Response of Surface Litter Decomposition to Fertilization in the Tarim Desert Highway Shelterbelt: Postprint

Authors: Xuemei Zhang, Yongdong Wang, Xinwen Xu, Jiaqiang Lei, Jingxin Sun

Date: 2017-03-22T00:00:00+00:00

Abstract

To investigate the response of decomposition rates and nutrient release dynamics of surface litter in desert highway shelterbelts to fertilization, the litterbag method was employed to study the decomposition and nutrient release characteristics of assimilating branches of Calligonum arborescens, assimilating branches of Haloxylon ammodendron, and branches of Tamarix ramosissima in the Tarim Desert Highway shelterbelt under fertilization treatments. Results showed that after 420 days of decomposition, significant differences ($P < 0.05$) in mass residual rates of the three litter types were observed among the control (no fertilization), nitrogen fertilization, and phosphorus-potassium compound fertilizer treatments. The mass residual rates of C. arborescens assimilating branches, H. ammodendron assimilating branches, and T. ramosissima branches under the control treatment were 56.95%, 31.32%, and 50.24%, respectively. Under fertilization treatments, all three litter types exhibited the fastest decomposition rate for H. ammodendron assimilating branches, followed by T. ramosissima branches, with C. arborescens assimilating branches decomposing the slowest. Application of phosphorus-potassium compound fertilizer extremely significantly increased the decomposition rates of all three litter types ($P < 0.01$); nitrogen fertilization promoted the decomposition of T. ramosissima branches but inhibited that of C. arborescens and H. ammodendron assimilating branches. During decomposition, C, N, P, and K elements in the three litter types in the control group all showed net release; after fertilization, N, P, and K elements in the litter exhibited an immobilization-release pattern. Initial P content and C/N and C/P ratios were the dominant factors in the early decomposition stage, while initial K, lignin, and cellulose contents and C/N and lignin/N ratios were the main controlling factors in the later stage. The study demonstrates that fertilization significantly affects the decomposition of surface litter in desert

highway shelterbelts, increases nutrient return from surface litter, delays nutrient release timing, and improves soil fertility in the Tarim Desert Highway shelterbelt. The initial C/N ratio of litter is an important factor for predicting litter decomposition in the Tarim Desert, and the initial chemical composition influencing litter decomposition differs among decomposition stages.

Full Text

Preamble

ACTA ECOLOGICA SINICA ChinaXiv Partner Journal
Vol. 37, No. 5, March 2017
DOI: 10.5846/stxb201509061830

Effects of Fertilizer Addition on Surface Litter Decomposition in the Tarim Desert Highway Shelterbelt

ZHANG Xuemei[1,2,3], , WANG Yongdong[1], ,*, XU Xinwen[1], , LEI Jiaqiang[1], , SUN Jingxin[1,3],

[1] Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China
[2] College of Resources and Environmental Science, Xinjiang University, Urumqi 830046, China
[3] University of Chinese Academy of Sciences, Beijing 100049, China
National Engineering Technology Research Center for Desert-Oasis Ecological Construction, Urumqi 830011, China

*Corresponding author. E-mail: sms@ms.xjb.ac.cn

Abstract

Litter decomposition determines nutrient and carbon cycling processes and regulates nutrient return to the soil in many terrestrial ecosystems. Wood plant litter decomposition is a crucial biogeochemical process for carbon and nutrient cycling, especially in arid and nutrient-constrained ecosystems. However, the role of litter decomposition in extreme drought deserts and its determining factors remain debatable and poorly understood. The Tarim Desert Highway Shelterbelt consists of three artificial plant species that account for the majority of net primary productivity, and their litters are the major contributors to carbon and nutrient recycling. In such artificial desert shelter forests, fertilizer addition causes contradictory effects on litter decomposition and nutrient dynamics. This study aims to (1) examine how fertilizer addition affects surface litter decomposition and nutrient dynamics, and (2) determine the major factors influencing litter decomposition in arid deserts.

The litterbag method was used to investigate the decomposition of assimilative branches of *Calligonum arborescens* and *Haloxylon ammodendron*, and branches of *Tamarix ramosissima* in the Taklimakan Desert Research Station. Filled litterbags were placed on soil surfaces at different plots in March 2013. Fertilizer addition and irrigation were implemented from March to November during the experiment. Litterbags were collected in May, July, September, and November of 2013, and in March and May of 2014. The mass remaining, elemental content (carbon, nitrogen, phosphorus, and potassium), and decomposition rates of litter were analyzed at each decomposition stage.

