

Decomposition Characteristics of Long-established *Salix psammophila* Sand Barriers in an Arid Area, Northwestern China

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Salix psammophila has been extensively used as a sand barrier material for various desertification control applications. Elucidating the long-term decomposition characteristics and nutrient cycling process of this sand barrier in desert environments is of great importance. In this study, which was conducted for 1 to 9 years, changes in the mass loss percentage and the residual percentage in the decomposition process were explored of *S. psammophila* sand barriers in arid Northwestern China. In addition, the *S. psammophila* analysis nutrient elements release rule and its influence on soil properties were evaluated. The results showed that the decomposition process of *S. psammophila* sand barriers exhibited a "slow-fast" trend. After decomposition time for 9 years, mass decreased remarkably, and the residual percentage was 33.6%. Further, the nutrient release characteristics differed. C, P, and K were in the release state, whereas N was in the enrichment state. The decomposition percentage of the sand barriers was significantly correlated with N, P, K, C/N, C/P, and N/P ($p < 0.05$). The soil nutrient contents of C, P, and K contents increased 3.43, 2.23, and 2.08 g/kg compared to the initial values, respectively. The soil nutrient contents of N contents decreased 0.19 g/kg.

Keywords: *Salix psammophila* sand barriers; Desertification control; Degradation process; Nutrient release percentage; Soil nutrient; Mass loss percentage

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INTRODUCTION

Using plants to control the development of desertification has become the focus of desertification control technology research, and the comprehensive utilization and development of plant resources in sandy areas aims to make plants participate in the virtuous cycle of ecological environment (Zhang *et al.* 2019). *Salix psammophila* is a typical desert deciduous shrub or small tree that is drought-resistant and has other biological characteristics, such as strong adaptability, easy reproducibility, and rapid growth. It grows widely in harsh, windy, arid, sandy environments and is mainly distributed in mobile sand dunes, semifixed sand dunes, and lowlands between hills in northwest China (Gao and Gong 2013). To prevent wind erosion or sand burying and improve the growing environment of plants, sand barriers have been adopted to control desertification in northwest China (Wang *et al.* 2008). Various configurations of *S. psammophila* are set in the sand surface, and their stems control the direction, speed, and structure of the wind-

sand flow. Research has shown that the use of fast-growing *S. psammophila* as a sand barrier remarkably reduces near-surface wind speed, increases surface roughness, and increases vegetation coverage (Zhao *et al.* 2008; Gong 2012). The sand barrier can effectively improve the microenvironment of the sand dune and accelerate the process of vegetation restoration (Gao and Yi 1996; Wang *et al.* 2019). Further, *S. psammophila* sand barriers are low-cost, durable, and have a stable protection time.

Salix psammophila sand barriers are set for long-term establishment in desert environments. As the setting duration increases, *S. psammophila* buried in sand must endure changes in environmental temperature and humidity, rainwater erosion, and microbial degradation. *S. psammophila* sand barriers degrade to different degrees due to decay (Gong 2012; Wang *et al.* 2020). The decomposition of natural biomaterials is the link between the growth of psammophytes and the nutrient cycle of soil, which can promote the recovery and growth of vegetation, improve soil fertility, and play an important role in the desert ecosystem (Yu *et al.* 2015; Parton *et al.* 2007). Information on the decomposition process and nutrient release characteristics of *S. psammophila* sand barriers is limited, and research on the decomposition of *S. psammophila* sand barriers in desert environments has yet to be published. Compared to other environments, the desert environment is more extreme and more sensitive to extreme climate change and disturbance by human activity (Allington and Valone 2010).

The decomposition of natural biomaterials and their nutrient release change the carbon and nutrient cycles of ecosystems and their responses to environmental changes, and they have important effects on the accumulation of soil organic matter and the dynamics and availability of major nutrients. Decomposition plays an important role in important ecological processes, such as material circulation, structure, and functional maintenance of ecosystems (Goebel *et al.* 2011; Xu *et al.* 2013; He *et al.* 2019). Thus, there is a need to better understand the general laws of nutrient release and its response to the environment during the degradation of *S. psammophila* sand barriers to predict the biogeochemical cycle of the desert ecosystem.

In this study, *S. psammophila* sand barriers set in arid northwestern China for 1 to 9 years were studied. The decomposition characteristics of *S. psammophila* sand barriers and changes in the degradable residue percentage and substrate quality during decomposition were analyzed. The release and enrichment characteristics of C, N, P, and K during *S. psammophila* sand barrier decomposition were studied. Combined with the variation characteristics of soil nutrients (C, N, P, and K) and elements in the area surrounding the barrier, the effects of *S. psammophila* sand barrier degradables on soil nutrients in the degradation process were considered to promote material circulation in the ecological environment of the desert and provide information on the biogeographic element circulation process in the desert ecosystem.

EXPERIMENTAL

Study Site Description

The study was conducted at the Hangjin Banner, Ordos, Inner Mongolia in arid northwestern China (108°41'21"E, 40°29'34"N), as illustrated in Fig. 1. The study area had a plateau continental climate. There was sufficient sunshine and a large temperature difference between day and night. In addition, it had an annual average temperature of 6.3 °C, a maximum temperature of 38.1 °C, a minimum temperature of -30.5 °C, and a frost-

free period of 135 d. Sand dune and dune slack were distributed alternately in the vegetation restoration area, and the primary geomorphic types were active dune, semiactive dune, fixed dune, semifixed dune, and dune slack. The zonal soils in the region were chestnut soil and brown calcic soil, whereas the nonzonal soils were eolian sandy soil and meadow soil (Na 2010). Artificial vegetation was the primary vegetation type in the studied area, which included shrub species (*e.g.*, *Psammochloa villosa*, *Agriophyllum squarrosum*, and *Artemisia ordosica*) (Na 2010).

