN, and STP have also been confirmed by many studies [9]. However, research work has mainly concentrated on the variations in SOC, STN, and STP concentrations and stocks on the whole or in the upper 30 cm of soil horizon [7,10–13]. Moreover, the change patterns of SOC, STN, and STP vary with soil horizons for uneven distribution of root systems in the soil profile [14]. In order to know the changes of SOC, STN, and STP concentrations and stocks in each soil horizon, it is crucial to find out the dynamic variations of SOC, STN, and STP in different soil horizons after the conversion of grassland. However, most studies on SOC, STN, and STP adopted the mechanical stratified sampling method [15,16]. The method comprised stratified sampling of soil by fixed depths, so it ignored the influence of spatial distribution pattern and soil genesis on SOC, STN, and STP. Studies have shown that for different soil pedogenic horizons, the dynamic driving mechanisms of SOC and STN were different [17]. Therefore, it is necessary to understand the effect of grassland conversion on concentrations and stocks in each soil pedogenic horizon. Hence, by sampling according to the soil pedogenic horizon and by separately analyzing the SOC, STN, and STP concentrations and stocks characteristics, the influence of grassland conversion on the nutrients in each soil pedogenic horizon can be revealed.

Land use change has notable impacts on the amount and distribution of SOC, STN, and STP; but the change patterns of SOC, STN, and STP vary, largely depending on the soil conditions. In response to land use change, the changes in SOC, STN, and STP concentrations and stocks are influenced by soil physical and chemical characteristics, such as soil texture, bulk density, calcium carbonate, and pH [13,18]. Soil texture may have a great effect on nutrient absorption capacity [14]. Grassland has greater plant-accessible water in coarse-textured soils than in fine-textured soils, inducing great plant growth, therefore resulting in high nutrient levels [2,19]. However, tillage has been found to induce a loss of C-rich coarse particles and a gain of C-depleted fine particles [20]. Furthermore, the changes of soil pH value can prominently influence nutrients adsorption and ion exchange [21]. Calcium carbonate (CaCO$_3$) significantly increases soil pH and decrease microbial diversity, which may contribute to SOC accumulation [22]. SOC, STN, and STP variations respond to the changes of soil physical and chemical characteristics after grassland conversion are complicated. Moreover, it is unclear which factor controls these variations in different soil pedogenic horizons.

Therefore, this study selected three sampling sites (natural grassland, shelterbelt, and cropland) in the Chinese Chernozem region and compared the changes of SOC, STN, and STP concentrations and stocks at a 0–100 cm depth along the soil pedogenic horizon after grassland conversion. The expectations of this study were to (1) evaluate the effects of grassland conversion on SOC, STN, and STP concentrations and stocks along the soil pedogenic horizon; (2) detect the changes (compared to the grassland) in the SOC, STN, and STP stocks at different soil horizons after grassland conversion; and (3) explore the main factors determining the SOC, STN, and STP in each soil pedogenic horizon.

2. Materials and Methods
2.1. Study Area

The study was conducted in Guyang Village and Dafu Village of Songyuan City, and Wanshun Village of Nong’an County, Jilin Province (43°53′–44°54′ N, 123°59′–124°59′ E) (Figure 1), which is located in the central Songnen Plain of Northeast China. The study area belongs to the temperate zone, which is a semiarid continental monsoon climate area. The mean annual evaporation of the study area is 800–900 mm, and the mean annual temperature is 4–5 °C [23]. The mean annual precipitation ranges from 370 to 470 mm, with more than 70% of the precipitation occurring during June, July, and August. The soil is identified as Chernozem by Chinese Soil Taxonomy, or as Ustoll by US Soil Taxonomy. The main native vegetation is meadow steppe, which initially covered the whole study
area. There is an obvious accumulation of calcium carbonate under the humus horizon. Moreover, the humus horizon in the area is thin. At present, a considerable part of the natural vegetation in the area of Chernozem have been successively reclaimed for farmland, resulting in fertility degradation and acidification of soil.

Figure 1. Location of the study area and sampling sites for different land-use types in the Chinese Chernozem region. Lowercase letters: a represents grassland, b represents shelterbelt, and c represents cropland. Numbers after lowercase letters indicate the replicate sites for each land use. Site 1 was located in Guyang Village, site 2 was located in Dafu Village, and site 3 was located in Wanshun Village.

2.2. Soil Sampling and Measurements

Samples were collected following soil pedogenic horizons for a depth of 100 cm in late October 2017. Three sampling sites were covered by native grassland (meadow steppe), shelterbelt (Populus simonii Carr.) as farmland shelterbelt, and cropland (Figure 1). The shelterbelt and cropland are adjacent. The dominant plant species in the grassland was Leymus chinensis (Trin.) Tzvel. The crop species primarily planted in the cropland was maize (Zea mays L.). The cropland was converted from grassland in the 1960s, and the shelterbelt was converted in the 1980s. The grassland was only grazed in the autumn and winter, with hay cut in the autumn. At each sampling site center, we established three representative plots (1 × 1 m for grassland and cropland, 5 × 5 m for shelterbelt) with a spacing of 15–30 m. Soil samples were gathered at five soil pedogenic horizon from top to bottom, such as A-horizon (humus horizon), AB-horizon (transition horizon), Bk-horizon (eluvial horizon, that is caliche), BC-horizon (transition horizon), and C-horizon (parent material horizon), by Soil Taxonomy according to soil color, lime reaction, lime pseudomycelium, plant root distribution, and clay for each plot using a soil shovel. Under three land use types, the average depth of each soil pedogenic horizon was 0–30, 30–55, 55–76, 76–90, and 90–100 cm. Therefore, a total of 135 composite soil samples (3 sites × 9 plots × 5 soil horizons) were collected. Soil samples did not exceed 100 cm depth, because the parent material horizon was generally above 100 cm depth, as well as for comparison analysis between different land uses.

