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Patterns of soil nitrogen mineralization under a land-use change from desert to farmland

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Abstract

Understanding how soil nitrogen (N) mineralization (N_{min}) responds to environmental changes is critical for improving ecosystem management, especially in a resource-constrained region. Intensive land exploitation in arid land has profound influences on soil ecosystems and thus on soil N_{min}. A local-scale field investigation was conducted to reveal the temporal dynamics of N_{min} under land-use change from desert to farmland, and to verify the mechanisms controlling N_{min} change during this process in a typical desert oasis region. The results showed that N_{min} ranged from −0.14 to 2.69 mg N kg^{-1} day^{-1}, with an average value of 0.74 mg N kg^{-1} day^{-1}. N_{min} in old oasis farmland (OOF) was significantly higher than that in GCF (Gobi desert conversion farmland) and SCF (sandy desert conversion farmland), and the average change rates of N_{min} were 0.036 and 0.032 mg N kg^{-1} day^{-1} year^{-1} in GCF and SCF, respectively. Structural equation modelling (SEM) was used to test whether the measured variables affected N_{min}, and the results showed that soil organic matter (SOM), bulk density (BD) and sand content were the main soil factors affecting N_{min}. These soil factors, together with farmland type and cropping time, can explain 31% of the variation in N_{min}. Our observations revealed that N_{min} changed substantially under the land conversion process from desert to farmland, and our findings will help with assessments and predictions of future N cycles in desert oasis regions in response to land-use change.

Highlights

- We used N_{min} as an observed variable to evaluate the dynamics of the soil evolution process under a land-use change from desert to farmland.
- Cropping year was identified by using map image data to reveal temporal trend of N_{min}.
- N_{min} was primarily affected by soil organic matter, bulk density and sandy content. Intensive land exploitation in arid land profoundly influences soil N_{min}.

KEYWORDS
desert oasis, land-use change, nitrogen mineralization, sand content, soil organic matter

1 | INTRODUCTION

Nitrogen (N) is an essential element for life and is often the limiting nutrient in terrestrial ecosystems (Navarro-Gonzalez, McKay, & Mvondo, 2001). The N cycle is of particular interest to ecologists because N availability can affect the rate of key ecosystem processes, including primary production and decomposition (LeBauer & Treseder, 2008). In most ecosystems, soil N availability is largely determined by the processes of soil N mineralization (N_{min}) (Raison, Connell, & Khanna, 1987), and the conversion of organic N to inorganic N as a result of microbial activity. Understanding how environmental factors influence N_{min} is essential for the provision of sustainable ecosystem services, especially in a resource-constrained ecosystem (Urakawa et al., 2016). Land use change can be a major driver of nutrient cycles through mediating nutrient accumulation, turnover and transportation (Laganiere, Angers, & Pare, 2010). A growing body of evidence (Batlle-Aguilar, Brovelli, Porporato, & Barry, 2010; Yang, Zhang, Gao, Mao, & Liu, 2010) has demonstrated that land-use changes have the potential to alter ecosystem N_{min} processes, but the magnitude and direction of the alteration depend on environmental conditions and management practices. Elucidating the effects of land-use change on the N_{min} processes under different climate, land use, soil and scale scenarios will help to predict soil nutrient availability and dynamics under the various land-use conversion processes. However, experimental evidence in this field is still scarce in desert oasis areas.

Over recent decades, increased demand for food and fibre because of the rapidly growing human population in desert oasis regions has led to the extensive conversion of native desert in the fringes of oases into intensively managed agricultural lands (Yang, Su, Wang, & Yang, 2016). The evolution of the soil ecosystem in this transformation process is a long-standing issue and has gained renewed interest among ecologists in recent years, driven by concerns that the intensive land exploitation in the region may lead to changes in soil properties, ecosystem functioning and stability (Smith et al., 2016; Su, Yang, Liu, & Wang, 2010). However, it remains unclear how biochemical nutrient cycle processes, such as N_{min}, have responded to these land-use changes, and the evidence for the dynamics of soil nutrient cycles in arid land regions has mainly come from the experiments located in single land-use types (Hu, Wang, Pan, Zhang, & Zhang, 2014). Furthermore, much of the uncertainty on how land conversion processes affect ecosystem structure, function and stability originates from the lack of risk assessment of excessive land exploitation in desert oases. Thus, more useful evaluation indices for ecosystem evolution following land-use change in desert oasis regions are needed.

Therefore, a local-scale sampling investigation was performed in a typical desert oasis region, and the soil N_{min} was selected as an observed variable to evaluate the dynamics of soil ecosystem development under a land conversion process from desert to farmland. The main objectives of this study were to contrast the N_{min} differences between the different land-change types, to reveal the temporal dynamics of N_{min} under the land-use conversion process and to verify the mechanism controlling N_{min} change in this conversion process.

