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# Effect of biochar on the soil nutrients about different grasslands in the Loess Plateau

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ABSTRACT

Serious soil erosion across the Loess Plateau has decreased the concentration of soil nutrients to low levels. Biochar amendments to the soil are an efficient method of improving soil nutrients; however, the effects of biochar amendments on the different soil types in the Loess Plateau are not well understood. In our experiments, we compared the effects of biochar on the soil organic matter, nitrogen and phosphorus content in the Loess Plateau. Four different grasslands abandoned in 1985, 1992, 2000 and 2005 were selected for the experiment. A 3-year field study was conducted in 2 m × 1 m plots to investigate changes in soil nutrient retention caused by biochar amendments at rates of 0 g/kg (control), 4 g/kg, 8 g/kg and 16 g/kg. The 0–40 cm soil profile was collected in layers of 0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm and the soil organic matter, total nitrogen, total phosphorus, ammonium nitrogen and nitrate nitrogen contents were measured after three years of biochar applications. The results showed that biochar amendments resulted in significant improvements to soil organic carbon, nitrate nitrogen and soil total nitrogen. When biochar was added to the 0–20 cm layer at 4 g/kg, 8 g/kg and 16 g/kg, the soil organic carbon content was increased by 2.67 g/kg, 5.34 g/kg and 10.67 g/kg, respectively; soil total nitrogen was increased by 0.24 g/kg, 0.47 g/kg and 0.83 g/kg, respectively; and soil nitrate nitrogen was increased by 0.56 mg/kg, 0.91 mg/kg and 1.63 mg/kg, respectively. Biochar amendments did not show a significant influence on soil ammonium nitrogen in the 0–20 cm soil layer. However, the soil phosphorus content decreased with increasing amounts of biochar, especially at high biochar application rates. These results show that the incorporation of biochar into the soil of the Loess Plateau has the potential to enhance the soil organic carbon and soil nitrogen contents, although it must be used in conjunction with a phosphorus fertilizer.


## 1. Introduction

The Loess Plateau covers an area of approximately $6.4 \times 10^5$ km$^2$ and is the largest continuous area of loess in the world (Wu et al., 2015). The Loess Plateau is well known for its serious soil erosion issues and long-term agricultural activity (Wang et al., 2011). Overgrazing, intensive cultivation and severe soil erosion have resulted in soil degradation (Wang et al., 2012). A number of approaches have been proposed to mitigate the degradation of the Loess Plateau and to establish a healthy ecosystem, including engineering (Xu et al., 2004) and biological approaches. The "Grain-for-Green" eco-restoration program (Deng et al., 2014), a long-term policy-driven approach established in 1999, showed that re-vegetation is the most effective method of reducing soil degradation (Zhao et al., 2015). However, trees and shrubs on the Loess Plateau have died recently, because of low nutrients and rainfall, especially in water-limited areas (Cao et al., 2010). Thus, the establishment of a healthy ecosystem requires improvements in the soil nutrient status and water content. Compost (Edmeades, 2003) and manure (Quilty and Cattle, 2011) can be used to improve the soil nutrients and water retention. However, the turnover rate of nutrients in compost and manure is rapid. Additionally, the mineralization of soil organic matter is accelerated and limits the use of organic fertilizers in the Loess Plateau (Kaur et al., 2008).

Biochar is a type of black carbon produced from animal manure or plant residues through controlled pyrolysis. The pyrolytic process converts biomass acids into a bio-oil component, and the alkalinity is inherited by the solid biochar (Laird et al., 2010). Various study results have shown that biochar application can enhance soil nutrients (Sohi et al., 2010), improve plant growth and crop yields (Major et al., 2010), and limit greenhouse gas emissions from the soil (Liu et al., 2014; Li et al., 2015). Biochar application can improve the soil water retention capacity (Peake et al., 2014; Tammeorg et al., 2014), and compared with the parent plant biomass or typical carbon forms in soil, biochar is a much more durable form of carbon (Santos et al., 2012; Knicker et al., 2013). Hence, the application of biochar to the soil has been proposed to increase the stable nutrient pool and water retention capacity. However, limited research is available on the priming effects of

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biochar on native nutrients over a long time scale. For example, biochar has been shown to increase (positive priming), decrease (negative priming) or have no effect on soil organic matter (Luo et al., 2011; Keith et al., 2011; Awad et al., 2012; Santos et al., 2012; Jones et al., 2012). Furthermore, the available research shows that the direction and magnitude of the priming effect on native soil carbon caused by biochar might change according to the incubation period. For example, studies have shown a positive priming effect in the first 2 to 3 months (Farrell et al., 2013), which decreased to either negligible or negative priming over time (Zhu et al., 2014). Biochar application can improve the soil fertility of acidic soil or rapidly lower the nutrient concentrations in tropical soils (Major et al., 2010; Vaccari et al., 2011; Zhang et al., 2012). Before applying biochar to Loess Plateau soil over a wider scope, we must first study the impacts of biochar on loess soil nutrients because these effects have not yet been demonstrated under field settings on the Loess Plateau in China.

Therefore, the aim of this work was to investigate the impacts of biochar on soil properties in the Loess Plateau. In this study, four different soil types were selected as the subjects, and the experiment was designed to meet the following two objectives: 1) study the effects of biochar application rates and 2) assess the responses of the properties of the different sol types to the biochar application. If all of the effects indicate positive priming for the soil properties, biochar will be applied as a soil amendment material on the Loess Plateau.