Samples were allowed to air dry and were ground through a 2 mm sieve to measure soil texture. Samples that were sifted through a 0.25 mm mesh were used to determine the
SOIC, STN, and calcium carbonate (CaCO$_3$). Samples that were sifted through a 0.15 mm mesh were used to determine the STP concentration. Undisturbed samples were also excavated to measure the soil bulk density (BD) in the center of each horizon by using a metal cutting ring (diameter: 5 cm, length: 5 cm). The SOC concentration was measured by the dichromate oxidation method [13]. The STN concentration was measured by the Kjeldahl method [13]. The STP concentration was measured by acid-soluble molybdenum antimony colorimetric method after digesting with HClO$_4$-H$_2$SO$_4$ at high temperatures [13]. The CaCO$_3$ content was determined by using the acid-alkali neutralization titrimetric method [24]. The soil texture was determined according to the pipette method [24]. The soil bulk density was measured by oven-drying each soil sample at 105 °C for 24 h. The soil physicochemical characteristics of the three land uses are shown in Table 1.

| Land Use | Soil horizon | BD (g cm$^{-3}$) | CaCO$_3$ (%) | pH | Clay (%) | Silt (%) | Sand (%) |
|----------|--------------|-----------------|--------------|----|----------|----------|----------|
| Grassland A | 1.23 Ac | 4.33 Ac | 7.76 Ad | 17.03 Bb | 9.33 Cc | 73.63 Aa |
| AB | 1.32 Bb | 7.15 Ab | 7.94 Ac | 18.36 Bb | 9.47 Bc | 72.18 Aa |
| Bk | 1.36 Ab | 8.06 Aa | 8.15 Ab | 18.28Cb | 11.47Bb | 70.25 Aa |
| BC | 1.43 Aa | 6.73 Ab | 8.19 Ab | 22.11 BAa | 12.19 Ba | 66.02 Ab |
| C | 1.46 Aa | 4.67 Ac | 8.26 Aa | 22.19 Aa | 12.40 Ba | 65.41 Ab |
| Shelterbelt A | 1.24 Ab | 3.79 Bb | 7.63 Ba | 18.51 Bd | 10.28 Bb | 71.21 Aa |
| AB | 1.19 Cc | 4.88 Ba | 7.63 Ba | 20.30 Ac | 9.55 Bb | 70.15 Aa |
| Bk | 1.31 Aa | 4.56 Ca | 7.66 Ba | 26.26 Aa | 15.29 Aa | 58.45 Cc |
| BC | 1.32 Ba | 3.49 Bb | 7.66 Ba | 23.25 Ab | 15.49 Aa | 61.25 Ab |
| C | 1.38 Bb | 3.50 Bb | 7.69 Ba | 23.32 Ab | 14.99 Aa | 61.69 Ab |
| Cropland A | 1.22 Ac | 4.14 Ab | 7.55 Cb | 21.01 Aa | 11.49 Ab | 67.50 Bb |
| AB | 1.43 Aa | 4.64 Bb | 7.60 Bab | 17.65 Bb | 11.25 Ab | 71.11 Aa |
| Bk | 1.27 Bc | 6.73 Ba | 7.63 Ba | 20.32 Bab | 12.31 Ba | 67.38 Bb |
| BC | 1.35 Bb | 3.76 Bc | 7.64 Ba | 20.07 Bab | 10.55 Cc | 69.05 Aab |
| C | 1.36 Bb | 3.52 Bc | 7.64 Ba | 21.35 Aa | 12.89 Ba | 65.76 Ac |

Note: Different uppercase letters represent the significant differences among different land use types ($p < 0.05$), and the lowercase letters represent the significant differences among different soil horizons for each land use ($p < 0.05$).

2.3. Calculations and Statistical Analyses

The SOC, STN, and STP stocks were used to show the SOC, STN, and STP weight of the unit area of a certain soil horizon, which were calculated by the following equation [25]:

$$Stock = \sum_{i=1}^{n} 0.01 \times Con_i \times BD_i \times (1 - ST_i) \times \Delta d_i$$  \hspace{1cm} (1)$$

where $Stock$ (kg m$^{-2}$) is the storage of SOC, STN, and STP; $Con_i$ is the SOC, STN, and STP concentration of the $i$th horizon (g kg$^{-1}$); $BD_i$ is the soil bulk density of the $i$th horizon (g cm$^{-3}$); $ST_i$ is the proportion of coarse fragments (>2 mm) of the $i$th horizon (ST can be considered to be zero, for no visible coarse fragments); $\Delta d_i$ is the thickness of the $i$th horizon (cm); and $n$ is the number of soil pedogenic horizons. The factor 0.01 is the unit conversion coefficient.

Statistical analyses were carried out with SPSS 17.0 statistics software. One-way ANOVA and the least significant difference (LSD) test were used to determine differences between treatment means when the land use change and/or soil pedogenic horizon effects were significant. Two-way ANOVA was used to analyze the interaction between soil pedogenic horizons and land uses on the soil nutrients concentrations and stocks. We investigated the relationships among SOC, STN, STP, and influencing variables using the Pearson correlation coefficients analysis. Then, in order to explore the contribution of different soil properties to the variation of SOC, STN, and STP concentrations, redundancy analysis (RDA) was performed with CANOCO 5.0. RDA is a linear constrained
ordination method [26], which conforms to the explanatory variable gradient of <3.0 SD (Standard Deviation) in the study case. The factors, log (1 + x) transformed, centralized, and standardized in CANOCO 5.0, were identified to show the most influential gradients by forward selection. Adding explanatory variables until further adding of variables did not significantly (p < 0.05) improve the explanatory ability of the model. This was assessed with Monte Carlo permutations test.