2 | MATERIALS AND METHODS

2.1 | Study site

This study was conducted in a marginal oasis farmland area (between 39°18′ and 39°23′N and 99°56′ and 100°11′E, with an altitude ranging from 1,361 to 1,470 m) in Pingchuan town, which is located beside the Heihe River in Linze County (2,727 km^2), Gansu Province, northwest China (Figure 1). The study area is adjacent to Gobi and sandy desert areas in the northeast. It has a typical desert climate, according to the Köppen climatic classification system, and is characterized by cold winters and dry hot summers. The long-term mean annual precipitation is approximately 117 mm, which is only one-twentieth of the mean annual pan potential evaporation (2,390 mm), and 90% of the total precipitation is distributed from June to September. The mean annual temperature is 7.6°C, varying from −10.7°C in January to 23.8°C in July. According to the Chinese Soil Taxonomy classification system, the soils are identified as *Siltigi-Orthic Anthrosols* in old oasis farmland (farmland in oasis interior with long-term agricultural-use history), *Calci-Orthic Aridosols* in Gobi desert, and *Aridi-Sandic Primosol* in sandy desert (Li et al., 2013; Su, Wang, Zhang, & Du, 2007a). Pingchuan town is an ecotone of desert and oasis, and land-use expansion from oasis fringes towards the desert has been very intensive in recent years. According to our unreported study results, the area of oasis increased from 78.65 km^2 in 1973 to 129.59 km^2 in 2011. In many marginal oasis farmlands, the soil of newly reclaimed farmland still has typical characteristics of desert soil; the absolute amounts of soil aggregate and nutrients are still low after 40 years of cropping and are insufficient to support sustainable crop production (Su et al., 2010). The natural vegetation outside of the oasis is classified as a desert grassland in which shrubs and subshrubs, such as *Calligonum mongolicum* Turcz., *Nitraria sphaerocarpa* Maxim., *Reaumuria soongorica* (Pall.) Maxim., *Haloxylon ammodendron* (C.A. Mey.) Bge., *Caragana korshinskii* Kom. and *Tamarix chinensis* Lour., are dominant. The staple crops in the oasis are spring wheat (*Triticum aestivum* L.),

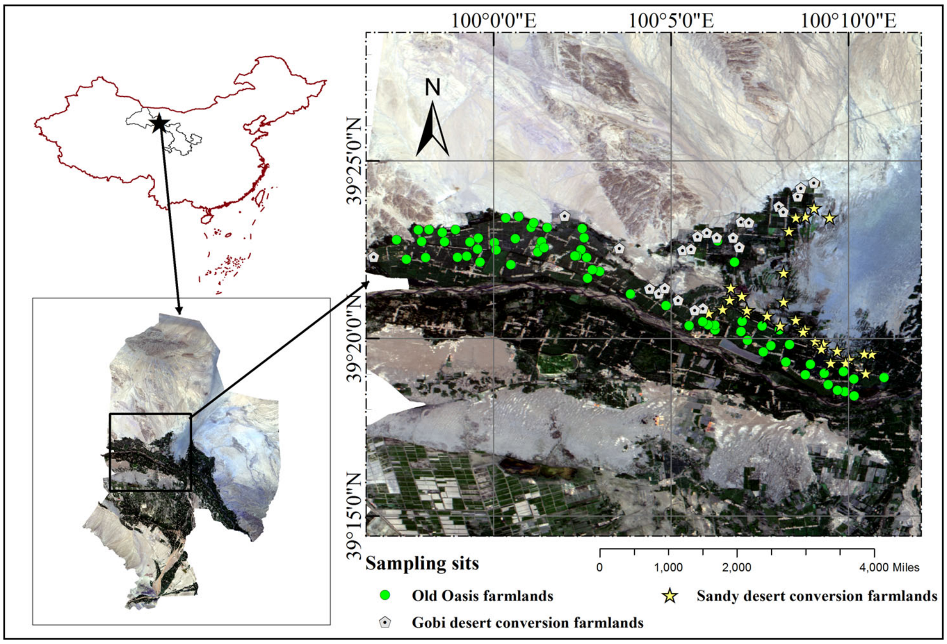

FIGURE 1 Location map of Linze County in China and spatial distribution of the sampling sites across farmlands on the oasis fringes

maize (*Zea mays* L.) and cotton (*Gossipium* spp. L.) (Su et al., 2007b).

2.2 | Field sampling and laboratory measurement

Soil samples were taken in September 2011 from 118 sampling sites in the farmlands of oasis fringes (Figure 1). The rough sampling sites were randomly signed on the map using a uniform distribution principle. Local farmers directed us to the location of each site, and then the accurate information on position was determined by a global positioning system (GPS) as the soil samples were collected. At each of the sampling sites, five samples (0–20 cm) were taken by using a 5-cm diameter soil auger from a 10 × 10 m area to make one mixed soil sample, and one undisturbed core sample was collected synchronously by using a steel cylinder (volume 100 cm^3) from the 0–20-cm soil layer. The mixed samples were air-dried at room temperature and separated into two subsamples. One subsample was ground to pass through a 2-mm mesh and subjected to particle-size analysis by the pipette method in a sedimentation cylinder using sodium hexametaphosphate as the dispersing agent (Gee & Bauder, 1986). Soil pH and electrical conductivity (EC, μS cm^{-1}) were measured in a soil-water suspension (1:1 and 1:5 soil:water ratio, respectively). The other subsamples were ground and passed through a 0.25-mm mesh for chemical analysis. Soil organic matter (SOM, g kg^{-1}) was measured by the dichromate oxidation method of Walkley-Black (Nelson & Sommer, 1982), and total nitrogen (TN, g kg^{-1}) was measured by the micro-Kjeldahl procedure (Bremmer & Mulvaney, 1982). Undisturbed soil core samples were used to determine soil bulk density (BD, g cm^{-3}), field water-holding capacity (FC, %) and saturated water-holding capacity (SC, %) by the Wilcox method (Cassel & Nielsen, 1986).