## 2. Materials and methods

### 2.1. Experimental site

This experiment was conducted at the Ansai research station of soil and water conservation, Chinese Academy of Science, which is located in Ansai county, Shaanxi province, NW China (36°51′6.7″–36°51′54.5″

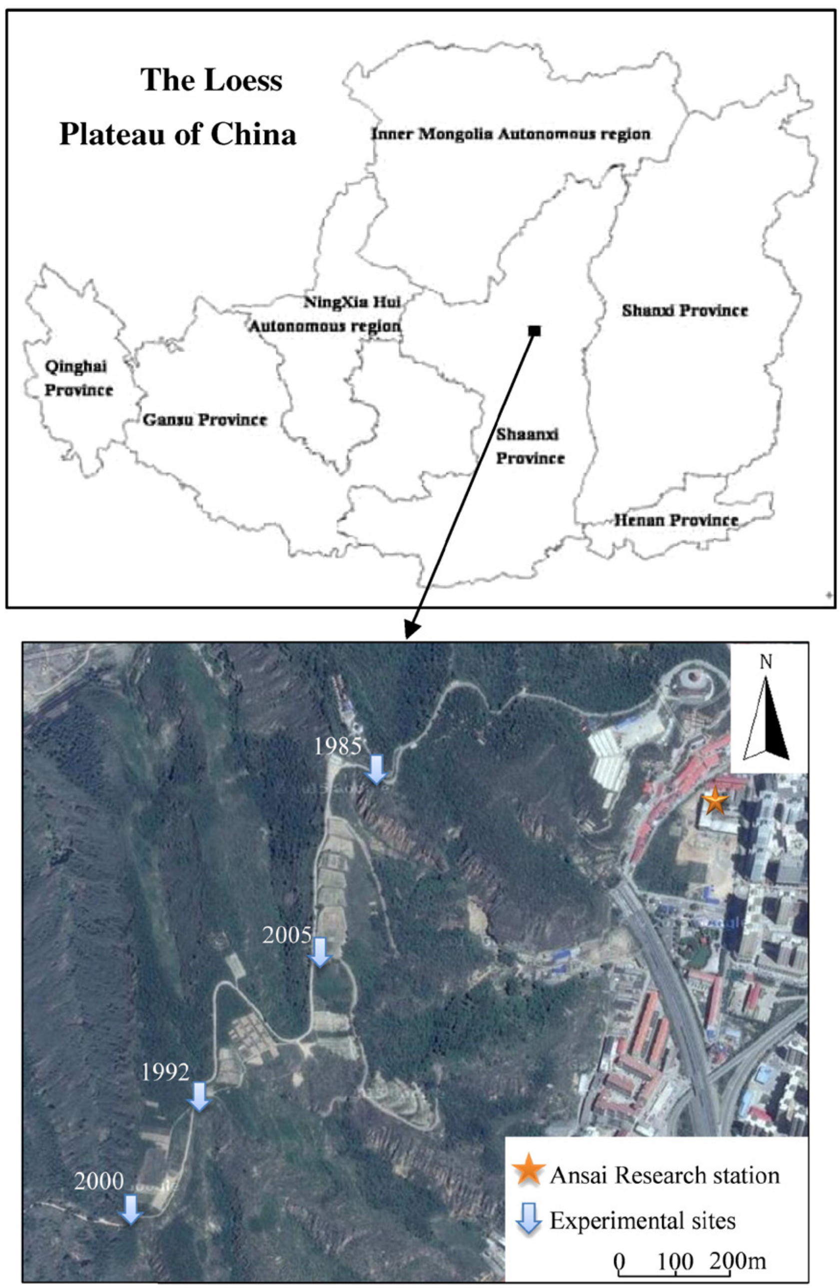


**Fig. 1.** Location of experimental sites.

N, 109°18′45.6″–109°19′1.6″E, 1277–1284 m altitude). Four different grasslands abandoned in 1985, 1992, 2000 and 2005 were selected for the experiment (Fig. 1). Ansai has a temperate and semi-arid climate with a mean annual temperature between −23.6 °C and 36.8 °C. The average precipitation is approximately 541.2 mm every year, and more than 75% of the precipitation is concentrated between July and September, during which severe rainstorms often occur. The frost-free period is approximately 157 days. The soil type is representative loess soil, and the soil texture is uniform and composed of 65% sand, 24% silt and 11% clay. The soil organic carbon, total nitrogen, total phosphorus, pH, cation exchange capacity (CEC) and electrical conductivity (EC) were 3.42 g/kg, 0.42 g/kg, 0.5 g/kg, 8.82, 8.6 cmol/kg and 3.9 ms/cm, respectively (Table 1) and the available nitrogen and available phosphorus of the Loess soil were 20.51 mg/kg and 2.59 mg/kg (Li et al., 2013).

### 2.2. Biochar

The biochar used in this study was produced from Chinese pine and locust via pyrolysis at approximately 600 °C for almost 2 h. In this experiment, the biochar was ground and passed through a 2 mm sieve. The characteristics of the biochar were measured (Table 1), and scanning electron microscope (SEM) images of the biochar showed that the structure was rough and porous (Fig. 2). The biochar was composed of 66.67% carbon, 3.22% hydrogen, 2.21% nitrogen, 0.58% phosphorus, 27.9% oxygen, and 12.5% ashes. The BET of the biochar was 247 $m^2$/g.

### 2.3. Experimental design and soil sample collection

The histories of the four sites were determined via rental contracts or interviews with village elders and local farmers. These sites were covered with grass, the slope gradients were near 15°, and they had the same aspect and elevation. Prior to our experiment, 2 m × 1 m plots were established, and the grass in these plots was removed. In the different plots, biochar was mixed with the surface soil (0–20 cm) at rates of 0 g/kg (control), 4 g/kg, 8 g/kg, and 16 g/kg ($C_0$, $C_4$, $C_8$, and $C_{16}$, respectively). Each treatment contained two replications, for a total of 32 plots. After adding the biochar in November 2010, the plots were enclosed to retain the natural vegetation until soil samples were collected in November 2013. In this study, the 0–40 cm soil profile was collected in layers of 0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm, and the collection was repeated twice for each plot. All of the soil samples were collected using a hand auger with a diameter of 5 cm. After air-drying, the soil samples were ground, passed through a 2 mm sieve, and then analyzed to measure the soil nutrient contents.