3. Results

3.1. Variations in SOC, STN, and STP Concentrations

After grassland conversion, SOC concentration demonstrated significant differences (p < 0.01) among the whole profile (except AB-horizon and Bk-horizon), especially in the A-horizon (p < 0.001) (Figure 2). Higher SOC concentration occurred in grassland than shelterbelt and cropland among the whole profile, with the exception of A-horizon (Figure 2a). Compared with grassland, SOC concentration decreased by 17–43% in shelterbelt site (except A-horizon) and decreased by 2–35% in cropland site for different soil horizons, with an average loss of 0.73 g kg\(^{-1}\) and 1.24 g kg\(^{-1}\), respectively.

![Figure 2](image-url). Horizon distribution of (a) soil organic carbon (SOC) concentration, (b) soil total nitrogen (STN) concentration, and (c) soil total phosphorus (STP) concentration in grassland, shelterbelt, and cropland. Error bars represent the standard error of the mean. Within each horizon, different lowercase letters indicate significant differences in the SOC, STN, and STP concentrations among the three land uses (p < 0.05). On the vertical axis, A represents A-horizon, AB represents AB-horizon, Bk represents Bk-horizon, BC represents BC-horizon, and C represents C-horizon.

The profile distribution of the STN concentration was similar to that of SOC after grassland conversion. The profile distribution of the STN concentration exhibited much less fluctuation than the SOC concentration (Figure 2b). Higher STN concentration occurred in grassland than shelterbelt among the whole profile (except A-horizon), but that in the soils of cropland showed a slight change more than the soils of grassland in the AB-horizon and Bk-horizon. Compared with grassland, STN concentration decreased by 2–18% in the shelterbelt site (except A-horizon) and decreased by 3–21% in cropland site (except A-horizon).
AB-horizon and Bₖ-horizon) for different soil horizons, with an average loss of 0.05 g kg⁻¹ and 0.03 g kg⁻¹, respectively.

The mean STP concentration exhibited slight differences from Bₖ-horizon to C-horizon responses to the conversion of grassland (Figure 2). STP concentration of grassland was lower than shelterbelt and cropland above the Bₖ-horizon, but higher than shelterbelt and cropland below the Bₖ-horizon (Figure 2c). Moreover, STP concentration of grassland had the least changes among the whole profile with respect to cropland and shelterbelt. STP concentration increased by an average of 6% in the shelterbelt site and increased by an average of 22% in the cropland site compared with the grassland site for different soil horizons.

3.2. Changes in SOC, STN, and STP Stocks

The study found that land use changes significantly affected SOC, STN, and STP stocks (Figure 3). The total SOC stocks in the grassland were notably different (p < 0.001) from, and more than, those of the shelterbelt and cropland. The distribution of SOC stocks was highly significantly (p < 0.001) greater in the grassland than in the shelterbelt and cropland from the Bₖ-horizon to the C-horizon (Figure 3a). The total STN stocks in the grassland were higher than those of the shelterbelt and cropland, but not significantly different from the Bₖ-horizon and the C-horizon (Figure 3b). The STP stocks of grassland were significantly lower (p < 0.05) than the shelterbelt (except AB-horizon) and cropland above Bₖ-horizon, but were significantly higher (p < 0.05) than shelterbelt and cropland below Bₖ-horizon (Figure 3c).

![Figure 3](image-url)

Figure 3. The amount of (a) SOC, (b) STN, and (c) STP stocks in each horizon of the soil profile under different land use types. Different lowercase letters indicate significant differences in the SOC, STN, and STP stocks among different land use types in the same soil horizon (p < 0.05). The error bars are the standard errors. On the vertical axis, A represents A-horizon, AB represents AB-horizon, Bk represents Bₖ-horizon, BC represents BC-horizon, and C represents C-horizon.

Compared to the grassland, the ∆SOC, ∆STN, and ∆STP stocks in cropland and shelterbelt express the carbon sequestration capability of land use changes. Positive values of ∆SOC, ∆STN, and ∆STP stocks illustrate carbon, nitrogen, and phosphorus accumulations; however, negative values illustrate carbon, nitrogen, and phosphorus losses. The ∆SOC stocks indicated carbon generally lost in the whole profile after conversion of grassland, with the exception of the A-horizon in shelterbelt and AB-horizon in cropland (Figure 4a). The highest SOC loss was detected in the cropland (Figure 4a), especially in the A-
horizon. ∆STN stocks indicated that nitrogen was lost through the whole profile, with the exception of the A-horizon in the shelterbelt and AB-horizon in the cropland (Figure 4b). In contrast to the ∆SOC and ∆STN stocks, positive ∆STP stocks were detected after the grassland conversion to cropland and shelterbelt in the A-horizon and AB-horizon; however, negative ∆STP stocks were found under Bk-horizon (Figure 4c). The mean ∆SOC, ∆STN, and ∆STP stocks of each horizon in the shelterbelt site and the cropland site were −0.26 and −0.33 kg m\(^{-2}\), −0.02 and −0.01 kg m\(^{-2}\), 0.01 and 0.03 kg m\(^{-2}\), respectively.

**Figure 4.** Distributions of (a) ∆SOC, (b) ∆STN, and (c) ∆STP stocks under different land use types with respect to grassland in different soil pedogenic horizons. On the horizontal axis, A represents A-horizon, AB represents AB-horizon, Bk represents Bk-horizon, BC represents BC-horizon, and C represents C-horizon.