The water-logged incubation method was used to measure soil N_{min}, and the incubation experiment was conducted using mixed samples in the laboratory (Jiang, 2000). First, 20 g of air-dried soil samples were placed in incubation bottles and mixed with 20 mL of deionized water. Then the incubation bottles were sealed, shaken for 30 min at 260 rpm, and placed on a digital biochemical incubator for 1 week (7 days) at 40°C. After KCl (2 mol L^{-1}) was extracted and filtered, inorganic N (NH_4^+-N plus NO_3^--N) was analysed using a direct-read discrete analyser for simple and automated chemistries (SmartChem 140, Alliance Instruments, Paris, France). The initial soil inorganic N was analysed using another 20 g of subsamples with no incubation. N_{min} was then calculated as follows:

$$N_{\min} = (A_1 - A_0)/\Delta t, \tag{1}$$

where N_{min} is the soil N mineralization rate (mg kg^{-1} day^{-1}), A_1 is the total inorganic N after incubation (mg kg^{-1}), A_0 is the initial total inorganic N (mg kg^{-1}) and Δt is the incubation time (days).

2.3 | Statistical analyses

The normality of the data was evaluated using the Kolmogorov–Smirnov test, and all variables exhibited a normal distribution. To evaluate the effect of land-use change on N_{min}, the farmlands were classified into separate groups with different land use histories. Google Earth image data from 1984 were used to identify land use types as farmland, Gobi desert and sandy desert. According to the land use type in 1984, the farmlands were thus divided into three types, which included old oasis farmland (OOF, the farmland since 1984) and two conversion farmland types (conversion from other land use types after 1984). The conversion farmland types were then defined as Gobi desert conversion farmland (GCF, converted from Gobi desert) and sandy desert conversion farmland (SCF, converted from sandy desert). We then compared the N_{min} differences among the different groups using a general linear model (GLM) with the least significant difference (LSD) tests. Conversion year in each sampling site was determined with the map image data using Google Earth Timelapse (Google Inc., Santa Clara, California, USA), and cropping time then was confirmed. Thus, the temporal change trend of N_{min} under the two land-conversion processes was analysed using a linear regression model.

Pearson correlation analysis was performed to reveal the relationship between N_{min} and soil physical (BD, FC, SC, sand content, silt content and clay content) and chemical properties (SOM, TN, pH and EC). To estimate the main factors influencing N_{min} variations, a structural equation model (SEM) was generated. An SEM is a multivariate statistical tool that uses the covariance among many variables to build models that test pathways of influence among those variables (Colman & Schimel, 2013). The model was used to discriminate the direct and indirect factors influencing N_{min}. First, following current concepts, we proposed an *a priori* model of the hypothesized relationship within a drafted path diagram, in which we included all correlated variables, to depict the direct and indirect effects of environmental variables on the response variables (N_{min}) (Grace, 2006). We assumed that soil properties could directly influence the response variables, whereas farmland type and cropping time would have both indirect and direct effects through their influence on soil properties. Second, the model was tested and path coefficients were obtained using the maximum likelihood estimation technique. The traditional χ^2-goodness-of-fit test was performed to estimate the modelling, and a low χ^2 and high *p*-value (>0.05) was the desired goal. The normed fit index (NFI) and root mean square error of approximation (RSEA) indices were also considered and checked according to Schermelleh-Engel, Moosbrugger, and Müller (2003). Then, the model was optimized to increase the whole-model *p*-value by removing the path and variables with a coefficient < 0.10 from the model and enacting the changes according to modification indices. This iterative process continued until model fit was consistent with the data (Colman & Schimel, 2013).

All statistical analyses were conducted in SPSS (SPSS for Windows, Version 19.0; SPSS, Chicago, IL, USA). The linear function was fitted using regression functions in Origin software (OriginLab for Windows, Version 8.5; OriginLab, Northampton, MA, USA) and the SEM analyses were performed with AMOS 22.0 (Amos Development Co., Armonk, NY, USA).

3 | RESULTS

3.1 | N_{min} patterns

N_{min} varied from −0.14 to 2.69 mg N kg^{-1} day^{-1}, with an average of 0.74 mg N kg^{-1} day^{-1} across the study area. N_{min} showed a strong spatial variation, with a coefficient of variation (CV) value of 62%. The one-sample K-S test showed that N_{min} followed the normal distribution (K-S, N_{min} $p > 0.05$).

3.2 | Land conversion effect on N_{min}

Land conversion processes have significant effects on soil N_{min} (Table 1). The mean values of N_{min} were 0.87, 0.60 and 0.58 mg N kg^{-1} day^{-1} in OOF, GCF and SCF, respectively. N_{min} was also significantly higher under OOF than under GCF, by 45%, and under SCF by 50%, but the difference between N_{min} under GCF and SCF was not statistically significant at the $p = 0.05$ level. GCF and SCF showed stronger N_{min} variations than OOF, and the CV values of N_{min} were 27 and 7% higher in GCF and SCF than in OOF. Both under GCF and SCF, N_{min} was strongly negatively associated with cropping time, and N_{min} ($R^2 = 0.16$, $p = 0.03$; $R^2 = 0.26$, $p < 0.01$) decreased significantly with cropping time (Figure 2). The change rates of N_{min} were 0.036 and 0.032 mg kg^{-1} day^{-1} $year^{-1}$ under GCF and SCF (slopes of the linear regression equation in Figure 2).

