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Effects of different land use patterns on soil properties and N₂O emissions on a semi-arid Loess Plateau of Central Gansu

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Nitrous oxide (N₂O) is one of the significant greenhouse gases in the atmosphere. Different land use patterns are the sink or source of N₂O, which plays a vigorous role in controlling N₂O emissions. Yet, how different land use patterns affect soil N₂O emissions in the Loess Plateau of Central Gansu is still not clear. Therefore; in order to fill this gap, six different land use patterns, including *Picea asperata* (PA), *Hippophae rhamnoides* (HR), *Medicago sativa* (MS), No-tillage wheat field (NT) and Conventional tillage wheat field (T) were studied. The objective of this study was to examine the impact of different land use patterns on soil properties and N₂O emission flux. Our results showed that compared with other treatments, *Picea asperata* woodland increased the soil bulk density, organic matter and soil water content, total nitrogen accumulation and microbial biomass nitrogen whilst reduced the soil pH. The wheat field is more favorable to accumulating soil nitrate nitrogen and ammonium nitrogen. Moreover, soil N₂O emission rates followed the trend of T>NT>HR>GL>MS>PA. In addition, soil physicochemical properties were closely related to N₂O emission flux and soil temperature was the most significant factor affecting N₂O emission. General, *Picea asperata* woodland could significantly increased soil nutrient and reduce N₂O emissions. We suggest that more forest land should be selected as the optimal site for nitrogen fixation and emission reduction for sustainable development of the terrestrial ecosystem on the Loess Plateau in Central Gansu.

KEYWORDS

land use patterns, microbial biomass nitrogen, N₂O emission, nitrogen accumulation, soil properties, semi-arid

1. Introduction

With the progressively severe global greenhouse effect, the nitrous oxide (N₂O) emission has become close attention of scientists globally (Ravishankara et al., 2009; IPCC, 2021). The N₂O is one of the important greenhouse gas in the atmosphere which increases the global warming (IPCC, 2021). Its concentration in the atmosphere is less compared with carbon dioxide (CO₂) and methane (CH₄) but its warming potential is 296 times greater than CO₂ and nine times greater than CH₄ on a 100-year scale, and it can remain in the atmosphere for long

periods and participate in a variety of photochemical reactions that damage the ozone layer (IPCC, 2013). Studies have shown that land use change has now been identified as the second-largest source of greenhouse gas emissions (Arneeth et al., 2017). Different land use patterns can alter soil properties and affect soil nutrient distribution and biogeochemical cycling processes, thereby influencing global climate (Eduardo et al., 2011). In addition, different land use patterns have different ecosystem structures, community compositions, and biomass, which absorb and fix nutrients at different rates, which can cause dynamic changes in soil GHG emissions (Shigehiro et al., 2002). Therefore, studying soil N₂O emissions under different land use patterns is important for promoting regional carbon and nitrogen balance, mitigating N₂O emissions and global warming (Chiti et al., 2018).

As the most significant manifestation of human utilization of natural resources, land use impacts regional soil and water conservation, ecological development, and climate change (Shi et al., 2014). However, different scholars have different views on the impact of land use methods on soil physical, chemical, and biological properties and greenhouse gas emissions. A study by Merino et al. (2011) on soil greenhouse gas emissions from arable, pasture, and woodland in southern Europe concluded that N₂O emissions from arable and pasture land were three and six times higher than woodland. Similarly, Li et al. (2012) pointed out that the net balance between soil carbon and nitrogen input (such as litter input) and output (such as greenhouse gas emissions) as soil carbon and nitrogen accumulation in subtropical regions is huge. At the same time, Zhang et al. (2019) also showed that the nitrogen mineralization of forest land is higher than that of garden land and agricultural land. In recent decades, due to socioeconomic reasons, the scale of land use in most arid and semi-arid areas has expanded rapidly, but the impact of different land use patterns on N₂O emission in arid and semi-arid areas have not well studied yet. The lack of research in this area may limit our understanding of land use changes on the global climate, especially in the Loess Plateau region where vegetation is destroyed and soil erosion is serious.

Land use changes are often accompanied by changes in the soil matrix, soil microbial properties and chemistry (Hong et al., 2021), which individually or interactively affect N₂O production, consumption, and diffusion processes (Lubbers et al., 2013; Lagomarsino et al., 2016). Several studies have shown that soil water content and temperature can strongly regulate soil N₂O emissions under land use change. Within the soil saturation range, soil water content has a linear relationship with soil N₂O emissions and water content is greater than soil saturation. Soil denitrification is enhanced, a large amount of N₂O generates N₂, and soil N₂O emissions are reduced. At the same time, increased temperature stimulates microbial activity, which in turn promotes the release of N₂O from the soil (Frey et al., 2013). In addition, the production of N₂O in soils is influenced by the carbon and nitrogen content of the substrate (Chadwick et al., 2000). Liu et al. (2021) found that the available nitrogen content of farmland soil is high, while the available carbon content of grassland soil is high, and the difference in carbon and nitrogen in the two soils will lead to different conditions for N₂O production and emission. Although soil N₂O may be sensitive to changes in the soil matrix, soil microbial properties, and chemistry following land use change, it is not clear which major factors play a decisive role in influencing soil N₂O emissions.

The Loess Plateau is located in the north-central part of China, due to its increasingly severe ecological environment and complex geographical conditions, it has become one of the key research areas in ecology and related sciences (Na et al., 2020). In recent years, the infertile soils of the Loess Plateau, the low carrying capacity of the land, and the increase in greenhouse gas emissions have become increasingly prominent due to continuous human interference and unsuitable land use practices and the ecological environment of the region is likely to continue to deteriorate with global climate change (Sun et al., 2021). Therefore, our understanding of soil properties and N₂O flux under different land use patterns in the semi-arid region of the Loess Plateau is necessary. This study will provide a theoretical basis for the carbon and nitrogen sequestration during the restoration of the Loess Plateau ecosystem in Central Gansu and the optimal site type for reduction of nitrous oxide emission. The specific objectives of this study were: (1) evaluate the effects of different land use patterns on soil temperature, gravimetric water content, nitrate nitrogen, ammonium nitrogen, total nitrogen, microbial biomass nitrogen and soil organic carbon; (2) explore the influence of different land use patterns on soil N₂O emission; (3) capture the response of soil N₂O flux to variations in environmental variables due to different land use patterns.