### 3.3. Factors Affecting SOC, STN, and STP

Significant influences of land use change and soil horizon on the concentrations and stocks of SOC, STN, and STP (p < 0.05) can be seen in Table 2. However, land use change had lower effects than soil horizon on nutrients. For example, land use change had weaker influences on STN concentrations and stocks with respect to soil horizon. Some interactions between land use change and soil horizon had a highly significant effect on nutrient elements (p < 0.05), whereas effects on the concentrations and stocks of STN weakened (p < 0.05).

**Table 2.** Statistical difference for concentrations and stocks of SOC, STN, and STP between land use change and soil horizon.

| Factor                | SOCc | STNc | STPc | SOCs | STNs | STPs |
|-----------------------|------|------|------|------|------|------|
| Land use              | 0.012 * | 0.041 * | 0.024 * | 0.018 * | 0.044 * | 0.030 * |
| Soil horizon          | 0.000 ** | 0.000 ** | 0.000 ** | 0.000 ** | 0.000 ** | 0.000 ** |
| Land use * Soil horizon | 0.000 ** | 0.025 * | 0.018 * | 0.001 ** | 0.038 * | 0.027 * |

Note: SOCc, STNc, and STPc are concentrations of SOC, STN, and STP, respectively. SOCs, STNs, and STPs are stocks of SOC, STN, and STP respectively. The p-values from two-way ANOVA tests are presented. * Significant effect at the 95% confidence interval. ** Significant effect at the 99% confidence interval.

Pearson correlation analysis indicated that SOC, STN, and STP concentrations were mainly correlated with CaCO\(_3\), pH, and soil texture (Table 3). CaCO\(_3\) content significantly affected soil nutrients, which usually occurred from the Bk-horizon to the C-horizon. pH value significantly affected SOC, and STN was usually under the Bk-horizon. Soil texture significantly influenced SOC, STN, and STP concentrations in the Bk-horizon. Therefore, CaCO\(_3\), pH, and soil texture mainly controlled the spatial patterns of nutrients in the deep horizons. However, land use changes significantly affected the soil nutrients in the surface horizons, mainly above the Bk-horizon (Figure 2).
Table 3. Correlation coefficients between soil properties and SOC, STN, and STP concentrations.

| Variables | Soil Horizon | BD | CaCO3 | pH  | Clay | Silt | Sand |
|-----------|--------------|----|-------|-----|------|------|------|
| SOC       | A            | 0.024 | -0.276 | 0.093 | -0.280 | -0.137 | 0.235 |
|           | AB           | 0.343 | -0.009 | 0.114 | -0.444 * | -0.214 | 0.370 |
|           | Bk           | -0.457 * | 0.504 ** | 0.503 ** | -0.510 ** | -0.619 ** | 0.570 ** |
|           | BC           | 0.511 ** | 0.485 * | 0.596 ** | 0.221 | -0.104 | -0.136 |
|           | C            | 0.407 | -0.056 | 0.797 ** | 0.121 | -0.162 | -0.002 |
| STN       | A            | -0.181 | 0.288 | 0.127 | -0.233 | -0.078 | 0.181 |
|           | AB           | 0.095 | 0.372 | 0.313 | -0.453 * | -0.190 | 0.367 |
|           | Bk           | -0.626 ** | 0.501 ** | 0.042 | -0.577 ** | -0.479 * | 0.514 ** |
|           | BC           | -0.402 | -0.045 | 0.315 | 0.367 | -0.331 | -0.146 |
|           | C            | 0.692 ** | 0.051 | 0.553 ** | 0.308 | -0.147 | -0.123 |
| STP       | A            | -0.142 | -0.139 | -0.475 * | 0.276 | 0.150 | -0.237 |
|           | AB           | 0.420 | -0.580 ** | -0.551 ** | 0.329 | 0.616 ** | -0.440 |
|           | Bk           | -0.406 | 0.549 ** | -0.130 | 0.532 ** | 0.530 ** | -0.495 * |
|           | BC           | -0.564 ** | 0.096 | 0.159 | 0.544 ** | -0.152 | -0.377 |
|           | C            | -0.099 | 0.468 * | 0.401 | -0.267 | -0.208 | 0.255 |

Note: * Significant at 0.05 levels (bilateral), ** Significant at 0.01 levels (bilateral).

The RDA was also conducted to study the relative contributions of the dominating soil factors to SOC, STN, and STP in each soil horizon (Figure 5). On average, land use, CaCO₃, pH, and clay + silt explained 17.1%, 15.4%, 17.6%, and 29.1% of the variations in the SOC concentrations; 11.4%, 22.4%, 18.4%, and 27.3% of the variations in the STN concentrations; 11.4%, 22.4%, 18.4%, and 23.4% of the variations in the STP concentrations, respectively. The relative contributions of land use were greater than other factors in the A-horizons (except to STP). Nevertheless, as soil horizons down, the impacts of land use generally reduced, contributing the least to SOC, STN, and STP concentrations in the Bk-horizon. The effects of pH did not control soil nutrients steadily. CaCO₃ and clay + silt contents have begun to play a significant role from Bk-horizon to C-horizon. Therefore, land use changes controlled the distributions of SOC, STN, and STP concentrations in the upper horizons, whereas CaCO₃ and soil texture principally influenced the soil nutrients in the deep horizons.

Figure 5. Relative contributions of factors to (a) SOC, (b) STN, and (c) STP concentrations at different soil horizons. On the vertical axis, A represents A-horizon, AB represents AB-horizon, Bk represents Bk-horizon, BC represents BC-horizon, and C represents C-horizon.
4. Discussion

4.1. Changes of Nutrients along Soil Pedogenic Horizons After Grassland Conversion

Land use changes, soil pedogenic horizon, and their interactions significantly affected concentrations and stocks of SOC, STN, and STP (Table 2).