3.3 | Main factors influencing N_{min} variations

The correlation analysis showed that N_{min} was significantly influenced by soil chemical and physical properties (Table 2). SOM, TN, EC, FC, SC, silt content and clay content were positively correlated with N_{min}, but pH, BD and sand content were negatively correlated with N_{min}. The results of SEM showed that SOM, BD and sand content were the main soil factors affecting N_{min} (Figure 3) and that they can explain 31% of the variation in N_{min} together with farmland type and cropping time. With a high direct effect, the SOM and sand content effects on N_{min} were further analysed by partitioning SOM into series categories (0–6, 6–9, 9–12, 12–15, 15–18 g kg^{-1}) (Figure 4a) and classifying soil texture into

TABLE 1 Soil nitrogen mineralization rates (N_{min}, mg N kg^{-1} day^{-1}) of farmlands' response to land-use type

Source of variation	*df*	Mean square	F	*p*
Land use type	2	1,198	6.20	0.003
Error	115	0.19		

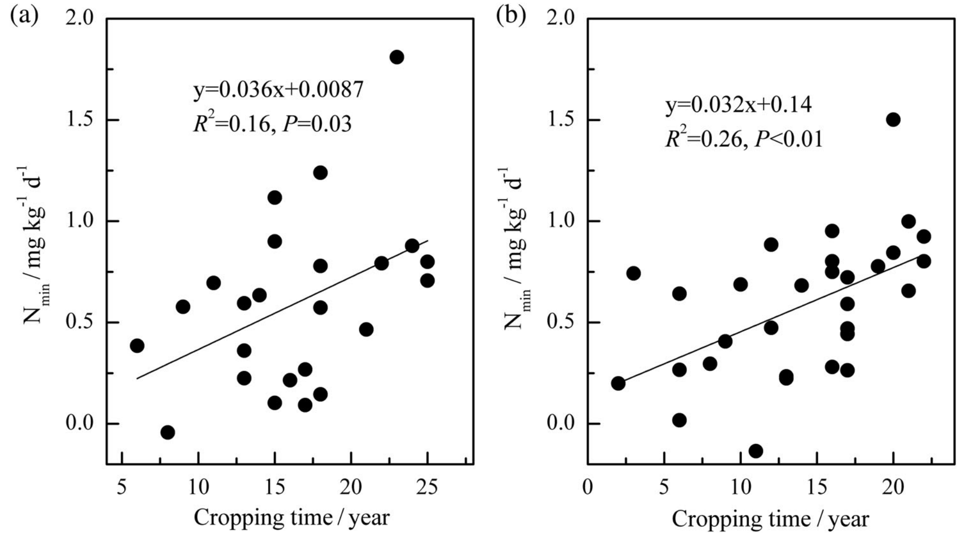

FIGURE 2 Change trends in soil nitrogen mineralization (N_{min}) along with the cropping time under a Gobi desert conversion process (a) and sandy desert conversion process (b)

several types using the United States Department of Agriculture Textural Classification System (Figure 4b). The results showed that N_{min} was especially small in soils with low organic matter contents and sandy textured soils.

4 | DISCUSSION

4.1 | Soil N_{min} in farmlands of the marginal oasis ecosystem

The mean value of soil N_{min} was 0.74 mg kg^{-1} day^{-1} across all farmlands in this marginal oasis area, and this value was 71, 75 and 76% lower than that on global, Asia and China scales, respectively, according to the soil N_{min} estimations from other studies (Liu et al., 2016, 2017). The lower soil N_{min} observed in this study can be linked to lower soil nutrient levels (Schlesinger, Raikes, Hartley, & Cross, 1996) and limited microbial biomass (Gallardo & Schlesinger, 1992) in the desert soils. This conclusion can be confirmed by a study from Colman and Schimel (2013), who reported that lower soil nutrients and microbial biomass caused the lower N_{min} in desert ecosystems. Furthermore, the chosen analysis methodology of water-saturated incubation could also contribute to the low soil N_{min}, because water-saturated incubation of soil samples can result in microbial cell death, and some N mineralized during the incubation is believed to be derived from lysed cells.

4.2 | Changes in N_{min} under a conversion process from desert to farmland

Nitrogen mineralization under OOF was significantly higher than that under GCF and SCF. This difference indicated that

TABLE 2 Pearson correlation coefficients between nitrogen mineralization rates (N_{min}, mg N kg^{-1} day^{-1}) and soil physical and chemical properties (n = 118)

	Soil chemical properties				Soil physical properties					
	SOM	TN	pH	EC	BD	FC	SC	Sand	Silt	Clay
TN	**0.92**									
pH	**−0.42**	**−0.43**								
EC	0.092	0.064	−.095							
BD	−0.11	**−0.24**	**0.25**	−.082						
FC	*0.19*	**0.28**	**−0.41**	0.13	**−0.47**					
SC	0.058	*0.19*	*−0.22*	0.13	**−0.91**	**0.58**				
Sand	**−0.27**	**−0.37**	**0.36**	**−0.24**	**0.51**	**−0.65**	**−0.53**			
Silt	**0.28**	**0.39**	**−0.44**	*0.21*	**−0.49**	**0.61**	**0.47**	**−0.92**		
Clay	0.073	0.16	*−0.18*	*0.21*	**−0.47**	**0.53**	**0.52**	**−0.88**	**0.70**	
N_{min}	**0.41**	**0.46**	**−0.28**	0.13	**−0.30**	**0.34**	*0.22*	**−0.45**	**0.44**	**0.34**

[a]SOM: soil organic matter; TN: soil total nitrogen; EC: electrical conductivity; BD: soil bulk density; FC: field moisture capacity; SC: saturation moisture capacity. The bold values of r are significant at p < 0.01, italic values are significant at p < 0.05 and those in plain font are not significant.