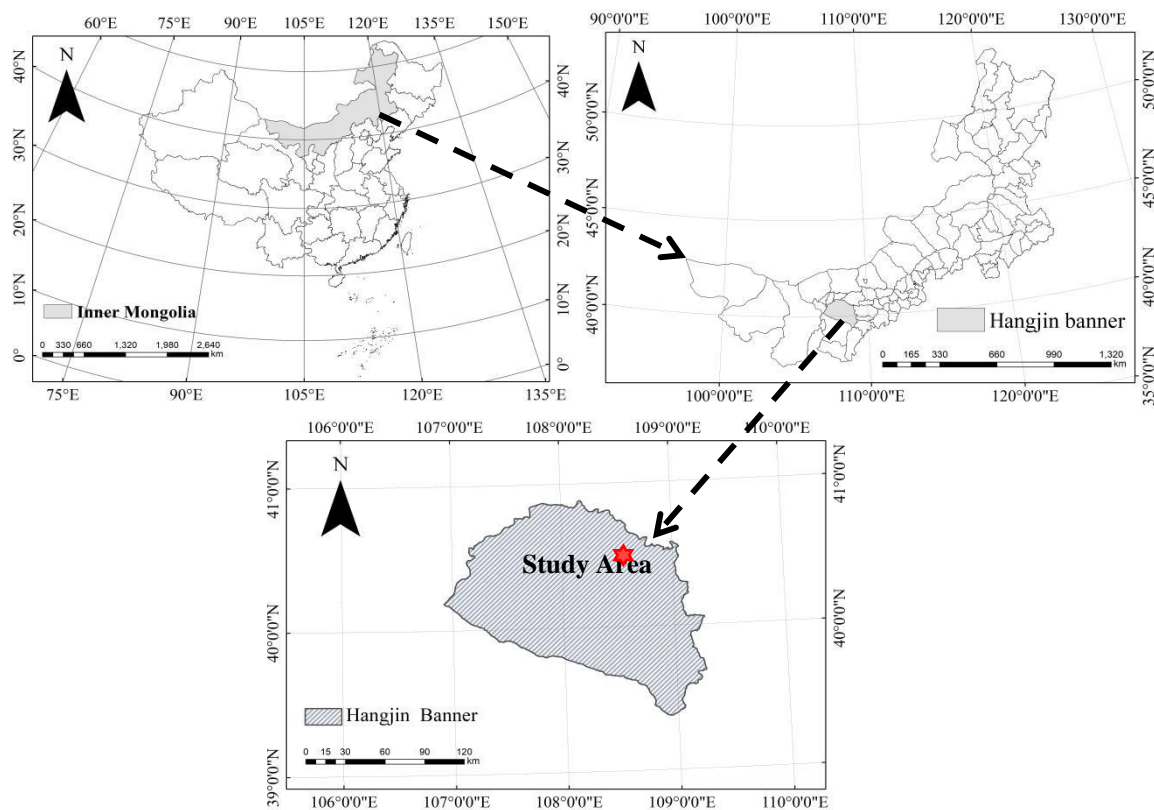


Fig. 1. Location of the study area (Hangjin Banner, Ordos, Inner Mongolia, China)

Materials

The experimental materials were collected from the research area in November 2019 *via* field investigation. The local *S. psammophila* sand barrier was divided accurately according to the setting year. After determining the overall situation of the sand barrier setting at the test site, the “space instead of time” method was used for sampling and investigation. From 2011 to 2019, the *S. psammophila* sand barrier and surrounding soil that had been setting for 1 y to 9 y were collected in gentle dunes from the sampling site and photographed, as illustrated in Fig. 2. At the same time, the sand barrier and soil just set up on the gentle dune for one month were taken as the control and recorded as 0 years.

S. psammophila sand barrier sampling

Sand barrier samples with a length of 7 cm was intercepted at a vertical depth of 20 ± 0.5 cm from the dune surface. Three representative sample sites were selected in each year, and 6 samples were taken from each sample site to reach a total of 162 samples. After removal, photos were taken for recording.

The sand barriers collected from the field were pretreated, the soil and impurities attached to the surface were cleaned with a brush, and they were then stored in a sealed bag for sealing. After transportation to the laboratory, the samples were placed into the oven, dried at 80 °C to a constant weight, and then removed from the oven. After the samples were dried, they were ground into powder and passed through a 40-mesh to 60-mesh sieve to determine the nutrients of the *S. psammophila* sand barriers.



Fig. 2. Schematic diagram of *S. psammophila* sand barrier in desert environment

Surrounding soil sampling of S. psammophila sand barrier

The *surrounding* soil samples collection of surrounding soil corresponded to the collection of *S. psammophila* sand barrier plant material samples. The soil was collected within a horizontal radius of 5 cm and a vertical depth of the minimum and maximum distances from the soil surface are 13 and 25 cm respectively (including 7 cm of plant material and 5 cm below the plant material, a total of 12 cm). Three representative barriers on the same contour line of each year were selected, and three replicates were set in the area with an interval of 2 m. Fifteen samples were taken from each dune, and a total of 135 samples were taken and brought back to the laboratory.

Methods

The nutrient contents C, N, P, and K of the *S. psammophila* sand barrier were determined after the samples were crushed by a grinder and ground into powder through a 40-mesh to 60-mesh sieve. Soil samples collected from the field were naturally air-dried, and their nutrient content was determined. The total C contents of the *S. psammophila* sand barrier and the surrounding soil were determined *via* the potassium dichromate volumetric method. The N content was determined *via* the perchloric acid-sulfuric acid digestion method. The total N content of the soil was measured with the semimicro-kjeldahl method using a Kjeldahl apparatus (Kjeldahl 2200 Auto Distillation Unit, FOSS, Scandinavia, Sweden), whereas the total P and K concentrations were obtained *via* the HF-HClO₄-HNO₃ digestion method using a 6300 ICP-AES (Thermo Scientific, Waltham, MA, USA).