Grassland conversion has been displayed to diverge significantly in some soil characteristics, particularly in the allocation of C, N, and P along soil pedogenic horizons [3,14,27]. Generally, the study discovered that grassland conversion depleted SOC, while STN pools increased STP pools. Meanwhile, land use changes played a significant role on SOC, STN, and STP, mainly in the A-horizon, which was consistent with previous research results [5]. The soil pedogenic horizon provides a vital role by influencing nutrient profile distributions. The topsoil nutrients are mainly extracted from litter, plant roots, and root exudates; however, the subsoil nutrients are mainly extracted from root shedding and leaching of nutrients [28]. Therefore, the effects of land use change on SOC, STN, and STP were significant in surface soils. However, the effect of grassland conversion should not be ignored below the Bk-horizon (Figure 5).

Intriguingly, grassland conversion led to significant differences in SOC concentrations and stocks ($p < 0.05$) throughout the whole profile (Figures 2 and 3). STN concentrations and stocks exhibited much less variation than SOC concentrations and stocks. STP concentration, however, showed slight differences after grassland transition to shelterbelt and cropland under the Bk-horizon. P is a sedimentary element, mainly from lengthy time periods of rock weathering. Nevertheless, the soil material in the study area is mainly Quaternary loess deposits, the source of soil P is relatively fixed, and the degree of weathering in the whole profile difference is not large. Thus, the spatial distribution of soil P storage between soil pedogenic horizons is relatively stable [29]. The highest STP stocks were found in the cropland, which can be primarily attributed to the input of external phosphate fertilizer.

The grasslands are mainly composed of poaceae and legume grasses with high above-ground biomass and high hay yield [30]. It suggested that grassland vegetation as a dominant genus had the highest C and N storage in the study area. The SOC and STN stocks in the grassland were 11.30 and 1.18 kg m$^{-2}$, respectively. The SOC stocks were just slightly less than the overall grassland SOC stocks trends in China (13.16 kg m$^{-2}$) [25], and the STN stocks were also slightly less than the overall grassland STN stocks trends in China (1.25 kg m$^{-2}$) [31]. Meanwhile, the SOC and STN stocks in the non-degraded grassland were 8.51 and 0.96 kg m$^{-2}$ in the whole profile (0–20 cm) of the Qinghai-Tibetan Plateau [32]. Due to the spatial heterogeneity of soil, the SOC and STN stocks in our studied grassland site were unlike those in other areas.

4.2. Effects of Grassland Conversion and Soil Pedogenic Horizon on Changes of Nutrient Stocks

Increasing populations inevitably gave rise to a wide range of land use conversions. Moreover, land use changes had various influences on soil carbon and soil nitrogen sequestration [33]. In particular, land use transitions to or from grass will promote significant shifts in soil C and N storage [34]. The results illustrated this point (Figure 4). In the study area, the cropland exhibited a large loss in SOC and STN stocks, the ratio of which reached 15% and 4%, compared with grassland. Due to lack of nutrient replenishment in the shelterbelt, SOC and STN stocks were lost at about 12% and 9% respectively, with respect to grassland. Generally, the root system, root exudates, and dissolved organic matter are considered the primary sources of C and N in the lower soil horizons [35]. Grasslands usually have a well-developed deep root system, and root biomass reductions were slower from upper horizons to deeper horizons than shelterbelt and cropland, thus causing slower reductions in SOC and STN storage in the lower soil horizons than in the shelterbelt and cropland. Thus, the grassland may be a better choice for soil carbon and nitrogen sequestration in the study sites of semiarid areas with precipitation ranging from 370 mm to 470 mm.
The results indicated that grassland conversion depleted cropland the most in terms of SOC and STN sources in the A-horizon, causing 23% and 16% losses, respectively, but contributed to cropland the most in terms of STP storage in the A-horizon with respect to other soil horizons. This finding conformed to the results of a few studies [23,36]. The decreases in SOC and STN stocks in the A-horizon after the transformation from grassland to cropland were potentially due to agricultural activities. Tillage could give rise to soil erosion and disruption in soil aggregates, which might wash away the soil organic matter [37]. In addition, decreases in the SOC, STN, and STP storage after conversion from grassland to cropland were also discovered from B\textsubscript{k}-horizon to C-horizon (except that STP stocks increased in the B\textsubscript{k}-horizon) (Figure 4), indicating that C, N, and P in the deep soil horizons could also be exhausted by agricultural practices.

Grassland conversion led to 12% SOC accumulations in the A-horizon of the shelterbelt, whereas it resulted in massive losses in other horizons. This corresponded with the study showing that a significantly higher SOC concentration in shelterbelt thaningrassland was evident only in the topsoil [38]. Therefore, grassland conversion to shelterbelt led SOC stocks loss of 1.31 kg m\textsuperscript{-2} in sum. Additionally, differences in STN losses between shelterbelt and cropland were small, and STPs of two sites above B\textsubscript{k}-horizon were all accumulated for the two adjacent sites [39]. To sequester C and N, the shelterbelt is not suitable for all circumstances, so more grassland than shelterbelt should be established in sandy land and low hills [40].

4.3. Variation of Nutrients with Soil Properties

Land use changes contributed to SOC, STN, and STP mainly at the surface horizon; however, the effects of this could not be ignored in the deep horizons. Grassland conversion changed the basic physical and chemical properties of soil, which were associated with changes in SOC, STN, and STP. Some research enables us to better understand the relationship between soil physical and chemical characteristics and SOC, STN, and STP sequestrations after conversion of grassland [5,9,32].