2. Materials and methods

2.1. Site description

This study was carried out under the supervision of the department of Soil and Water Conservation at Dingxi Gansu Province (35°34'53" N, 104°38'30" E longitude with an altitude of 2000 m above sea level), Northwestern region of China (Figure 1). The research area is a typical hilly and gully area of the Loess Plateau. The climatic condition of study zone is semi-arid, with a large annual temperature difference. The average annual temperature is 6.9°C, the average annual precipitation is 400 mm, mainly concentrated in July–September, the average annual solar radiation is 5,930 MJ m⁻² with 2,480 h of sunshine per year, a frost-free period of 140 days. The soil of study areas is typical loess with sandy loam in texture. The area is dry with water deficient and the vegetation is scant. The natural vegetation is dominated by grasses such as Gramineae, Leguminosae, Compositae, mostly *Medicago sativa*, *Onobrychis viciifolia* and a small number of shrubs are distributed such as *Caragana Korshinski*, *Hippophae rhamnoides*. The arbor species are mainly *Platycladus orientalis*, *Picea asperata*, *Xanthoceras sorbifolium*, etc. The main crops of this area are *Zea mays*, *Solanum tuberosum*, *Linum usitatissimum*, *Triticum aestivum*.

2.2. Experimental setup and design

Based on the field investigation of the ecological environment characteristics and vegetation characteristics of the study area we took six different land use patterns viz., PA (*Picea asperata*), HR (*Hippophae rhamnoides*), MS (*Medicago sativa*), NT (no-tillage in wheat field), T (Conventional tillage in wheat field), on Loess Plateau in Central Gansu (Table 1; Figure 2). Three small plots were randomly selected in each experimental area, and the size depended on the vegetation type:

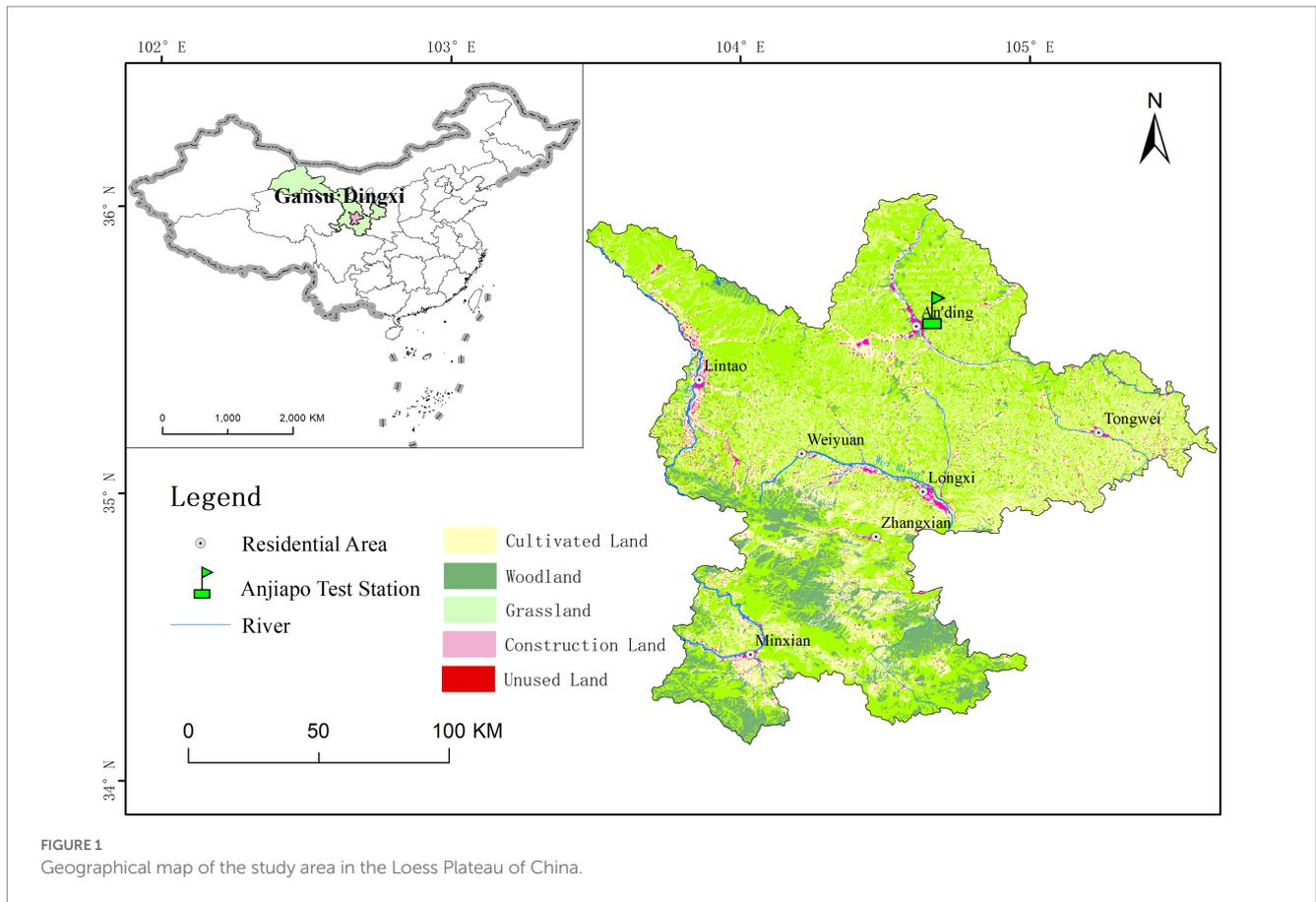


FIGURE 1
Geographical map of the study area in the Loess Plateau of China.

wheat field, grassland, *Medicago sativa* grassland 4 m × 6 m, *Hippophae rhamnoides* woodland 10 m × 10 m, *Picea asperata* woodland 20 m × 20 m. The selected wheat field was the local spring wheat “Ganchun 35” as the test variety, which was sown on March 25, 2021 and harvested on August 5. The seeding rate of each plot was 187.5 kg/hm², and the row spacing was 25 cm. A combination of 150 kg/hm² of diammonium superphosphate (N + P₂O₅) and 62.5 kg/hm² of urea was used as the basal dose. At the same time, a fixed gas extraction area of 0.5 m × 0.5 m was randomly set up in each fixed sample plot to collect and determine N₂O flux under different land use patterns.