Data analyses

Because it is impossible to directly measure the quality of the sample before the decomposition of the *S. psammophila* sand barrier, it was simulated by using several calculations. The initial mass of the *S. psammophila* sand barrier was calculated with the density and volume method. Therefore, a large number of control samples were needed to simulate the density of *S. psammophila* sand barriers (Gong 2012). In the early stages, an experimental analysis was performed on the density of sand barriers, and 274 groups were sampled from the field test site. The density prior to decomposition the *S. psammophila* sand barrier was calculated as the average of the normal density, which was $\rho_0 = 0.5534 \text{ g/cm}^3$. The mass loss percentage of the *S. psammophila* sand barrier was calculated with Eq. 1,

$$D_{mi}(\%) = (\rho_0 V - M) / \rho_0 V \times 100 \quad (1)$$

where D_{mi} (%) is the mass loss percentage, ρ_0 is the average density (g/cm^3) of the control sample, M is the mass of the *S. psammophila* sand barrier samples (g), and V is the volume of the *S. psammophila* sand barrier samples (g/cm^3).

The nutrient accumulation index (NAI) was used to represent the accumulation or release of nutrient elements during the decomposition process of *S. psammophila* sand barrier (Eq. 2),

$$NAI(\%) = (M_t \times C_t) / (M_0 \times C_0) \times 100 \quad (2)$$

where NAI (%) is the nutrient accumulation percentage, M_t is the *S. psammophila* sand barrier residual mass (g), M_0 is the initial contrastive mass (g), C_t is the remaining nutrient concentration (g/kg), and C_0 is the contrastive nutrient concentration (g/kg).

All statistical analyses were conducted using the SPSS 19.0 statistical software package (SPSS Inc., Chicago, IL, USA) with a significance level of $p < 0.05$, and figures were prepared with Origin 8.0 (OriginLab Corp., Northampton, MA, USA).

In addition, the correlations between mass loss percentage and the nutrient contents of the *S. psammophila* sand barriers were also examined using Pearson correlation coefficient analysis.

RESULTS

Changes in the Mass Residual Percentage and Mass Loss Percentage in the Decomposition Process of *S. psammophila* Sand Barriers

Figure 3 shows that the residual percentage of *S. psammophila* sand barrier decreased during the decomposition process from 1 y to 9 y. There were significant differences in the mass residual percentage during the decomposition process ($p < 0.05$). The decomposition process was divided into two stages. The initial stage (1 y to 5 y), in which the mass residual percentage changed a small amount, indicated that the decomposition of the *S. psammophila* sand barrier was slow. At the later stage (5 y to 9 y), the overall residual percentage reached the minimum of 33.62%.

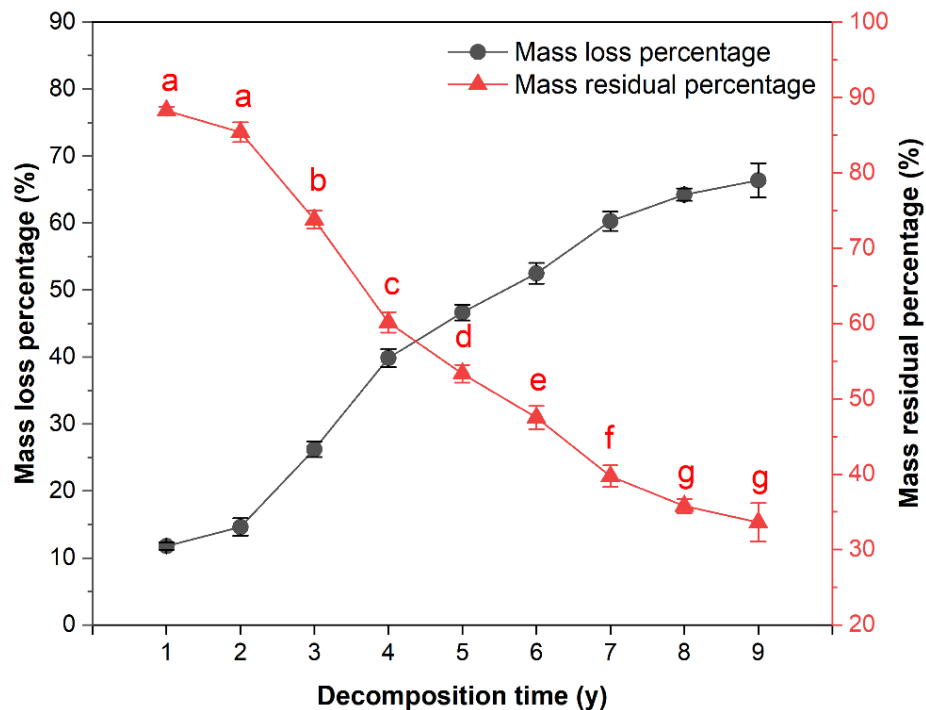


Fig. 3. Changes in the mass residual percentage and mass loss percentage in the decomposition process of *S. psammophila* sand barriers. Note: Different lowercase letters in the figure indicate significant differences between different decomposition years of the sand barrier ($p < 0.05$).

The mass loss percentage of the *S. psammophila* sand barrier increased as decomposition time increased. The changes in the mass loss percentage were different in different stages. During the decomposition period of 1 to 3 years, the mass loss percentage was 14.6% after decomposition 3 y. With the change of environmental factors, the microbial activity was enhanced, and the decomposition speed was accelerated, which resulted in a rapid change in the mass loss percentage. The loss percentage was 60.3% after decomposition 5 y. Beyond after decomposition 5 y, the decomposition decreased and reached the maximum value of 66.4% after decomposition 9 y (later stage of decomposition).