Chernozem has a calcic horizon (B\textsubscript{k}-horizon) under the humus horizon and with typical morphological characteristics, including aggregations of CaCO\textsubscript{3}. The results showed that CaCO\textsubscript{3} content of the soil had significant effects on the SOC, STN, and STP concentrations from the B\textsubscript{k}-horizon to the C-horizon (Table 3, Figure 5). The large aggregations of CaCO\textsubscript{3} in the B\textsubscript{k}-horizon, to some extent, can protect SOC from rapid mineralization. CaCO\textsubscript{3} can increase the physical protection of organic carbon in soil aggregates and provide chemical protection of organic carbon through calcium ion bridge effect, which reduces the sensitivity of organic carbon to be decomposed by microorganisms [41–43]. The mean CaCO\textsubscript{3} content of grassland was the highest among the three land uses, so grassland can be expected to protect more SOC within Ca\textsuperscript{2+} aggregates, forming stable SOC. However, the mechanisms of how CaCO\textsubscript{3} affects STN and STP are not presently well understood.

In the study, it was discovered that SOC, STN, and STP were mainly positively correlated with pH, suggesting that grassland conversion aggravated the SOC, STN, and STP losses by changing the pH of soil. The content of CaCO\textsubscript{3} increases soil pH value, maintaining the capacity of SOC absorption [44].

Grassland was dominated by sandy soil texture with raised clay contents along the soil pedogenic horizon in our study area, which was associated with rapid grassland establishment and high productivity. Generally, clay content in soil was conducive to enhancing the soil fertility and plants, as well as growth nutrient absorption capacity of plants. Approximately 55–57% of the organic C and 62–68% of the organic N were stored in the clay composition [45]. The variation of clay in shelterbelt and cropland reached the maximum in the B\textsubscript{k}-horizon, compared with grassland. Soil texture markedly influenced SOC and STN concentrations in the B\textsubscript{k}-horizon, mainly by reducing microbial decomposition or increasing water holding capacity [46]. However, the increase in CaCO\textsubscript{3} appears to induce the proportion of particles <0.25 mm to decrease [47,48]. In accordance with this, the mean CaCO\textsubscript{3} content was the highest in grassland, which had the lowest
clay among the three land uses. However, the decrease in clay in grassland without the decrease in SOC and STN suggested that it may have resulted from high aboveground biomass and the strong root system of grassland.

5. Conclusions

Variations in soil nutrients concentrations and stocks along the soil pedogenic horizons after conversion of grassland in the Chinese Chernozem region were revealed in this study. The results showed that changes in SOC, STN, and STP mainly depended on soil pedogenic horizons, land use changes, and soil properties. Grassland conversion notably impacted the SOC, STN, and STP concentrations and stocks along the soil pedogenic horizons \( (p < 0.05) \). Conversion of grassland resulted in losses of soil carbon and nitrogen but accumulations of phosphorus. It had different edaphic factors controlling the accumulation of SOC, STN, and STP in different soil pedogenic horizons with grassland conversion. The upper soil pedogenic horizons were found to be principally influenced by land use changes, while the soil below the Bk-horizon was controlled by both land uses and soil properties. CaCO\(_3\) and soil texture affected the nutrients concentrations in and below the Bk-horizon, possibly for the aggregations of CaCO\(_3\) in the Bk-horizon. Based on the research, grassland conversion should be paid more attention in semiarid regions.

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References

1. Bormann, H. Analysis of the suitability of the German soil texture classification for the regional scale application of physical based hydrological model. *Adv. Geosci.* 2007, 11, 7–13. [CrossRef]
2. Samuel, E.; Sheila, M.P.; Pippa, J.C. Soil organic carbon stock in grasslands: Effects of inorganic fertilizers, liming and grazing in different climate settings. *J. Environ. Manag.* 2018, 223, 74–84. [CrossRef]
3. Ross, D.J.; Tate, K.R.; Scott, N.A.; Feltham, C.W. Land-use change: Effects on soil carbon, nitrogen and phosphorus pools and fluxes in three adjacent ecosystems. *Soil Biol. Biochem.* 1999, 31, 803–813. [CrossRef]
4. Wiesmeier, M.; Spörlein, P.; Geuß, U.; Hangen, E.; Haug, S.; Reischl, A.; Schilling, B.; Lützow, M.; Kögel-Knabner, I. Soil organic carbon stocks in southeast Germany (Bavaria) as affected by land use, soil type and sampling depth. *Glob. Chang. Biol.* 2012, 18, 2233–2245. [CrossRef]
5. Li, S.C.; Xu, J.H.; Tang, S.M.; Zhan, Q.W.; Gao, Q.H.; Ren, L.T.; Shao, Q.Q.; Chen, L.; Du, J.L.; Hao, B. A meta-analysis of carbon, nitrogen and phosphorus change in response to conversion of grassland to agricultural land. *Geoderma* 2020, 363, 114149. [CrossRef]
6. Tang, S.M.; Guo, J.X.; Li, S.C.; Li, J.H.; Xie, S.; Zhai, X.J.; Wang, C.J.; Zhang, Y.J.; Wang, K. Synthesis of soil carbon losses in response to conversion of grassland to agriculture land. *Soil Tillage Res.* 2019, 185, 29–35. [CrossRef]
7. Christopher, P.; Axel, D.; Lars, V.; Jens, L.; Bas van, W.; Jens, S.; Andreas, G. Temporal dynamics of soil organic carbon after land-use change in the temperate zone-carbon response functions as a model approach. *Glob. Chang. Biol.* 2011, 17, 2415–2427. [CrossRef]
8. Claudia, G.; Lars, V.; Damiano, G.; Mirco, R. Changes in soil organic carbon and nitrogen following forest expansion on grassland in the Southern Alps. *For. Ecol. Manag.* 2014, 328, 103–116. [CrossRef]
9. Liu, X.; Li, L.H.; Wang, Q.; Mu, S.Y. Land-use change affects stocks and stoichiometric ratios of soil carbon, nitrogen, and phosphorus in a typical agro-pastoral region of northwest China. *J. Soils Sediments* 2018, 18, 3167–3176. [CrossRef]
10. Wang, Q.; Zhang, L.; Li, L.; Bai, Y.; Cao, J.; Han, X. Changes in carbon and nitrogen of Chernozem soil along a cultivation chronosequence in a semi-arid grassland. *Eur. J. Soil Sci.* 2009, 60, 916–923. [CrossRef]
11. Ikabongo, M.; Mariko, S.; Ryusuke, H. Short-term land-use change from grassland to cornfield increases soil organic carbon and reduces total soil respiration. *Soil Tillage Res.* 2019, 186, 1–10. [CrossRef]