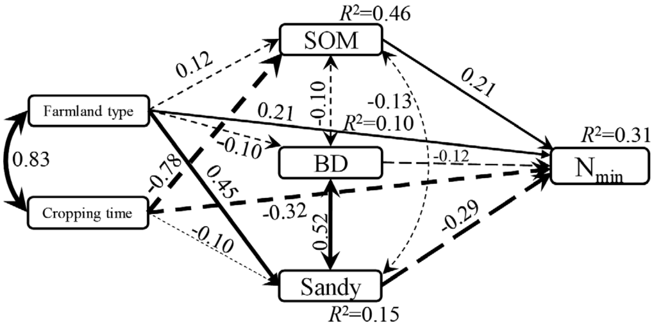

FIGURE 3 Base structural equation model with variables and potential causal relationships. Structural equation model depicting the direct and indirect effects of farmland type, cropping time, soil organic matter (SOM), soil bulk density (BD) and sand content on soil nitrogen mineralization (N_{min}). Boxes indicate measured variables entered in the model. Numbers adjacent to arrows are standardized path coefficients. Continuous and dashed arrows indicate positive and negative relationships, respectively. Single-headed arrows represent causal relationships and double-headed arrows represent covarying variables. The path widths are scaled proportionally to the path coefficients and R^2 indicates the proportion of variance explained. The model for N_{min} ($\chi^2 = 0.03$, $p = 0.87$, normed fit index (NFI) = 0.998, root mean square error of approximation (RMSEA) < 0.05) was suggested by the results of goodness-of-fit tests

cultivation and soil amendments tend to increase soil N_{min}, which is consistent with a previous study in a semiarid area (Zhang, Wang, Li, & Han, 2008). Two factors may have contributed to this general pattern. First, the naturally poor soil nutrients in newly converted farmland (GCF and SCF) provide a poor substrate supply for N_{min} processes in the desert soils, but there was a relatively high soil nutrient and N level in OOF because of the long-term input of N fertilizer, organic matter and crop residues. Second, the changes in soil microbial biomass and composition should be considered in explaining the differences in N_{min} between different land-use types (Colman & Schimel, 2013; Gallardo & Schlesinger, 1992; Schlesinger et al., 1996). For example, Koberl, Muller, Ramadan, and Berg (2011) found a drastic shift in the bacterial communities in desert soil after long-term farming, and bacterial communities in agricultural soil showed higher diversity and better ecosystem functioning for plant health but a loss of extremophilic bacteria. Regardless of the underlying mechanisms, our results suggest that cultivation and soil amendment under a land conversion process from desert to farmland dramatically alter soil N pools and N_{min} and play an important role in mediating soil N availability.

Changes in N_{min} under a land conversion process could be estimated by calculating the CVs of N_{min} among different sites and the relationships between N_{min} and cropping time. The coefficients of variation of N_{min} between different sampling sites were calculated for the different land-use types, and GCF and SCF had much higher CVs for N_{min} than OOF. This indicated that the OOF had a relatively stable N_{min} and that GCF and SCF are undergoing a change process. Although the CV of TN was slightly different between GCF and SCF, the CV of N_{min} was 19% higher in GCF than in SCF. This could be because of differences in soil type or other initial environmental conditions as a result of differences in historical land use. If this is the case, it is expected that there would be a change rate in N_{min} that is in line with a temporal trend of land conversion. Our results are in agreement with this expectation, as N_{min} increased significantly

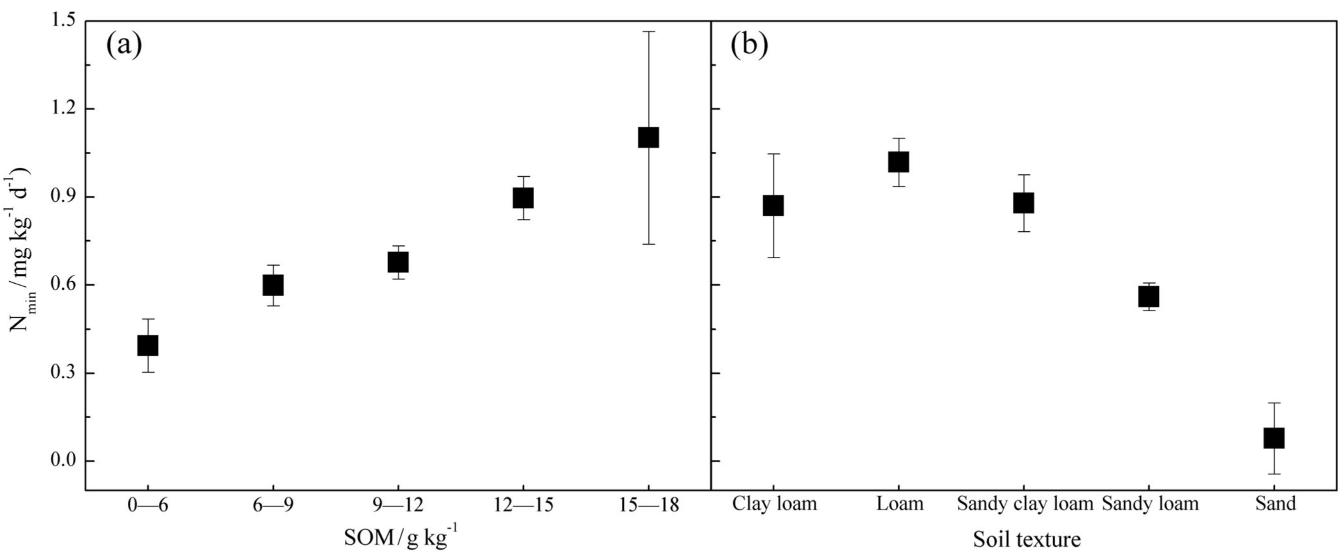

FIGURE 4 The effect of (a) soil organic matter (SOM) and (b) soil texture on soil nitrogen mineralization (N_{min}). SOM was partitioned into five categories with a 3 g kg^{-1} interval (0–6 were considered as one category because only one of the values falls into 0–3), and soil texture was classified into five types according to the United States Department of Agriculture textural classification system. The whiskers and the small squares represent the standard error (SE) and mean values, respectively