2.3. Soil sampling and analysis

The disturbed soil samples from different experimental treatments (GL, PA, HR, MS, T and NT) were collected with an auger of 5 cm diameter, from March 2021 to February 2022 for the determination of soil properties. Five soil samples were taken from each individual plot and placed in a plastic bag and transported to laboratory for physical chemical analysis. The soil temperature was monitored by using the EM50 data collector after every 30 min. Soil water content, soil organic carbon, total nitrogen, nitrate nitrogen, ammonium nitrogen, microbial biomass nitrogen and soil pH electrical conductivity were determined in laboratory after passing soil samples through a 2 mm sieve. The oven-drying method was used for gravimetric soil water content determination (Défossez et al., 2021). The soil pH was measured by Potentiometric method (soil water ratio = 1:2.5) (Mao et al., 2016). The core sampler method was used for determination of soil bulk density

(Lu et al., 2019). Soil organic carbon (SOC) was determined by using the Walkley-Black dichromate oxidation method (Nelson, 1982). Soil TN was determined by the oxidation-external heating titration method (Huang et al., 2021), and soil microbial nitrogen (MBN) was determined using a chloroform fumigation-H₂SO₄ leaching method (Chen et al., 2021). The soil NO₃⁻-N and NH₄⁺-N were determined by the MgO-Devarda's alloy distillation method (Yang et al., 2014).

2.4. Determination and calculation of soil N₂O

N₂O emissions from soil shall be measured every half month from March 2021 to February 2022. Two weeks prior to starting measurements, three stainless steel bases (50 cm × 50 cm × 20 cm) were permanently installed in the soil at each site with at least a 5 m buffer zone between each steel base. The upper part of each base had a collar (3 cm) to support the sampling chamber. Located at the top of each open-bottom opaque stainless steel chamber (50 cm × 50 cm × 50 cm) were two fans powered by 12 v batteries used to mix the air inside the chamber during the N₂O flux measurements. A rubber seal strip was attached to the bottom perimeter of each chamber to provide an airtight seal when placed over the collar on the base in the soil. As done in previous studies (Ma et al., 2018), all samples were collected between 09:00 a.m. and 11:00 a.m. (local time) on the same day each week when the soil temperature was close to the daily mean soil temperature (Zou et al., 2005; Yao et al., 2013). After the chamber was closed, air

TABLE 1 Basic information on different land types.

Land use patterns	Geographic coordinates	Coverage (%)	Main species	Disturbance history of sample land and farming system
GL	104°37'57"E 35°34'54"N	>90	<i>Agropyron cristatum</i> (Linn.) Gaertn, <i>Artemisia frigida</i> Willd. Sp. Pl., <i>Stipagrandis</i> P. Smirn.	Abandoned in 1990, it was naturally restored to a grassland
PA	104°38'51"E 35°34'51"N	60	<i>Picea asperata</i> , <i>Agropyron cristatum</i> (Linn.) Gaertn	In 2005, Qinghai <i>Piceacracsi-folia</i> Kom, and after all the trees survived, it will naturally restore to spruce woodland.
HR	104°38'60"E 35°34'48"N	85	<i>Hippophae rhamnoides</i> , <i>Medicago sativa</i> , <i>Agropyron cristatum</i> (Linn.) Gaertn	It was felled and reclaimed before the 1990s, and in 2000, the "returning farmland to the forest (grass)" was implemented and naturally restored into a shrub community
MS	104°19'01"E 35°34'48"N	>90	<i>Medicago sativa</i> , <i>Agropyron cristatum</i> (Linn.) Gaertn	In 2015, alfalfa was planted based on cultivated land and enclosed, and no management, protection, or harvesting measures were carried out after survival.
T	103°52'E, 34°26'N	70	(<i>Triticum aestivum</i>)	After harvesting the wheat crop, the fields were ploughed thrice with shovel and harrowed 2 times followed by planting. The first ploughing was done in early-August immediately after harvesting the spring wheat crop, in late-August and early-September, the second and third ploughing, respectively, were done. The depths of plough were 20 cm, 10 cm and 5 cm, respectively. The field harrowing was done before the ground was frozen. This is the typical conventional tillage technique in the Dingxi zone of China. The spring wheat crop was planted with a small seeder drawn by a 13.4 kW (18 HP) tractor and designed by China Agricultural University, letting fertilizer's to be positioned under the seed-rows, followed by concave rubber press wheels in one operation.
NT	105°13' E, 35°35' N	70	(<i>Triticum aestivum</i>)	Sowing was done with no-tillage planter without using any tillage implement.

GL, Grassland; PA, *Picea asperata*; HR, *Hippophae rhamnoides*; MS, *Medicago sativa*; T, traditional tillage wheat field; NT, no-tillage wheat field.

samples (five in total) were taken from inside the chamber at 8 min intervals (at minutes 0, 8, 16, 24, and 32) using a 100 ml polypropylene syringe equipped with a three-way plug valve. The air samples were transferred to pre-evacuated E-Switch aluminum foil composite film gas sampling bags (Shanghai Shenyuan Scientific Instruments Co., Ltd., Shanghai, China) via the three-way plug valve. Within 48 h, the samples were returned to the laboratory for analysis of N₂O concentrations using a gas chromatograph (Agilent 4890D, Agilent Technologies, Wilmington, Delaware, USA). The ratios of each set of 5 samples were linearly fitted to the corresponding sampling intervals. When the linear regression coefficient R² > 0.75, it is regarded as valid data and used to calculate the emission flux of the target gas.

Calculation of the emission flux of N₂O:

$$F = \rho \times \frac{V}{A} \times \frac{\Delta c}{\Delta t} \times \frac{273}{273 + T}$$

In the formula: F is the emission flux of N₂O, $\mu\text{g}\cdot(\text{m}^2\cdot\text{h})^{-1}$, ρ is the density of N₂O in the quasi-state ($\text{kg}\cdot\text{m}^{-3}$), V is the adequate space volume in the airtight box (m^3), A is the water surface area covered by the closed box (m^2), ΔC is the concentration difference of N₂O gas (expressed as the volume fraction of air), Δt is the sampling interval (h), T is the temperature of the closed box during sampling ($^{\circ}\text{C}$).

Calculation of N₂O cumulative emissions:

$$M = \sum_{i=1}^n \left(\frac{F_i + F_{i+1}}{2} \right) \times (t_{i+1} - t_i) \times 24$$

In the formula: M is the cumulative N₂O emission ($\text{kg}\cdot\text{hm}^{-2}$), F is the emission flux of N₂O, $\mu\text{g}\cdot(\text{m}^2\cdot\text{h})^{-1}$, $t_{i+1} - t_i$ is the time interval of the i th and $i + 1$ sampling (d), n is the total number of measurements during the observation period.