Results showed that after 420 days of decomposition, significant differences were found among control (without fertilizer), nitrogen fertilizer addition, and phosphorus-potassium compound fertilizer treatments. The mass remaining for the assimilative branches of *H. ammodendron*, branches of *T. ramosissima*, and assimilative branches of *C. arborescens* without fertilizer addition were 56.95%, 31.32%, and 50.24%, respectively. The decomposition rate among different litters was highest for the assimilative branches of *H. ammodendron*, followed by branches of *T. ramosissima*, and then assimilative branches of *C. arborescens*. The addition of phosphorus-potassium compound fertilizer significantly accelerated the litter decomposition rate of the three plant species, whereas nitrogen fertilizer increased the decomposition rate of *T. ramosissima* branches and restrained the decomposition rate of assimilative branches of *C. arborescens* and *H. ammodendron*.

During the decomposition process, litter nutrients presented net release patterns in the treatments without fertilizer. In contrast, the nitrogen, phosphorus, and potassium contents of the fertilizer treatments showed an accumulation-release pattern. The litter decomposition rate was determined by the initial phosphorus content and C/N and C/P ratios at the initial decomposition stage. However, the decomposition rate was controlled by the initial potassium, lignin, and cellulose contents and C/N and lignin/N ratios at the final stage. Overall, the results suggest that fertilizer addition significantly changed the decomposition rate of surface litters, increased the amount of returned nutrients, and postponed the time of nutrient release. Improving soil fertility in the Tarim Desert Highway shelterbelt is essential in enhancing the quality of this valuable ecosystem. The initial litter C/N ratio is critical to surface litter decomposition in the Tarim Desert, and the initial chemical composition' s influence on decomposition rate varies at different decomposition stages.

Keywords: mass remaining; litter decomposition rate; nutrients; fertilizer addition; Tarim Desert Highway shelterbelt

---

1. Study Area Overview

The study area is located in the hinterland of the Taklimakan Desert, characterized by large annual and diurnal temperature variations, long sunshine hours, and strong wind-sand activity. Geographic coordinates are 39°01 N, 83°36 E, with an elevation of 1100 m. Precipitation is unevenly distributed throughout the year, concentrated mainly in the warm temperate zone with an extremely arid continental climate. The potential evapotranspiration is as high as 3638.6 mm, while annual precipitation is only 11-50 mm. The soil type is predominantly mobile aeolian sandy soil. The Tarim Desert Highway traverses the flowing desert area, lacking surface runoff but with substantial groundwater storage. The special geographic environment and limited irrigation water resources of the Tarim Desert Highway shelterbelt determine the extremely scarce plant resources.

The shelterbelt is dominated by highly stress-resistant shrubs and small trees, primarily *Calligonum* spp., *Haloxylon ammodendron*, and *Tamarix* spp., which are windbreak and sand-fixation species with drought and salt resistance. The groundwater used for irrigation has a salinity of 2.6–30 g/L, with most sections exceeding 4 g/L.

---

2. Methods

The experiment was conducted at the Taklimakan Desert Research Station in the hinterland of the Tarim Desert. Three fertilizer treatments were established: control (CK), nitrogen fertilizer (NF), and phosphorus-potassium compound fertilizer (PK). Each treatment had three replicate plots. At the end of the growing season in October–November 2013, naturally fallen assimilative branches of *Calligonum arborescens* and *Haloxylon ammodendron*, and branch litter of *Tamarix ramosissima* were collected from representative shelterbelt plots planted in the same year as the highway shelterbelt. After removing impurities, samples of each plant species were mixed uniformly.

For each litter type, 20.00 g of samples were weighed and placed into nylon mesh decomposition bags measuring 20 cm × 20 cm with a mesh diameter of 0.25 mm. A total of 15 bags per litter type were placed in each plot (5 sampling times × 3 replicates). The bags were laid flat on the soil surface of corresponding plots. The initial dry weight of litter samples was calculated after oven-drying a portion of the samples. Dried samples were ground to determine initial chemical composition.

Fertilizer was dissolved in irrigation water according to the Tarim Desert Highway irrigation and fertilization management system (March–November 2013). The irrigation water was locally extracted groundwater. For the PK treatment, potassium dihydrogen phosphate (KH PO) was applied at 5 g/L concentration. For the NF treatment, nitrogen fertilizer ((NH)) was applied at 4.04 g/L concentration. Each plot received 30 L/m of water per irrigation event. The prepared fertilizer solution was uniformly applied to litter decomposition bags using a watering can.