Decomposition Nutrient Release Characteristics of the *S. psammophila* Sand Barriers

The release and enrichment of nutrients (C, N, P, and K) were different during the decomposition process of the *S. psammophila* sand barrier, and the release and enrichment percentage of nutrients accelerated as laying time increased. The period from 0 y to 3 y was a slow release and enrichment period, the period from 3 y to 5 y was a mixed period of enrichment and release, and the duration of 5 years later was the last instance of nutrient release or enrichment.

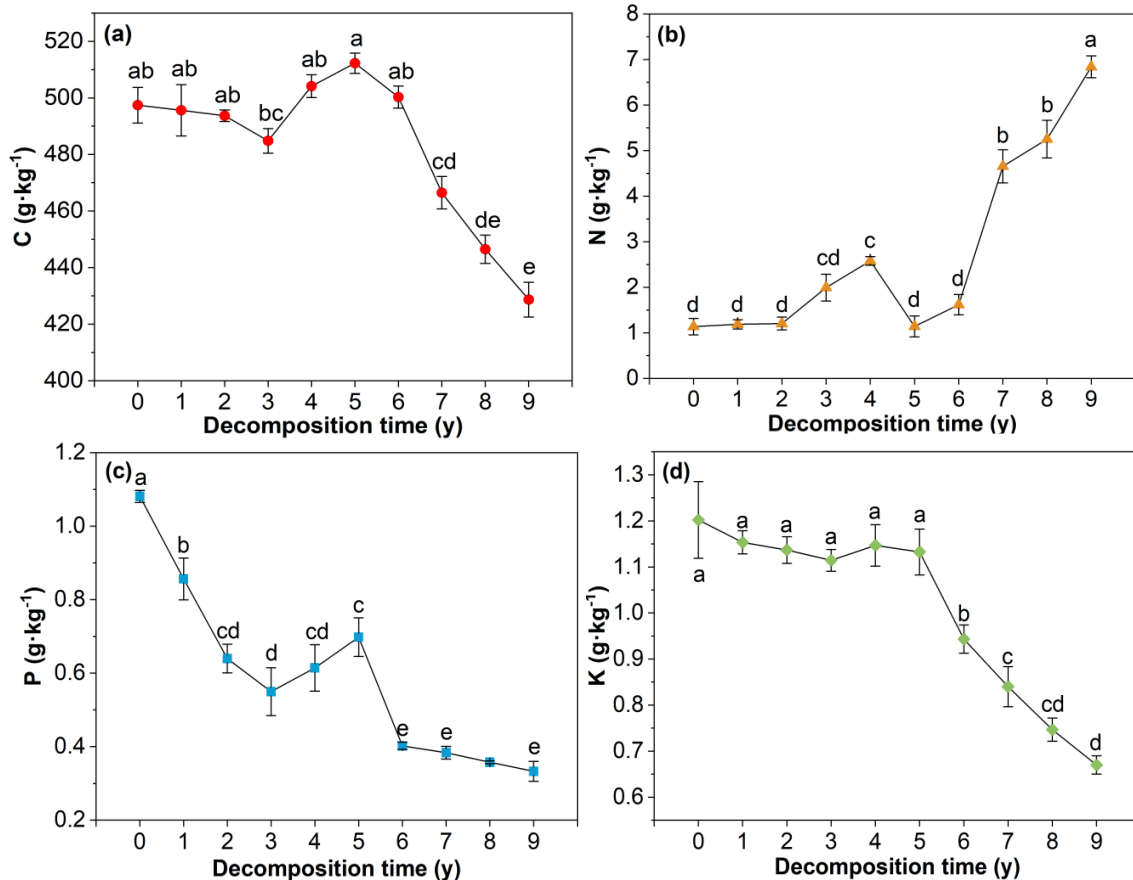


Fig. 4. The decomposition nutrient release characteristics of the *S. psammophila* sand barriers. Note: Different lowercase letters in the figure indicate significant differences between different decomposition years of the sand barrier ($p < 0.05$).

Figure 4a shows that in the desert environment, the degree of decomposition of the *S. psammophila* sand barrier varied with the time after decomposition time increased. The C content showed a fluctuating trend of decreasing, rising, and decreasing with the increase in decomposition time. Decomposition for 0 y to 5 y resulted in nutrient C content being basically maintained within a small range of fluctuations. After decomposition for 5 y to 9 y, the C content gradually decreased to the lowest figure at 9 y of setting, which represented a decrease of 68.7 g/kg from the initial value. Throughout the decomposition process, the change in the C accumulation index was the same as the change in C content, as shown in Fig. 5a. The change of the overall change rule is the release state, and the release percentage of C varies significantly with the increase of decomposition time ($p < 0.05$). Among them, 20.0% of the C content was released from 0 y to 3 y. The content of nutrient C fluctuated

from 3 y to 5 y. After decomposition 5 y, the C content accumulation index gradually decreased to the lowest figure at 9 y of decomposition, 27.05%.

Figure 4b shows that the N content in the decomposition process of the *S. psammophila* sand barrier had a fluctuating trend of rising, decreasing, and rising as the decomposition time increased. There were significant differences in the decomposition process ($p < 0.05$), and the N content increased from 0 y to 4 y of decomposition time within a small range, and the maximum value was 2.58 g/kg. After decomposition time for 4 y, the N content gradually decreased. The N content showed an upward trend after 5 y with a large increase range, and it gradually decreased to the highest figure at 9 y of decomposition, 6.83 g/kg. The N accumulation index of the *S. psammophila* sand barrier showed a fluctuating increasing trend as the decomposition time increased. As shown in Fig. 5b, the *S. psammophila* sand barrier was in a state of enrichment overall. The sand barrier was in a state of slow enrichment from 0 y to 4 y of decomposition and showed a small release after 4 y. The sand barrier began to enrich after 5 y, and the C content accumulation index reached the maximum at 9 y of decomposition, 190%.