### 2.4. Laboratory analysis

The total carbon, hydrogen and nitrogen contents of the biochar were characterized by dry combustion using a CHN automatic element analyzer (Yanaca CDRDER MT-3). The total ash content was determined by ignition at 800 °C in a muffle furnace for 2 h. The CEC of biochar and soil samples was determined using the NaOAc exchange and flame luminosity method described by Bao (1999). The pH levels of the biochar and soil samples were measured using a 1:2.5 biochar or soil/water suspension and a compound glass electrode (REX pHS-3C meter, China). The biochar surface areas were determined using the Brunauer, Emmett and Teller method (V-Sorb 4800P, Gold Spectrum Technology Co., Ltd., China), The soil organic carbon content was measured using a wet digestion method. Total nitrogen was measured via the semi-micro Kjeldahl method and a Kjeltec System 1026 Distilling Unit, and the total phosphorus content of the biochar and soil samples was measured colorimetrically after wet digestion with $H_2SO_4 + HClO_4$. The $NH_4^+$–N and $NO_3^-$ N contents in the soil samples were measured using a FIAstar 5000 Analyzer FOSS TECATOR instrument. The electrical conductivity was measured in 1:5 w/v slurry of ultra-pure water using a CDM210 conductivity meter (Radiometer Analytical SAS, Lyon, France). Available N, Olsen P and the carbonate content of the soil were analyzed according to soil agricultural chemistry methods (Bao, 1999).

**Table 1**
The characteristics of biochar and loess soil.

| Biochar | | Loessial soil | |
|---|---|---|---|
| Parameter | Account | Parameter | Account |
| C (%) | 66.67 | C (g/kg) | 3.42 |
| O(%) | 27.9 | $CO_3^{2-}$ (%) | 0.02 |
| H (%) | 3.22 | TN (g/kg) | 0.42 |
| N (%) | 2.21 | TP (g/kg) | 0.50 |
| P (g/kg) | 0.58 | pH (1:2.5$H_2O$) | 8.82 |
| pH (1:2.5$H_2O$) | 8.38 | CEC (cmol/kg) | 8.6 |
| CEC (cmol/kg) | 31.58 | EC (ms/cm) | 3.9 |
| Ash (%) | 12.50 | AT (mg/kg) | 20.51 |
| BET ($m^2$/g) | 247 | AP (mg/kg) | 2.59 |

### 2.5. Data analysis

The different effects of the biochar, with respect to the various application rates, soil layers and abandonment years were examined using one-way analysis of variance, and a least significant difference (LSD) comparison test was applied simultaneously to compare the means between the treatment plots ($G_4$, $G_8$ and $G_{16}$) and control plots ($G_0$). Analyses of variance were performed using SPSS 16.0 statistical software. Before analyses of variance, the normal distribution of the datasets has been checked.

## 3. Results

### 3.1. Effects of biochar on soil organic matter content

The four studied grasslands were originally farmland that was abandoned in 1985, 1992, 2000, and 2005. The results showed that increases in the time since abandonment coincided with increases in soil organic matter, and this finding is consistent with the results of many studies (Wang et al., 2011; Deng et al., 2014; Han et al., 2015). Therefore, in this paper, we primarily focused on the effects of the biochar on the soil nutrients. In the different grasslands, the soil organic matter content increased with increasing biochar application rate, especially in the 0–20 cm soil layer because the biochar was mixed with this soil layer (Fig. 3). Similar increasing tendencies were observed for the 1992, 2000 and 2005 grasslands; however, the soil organic matter content in the 1985 grassland did not show substantial increases until 16 g/kg of biochar was added. There were significant differences in the soil organic matter content in the 0–20 cm layer of the biochar and control plots. The difference in the soil organic matter content in the 0–40 cm layer was smaller than that measured in the 0–20 cm layer except for the 1985 grassland. The differences in the soil organic matter contents between the treated and control plots were significant (Table 2).

### 3.2. Effects of biochar on soil nitrogen content

The difference in the soil nitrogen content after different application rates of biochar were mixed with the different grassland soils is shown in Fig 4. At a depth of 0–20 cm, the soil total nitrogen of all grassland plots increased with an increase in the amount of biochar. In the 0–40 cm layer, variations occurred among the four grasslands, with the grasslands abandoned in 1992, 2000 and 2005 exhibited an increasing tendency in the total nitrogen content with an increase in the biochar application rate, especially in the 2005 grassland, whereas in the 1985