During the experiment, litterbags were collected at intervals: May, July, September, and November 2013, and March and May 2014. At each collection, three bags of each litter type were retrieved from each plot. Retrieved bags were cleaned to remove surface residue, and litter samples were quickly rinsed with distilled water, oven-dried to constant weight, and weighed to obtain dry mass remaining. A portion of dried samples was ground and passed through a 0.25 mm sieve for determination of total C, N, P, and K contents. Carbon was measured by combustion method, nitrogen by Kjeldahl digestion, phosphorus by molybdenum blue colorimetry, and potassium by atomic absorption spectroscopy after acid digestion. Lignin and cellulose were determined using the Van Soest detergent fiber analysis method.

---

3. Data Processing

Litter decomposition dynamics were described and predicted using the Olson exponential decay model:

$$M_t/M_0 = e^{-kt}$$

where M_0 is the initial dry mass (g), M_t is the mass remaining after time t (g), k is the decomposition coefficient, and t is decomposition time. The time required for 50% decomposition (half-life, $t_{0.5}$) and 95% decomposition ($t_{0.95}$) were calculated accordingly.

Element remaining rate during decomposition was calculated as:

$$NR = (M_t \times X_t)/(M_0 \times X_0) \times 100\%$$

where X_0 is the initial element concentration (mg/g), X_t is the element concentration at time t (mg/g), M_0 is the initial dry mass (g), and M_t is the dry mass remaining at time t (g). When $NR < 100\%$, net release occurred; when $NR > 100\%$, net accumulation occurred.

Statistical analysis was performed using SPSS 16.0 and Origin 8.0. Multi-factor ANOVA and least significant difference (LSD) tests were used to analyze significant effects of species, treatment, and their interactions on mass remaining, decomposition rate, and element remaining rates. Correlation analysis was applied to examine relationships between decomposition rates and initial chemical composition. Significance level was set at $\alpha = 0.05$. Exponential regression was used to fit the negative exponential decay equations for litter mass remaining.

---

2. Results and Analysis

2.1 Initial Chemical Properties of Litter

The initial chemical properties of the three litter types showed significant overall differences (Table 1). The initial total nutrient concentrations followed the pattern: *H. ammodendron* assimilative branches > *T. ramosissima* branches > *C. arborescens* assimilative branches ($P < 0.05$). Conversely, recalcitrant substances (lignin and cellulose) showed the opposite trend, with *C. arborescens* assimilative branches having the highest content and *H. ammodendron* the lowest. The significant differences in initial chemical composition among the three litter types were determined by the ecological characteristics and litter properties of *C. arborescens*, *H. ammodendron*, and *T. ramosissima*.

Initial chemical properties of litters (mean ± SD)

2.2 Effects of Fertilization on Litter Decomposition

Under fertilization treatments, the dry mass remaining of the three litter types decreased rapidly during the early decomposition stage (0–120 days), then gradually leveled off. The mass loss during 0–120 days accounted for 31.78%–82.93% of total mass loss throughout the decomposition period, with significantly greater reduction amplitude than other periods. After 420 days, mass remaining differed significantly among treatments ($P < 0.05$). Among species, *H. ammodendron* assimilative branches had the lowest mass remaining (31.32%), followed by *T. ramosissima* branches, while *C. arborescens* assimilative branches had the highest (56.95%).

Fertilization significantly affected decomposition rates. The PK treatment significantly accelerated decomposition of all three litter types, while NF treatment increased decomposition rate of *T. ramosissima* branches but inhibited decomposition of *C. arborescens* and *H. ammodendron* assimilative branches. Decomposition time and treatment interaction had extremely significant effects on mass remaining ($P < 0.01$).

[Figure 1: see original paper] Effects of fertilization on litter mass remaining

The Olson negative exponential decay equations showed that PK treatment increased decomposition coefficients for all three species, shortening decomposition time. Compared with CK, the time required for 95% decomposition was reduced by 11.19%-24.84% for *C. arborescens* and *H. ammodendron*, and by 3.11% for *T. ramosissima* under PK treatment. Conversely, NF treatment extended decomposition time by 10.60%–20.45% for *C. arborescens* and *H. ammodendron*, but reduced it by 16.05% for *T. ramosissima*.