2.5. Statistical analysis

The study data obtained from the research field were tested at 5% probability level with one-way factor interaction ANOVA by using an appropriate SPSS 25 (IBM Corp., Chicago, IL, USA) computer software program. The significant differences among different experimental treatments and their interaction were compared with an LSD test. The relationships amongst different soil properties were analyzed using Pearson's correlation coefficient. The study data is presented as the mean values of three replications with standard deviation. Furthermore, principle component analysis (PCA) was done in order to assess the multivariate variability introduced by the different treatments for soil properties and N₂O emission in the soil system.

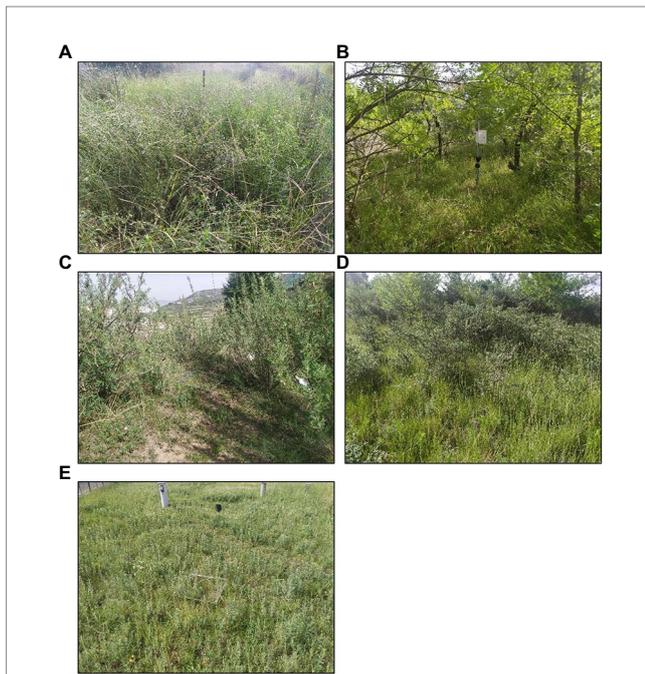


FIGURE 2
Photographs of sampling plots with different land use patterns: (A) Grassland; (B) *Picea asperata*; (C) *Hippophae rhamnoides*; (D) *Medicago sativa*; (E) The wheat field.

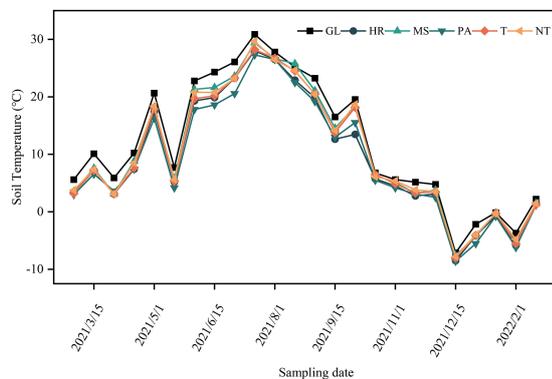


FIGURE 3
Soil temperature under different land use patterns on a semi-arid Loess plateau China.

3. Results

3.1. Soil properties under different land use patterns

Seasonal soil temperature variation under six different land use patterns was consistent. From the beginning of the growing season, the soil temperatures fluctuated upward as arial temperatures gradually warmed (Figure 3). The soil temperature peaked from mid-July to mid-August during summer whilst it declined in December during winter. Soil temperature under GL treatment was highest and it was lowest under PA treatment. The mean soil temperature under the GL, PA, HR, MS, T and NT treatments was 11.66, 8.78, 9.31, 10.16, 9.68 and 10.01°C, respectively.

Land use patterns significantly affected soil properties (Table 2). Compared with GL treatment, *Picea asperata* woodland significantly increased soil bulk density, soil water content and soil SOC and decreased soil pH value. Soil pH values showed that the soils of experimental site were alkaline, and the average pH of wheat fields was similar and significantly higher than that of the control sites, with the highest in T treatment and the lowest in PA treatment. Soil water content was the highest in PA treatment and lowest in T treatment. The soil SOC contents under the six land use patterns were PA > GL > T > NT > HR > MS, being significantly higher under *Picea asperata* woodland than other land use patterns. There was no significant difference between CT and NT treatments in the wheat field.

Soil nitrogen is an important indicator reflecting soil fertility and biological activity. It can be seen from Figure 4 that among the six different land use patterns, the soil TN content of the GL plot was significantly lower than that of the other five vegetation types ($p < 0.05$), and the specific trend was PA > HR > MS > NT > T > GL. Compared with GL, the contents of TN increased by 41.44, 30.63, 25.45, 15.99 and 11.04% under PA, HR, MS, NT, and T treatments, respectively. There was no significant difference was noted between HR, MS, T and NT treatments; however, significant difference ($p < 0.05$) was seemed between PA treatment and other treatments. Soil MBN content was significantly affected between different land use patterns (Figure 4B). The PA treatment had significant higher MBN (28.28 mg kg^{-1}) whilst T treatment had lowest (18.03 mg kg^{-1}) MBN value. The PA, HR and MS increased MBN by 38.36, 22.11 and 9.05%, respectively. Our results showed that *Picea asperata* woodland increased TN and MBN accumulation.

TABLE 2 Soil physicochemical properties at 0–20cm under different land use patterns.

Land use patterns	Soil bulk density $\text{g}\cdot\text{cm}^{-1}$	pH (1:2.5)	Soil moisture content %	SOC ($\text{g}\cdot\text{kg}^{-1}$)
GL	1.11 ± 0.017D	7.90 ± 0.011B	16.56 ± 0.105 BC	11.30 ± 0.330B
PA	1.22 ± 0.015A	7.62 ± 0.005E	17.83 ± 0.432A	12.04 ± 0.260A
HR	1.12 ± 0.006D	7.71 ± 0.015D	16.15 ± 0.007C	9.52 ± 0.501CD
MS	1.13 ± 0.010D	7.81 ± 0.015C	16.90 ± 0.725B	9.23 ± 0.064E
T	1.15 ± 0.006C	8.33 ± 0.010A	14.96 ± 0.083D	9.85 ± 0.172C
NT	1.17 ± 0.006B	8.32 ± 0.011A	16.22 ± 0.067C	10.06 ± 0.230C

GL, Grassland; PA, *Picea asperata*; HR, *Hippophae rhamnoides*; MS, *Medicago sativa*; T, traditional tillage wheat field; NT, no-tillage wheat field. Different capital letters indicate a significant difference between treatments at ($p < 0.05$) level.