12. Chen, C.R.; Condron, L.M.; Davis, M.R.; Sherlock, R.R. Seasonal changes in soil phosphorus and associated microbial properties under adjacent grassland and forest in New Zealand. *For. Ecol. Manag.* 2003, 177, 539–557. [CrossRef]

13. Shang, Z.H.; Cao, J.J.; Guo, R.Y.; Henkin, Z.; Ding, L.M.; Long, R.J.; Deng, B. Effect of enclosure on soil carbon, nitrogen and phosphorus of alpine desert rangeland. *Land Degrad. Dev.* 2014. [CrossRef]

14. Cao, Z.W.; Fang, X.; Xiang, W.H.; Lei, P.F.; Peng, C.H. The vertical differences in the change rates and controlling factors of soil organic carbon and total nitrogen along vegetation restoration in a subtropical area of China. *Sustainability* 2020, 12, 6443. [CrossRef]

15. Qiao, J.B.; Zhu, Y.J.; Jia, X.X.; Huang, L.M.; Shao, M.A. Vertical distribution of soil total nitrogen and soil total phosphorus in the critical zone on the Loess Plateau, China. *Catena* 2018, 166, 310–316. [CrossRef]

16. Meena, V.S.; Mondal, T.; Pandey, B.M.; Mukherjee, A.; Yadav, R.P.; Choudhary, M.; Singh, S.; Bisht, J.K.; Pattanayak, A. Land use changes: Strategies to improve soil carbon and nitrogen storage pattern in the mid-Himalaya ecosystem, India. *Geoderma* 2018, 321, 69–78. [CrossRef]

17. Grimm, R.; Behrens, T.; Märbker, M.; Elsenbeer, H. Soil organic carbon contents and stocks on Barro Colorado Island-Digital soil mapping using Random Forests analysis. *Geoderma* 2008, 146, 102–113. [CrossRef]

18. Yang, W.J.; Cheng, H.G.; Hao, F.H.; Ouyang, W.; Liu, S.Q.; Lin, C.Y. The influence of land-use change on the forms of phosphorus in soil profiles from the Sanjiang Plain of China. *Geoderma* 2012, 189, 207–214. [CrossRef]

19. Epstein, H. Soil mediation in grasslands. *Nat. Clim. Chang.* 2012, 2, 711–712. [CrossRef]

20. Six, J.; Paustian, K.; Eliott, E.T.; Combrink, C. Soil structure and soil organic matter: I. Distribution of aggregate size classes and aggregate associated carbon. *Soil Sci. Soc. Am. J.* 2000, 64, 681–689. [CrossRef]

21. McCauley, A.; Jones, C.; Jacobsen, J. Soil pH and organic matter. *Nutr. Manag. Modul.* 2009, 8, 1–12.

22. Xiao, D.; Huang, Y.; Feng, S.Z.; Ge, Y.H.; Zhang, W.; He, X.Y.; Wang, K.L. Soil organic carbon mineralization with fresh organic substrate and inorganic carbon additions in a red soil is controlled by fungal diversity along a pH gradient. *Geoderma* 2018, 321, 79–89. [CrossRef]

23. Jilin Soil and Fertilizer Station. *Soil of Jilin Province*; China Agriculture Press: Beijing, China, 1998.

24. Bao, S.D. *Soil and Agrochemistry Analysis*; China Agricultural Press: Beijing, China, 2000. (In Chinese)

25. Ni, J. Carbon storage in Digital Forests analysis. *Geoderma* 2002, 50, 205–218. [CrossRef]

26. TerBraak, C.J.F.; Verdonschot, P.F.M. Canonical correspondence analysis and related multivariate methods in aquatic ecology. *Aquat. Sci.* 1995, 57, 255–289. [CrossRef]

27. Xu, C.H.; Xiang, W.H.; Gou, M.M.; Chen, L.; Lei, P.F.; Fang, X.; Deng, X.W.; Ouyang, S. Effects of Forest Restoration on Soil Carbon, Nitrogen, Phosphorus, and Their Stoichiometry in Hunan, Southern China. *Sustainability* 2018, 10, 1874. [CrossRef]

28. Chapin, F.S. Effects of plant traits on ecosystem and regional processes: A conceptual framework for predicting the consequences of global change. *Ann. Bot.* 2003, 91, 455–463. [CrossRef]