Negative exponential decomposition equations of litter

Correlation analysis revealed that initial litter chemistry strongly predicted decomposition rates. Early-stage decomposition rate (0–120 days) was significantly positively correlated with initial cellulose content and C/N ratio ($P < 0.05$), but significantly negatively correlated with initial P content and C/P ratio ($P < 0.01$). Late-stage decomposition rate (240–420 days) was significantly positively correlated with initial K content, and significantly negatively correlated with lignin, cellulose, C/N, and lignin/N ratios ($P < 0.01$).

Pearson correlation relationship between initial chemical composition and decomposition rate

2.3 Nutrient Release Patterns During Decomposition

Nutrient migration during litter decomposition primarily involves leaching, release, and immobilization patterns. Under CK treatment, all nutrient elements showed net release patterns. In fertilized treatments, N, P, and K exhibited accumulation-release patterns.

Carbon remaining rates decreased over time, showing net release. Nitrogen remaining rates showed species-specific patterns: under CK, *C. arborescens* N remaining fluctuated upward while *H. ammodendron* and *T. ramosissima* showed net release. Phosphorus remaining rates generally decreased slowly, maintaining net release status. Potassium remaining rates showed initial increase followed by decrease in most cases.

Decomposition time, treatment, and their interactions had extremely significant effects on N and P remaining rates ($P < 0.01$), but no significant effect on K remaining rate among species ($P > 0.05$).

[Figure 2: see original paper] Effects of fertilization on element remaining during decomposition

---

3. Discussion and Conclusion

The mass remaining of all three litter types showed rapid decline during early decomposition (0–120 days) followed by gradual stabilization. Early mass loss primarily resulted from leaching of soluble substances and rapid decomposition of labile compounds. The large diurnal temperature variations in the study area (average summer maximum 28.2°C, winter minimum -8.1°C) created freeze-thaw cycles that accelerated decomposition.

Fertilization differentially affected decomposition rates among species, reflecting both litter substrate quality heterogeneity and species-specific nutrient requirements during decomposition. PK fertilizer significantly enhanced decomposition by altering microbial community composition and enzyme activities, increasing nutrient availability for decomposers. The accumulation of N, P, and K in fertilized treatments indicated microbial immobilization of these elements, which accelerated decomposition when nutrient availability improved.

The initial C/N ratio was the primary control factor during early decomposition, while lignin/N and C/P ratios became dominant during later stages. This shift reflects the transition from labile to recalcitrant compound decomposition. The PK treatment proved most effective for improving soil fertility in this extreme desert environment by increasing nutrient return and extending the nutrient release period.

In conclusion, fertilization significantly altered decomposition rates and nutrient release patterns in the Tarim Desert Highway shelterbelt. Phosphorus-potassium compound fertilizer application promoted surface litter decomposition, increased nutrient return, and delayed nutrient release timing. The initial litter C/N ratio is critical for predicting decomposition in this desert ecosystem, with different chemical components controlling decomposition at various stages. These findings provide theoretical support for sustainable management of artificial shelterbelt forests in arid regions.

References

[1] [2] Forest litter decomposition research progress. *Journal of Ecological Environment*, 2010, 19(1): 239-243.
[3] Fisher FM, Zak JC, Cunningham GL, Whitford WG. Water and nitrogen effects on growth and allocation patterns of creosotebush in the northern Chihuahuan Desert. *Journal of Range Management*, 1988, 41(5): 387-391.
[4] [5] Three Gorges Reservoir area *Pinus massoniana* forest soil enzyme activity effects on litter decomposition. *Chinese Journal of Applied Ecology*, 2014, 34(9): 2228-2237.
[6] Robinson CH. Controls on decomposition and soil nitrogen availability at high latitudes. *Plant and Soil*, 2002, 242(1): 65-81.
[7] Litter role in forest ecosystems and research progress. *Journal of Hubei Agricultural College*, 2003, 23(2): 140-145.
[8] Gholz HL, Fisher RF, Pritchett WL. Nutrient dynamics in slash pine plantation ecosystems. *Ecology*, 1985, 66(3): 647-659.
[9] Fog K. The effect of added nitrogen on the rate of decomposition of organic matter. *Biological Reviews*, 1988, 63(3): 433-562.
[10] Response of surface litter decomposition to increased seasonal precipitation in desert regions. *Chinese Journal of Plant Ecology*, 2012, 36(6): 471-582.
[11] Gallardo A, Merino J. Leaf decomposition in two Mediterranean ecosystems of southwest Spain: influence of substrate quality. *Ecology*, 1993, 74(1): 152-161.
[12] Martínez-Yrízar A, Núñez S, Búrquez A. Leaf litter decomposition in a southern Sonoran Desert ecosystem, northwestern Mexico: effects of habitat and litter quality. *Acta Oecologica*, 2007, 32(3): 291-300.
[13] Research progress on environmental factors affecting litter decomposition in arid and semi-arid regions. *Chinese Journal of Applied Ecology*, 2013, 24(11): 3300-3310.
[14] Neff JC, Townsend A, Gleixner G, Lehman SJ, Turnbull JC, Bowman WD. Variable effects of nitrogen additions on the stability and turnover of soil carbon.