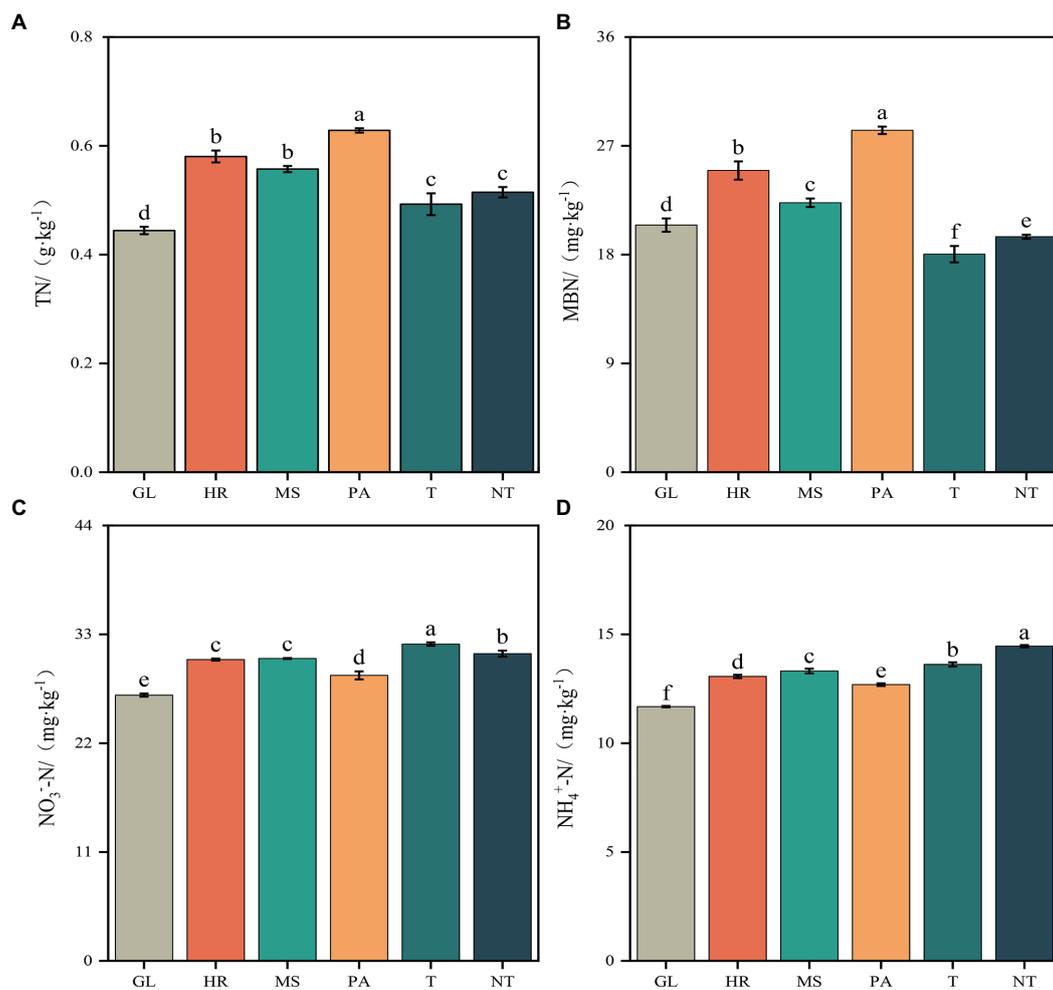


FIGURE 4

Changes in soil nitrogen composition under different land use patterns. Response of soil nitrogen contents to different land use patterns. Vertical error bars represent the standard error of mean values. Different lower-case letters show significant differences between different treatments at $p < 0.05$. Panel (A) is the soil total nitrogen values as influenced by the land use patterns. Panel (B) is the microbial biomass nitrogen under different land use patterns. Panel (C) is the nitrate nitrogen under different land use patterns. Panel (D) is the ammonium nitrogen as affected by the different land use patterns.

The content of soil NO_3^- -N (32.02 mg/kg) was the highest under T treatment and the lowest in treatment GL (26.85 mg/kg), followed the trend of $T > NT > MS > HR > PA > GL$. In addition, the content of NH_4^+ -N under GL treatment was lower than that of other land use patterns. Compared with GL treatment, the NT, T, MS, HR, and PA treatments increased soil NH_4^+ -N by 23.8, 16.61, 14.04, 11.9 and 8.65%, respectively. In general; compared with GL, the contents of NO_3^- -N and NH_4^+ -N in soil under other land use patterns increased with varying degrees especially in conventional and no-tillage system in wheat field.

3.2. Response of soil N_2O flux to different land use patterns

Our study data depicted apparent seasonal variations in N_2O emission. The highest N_2O emission risen during summer months being peak occurring in July under CT followed by NT, HR, GL, MS and PA. In addition, there was no significant difference in soil N_2O

emissions under the different land use patterns during autumn and winter months (Figure 5).

All land use patterns served as nitrous oxide emitters during the study period. Our results showed that the T treatment had highest cumulative N_2O flux value whilst PA treatment had lowest cumulative N_2O flux value. The order of cumulative N_2O flux under all treatments was $T > NT > HR > GL > MS > PA$ (Figure 6). Compared with PA, the T, NT and HR treatments increased cumulative N_2O emission by 113.64, 91.02 and 16.66%, respectively.

3.3. Principle component analysis

According to Jolliffe cut-off value the Principle component analysis (PCA) permitted for isolating five principal components. The observation point made by a collaboration of PC1 and PC2 shows the general variance defined by the five main components in accordance with PCA analysis.

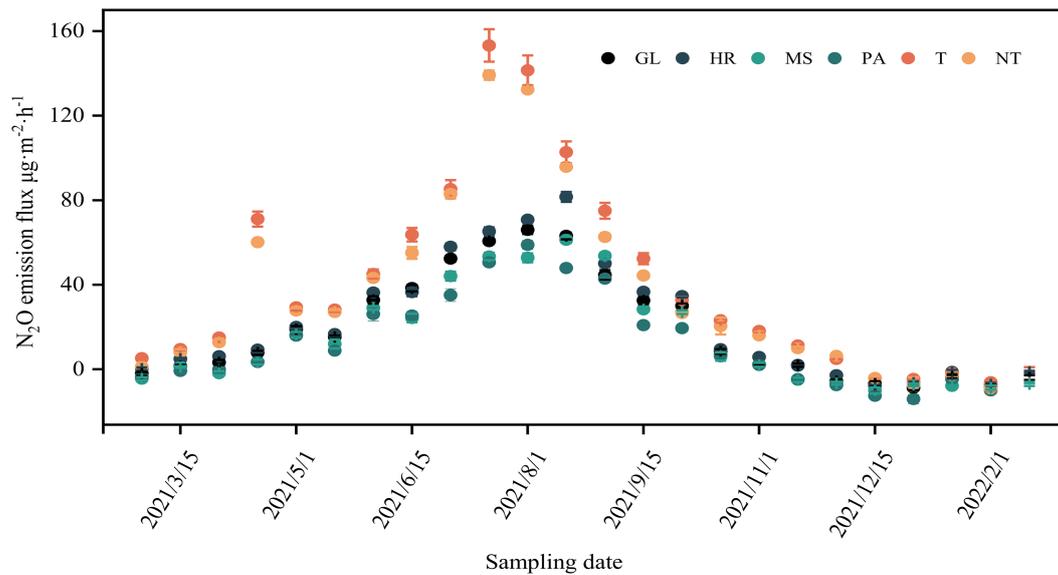


FIGURE 5
Seasonal changes of N₂O emission under different land use patterns.