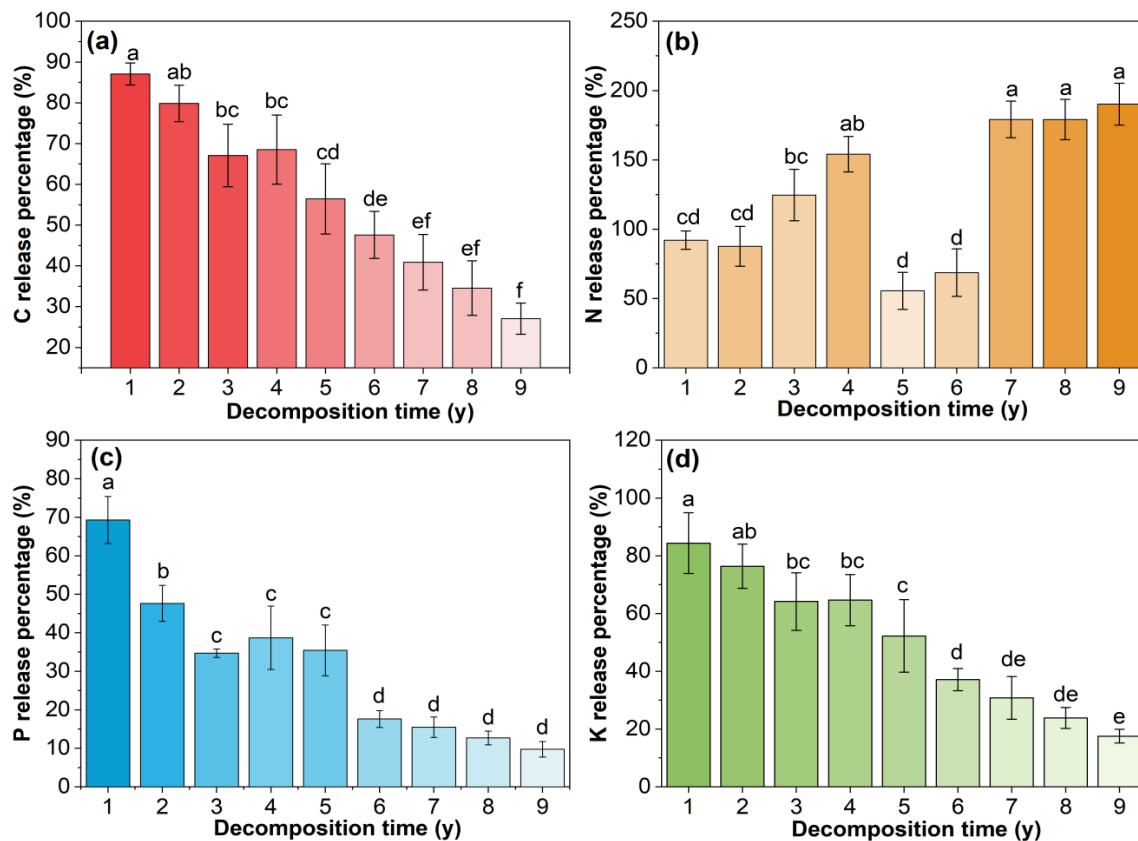


Fig. 5. The variation of the nutrient release percentages of the *S. psammophila* sand barriers during the decomposition process. Note: Different lowercase letters in the figure indicate significant differences between different decomposition years of the sand barrier ($p < 0.05$).

As shown in Fig. 4c, the P content of the *S. psammophila* sand barrier showed an decreasing, rising, and decreasing trend with the increase in decomposition time. After decomposition for 0 y to 3 y, the P content decreased rapidly, as it had a decrease of 0.53 g/kg compared to the initial value. Decomposition for 3 y to 5 y, showed an overall upward

trend. After decomposition for 5 y, the P content showed a slow downward trend, the P content gradually decreased to the lowest figure at 9 y of decomposition, 0.33 g/kg. Throughout the decomposition process, the P content changed as the cumulative index law changed. Fig. 5c shows the overall performance was the state of first release followed by enrichment and then release, which included a C content of nutrient release of 34.68% from 0 y to 3 y, P enrichment from 3 y to 5 y, and a quick release 5 y later. And the accumulation index gradually decreased to the lowest figure at 9 y of decomposition, 9.73%.

As shown in Fig. 4d, the K content of *S. psammophila* sand barrier had a decreasing trend decomposition for 0 y to 3 y, and it exhibited a decrease of 0.08 g/kg compared to the initial value. Decomposition for 3 y to 4 y, the K content showed an upward trend. After decomposition for 5 y, the K content gradually decreased to the lowest figure at 9 y of decomposition, 0.53 g/kg. The K accumulation index of the *S. psammophila* sand barrier showed a fluctuating decreasing trend as decomposing time increased. As shown in Fig. 5d, the K content exhibited a release-enrichment-release trend. The K content was in a state of release from 0 y to 3 y of decomposition time and began to be slightly enriched from 3 y to 4 y. After decomposition for 5 y, it was released rapidly, and the C content accumulation index decreased to the lowest figure at 9 y of decomposition, 17.52%.