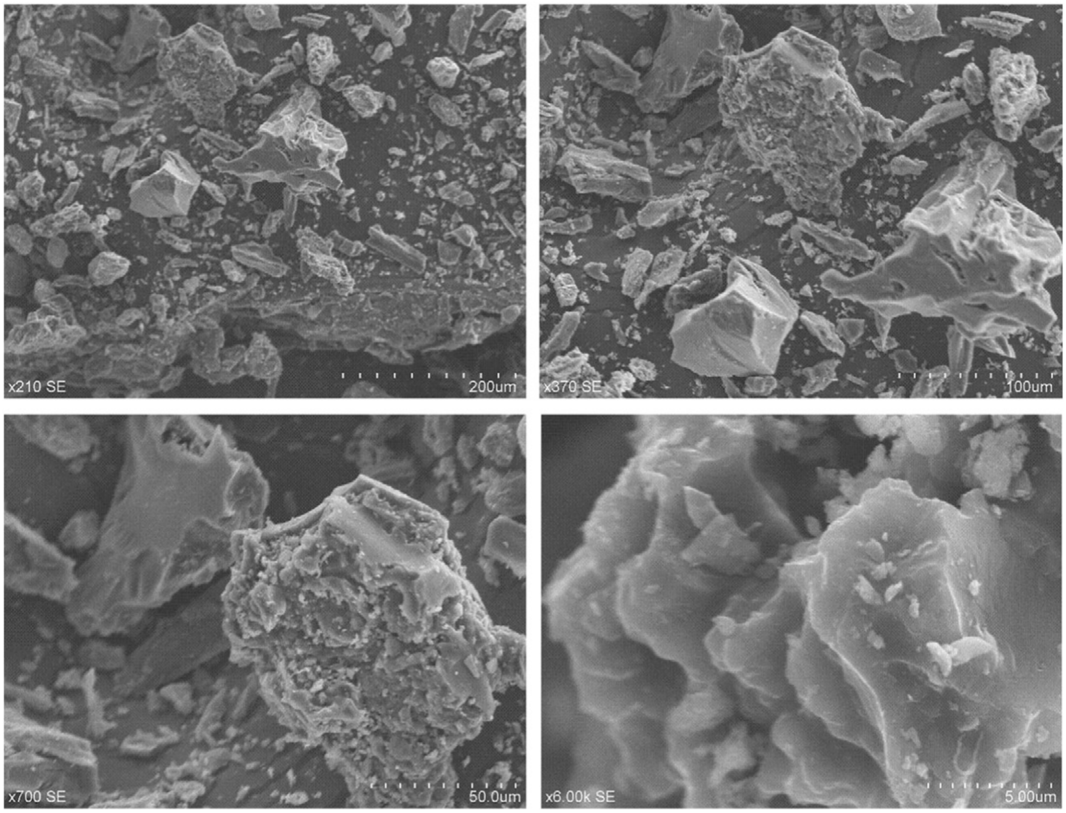


**Fig. 2.** SEM image of the biochar used in the experiments.

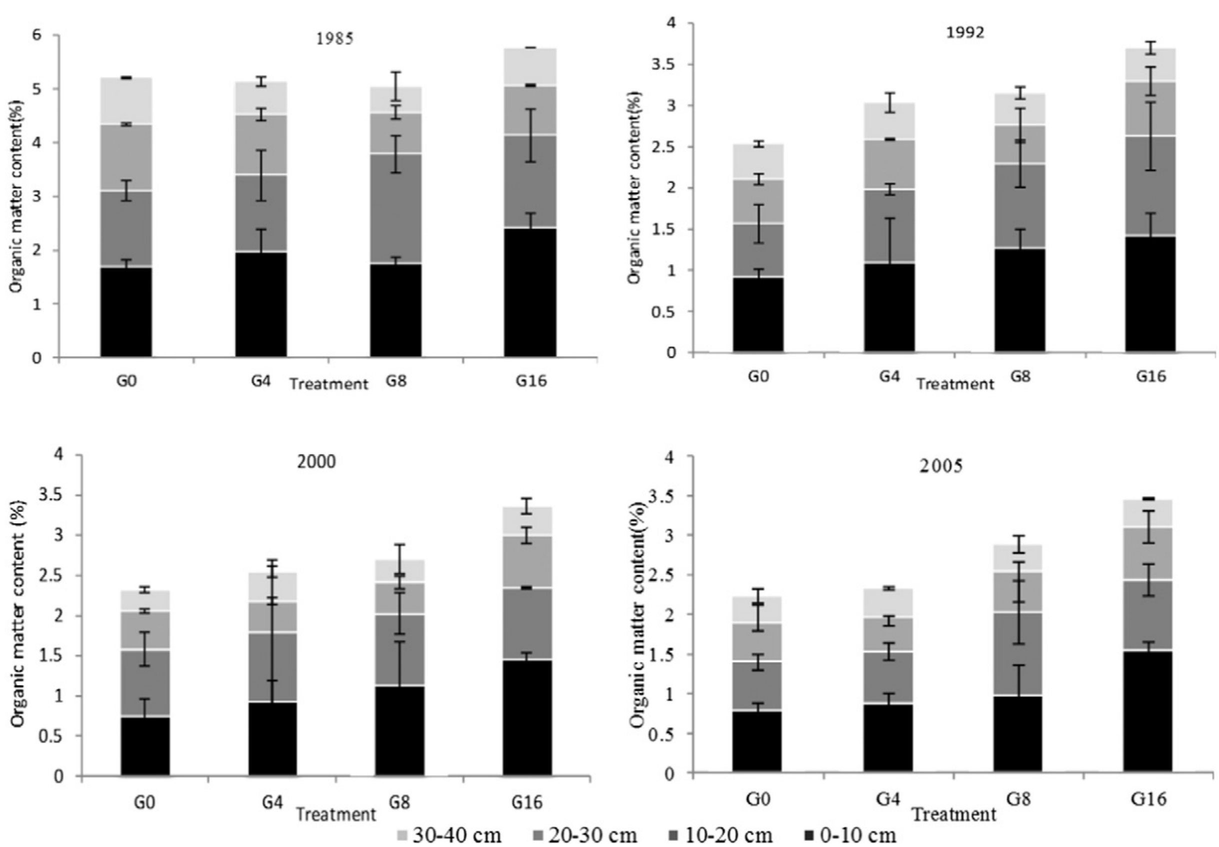


**Fig. 3.** Effects of biochar on the organic matter content in different grassland locations. In this paper, G0, G4, G8 and G16 indicate the addition of 0 g/kg, 4 g/kg, 8 g/kg and 16 g/kg biochar, respectively.

**Table 2**
Analysis of differences in soil organic matter under different amounts of added biochar.

| Year | Depth | Mean difference in soil organic carbon content (g/kg) | | |
|---|---|---|---|---|
| | | 4 | 8 | 16 |
| 1985 | 0–40 cm | 0.02 | 0.01 | 0.14** |
| | 0–20 cm | 0.15** | 0.34** | 0.52** |
| 1992 | 0–40 cm | 0.13** | 0.16** | 0.29** |
| | 0–20 cm | 0.21** | 0.37** | 0.53** |
| 2000 | 0–40 cm | 0.06* | 0.10** | 0.26** |
| | 0–20 cm | 0.11* | 0.22** | 0.38** |
| 2005 | 0–40 cm | 0.03* | 0.16** | 0.31** |
| | 0–20 cm | 0.07** | 0.32** | 0.52** |

** The mean difference is significant at the 0.01 level.
* The mean difference is significant at the 0.05 level.

grassland, a decreasing tendency was observed in response to 4 g/kg or 8 g/kg of biochar. Compared with the control plot, the total nitrogen content of the 0–40 cm soil increased with the addition of biochar, up to the highest rate of 16 g/kg of biochar. In the 0–20 cm soil layer, the difference in the total nitrogen content between the control plot and 4 g/kg added biochar plot was not significant except for in the 1985 grassland (Table 3). When biochar was added at 4 g/kg and 8 g/kg, the differences were significant, particularly in response to 8 g/kg of biochar. In the 0–40 cm soil layer, the difference in the total nitrogen content between the control plot and 8 g/kg biochar added plot was consistent with that of the 0–20 cm layer. However, limited increases were observed for the plots with 4 g/kg or 8 g/kg biochar, especially in the 1985 grassland, which showed a continual decrease.

The differences in the nitrate nitrogen content in the different grasslands are shown in Fig. 5, which indicates that limited changes occurred between the different treatment plots in the 2005 grassland. For all treatments in the remaining grasslands, the nitrate nitrogen content in the 0–40 cm soil layer continued to increase with increasing amounts of biochar. Highly significant differences were observed in the 0–20 cm soil layer of the control and biochar treated plots in the 1992 and 1985 grasslands (Table 3). However, in the 2000 and 2005 grasslands, limited increases were observed until 16 g/kg of biochar was added. In the 0–40 cm soil layer, the differences in the nitrate nitrogen content between the control plots and biochar-treated plots were significant except for the 2005 grassland plots to which 4 g/kg of biochar was added.