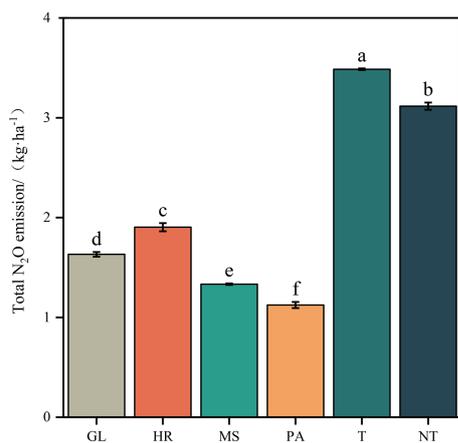


FIGURE 6
Response of cumulative N₂O flux to different land use patterns on a semi-arid Dingxi. Vertical error bars represent the standard error of mean values. Different lower-case letters show significant differences between different treatments at $p < 0.05$.

In the PCA analysis of nine variables (*viz.*, ST, SWC, pH SOC, MBN, TN, N₂O, NO₃⁻-N and NH₄⁺-N), PC1 and PC2 were extracted with eigenvalues (>1) and explained 63.8% of the total variance. However, PC3, PC4, and PC5 do not permit the supplementary information addition; that is why they are not involved. The maximum loadings of PC1 comprise 42.3% of the total variance and in PC2 the higher loadings of 21.5% of the total variance were detected (Figure 7).

3.4. Factors influencing N₂O emissions

Our study showed significant positive correlation between N₂O emission and soil and environmental factors. Soil temperature had

significant positive correlation with N₂O emission. Furthermore, soil water content, soil pH, and soil NO₃⁻-N, NH₄⁺-N, TN and MBN were significantly positively correlated with N₂O emission. Additionally, a negative correlation was observed between N₂O emission with soil organic carbon. Fluctuations in N₂O emission appeared to be described by dissimilarities in soil temperature, moisture content and nitrogen contents with data variance 95% described by these soil and environmental variables (Figure 8).

4. Discussion

4.1. Effects of land use patterns on soil properties

Land use is one of the essential components of an ecosystem and its changes have a significant impact on soil properties (Deng et al., 2018). Previous study by Yan et al. (2021) have shown that there are overall soil pH differences among land use patterns and forest land has the lowest pH. Another study by Wang et al. (2020) found that the forest soil system has better water holding capacity and water supply capacity, and the SOC content in the forest is significantly higher than shrubs and grasslands. Our results found that compared with Grassland, *Picea asperata* woodland significantly increased soil bulk density, soil water content and soil SOC content, and decreased soil pH because arbor forest land was richer in vegetation, litter and root systems. There are more secretions, and the decomposition process of litter will cause soil acidification (Qiao et al., 2014). At the same time, forest vegetation can also change the forest environment, reduce solar radiation and temperature differences and increase soil moisture (Özkan and Gökbulak, 2017). Creating a stable environment for litter decomposition. In addition, due to the large degree of human disturbance in wheat fields and shrub grasslands, the vegetation community structure is relatively simple, and the litter and root densities are lower than those of arbor fields. Therefore, *Picea asperata*

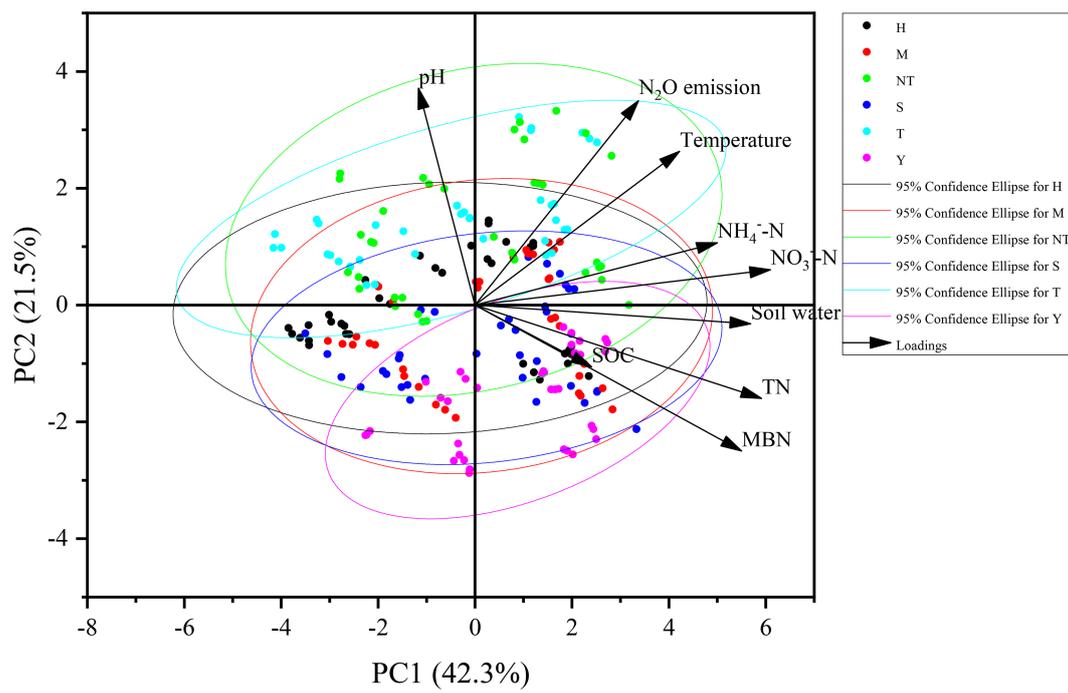


FIGURE 7
Principal component analysis of soil properties and N₂O emission under land use patterns.