Characterization of Stoichiometry During the Decomposition of the *S. psammophila* Sand Barriers

Figure 6a shows that the C/N content in the decomposition process of *S. psammophila* sand barrier had overall decreasing trend with the increase in decomposition time. In the decomposition process, C/N showed an decreasing trend from 0 y to 4 y, an increasing trend from 4 y to 5 y, and a decreasing trend after decomposition for 5 y. In the decomposition process, the C/P of the *S. psammophila* sand barrier showed an overall downward trend with the increase in setting years. As shown in Fig. 6b, C/P showed an increasing trend from 0 y to 3 y, and decomposition for 3 y showed an decreasing trend. After decomposition for 5 y, the C/P showed a upward trend, the C/P gradually increased to the highest figure at 9 y of decomposition. The change pattern of N/P was the same as that of C/P, as shown in Fig. 6c, in which N/P exhibited an increasing trend from 0 y to 3 y, a decreasing trend decomposition for 3 y, and increased decomposition for 5 y.

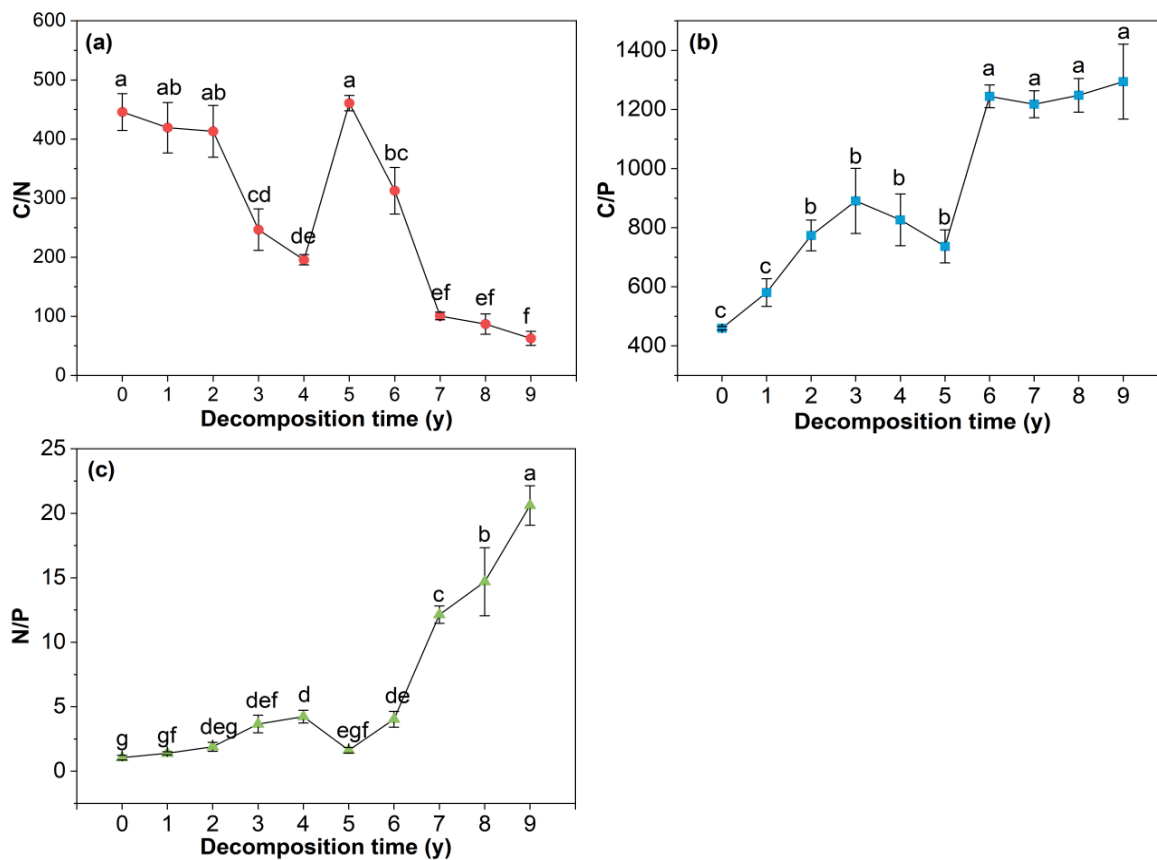


Fig. 6. Variation in the nutrient accumulation index of the *S. psammophila* sand barriers during the decomposition time. Note: Different lowercase letters in the figure indicate significant differences between decomposition years of the sand barrier ($p < 0.05$).

The Effect of the Decomposition of the *S. psammophila* Sand Barriers on Surrounding Soil Nutrients (C, N, P, and K)

As shown in Figure 7, the soil nutrient content surrounding the *S. psammophila* sand barrier were characterized by fluctuating increases and decreases with the increase in decomposition time. As shown in Fig. 7a, the surrounding soil C content showed increased when the C content of the *S. psammophila* sand barrier was released throughout the decomposition process, it gradually increased to the highest figure at 9 y of decomposition, which was an increase of 3.43 g/kg compared to the initial value. Figure 7b shows the soil N content had an overall downward trend, and it gradually decreased to the lowest figure at 9 y of decomposition, which was 0.19 g/kg lower than the initial value. Figure 7c shows that the soil P content featured a rising-declining-rising trend with decomposition time, showed an overall downward trend with the increase in setting years. This was due to the small amount of P contained in the *S. psammophila* sand barrier, which resulted in reduced accumulation of P in the soil during the decomposition process of *S. psammophila* sand barriers. Figure 7d shows that the soil K content was consistent with the change pattern of the C content of the soil, as it had a rising-declining-rising trend, and it it gradually increased to the highest figure at 9 y of decomposition, which was 2.08 g/kg higher than the initial value.