The impact of biochar on soil ammonium nitrogen was not significant. In the 1992, 2005 and 1985 grasslands, limited changes occurred in the soil ammonium nitrogen content in the 0–40 cm layer unless 16 g/kg of biochar was added (Fig 6). In the 0–40 cm layer, the largest change in the ammonium nitrogen content occurred in the 1985 grassland, which increased from 14.46 mg/kg to 17.4 mg/kg; however, this change was not significant. These results are presented in Table 3, and the impact of the biochar on the soil ammonium nitrogen content was only significant for the 2000 grassland.

### 3.3. Impact of biochar on soil phosphorus content

The impacts of the biochar on the soil phosphorus are shown in Fig. 7. Except for the 1992 grassland, all treatments had lower phosphorus content relative to the control plots. In the 1992 grassland, the soil phosphorus content increased with an increase in the amount of biochar; however, the changes were not significant (Table 4). This table

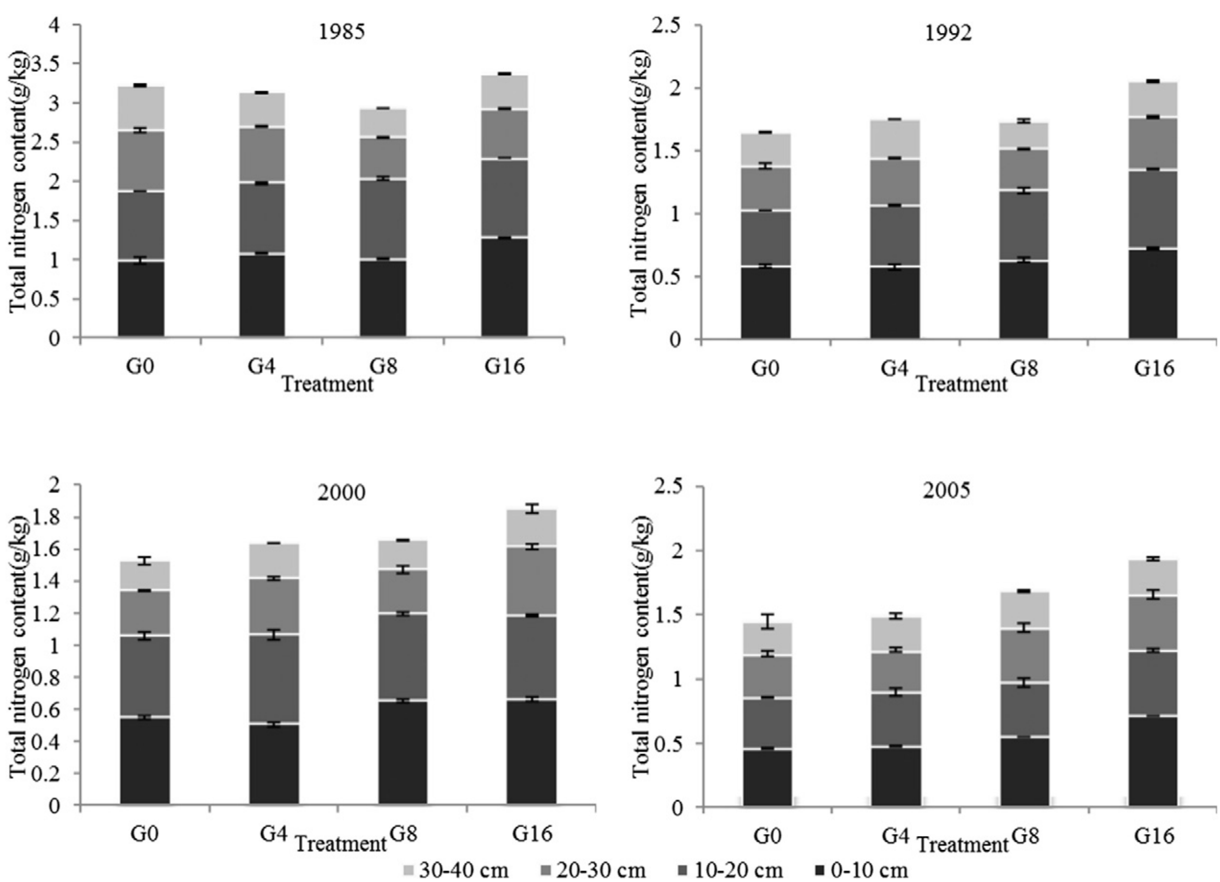


**Fig. 4.** Effects of biochar on the total nitrogen content in different grassland locations.

**Table 3**
Analysis of differences in soil nitrogen content under different amounts of added biochar.

| Nutrient type | Abandonment year | Depth (cm) | Biochar added (g/kg) 4 | 8 | 16 |
|---|---|---|---|---|---|
| Total nitrogen (g/kg) | 2005 | 0–20 | 0.02 | 0.06* | 0.19** |
| | | 0–40 | 0.01 | 0.06** | 0.12** |
| | 2000 | 0–20 | 0.01 | 0.07** | 0.06* |
| | | 0–40 | 0.03* | 0.01 | 0.05** |
| | 1992 | 0–20 | 0.02 | 0.08** | 0.16** |
| | | 0–40 | 0.03* | 0.02 | 0.10** |
| | 1985 | 0–20 | 0.06* | 0.08** | 0.21** |
| | | 0–40 | −0.02 | −0.07** | 0.04* |
| Nitrate nitrogen (mg/kg) | 2005 | 0–20 | 0.34* | 0.28 | 0.33* |
| | | 0–40 | 0.11 | 0.32* | 0.49** |
| | 2000 | 0–20 | 1.20 | 1.28 | 3.46** |
| | | 0–40 | 0.82* | 1.06* | 2.30** |
| | 1992 | 0–20 | 1.01** | 1.60** | 2.00** |
| | | 0–40 | 0.70** | 1.22** | 1.37** |
| | 1985 | 0–20 | 0.38* | 0.49* | 0.75** |
| | | 0–40 | 0.35** | 0.63** | 1.12** |
| Ammonium nitrogen (mg/kg) | 2005 | 0–20 | 0.06 | 0.01 | 0.79 |
| | | 0–40 | 0.10 | 0.01 | 0.30 |
| | 2000 | 0–20 | 0.28 | 0.32 | 0.37 |
| | | 0–40 | 0.34* | 0.42** | 0.42** |
| | 1992 | 0–20 | 0.12 | 0.62 | 0.85 |
| | | 0–40 | 0.00 | 0.03 | 0.45 |
| | 1985 | 0–20 | −0.11 | −0.08 | 1.08 |
| | | 0–40 | 0.08 | 0.13 | 0.74 |