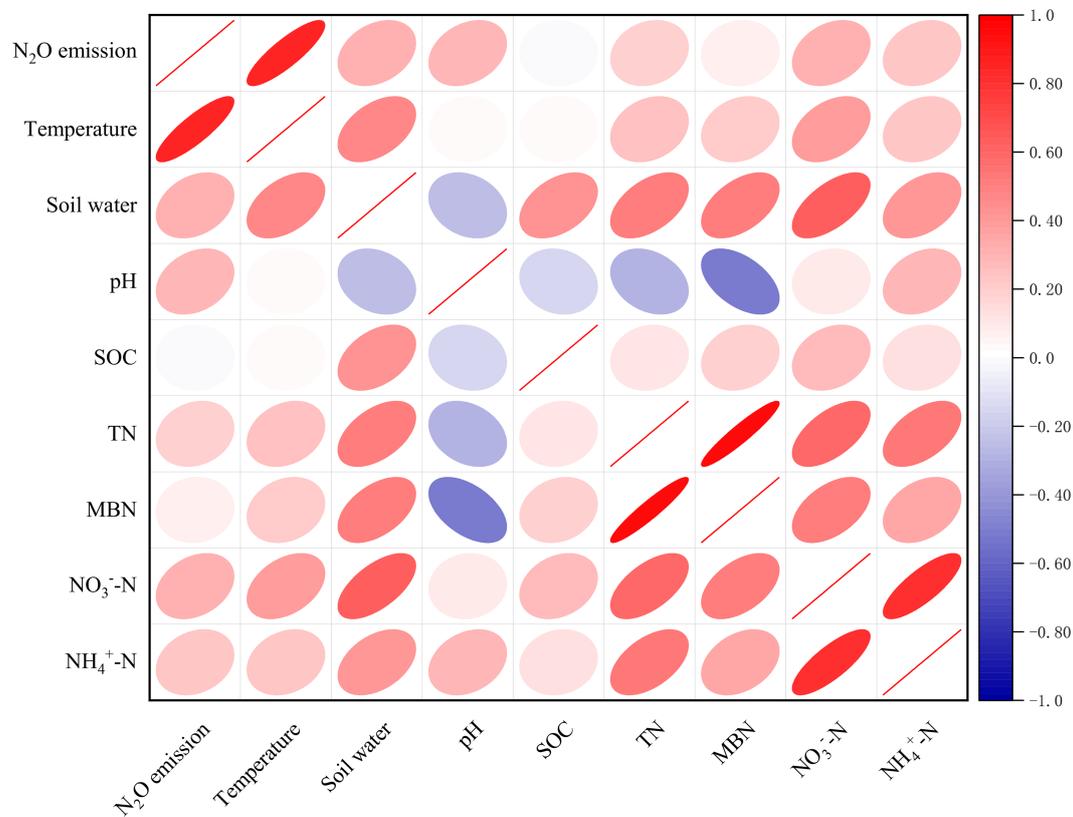


FIGURE 8
Correlation between soil N₂O emissions and soil properties under land use patterns.

woodland can increase the soil bulk density, organic matter and water content and reduce the soil pH value.

Different land use patterns can affect the content and distribution of nitrogen components in the soil to varying degrees (Cheng et al., 2013). Studies have shown that nitrogen-fixing tree species in forests can increase soil nitrogen stocks and promote soil nitrogen cycling (Rothe et al., 2002). This study showed that the soil N content of the five land-use patterns increased to varying degrees compared with that of the Grassland, with the total N and microbial N content of the *Picea asperata* woodland being significantly higher than that of the shrub grassland and wheatland. On the one hand, the *Picea asperata* woodlands have lush vegetation growth and are accompanied by a large number of herbs, so the *Picea asperata* woodlands provide a large amount of litter, animals, and microbial residues for the soil surface, which can effectively speed up the decomposition rate of vegetation litter and promote the return rate of nutrients. (Anurag et al., 2019). On the other hand, because the biomass of woodland vegetation is mainly concentrated in the above-ground part, and the surface soil is well-aerated and nutrient-rich, it is more conducive to soil microbial activity. In addition, the ripe harvest of crops will lead to the loss of a large amount of organic matter in the soil, and various tillage measures led to soil system changes, which accelerate the mineralization and decomposition of soil organic matter (Shi et al., 2013), thus leading to TN and MBN accumulation in forest soils. The content is significantly higher than that of agricultural grassland. The content of ammonium and nitrate nitrogen in wheat field was significantly higher than in the other treatments. The specific performance was that the soil ammonium nitrogen content was the largest under the NT treatment and the nitrate nitrogen content was higher under the T treatment. This is because the human disturbance in wheat fields is higher than that in forest and grassland, and the application of basal fertilizer during sowing will lead to the accumulation of ammonium and nitrate nitrogen in the soil. In addition, NT treatment reduced soil compaction and soil disturbance benefits the nutrient accumulation and crop root growth whereas plough layer under CT increased the soil compaction (Fiorini et al., 2020). The high NO_3^- -N content of the soil surface under conventional tillage is due to the destruction of the soil surface layer by conventional tillage, which results in the loss of soil nutrients and reduced moisture content, making it easier to convert NH_4^+ -N to NO_3^- -N which in turn leads to an increase in soil NO_3^- -N content (Pisani et al., 2017).

4.2. Effects of different land use patterns on soil N_2O emissions

The N_2O flux varies significantly under different land use patterns. In this study, the average N_2O flux from agricultural soils was more significant than that from grassland, which is consistent with the findings of Lin et al. (2009). The cumulative N_2O flux of farmland soil was highest, possibly due to the increase of nitrogen content by nitrogen fertilizer application in farmland, thus promoting N_2O emission. Furthermore, the systematic plowing of farmland can promote mineralization to generate ammonium and nitrate nitrogen thus increasing soil nitrogen accumulation. When soil temperature and humidity conditions are suitable, a large amount of N_2O is released. However, there is also a study by Schaufler et al. (2010) who declared that the grassland had more