Nature, 2002, 419(6910): 915-917.
[15] Song CC, Liu DY, Yang GS, Song YY, Mao R. Effect of nitrogen addition on decomposition of *Calamagrostis angustifolia* litters from freshwater marshes of Northeast China. *Ecological Engineering*, 2011, 37(10): 1578-1582.
[16] Hobbie SE. Contrasting effects of substrate and fertilizer nitrogen on the early stages of litter decomposition. *Ecosystems*, 2005, 8(6): 644-656.
[17] Micks P, Downs MR, Magill AH, Nadelhoffer KJ, Aber JD. Decomposing litter as a sink for N-enriched additions to an oak forest and a red pine plantation. *Forest Ecology and Management*, 2004, 196(1): 71-87.
[18] Prescott CE. Does nitrogen availability control rates of litter decomposition in forests? *Plant and Soil*, 1995, 168(1): 83-88.
[19] Dukes JS, Field CB. Diverse mechanisms for CO effects on grassland litter decomposition. *Global Change Biology*, 2000, 6(2): 145-154.
[20] Weather and climate of Taklimakan Desert and surrounding mountainous areas. *Science Press*, 2003: 201-574.
[21] Effects of saline water irrigation on plant growth in Tarim Desert Highway shelterbelt. *Journal of Desert Research*, 2011, 34(2): 215-221.
[22] Olson JS. Energy storage and the balance of producers and decomposers in ecological systems. *Ecology*, 1963, 44(2): 322-331.
[23] Experimental study on decomposition rate and model simulation of main tree species litter in various vegetation zones of Changbai Mountain. *Acta Ecologica Sinica*, 2006, 26(4): 1037-1046.
[24] Melillo JM, Aber JD, Muratore JF. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology*, 1982, 63(3): 621-626.
[25] Parton W, Silver WL, Burke IC, et al. Global-scale similarities in nitrogen release patterns during long-term decomposition. *Science*, 2007, 315(5810): 361-364.
[26] Berg B, Matzner E. Effect of N deposition on decomposition of plant litter and soil organic matter in forest systems. *Environmental Reviews*, 1997, 5(1): 1-25.
[27] Mo JM, Brown S, Peng SL, Kong GH. Nitrogen availability in disturbed, rehabilitated and mature forests of tropical China. *Forest Ecology and Management*, 2003, 175(1/3): 573-583.
[28] Treseder KK. Nitrogen additions and microbial biomass: a meta-analysis of ecosystem studies. *Ecology Letters*, 2008, 11(10): 1111-1120.
[29] Ramirez KS, Craine JM, Fierer N. Consistent effects of nitrogen amendments on soil microbial communities and processes across biomes. *Global Change Biology*, 2012, 18(6): 1918-1927.
[30] Ball BA, Bradford MA, Hunter MD. Nitrogen and phosphorus release from mixed litter layers is lower than predicted from single species decay. *Ecosystems*, 2009, 12(1): 87-100.
[31] Kozovits AR, Bustamante MMC, Garofalo CR, et al. Nutrient resorption and patterns of litter production and decomposition in a Neotropical Savanna. *Functional Ecology*, 2007, 21(6): 1034-1043.
[32] Smail SJ, Clinton PW, Greenfield LG. Nitrogen fertiliser effects on litter fall, FH layer and mineral soil characteristics in New Zealand *Pinus radiata*

plantations. *Forest Ecology and Management*, 2008, 256(4): 564-569.
[33] Lu M, Yang YH, Luo YQ, et al. Responses of ecosystem nitrogen cycle to nitrogen addition: a meta-analysis. *New Phytologist*, 2011, 189(4): 1040-1050.

Note: Figure translations are in progress. See original paper for figures.