4, 8, and 16 indicate the addition of 4 g/kg, 8 g/kg and 16 g/kg biochar, respectively.
** The mean difference is significant at the 0.01 level.
* The mean difference is significant at the 0.05 level.

also shows that in the 1985, 2000 and 2005 grasslands, the soil total phosphorus content decreased significantly in the 0–40 cm soil layer in response to the addition of 8 g/kg or 16 g/kg of biochar. Thus, the addition of biochar may result in a slight decrease in the soil phosphorus content.

## 4. Discussions

### *4.1. Biochar can increase the soil organic matter content*

Carbon sequestration in soil is of significant importance because it can enhance soil fertility (Lehmann, 2007) and reduce carbon dioxide emissions to the atmosphere (Zhang et al., 2012). Because of its relative inertness, biochar can increase soil carbon sequestration (Lu et al., 2014; Singh and Cowie, 2014). However, the mechanisms by which biochar impacts soil organic carbon are complicated and remain unclear. Biochar has a “priming effect” that can influence the mineralization of native soil organic carbon, which may have a positive metabolic effect on microbial growth and may provide habitats for microorganisms (Lehmann et al., 2011; Luo et al., 2011; Farrell et al., 2013). Biochar may also have a significant ability to improve soil structure and soil water capacity, which might contribute to positive priming (Zimmerman et al., 2011; Karhu et al., 2011). In addition, soil organic carbon mineralization may be suppressed in the presence of biochar because of the direct adsorption of native labile organic matter or the induced stabilization of relatively labile organic matter (Kasozi et al., 2010; Lin et al., 2012). The use of more labile carbon by microbial communities over a short time period is known as “preferential substrate utilization” (Kuzyakov et al., 2000; Gontikaki et al., 2013), which might also cause negative priming, especially for soils with a low carbon content (Guenet et al., 2010). In the grasslands in the present study, the soil organic carbon content ranged between 0.26% and 2.41%, and the carbon content of the biochar was 66.67%. When biochar was added at rates of 4 g/kg, 8 g/kg and 16 g/kg, the soil organic carbon in the 0–20 cm layer was expected to increase by 2.67 g/kg,