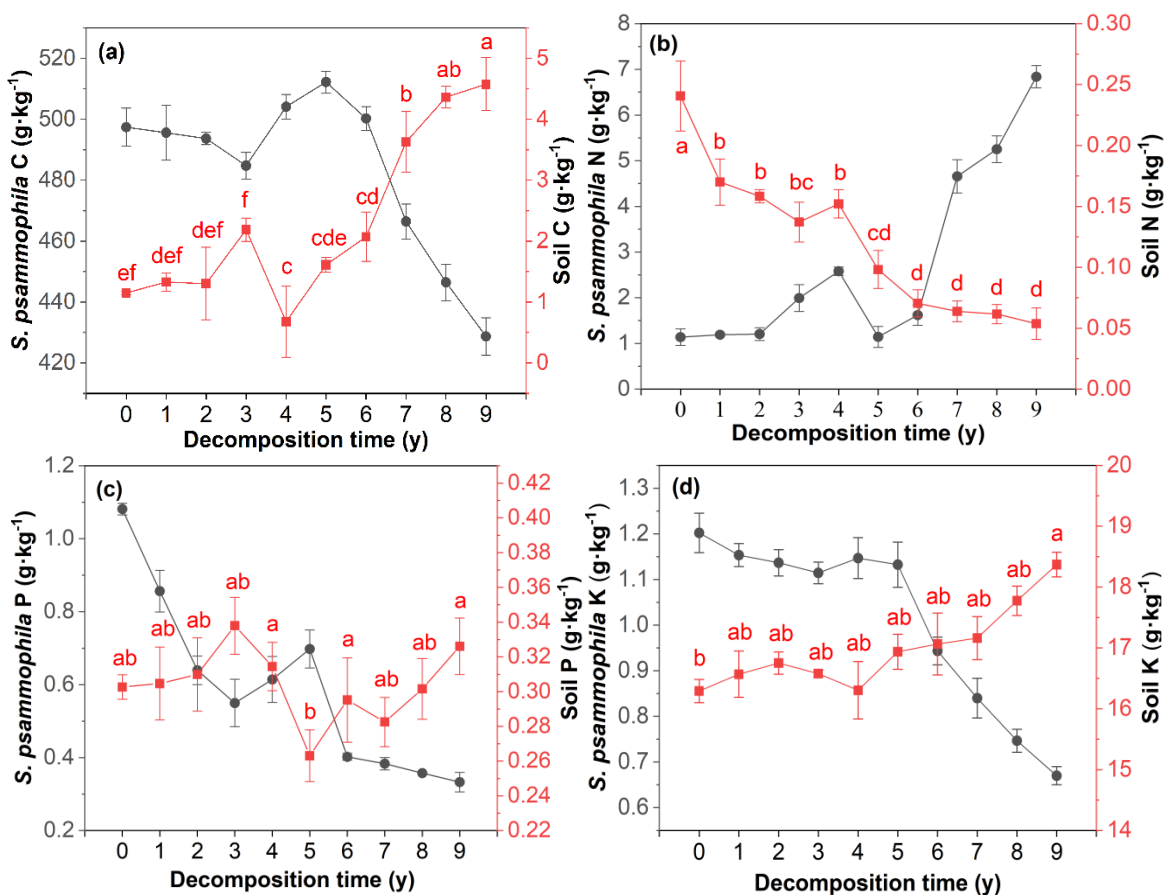


Fig. 7. The variation in the characteristics of surrounding soil C, N, P, and K during the decomposition process of the *S. psammophila* sand barriers. Note: Different lowercase letters in the figure indicate significant differences between different decomposition years of the sand barrier ($p < 0.05$).

DISCUSSION

The decomposition of *S. psammophila* sand barriers is a process of material exchange with the external environment that is governed by a variety of factors, in which soil biological metabolism interacts with the uptake and release of chemical elements under the action of soil leaching and decomposition (Burton *et al.* 2000). In the early stages of decomposition, soluble materials, such as carbohydrates, are rapidly leached due to environmental factors, such as soil temperature and soil water content (Parton *et al.* 2007; Tu *et al.* 2014) and decomposition liners. At a later stage, the decomposition process is mainly influenced by the biological action of depleting soluble compounds, whereas insoluble materials, such as lignin and cellulose, remain for microbial degradation. This study showed that the mass residual percentage of *S. psammophila* decreased as the time after decomposition time increased, and the mass residual percentage of the *S. psammophila* sand barrier was 73.8% after decomposition 3 y, but the mass residual percentage was only 39.7% after decomposition 7 y. In addition, the slope curve became slow after 7 y, and it reached the lowest value of 33.6% after decomposition 9 y. This result was related to the initial chemical properties of the *S. psammophila* sand barriers.

However, the drought and low rainfall in the study area limited the decomposition of the *S. psammophila* sand barriers.

The decomposition of the *S. psammophila* sand barriers was accompanied by changes in the nutrient elements, and the release/enrichment of these elements plays an important role in the cycling process and is a remarkable determinant of the growth of vegetation in the desert environment (Aerts and de Caluwe 1997). In this study, the relationship between the decomposition of *S. psammophila* sand barriers and decomposition time was characterized by different degrees of release and enrichment of nutrients (C, N, P, and K). However, their contents tended to increase as decomposition time increased (Fig. 4), which was determined by the decomposition of the *S. psammophila* sand barriers and the characteristics of the elements themselves. From 0 y to 3 y of decomposition time, most of the C in the *S. psammophila* sand barriers existed as small molecules, such as soluble sugars and amino acids, P and K existed mainly as soluble inorganic ions, and C, N, and P were continuously exchanged with the soil through fine root leaching (Fahey *et al.* 1984). After 5 y of decomposition, C exists mainly as insoluble substances, such as lignin, cellulose, and tannin, and under the action of soil microorganisms, a series of irreversible changes occur in the structure and properties of *S. psammophila* sand barriers, and the chemical composition begins to disappear rapidly, which leads to a faster decomposition percentage (Wang *et al.* 2021). The decomposition percentage was mainly affected by the physical and chemical properties of the *S. psammophila* sand barrier, such as nutrient content, water-soluble carbon compounds, and structural carbon compounds, and it provides a sufficient environment for the growth and reproduction of microorganisms, so that the decomposition percentage is faster. In the later stage, decomposition was inhibited by lignin or cellulose (Yang *et al.* 2004).