with time since conversion. It is easy to understand that with increasing time since the desert land was converted to farmland, there is an increase in the quantity of nutrient input, accompanied by a new microclimatic regime and enhanced organic matter protection (Laganiere et al., 2010), which promotes soil nutrient contents and N_{min}. Our study calculated the average change rates of soil N_{min} to be 0.036 and 0.032 mg kg^{-1} day^{-1} year^{-1} under GCF and SCF, respectively. The change trends with conversion age of N_{min} indicated that the converted farmlands require a long-term period to reach N supply levels close to those of OOF. However, the desert oasis is a water-limited ecosystem, and excessive farmland expansion towards the desert often meets with a serious lack of water resources (Cheng et al., 2014). Consequently, the converted land was abandoned under water-resource deficiency conditions. This is a major factor causing soil degradation in arid land (Wei, Shengkui, Haiyang, & Qi, 2009) and potentially leads to a reversal in the trend towards increasing soil nutrients and N_{min} in farmlands.

4.3 | The main factors influencing N_{min}

The significant relationships between soil physical and chemical properties have been widely reported, and SOM, TN, pH and soil texture were considered the main soil properties influencing N_{min} in some previous studies (Liu et al., 2016, 2017). Our results confirmed these relationships. Although there were significant correlations between the measured soil properties and N_{min}, the SEM results showed that only soil SOM, BD and sand content primarily affected N_{min}. Many studies confirmed that SOM is the most important factor influencing N_{min} by regulating the substrate supply (Bai et al., 2005), and SOM quality could explain a relatively large proportion of variation in N_{min} (Colman & Schimel, 2013). There were some disagreements on how soil texture affects N_{min}. For example, Hassink (1992) suggested that a large part of the organic matter is located in small soil pores, which constituted a higher percentage of the total pore space in loams and clays than in sandy soils, that could not be reached by microorganisms, and was therefore physically protected against decomposition and mineralization. However, N_{min} did not significantly differ under high SOM levels or in soil textures other than sandy clay loam. The results indicated that SOM and soil textures had a greater influence on N_{min} in the initial stage after land conversion, but their influence gradually decreased after soil nutrient and texture changes reached a certain threshold. On the other hand, the observed negative relationship between soil sand content and N_{min} in our study has also been reported in many studies (Liu et al., 2017). Although it is not the primary effect factor according to the SEM result, a significant negative correlation between pH and N_{min} was observed in our study. This result was confirmed by a study in adjacent forest and grassland soils (Cheng et al., 2013), but is inconsistent with other studies in which N_{min} increased with increasing soil pH because of its promoting effects on substrate availability (Fu, Xu, & Tabatabai, 1987) and the acidity limitation on soil microbial activity (Kemmitt, Wright, Goulding, & Jones, 2006). Soil moisture is also a major environmental factor affecting N_{min}. Field water-holding capacity and SC were positively correlated with N_{min} (Table 2) but were also not included in SEM result. This is mainly because they are highly correlated variables with BD and thus were excluded when BD already was selected for use in the model.

We used an SEM model to estimate the main factors influencing N_{min} variations and should acknowledge that SEM does not take into account the spatial autocorrelation of the samples, which increases the significance of the model coefficients. This is a limitation of SEM. The SEM model showed that soil properties, land use and length of cultivation can only explain 31% of the variation in N_{min}, and the result indicated that there were some other factors influencing N_{min} that were not considered. The strong effect of temperature and water on N_{min} was reported by some empirical studies (Kladivko & Kenney, 1987). The theory about cold and wet island effects of oases provided evidence that there were temperature and water gradients from desert to inner oasis in arid land ecosystems (Hao & Li, 2016). For example, Su and Hu (1988) reported a –5°C surface disturbance temperature gradient with ±5 km in the Hexi oasis, and these gradients could be another factor related to the variation of N_{min}. Additionally, soil microbes play a pivotal role in the soil N_{min} process, not only because they positively regulate soil N cycling (Hatch, Lovell, Antil, Jarvis, & Owen, 2000) but also because they are an important pool of readily mineralized organic N in soil (Bonde, Schnurer, & Rosswall, 1988). The effect of land-use changes on the microbial biomass and microbial community structure has been extensively reported in various terrestrial ecosystems (Acosta-Martinez, Dowd, Sun, & Allen, 2008; Bossio et al., 2005) and has also been reported in our study area (Wang et al., 2012). Furthermore, an increased quantity of organic manure input and frequency of the soil tillage with increasing cropping time could have a significant impact on the soil nutrients, structure, microbial community, temperature and water conditions during the process of desert conversion (Tuzzin de Moraes et al., 2016). These environmental changes resulting from anthropogenic activity should thus lead to greater variation in soil N_{min}.