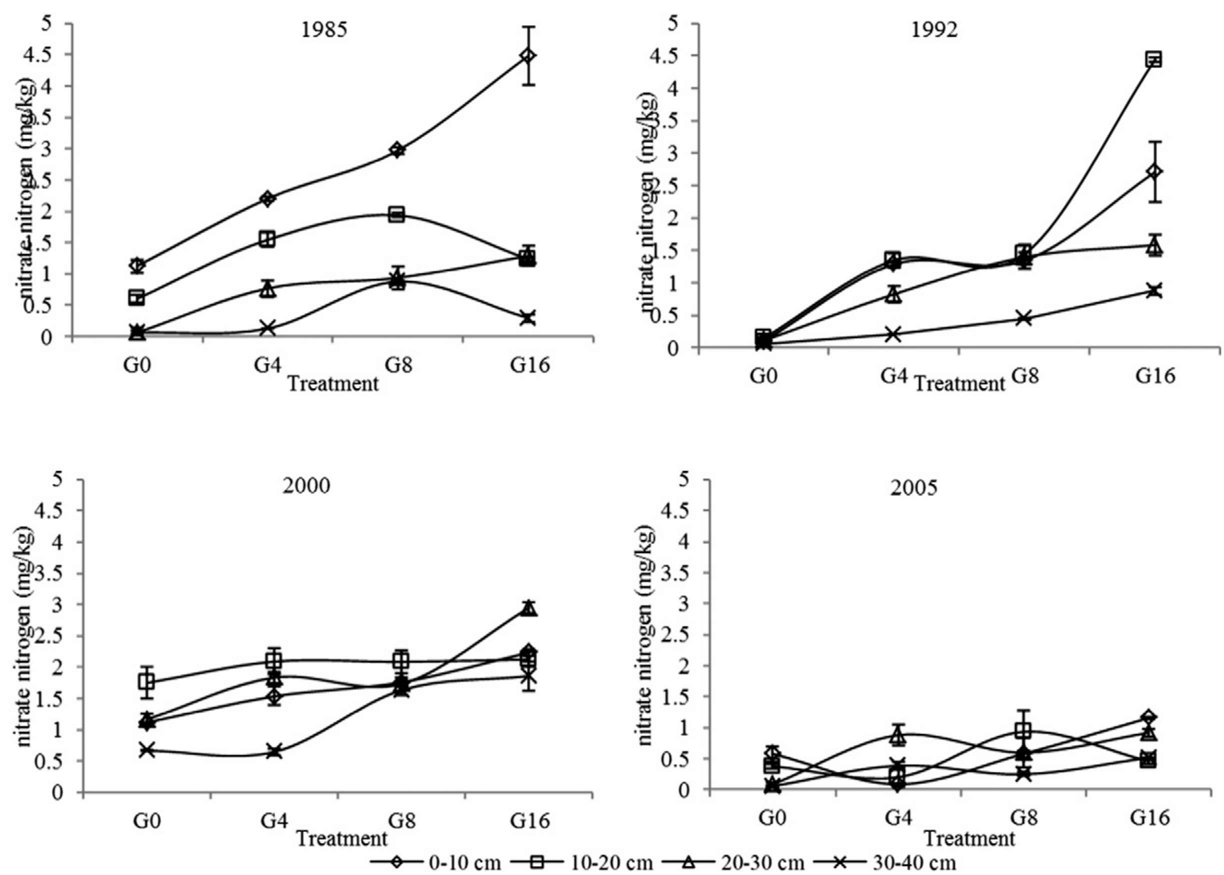


**Fig. 5.** Effects of biochar on the nitrate nitrogen content in different grassland locations.

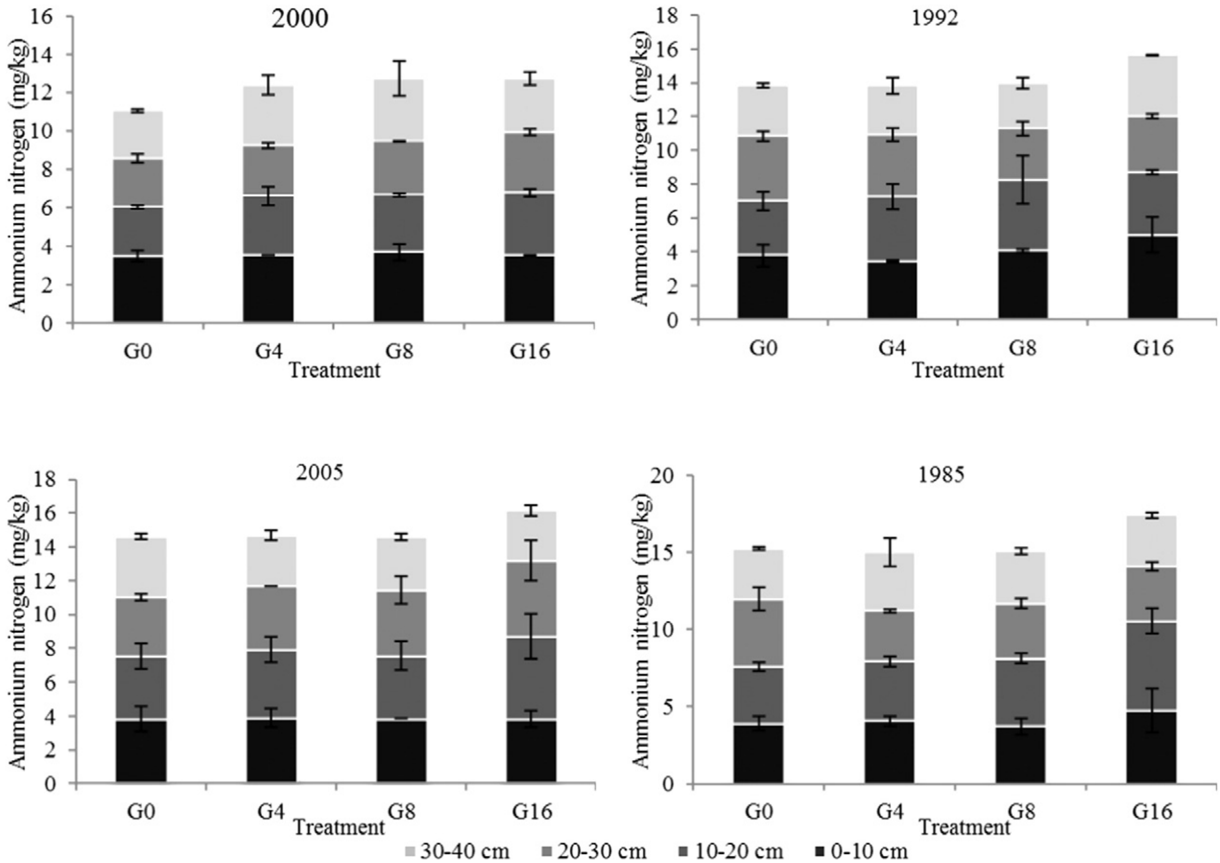


**Fig. 6.** Effects of biochar on the ammonium nitrogen content in different grassland locations.

5.34 g/kg and 10.67 g/kg, respectively. However, the mean increase of soil organic matter content in the 0–20 cm was approximately 1.3 g/kg, 3.1 g/kg, and 4.86 g/kg when 2.67 g/kg, 5.34 g/kg and 10.67 g/kg biochar was added, respectively. This result indicates that in the Loess Plateau, the use of biochar can increase soil carbon but may also stimulate soil organic carbon mineralization.

### *4.2. Biochar can manipulate the soil nitrogen cycle*

Biochar can improve the physical and chemical properties of the soil, change the soil pH and alter soil microbial populations, all of which can affect nitrogen cycling (Anderson et al., 2011; Anderson et al., 2014; Lentz et al., 2014). Research to date has shown that biochar has the ability to reduce nitrogen loss and manipulate the rates of nitrogen cycling in the soil (Clough and Condron, 2010; Huang et al., 2014). The direct mechanisms posited to explain the effect of biochar on nitrogen cycling processes are related to the properties of biochar such as its large surface area, highly porous structure and strong ion exchange capacity (Glaser et al., 2001). These properties of biochar are associated with nitrogen retention and soil water capacity. At the same time, the biochar contains nitrogen which can increase soil nitrogen directly or through the effects of priming, can improve the bioavailability of soil nitrogen (Luo et al., 2011). The main source of nitrate nitrogen loss in soil is $NO_3^-$ leaching, but biochar additions can significantly decrease $NO_3^-$ leaching (Zheng et al., 2013). The process of ammonium nitrogen volatilization can also be affected by biochar which can increase soil pH (Clough and Condron, 2010). However, in our study, the pH of the biochar was 8.38, but higher pH values were measured in the soils (Lou soil was 8.66, Black loessial soil was 8.71, Loessial soil was 8.82 and Aeolian sandy soil was 9). We used incubation experiments to study the effect of the biochar on the soil pH (Liu et al., 2012).The results showed that the application of biochar decreased the pH values of the soils, especially at higher biochar application rates. Moreover, biochar can indirectly affect nitrogen cycling by affecting the soil microbial community structure and thereby can have strong implications for soil microbial nitrogen processing (Anderson et al., 2011; Anderson et al., 2014).