29. Liu, W.J.; Chen, S.Y.; Qin, X.; Baumann, F.; Scholten, T.; Zhou, Z.Y.; Sun, W.J.; Zhang, T.Z.; Ren, J.W.; Qin, D.H. Storage, patterns, and control of soil organic carbon and nitrogen in the northeastern margin of the Qinghai-Tibetan Plateau. *Environ. Res. Lett.* 2012, 7, 035401. [CrossRef]

30. Chen, L.D.; Gong, J.; Fu, B.J.; Huang, Z.L.; Huang, Y.L.; Gui, L.D. Effect of land use conversion on soil organic carbon sequestration in the loess hilly area, loess plateau of China. *Ecol. Res.* 2007, 22, 641–648. [CrossRef]

31. He, N.P.; Han, X.G.; Yu, G.R. Carbon and nitrogen sequestration rate in long-term fenced grasslands in Inner Mongolia, China. *Acta EcologicaSinica* 2011, 31, 4270–4276. (In Chinese)

32. Li, Y.Y.; Dong, S.K.; Chen, L.; Wang, X.X.; Wu, Y. Soil carbon and nitrogen pools and their relationship to plant and soil dynamics of degraded and artificially restored grasslands of the Qinghai-Tibetan Plateau. *Geoderma* 2014, 213, 178–184. [CrossRef]

33. McLaughlan, K. The nature and longevity of agricultural impacts on soil carbon and nutrients: A review. *Ecosystems* 2006, 9, 1364–1389. [CrossRef]

34. Grange, I.; Rawson, A. Soil carbon variability of a grassy woodland ecosystem in south-eastern Australia: Implications for sampling. *19th World Congr. Soil Sci. Soil Solut. Chang.* World 2010, 82–85.

35. Bronick, C.J.; Lal, R. Manuring and rotation effects on soil organic carbon concentration for different aggregate size fractions on two soils in Northeastern Ohio, USA. *Soil Tillage Res.* 2005, 81, 239–252. [CrossRef]

36. Dong, S.K.; Wen, L.; Li, Y.Y.; Wang, X.X.; Zhu, L.; Li, X.Y. Soil-Quality Effects of Grassland Degradation and Restoration on the Qinghai-Tibetan Plateau. *Soil Sci. Soc. Am. J.* 2012, 76, 2256–2264. [CrossRef]

37. Wang, Y.Q.; Zhang, X.C.; Huang, C.Q. Spatial variability of soil total nitrogen and soil total phosphorus under different land uses in a small watershed on the Loess Plateau, China. *Geoderma* 2009, 150, 141–149. [CrossRef]

38. Rumpel, C.; Kögel-Knabner, I. Deep soil organic matter—a key but poorly understood component of terrestrial C cycle. *Plant Soil* 2011, 338, 143–158. [CrossRef]

39. Feng, S.Z.; Huang, Y.; Ge, Y.H.; Su, Y.R.; Xu, X.W.; Wang, Y.D.; He, X.Y. Variations in the patterns of soil organic carbon mineralization and microbial communities in response to exogenous application of rice straw and calcium carbonate. *Sci. Total Environ.* 2016, 571, 615–623. [CrossRef] [PubMed]
40. Wang, X.Y.; Li, Y.Q.; Chen, Y.P.; Lian, J.; Luo, Y.Q.; Niu, Y.Y.; Gong, X.W. Spatial pattern of soil organic carbon and total nitrogen, and analysis of related factors in an agro-pastoral zone in Northern China. *PLoS ONE* 2018, 13, e0197451. [CrossRef]

41. Clough, A.; Skjemstad, J.O. Physical and chemical protection of soil organic carbon in three agricultural soils with different contents of calcium carbonate. *Aust. J. Soil Res.* 2000, 38, 1005–1016. [CrossRef]

42. Hobbie, S.E.; Ogdahl, M.; Chorover, J.; Chadwick, O.A.; Oleksyn, J.; Zytkowiak, R.; Reich, P.B. Tree species effects on soil organic matter dynamics: The role of soil cation composition. *Ecosystems* 2007, 10, 999–1018. [CrossRef]

43. Fang, Y.Y.; Singh, B.; Palsingh, B. Effect of temperature on biochar priming effects and its stability in soil. *Soil Biol. Biochem.* 2015, 80, 136–145. [CrossRef]

44. Fornara, D.A.; Steinbeiss, S.; Menamara, N.; Gleixner, G.; Oakley, S.; Poulton, P.R.; Macdonald, A.; Bardgett, R.D. Increases in soil organic carbon sequestration can reduce the global warming potential of long-term liming to permanent grassland. *Glob. Chang. Biol.* 2011, 17, 1925–1934. [CrossRef]

45. Schimel, D.S.; Parton, W.J. Microclimatic controls of nitrogen mineralization and nitrification in shortgrass steppe soils. *Plant Soil* 1986, 93, 347–357. [CrossRef]

46. Baldock, J.A.; Aoyama, M.; Oades, J.M.; Susant, O.; Grant, C.D. Structural amelioration of a South Australian red-brown earth using calcium and organic amendments. *Aust. J. Soil Res.* 1994, 32, 571–594. [CrossRef]

47. Anderson, D.W.; Saggar, S.; Bettany, J.R.; Stewart, J.W.B. Particle Size Fractions and Their Use in Studies of Soil Organic Matter: I. The Nature and Distribution of Forms of Carbon, Nitrogen, and Sulfur. *Soil Sci. Soc. Am. J.* 1981, 45, 767–772. [CrossRef]

48. Acuña, S.P.C.; Jiménez, M.L.B.; Zambrano, J.J.M.; Sarmiento, H.A.R. Soil bacteria that precipitate calcium carbonate: Mechanism and applications of the process. *Acta Agron.* 2018, 67, 277–288. [CrossRef]