5 | CONCLUSIONS

Based on a local-scale soil sampling dataset, this study explored the pattern of soil N_{min} and the influencing factors across farmlands in an oasis fringe. Our results revealed an average N_{min} of 0.74 mg N kg^{-1} day^{-1}, and a trend that N_{min} in OOF was significantly higher than that in GCF and SCF. The results also showed that N_{min} increases with cropping time, and the average change rates of N_{min} were 0.036 and 0.032 mg N kg^{-1} day^{-1} $year^{-1}$ in GCF and SCF, respectively. Despite the difficulty of pinpointing all the environmental factors influencing N_{min} change in the land-use change process, our work demonstrates that SOM, BD and sand content can explain much of the variation in N_{min}, highlighting the importance of organic fertilizer input and soil texture improvement in soil management of converted desert farmland.

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Data availibility statement

The data used to support the findings of this study are available from the corresponding author upon request.

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REFERENCES

Acosta-Martinez, V., Dowd, S., Sun, Y., & Allen, V. (2008). Tag-encoded pyrosequencing analysis of bacterial diversity in a single soil type as affected by management and land use. *Soil Biology and Biochemistry*, *40*, 2762–2770.

Bai, J., Ouyang, H., Deng, W., Wang, Q., Chen, H., & Zhou, C. (2005). Nitrogen mineralization processes of soils from natural saline-alkalined wetlands, Xianghai National Nature Reserve, China. *Canadian Journal of Soil Science*, *85*, 359–367.

Batlle-Aguilar, J., Brovelli, A., Porporato, A., & Barry, D. A. (2010). Modelling soil carbon and nitrogen cycles during land use change. A review. *Agronomy for Sustainable Development*, *31*, 251–274.

Bonde, T. A., Schnurer, J., & Rosswall, T. (1988). Microbial biomass as a fraction of potentially mineralizable nitrogen in soils from long-term field experiments. *Soil Biology & Biochemistry*, *20*, 447–452.

Bossio, D. A., Girvan, M. S., Verchot, L., Bullimore, J., Borelli, T., Albrecht, A., … Osborn, A. M. (2005). Soil microbial community response to land use change in an agricultural landscape of Western Kenya. *Microbial Ecology*, *49*, 50–62.

Bremmer, J. M., & Mulvaney, C. S. (1982). Nitrogen-total. In A. L. Page, R. H. Miller, & D. R. Keeney (Eds.), *Methods of soil analysis, part 3 - chemical methods* (pp. 1085–1120). Madison, WI: American Society of Agronomy.

Cassel, D. K., & Nielsen, D. R. (1986). Field capacity and available water capacity. In A. Klute (Ed.), *Methods of soil analysis, part 1 - physical and mineralogical methods* (pp. 901–926). Madison, WI: American Society of Agronomy.

Cheng, G., Li, X., Zhao, W., Xu, Z., Feng, Q., Xiao, S., & Xiao, H. (2014). Integrated study of the water–ecosystem–economy in the Heihe River basin. *National Science Review*, *1*, 413–428.

Cheng, Y., Wang, J., Mary, B., Zhang, J., Cai, Z., & Chang, S. X. (2013). Soil pH has contrasting effects on gross and net nitrogen mineralizations in adjacent forest and grassland soils in Central Alberta, Canada. *Soil Biology and Biochemistry*, *57*, 848–857.

Colman, B. P., & Schimel, J. P. (2013). Drivers of microbial respiration and net N mineralization at the continental scale. *Soil Biology & Biochemistry*, *60*, 65–76.

Fu, M., Xu, X., & Tabatabai, M. (1987). Effect of pH on nitrogen mineralization in crop-residue-treated soils. *Biology & Fertility of Soils*, *5*, 115–119.

Gallardo, A., & Schlesinger, W. H. (1992). Carbon and nitrogen limitations of soil microbial biomass in desert ecosystems. *Biogeochemistry*, *18*, 1–17.

Gee, W. G., & Bauder, J. W. (1986). Particle-size analysis. In A. Klute (Ed.), *Methods of soil analysis, part 1 - physical and mineralogical methods* (pp. 383–412). Madison, WI: American society of agronomy.

Grace, J. B. (2006). *Structural equation modeling and natural systems*. Cambridge: Cambridge University Press.

Hao, X., & Li, W. (2016). Oasis cold Island effect and its influence on air temperature: A case study of Tarim Basin, Northwest China. *Journal of Arid Land*, *8*, 172–183.

Hassink, J. (1992). Effects of soil texture and structure on carbon and nitrogen mineralization in grassland soils. *Biology & Fertility of Soils*, *14*, 126–134.

Hatch, D. J., Lovell, R. D., Antil, R. S., Jarvis, S. C., & Owen, P. M. (2000). Nitrogen mineralization and microbial activity in permanent pastures amended with nitrogen fertilizer or dung. *Biology & Fertility of Soils*, *30*, 288–293.

Hu, R., Wang, X., Pan, Y., Zhang, Y., & Zhang, H. (2014). The response mechanisms of soil N mineralization under biological soil crusts to temperature and moisture in temperate desert regions. *European Journal of Soil Biology*, *62*, 66–73.

Jiang, R. F. (2000). Analysis of soil nitrogen and Sulphur. In S. D. Bao (Ed.), *Soil and agricultural chemistry analysis* (pp. 58–61). Beijing, China: China Agriculture Press.

Kemmitt, S. J., Wright, D., Goulding, K. W., & Jones, D. L. (2006). pH regulation of carbon and nitrogen dynamics in two agricultural soils. *Soil Biology & Biochemistry*, *38*, 898–911.

Kladivko, E. J., & Kenney, D. R. (1987). Soil nitrogen mineralization as affected by water and temperature interactions. *Biology & Fertility of Soils*, *5*, 248–252.