### *4.3. Biochar can enhance soil phosphorus availability*

Phosphorus undergoes many chemical processes in soil such as complexation, solubilization and adsorption. These processes are a complex function which can be affected by the $CaCO_3$ and silicate clays content and determine the phosphorus mobility and fate (Afif et al., 1993). The addition of biochar to soil has been reported to enhance phosphorus availability and plant growth (Farrell et al., 2014). Biochar application can also increase the amount of extractable phosphorus in the soil solution regardless of the temperature used for biochar production (Zhao et al., 2014). The effect of biochar on soil phosphorus is related to its chemical composition and surface characteristics. Chintala et al. (2014) studied phosphorus sorption and availability in response to different biochars. Their results showed that the application of alkaline biochars can transform phosphorus from readily available to less available pools. The biochar itself may be a potential phosphorus source. Qian et al. (2013) studied the effects of environmental conditions on the release of phosphorus from biochar. Their results showed that the amount of phosphorus released from biochar was influenced by the retention time, coexisting anions and the contents of other nutrient elements. The interaction between phosphorus species and the surface

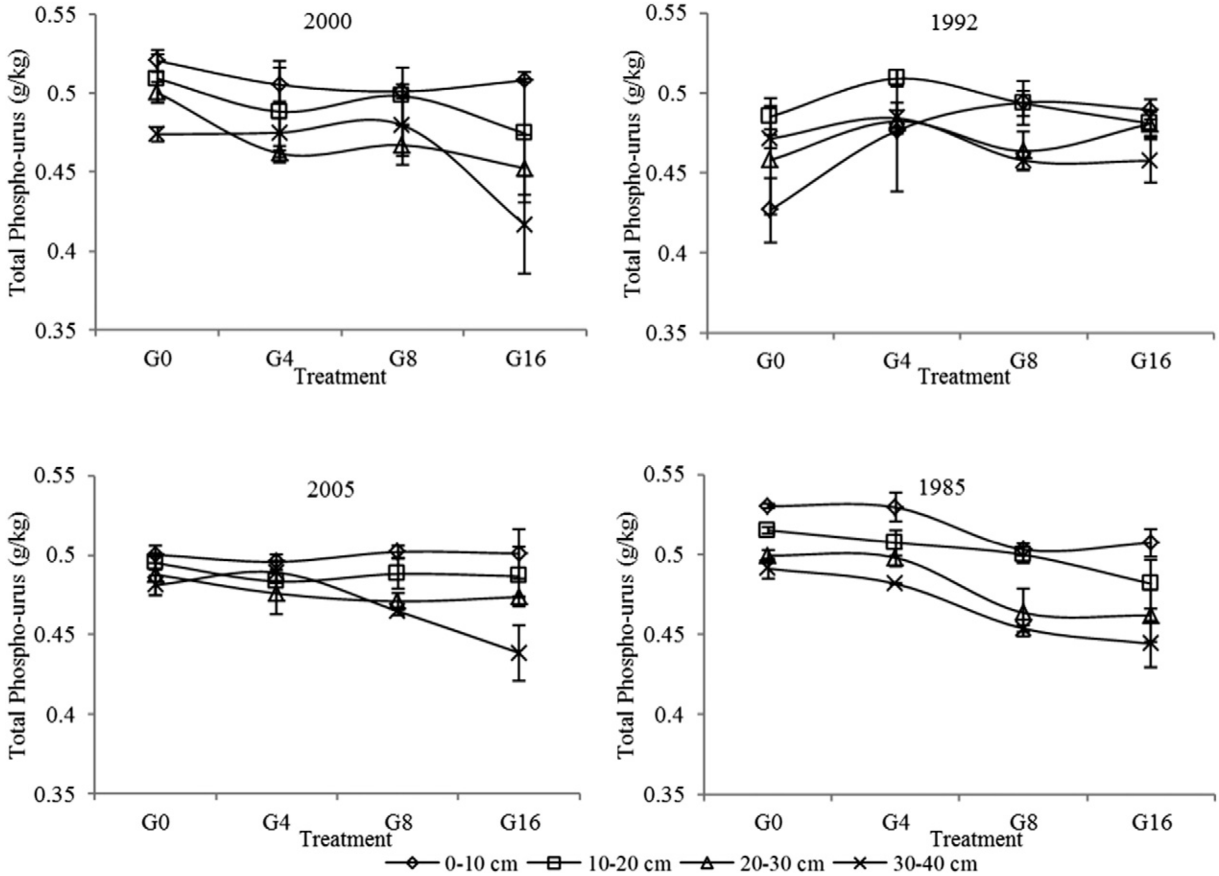


**Fig. 7.** Effects of biochar on the total phosphorus content in different grassland locations.

of the biochar is based on an "Ion Bridge", thus, cations and anions in solution may influence the migration of phosphorus.

## 5. Conclusions

In the Loess Plateau, biochar addition significantly increased the soil carbon content, especially in the 0–20 cm soil layer. However, soil organic carbon mineralization was simultaneously stimulated. The total nitrogen and nitrate nitrogen contents in the soil of four grasslands were improved by biochar application, especially at high rates. The biochar had limited effects on the soil ammonium nitrogen content, except in the 0–40 cm soil layer of the 2000 grassland, whereas the application of biochar could potentially decrease the phosphorus content in the 0–20 cm and 0–40 cm soil layers. Future field experiments should be performed to study the possible mechanism by which biochar affects soil nutrients.

**Table 4**
Analysis of differences in soil total phosphorus content under different amounts of added biochar.

| Nutrient type | Abandonment year | Depth (cm) | Biochar added (g/kg) | | |
|---|---|---|---|---|---|
| | | | 4 | 8 | 16 |
| Total phosphorus (g/kg) | 2005 | 0–20 | −0.01 | −0.005 | −0.005 |
| | | 0–40 | −0.005 | −0.01* | −0.015** |
| | 2000 | 0–20 | −0.02 | −0.015 | −0.025 |
| | | 0–40 | −0.018 | −0.015 | −0.038* |
| | 1992 | 0–20 | 0.035 | 0.04 | 0.03 |
| | | 0–40 | 0.028 | 0.018 | 0.018 |
| | 1985 | 0–20 | −0.005 | −0.02* | −0.03* |
| | | 0–40 | −0.005 | −0.03* | −0.04* |

4, 8, and 16 indicate the addition of 4 g/kg, 8 g/kg and 16 g/kg biochar, respectively.
** The mean difference is significant at the 0.01 level.
* The mean difference is significant at the 0.05 level.

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