The nutrient C content exhibits a variable release characteristic of *S. psammophila* sand barriers. The decomposition process of *S. psammophila* sand barriers is mainly dominated by C in the material cycling pattern. The leaching of soluble materials and the decomposition of easily decomposable carbohydrates both cause the release of C (Yang *et al.* 2006). The nutrient N content showed a small enrichment-release-enrichment pattern, and the enrichment of N content from 3 y to 5 y may have been due to the variation of N content related to the water and heat conditions, soil temperature and humidity, and the initial nutrients in the desert environment. Microbial reproduction and development require the uptake of large amounts of exogenous N from the external environment; therefore, N elements are enriched (Wu *et al.* 2007). From 3 y to 5 y of decomposition, there was a decreasing trend of the N content in the *S. psammophila* sand barriers, and microbial activities are frequent enough to satisfy the decomposition activities of soil microorganisms without absorbing N from the external environment for decomposition (Manzoni *et al.* 2008).

Table 1. Correlation Coefficients Between Mass Loss Percentage and Nutrient Contents of *S. psammophila* Sand Barriers

	C	N	P	K	C/N	C/P	N/P
Mass Loss percentage	-0.607	0.773*	-.841**	-0.845**	-0.729*	0.864**	0.786*

Note: * = Significant difference ($p < 0.05$) and ** = Extremely significant difference ($p < 0.01$)

There was a significant positive correlation between the mass loss percentage and the N content variation of the *S. psammophila* sand barriers, and a there was highly significant negative correlation between the mass loss percentage and C/N ($p < 0.05$) (Table 1). Related studies have suggested that decomposition percentages are influenced by both internal (preserved within the vegetation) and external (acquired by external factors) N concentrations (Tu *et al.* 2015). In other studies, the decomposition percentage was mainly dependent on the amount of lignin and initial C content rather than the initial N concentration (Chen *et al.* 2001), which was inconsistent with the results of this study. This may be due to the inhibition of lignin decomposition by remarkable lower soil temperature and moisture, whereas nitrogen is enriched during the decomposition of *S. psammophila* sand barriers.

During the decomposition process of the *S. psammophila* sand barriers, the P content was generally in a state of release, as it had essentially the same characteristics as the release of C content. The mass loss percentage was highly remarkable and negatively correlated with the nutrient P content. As P elements are easily leached, they exist mainly in the form of phosphate or compounds. Therefore, the release of P elements from *S. psammophila* sand barriers is faster, and the microbial decomposition is supported by the continuous release of phosphorus from the sand barriers themselves (Li *et al.* 2008). This results in a faster conversion percentage for *S. psammophila* sand barriers and a faster percentage of decomposition between 5 y and 9 y of decomposition time when soil microbial activity is intense and enzymatic activity for decomposing organic matter is enhanced (Lin *et al.* 2011). In other studies, nutrients were reported to be more likely to be released into the environment at higher initial concentrations, whereas nutrients are enriched at lower initial concentrations (Vogt *et al.* 1986).

As decomposition occurs, different nutrient elements in the *S. psammophila* sand barriers were accumulated or released, which resulted in different trends in their stoichiometric characteristics (Reich and Oleksyn 2004). In this study, C/N showed an overall decreasing trend during the decomposition of the *S. psammophila* sand barriers, whereas C/P and N/P showed a fluctuating trend of first decreasing and then increasing. The C/N content did not change notably with the C content, and the N content was the key factor that regulated the change of C/N during the decomposition of the *S. psammophila* sand barriers. The change in P content played an important role in the change of C/P and N/P, and if the value of C/P and N/P was small, the *S. psammophila* sand barriers were easily decomposed. In addition, due to the different environmental factors in the study area, the threshold values of C/N also differed greatly, which further led to the differences in the correlation between the decomposition process of the *S. psammophila* sand barriers and the dynamic change process of nutrients C and N.

The decomposition and nutrient cycling of *S. psammophila* sand barriers in arid ecosystems are important for the study of regional carbon and nitrogen cycles, and they provide a theoretical basis for vegetation restoration. The degradable *S. psammophila* sand barrier on soil nutrients promote material circulation in the ecological environment of the desert. The content of C, N, P, and K released during the decomposition of the *S. psammophila* sand barriers participated in the material cycle and returned nutrients to the soil, which remarkably affected the soil physical and chemical properties (McFee and Stone 1966). As the decomposition speed of the *S. psammophila* sand barriers increased, the impact on the physicochemical properties of the soil increased, which obviously improved the soil. This study showed that the decomposition of *S. psammophila* sand barriers could improve the C content of the soil, which was consistent with other findings

on desert ecosystems (Hu *et al.* 2016). Several studies have shown that the decomposition of natural biological materials is important for soil C input (Hobbie *et al.* 2010). Research has mentioned the different contributions of decomposers to soil organic carbon accumulation and the differences in their accumulation mechanisms (Peng and Liu 2002). Organic carbon stock has an important influence on the regional carbon cycle, and it influences the growth of vegetation in desert environments. The nutrients released during the decomposition of *S. psammophila* sand barriers (N and P) are important sources of soil N and P and determine the effectiveness of soil nutrients.

CONCLUSIONS

1. During the decomposition process from the after one to nine years of decomposition (1 y to 9 y), the overall decomposition trend of *S. psammophila* sand barriers was slow at first and then fast.
2. After decomposition for 9 years, the C, P, and K contents of the *S. psammophila* sand barriers were released in a fluctuating state. The N appeared to be enriched during the decomposition process.
3. There was obvious migration of C, N, P, and K between the *S. psammophila* sand barriers and the soil, and the decomposition of the *S. psammophila* sand barriers affected the change of soil C, N, P, and K contents.

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