Koberl, M., Muller, H., Ramadan, E. M., & Berg, G. (2011). Desert farming benefits from microbial potential in arid soils and promotes diversity and plant health. *PLoS One*, *6*, e24452.

Laganiere, J., Angers, D. A., & Pare, D. (2010). Carbon accumulation in agricultural soils after afforestation: A meta-analysis. *Global Change Biology*, *16*, 439–453.

LeBauer, D. S., & Treseder, K. K. (2008). Nitrogen limitation of net primary productivity in terrestrial ecosystems is globally distributed. *Ecology*, *89*, 371–379.

Li, F., Feng, Q., Liu, J., Sun, T., Ren, W., & Guan, Z. (2013). Effects of the conversion of native vegetation to farmlands on soil microarthropod biodiversity and ecosystem functioning in a desert oasis. *Ecosystems*, *16*, 1364–1377.

Liu, Y., He, N. P., Wen, X. F., Yu, G. R., Gao, Y., & Jia, Y. L. (2016). Patterns and regulating mechanisms of soil nitrogen mineralization and temperature sensitivity in Chinese terrestrial ecosystems. *Agriculture Ecosystems & Environment*, *215*, 40–46.

Liu, Y., Wang, C., He, N., Wen, X., Gao, Y., Li, S., … Yu, G. (2017). A global synthesis of the rate and temperature sensitivity of soil nitrogen mineralization: Latitudinal patterns and mechanisms. *Global Change Biology*, *23*, 455–464.

Navarro-Gonzalez, R., McKay, C. P., & Mvondo, D. N. (2001). A possible nitrogen crisis for Archaean life due to reduced nitrogen fixation by lightning. *Nature*, *412*, 61–64.

Nelson, D. W., & Sommer, L. E. (1982). Total carbon, organic, and organic matter. In A. L. Page (Ed.), *Methods of soil analysis, part 2 - chemical and microbiological properties* (pp. 539–579). Madison, WI: American Society of Agronomy.

Raison, R., Connell, M., & Khanna, P. (1987). Methodology for studying fluxes of soil mineral-N in situ. *Soil Biology & Biochemistry*, *19*, 521–530.

Schermelleh-Engel, K., Moosbrugger, H., & Müller, H. (2003). Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures. *Methods of Psychological Research Online*, *8*, 23–74.

Schlesinger, W. H., Raikes, J. A., Hartley, A. E., & Cross, A. E. (1996). On the spatial pattern of soil nutrients in desert ecosystems. *Ecology*, *77*, 364–374.

Smith, P., House, J., Bustamante, M., Sobocká, J., Harper, R., Pan, G., … Rumpel, C. (2016). Global change pressures on soils from land use and management. *Global Change Biology Bioenergy*, *22*, 1008–1028.

Su, C., & Hu, Y. (1988). Cold Island effect over oasis and lake. *Science Bulletin*, *33*, 1023–1026.

Su, Y., Wang, F., Zhang, Z., & Du, M. (2007a). Soil properties and soil aggregate characteristics in marginal farmlands of oasis in middle hexi corridor region. *Scientia Agricultura Sinica*, *6*, 706–714.

Su, Y. Z., Yang, R., Liu, W. J., & Wang, X. F. (2010). Evolution of soil structure and fertility after conversion of native sandy desert soil to irrigated cropland in arid region, China. *Soil Science*, *175*, 246–254.

Su, Y. Z., Zhao, W. Z., Su, P. X., Zhang, Z. H., Wang, T., & Ram, R. (2007b). Ecological effects of desertification control and desertified land reclamation in an oasis–desert ecotone in an arid region: A case study in Hexi corridor, Northwest China. *Ecological Engineering*, *29*, 117–124.

Tuzzin de Moraes, M., Debiasi, H., Carlesso, R., Cezar Franchini, J., Rodrigues da Silva, V., & Bonini da Luz, F. (2016). Soil physical quality on tillage and cropping systems after two decades in the subtropical region of Brazil. *Soil & Tillage Research*, *155*, 351–362.

Urakawa, R., Ohte, N., Shibata, H., Isobe, K., Tateno, R., Oda, T., … Kotani, A. (2016). Factors contributing to soil nitrogen mineralization and nitrification rates of forest soils in the Japanese archipelago. *Forest Ecology & Management*, *361*, 382–396.

Wang, B. Z., Zhang, C. X., Liu, J. L., Zeng, X. W., Li, F. R., Wu, Y. C., … Jia, Z. J. (2012). Microbial community changes along a land-use gradient of desert soil origin. *Pedosphere*, *22*, 593–603.

Wei, L., Shengkui, C., Haiyang, X., & Qi, F. (2009). Land use history and status of land desertification in the Heihe River basin. *Natural Hazards*, *53*, 273–290.

Yang, L., Zhang, F., Gao, Q., Mao, R., & Liu, X. (2010). Impact of land-use types on soil nitrogen net mineralization in the sandstorm and water source area of Beijing, China. *Catena*, *82*, 15–22.

Yang, R., Su, Y., Wang, T., & Yang, Q. (2016). Effect of chemical and organic fertilization on soil carbon and nitrogen accumulation in a newly cultivated farmland. *Journal of Integrative Agriculture*, *15*, 658–666.

Zhang, X. L., Wang, Q. B., Li, L. H., & Han, X. G. (2008). Seasonal variations in nitrogen mineralization under three land use types in a grassland landscape. *Acta Oecologica-International Journal of Ecology*, *34*, 322–330.

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