N_2O emission than farmland. The high activity of microorganisms in grassland stimulates the accumulation of soil nitrogen and the dense roots of grassland and litter on the ground are the reasons for the high N_2O emission from grassland. The N_2O flux is higher in spring and summer but lower in autumn and winter. The first emission peak of N_2O occurred around April 15, specifically for the T treatment. This is due to the application of basal fertilizer at sowing, which starts to take effect and allows some of the nitrogen to enter the soil and the soil to emit some of the N_2O through respiration but due to the low temperature and weak microbial activity of the soil at this time, the N_2O emissions are relatively low and therefore a small emission occurs. From July to August, the soil N_2O emission was more under all treatments being highest under T treatment because during summer the hydrothermal conditions are more good and suitable. The temperature regulates the N_2O emission from the soil through its influence on the activities of nitrifying bacteria, denitrifying bacteria and other microorganisms. In addition, the rainfall during summer months was relatively more concentrated and rainfall water infiltrated into the soil which led to an anaerobic conditions and promotes nitrification and denitrification processes. This is consistent with the findings of Pendall et al. (2010). In addition, at the end of spring wheat growth, the demand for nitrogen in the soil becomes less. At the same time, the surface litter returns nitrogen source to the soil through decomposers' decomposition, hence the concentration of nitrogen in the soil increases, thereby enhancing denitrification (Cao et al., 2019). The N_2O emission during winter months was very low and there was almost no difference in the soil N_2O emission under different land use patterns. This might be due to the low winter temperature, the soil's low moisture content and the inorganic nitrogen. The results of this study showed that compared with the GL treatment, the T treatment significantly increased soil N_2O emissions specifically $T > NT > HR > GL > MS > PA$. This is because of good and better water permeability and air permeability under conventional tillage. The conventional tillage system favors to the transformation of soil anaerobic environment to an aerobic environment, thus promotes the nitrification process to produce N_2O and also strengthens the gas diffusion and nutrient cycling, so that soil SOC, NH_4^+ -N, and NO_3^- -N move up from deep soil to surface soil again, so that surface dead vegetation enters into the lower soil layer and accelerates its decomposition, thereby promoting the emission of N_2O in the soil (Du et al., 2022). In addition, no-tillage increases the soil capacity and reduces the gas diffusion rate, which in turn allows the N_2O produced by nitrification and denitrification to be further reduced to N_2 before it can emit from the surface soil, thus reducing N_2O emissions (Du et al., 2022). In general, the woodland had lowest N_2O emissions, probably due to unfertilized woodland and also might be taller plants, denser plants growth, shady conditions throughout the year and relatively low soil temperature which reduces evaporation and leaching losses.

4.3. Factors affecting N_2O emission

N_2O emission is mediated by microbial nitrification (autotrophic/heterotrophic nitrification) and denitrification (Bond-Lamberty et al., 2004; Guetlein et al., 2018). Nitrifying (ammonia-oxidizing archaea,

AOA; ammonia-oxidizing bacteria, AOB) and denitrifying genes [nitrite reductase (encoded by *nirS/nirK*)], are considered to be the rate-limiting step in nitrification and denitrification, respectively, which are main process in the production of N_2O (Jones et al., 2014; Kits et al., 2019). At the same time, The environmental factors such as soil temperature and soil moisture influence on soil N_2O emissions. Our correlation analysis showed a very significant positive correlation between soil N_2O emissions and soil temperature. This is because of the nitrification and denitrification processes that can be carried out from 5°C to 35°C. The soil temperature regulates N_2O emissions mainly by influencing the structure of the *nirS*-type denitrifying microbial community, and the activity of denitrifying bacteria increases by 1.5 to 3.0 times for every 10°C increase in temperature (Xing et al., 2021). On the other hand, the soil temperature also increases the respiration of microorganisms in the soil which produces the anaerobic conditions for denitrifying organism's resultant in higher N_2O emission (Braker et al., 2010). This study also showed that soil N_2O emissions were significantly and positively correlated with soil water content, pH, and NO_3^- -N, TN and NH_4^+ -N which is consistent with the results of previous study (Qin et al., 2021). The higher soil moisture mainly affects the community structure of *nirK* and *nosZ* gene-containing microorganisms, stimulating the growth of some microorganisms in small abundance, including Bradyrhizobium with the *nirK* gene and Tardiphaga with the *nosZ* gene, thus regulating the emission of N_2O (Qin et al., 2021). In addition, an increase in soil moisture content also increases the enrichment of effective soil carbon and oxygen, affecting the distribution of oxygen concentrations in the soil and the activity of nitrifying and denitrifying microorganisms, which in turn causes N_2O emissions (Hu et al., 2015). Moreover, the soil pH can directly regulate N_2O emissions by affecting biological and abiotic processes (Zaman et al., 2012). It is generally believed that the pH in between 6 and 8 is most favorable for denitrifying bacterial activity. Soil microbial activity significantly enhanced with the increasing pH value, leading to enhanced soil denitrification and increased N_2O emission (Zaman et al., 2012). Moreover, increasing soil TN, nitrate nitrogen and ammonium nitrogen content will provide a good nitrogen source for nitrification and denitrification. It has been found that ammonia-oxidizing bacteria start to grow immediately after the addition of a nitrogen source. Ammonia-oxidizing bacteria (AOB) and ammonia-oxidizing archaea (AOA) can oxidize ammonia and produce N_2O (Kou et al., 2015; Dong et al., 2018). NO_2^- from soil denitrification, which can accumulate under certain conditions also has a large potential for N_2O emissions (Giguere et al., 2017). At the same time, available nitrogen in soil provides an electron donor for denitrifying microorganisms, promoting the occurrence of denitrification, thus increasing N_2O emissions (Cao et al., 2019).

5. Conclusion

Our results showed that *Picea asperata* woodland increased the soil bulk density, organic matter, soil water content, total nitrogen and microbial biomass nitrogen accumulation and decreased soil pH compared with other treatments. Moreover, the wheat field is more favorable to the accumulation of soil NO_3^- -N and NH_4^+ -N. In this study, land use patterns had a more significant impact on N_2O flux. Compared with abandoned land, *Picea asperata* woodland significantly

reduced N_2O flux, specifically T>NT>HR>GL>MS>PA. The correlation study showed that soil physicochemical properties were closely related to N_2O emission fluxes and soil temperature was the most significant factor affecting N_2O emission. Therefore, in combination with the restoration and sustainable development of the terrestrial ecosystem on the Loess Plateau in Central Gansu, we suggest that more forest land should be selected as the optimal site for nitrogen fixation and emission reduction in the future projects of returning farmland to forests and grasslands. This study provides vital scientific support for efficient land use and ecological environmental protection in the Loess Plateau of Central Gansu with poor soil and low land carrying capacity. However, considering that climatic factors, soil microbial community structure and field management measures will jointly affect soil N_2O emissions, we still need a deeper understanding and a more comprehensive study of the mechanism of different land use patterns on soil physical and chemical properties and greenhouse gases to achieve higher climate change mitigation.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

MD and JY: data processing, methodology, visualization, and writing – original draft. MZ: data processing. JW: investigation. GX, SL, and JL: sample collection and experimental operation. GL and LY: design test, supervision, and funding acquisition. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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