Effects of AMF on Root Growth and Nitrogen Uptake and Allocation in Tamarix ramosissima Seedlings and Alhagi sparsifolia under Drought Stress (Postprint)

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Abstract

Arbuscular mycorrhizal fungi (AMF) play crucial roles in plant drought resistance and nutrient acquisition; however, plant responses to AMF vary among different life forms under specific environmental stresses. This study examined the effects of AMF inoculation (non-inoculated control M- versus inoculated treatment M+) on root growth characteristics and nitrogen uptake and allocation in mixed plantings of Tamarix ramosissima (the dominant shrub in desert riparian forests of the lower Tarim River) and Alhagi sparsifolia (a common semi-shrub), compared with monoculture controls, under drought stress conditions (control: 70%$±5±$5% soil relative water content). The results demonstrated: (1) Under drought stress, mycorrhizal colonization rates decreased in both Tamarix ramosissima seedlings and Alhagi sparsifolia, whereas mixed planting significantly enhanced the mycorrhizal colonization rate of T. ramosissima seedlings ($P<0.05$); (2) Under drought stress, the mixed planting M+ treatment significantly increased both aboveground and belowground biomass of T. ramosissima seedlings; (3) Under drought stress, AMF significantly increased fine root length and fine root surface area of both species across all planting patterns, significantly reduced the specific root length of A. sparsifolia, and the mixed planting M+ treatment significantly decreased the fine root specific root length of T. ramosissima seedlings; (4) Compared with monoculture, AMF significantly increased nitrogen uptake and the proportion allocated to aboveground parts in mixed-planted T. ramosissima seedlings under drought stress. Therefore, AMF exerts a significant compensatory effect on growth and nitrogen uptake of T. ramosissima seedlings coexisting with A. sparsifolia under drought stress, which may facilitate the successful establishment of T. ramosissima seedlings in the lower Tarim River region during their vulnerable growth period.

Full Text

Effects of Drought Stress and Arbuscular Mycorrhizal Fungi on Root Growth, Nitrogen Absorption, and Distribution in *Tamarix ramosissima* and *Alhagi sparsifolia* Seedlings

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Abstract

Arbuscular mycorrhizal fungi (AMF) play a crucial role in plant drought resistance and nutrient absorption, yet plant responses to AMF vary among different life forms under specific environmental stresses. This study examined the dominant shrub *Tamarix ramosissima* and the common subshrub *Alhagi sparsifolia* in the desert riparian forest of the lower Tarim River. We analyzed the effects of drought stress treatments (control group with 70% ± 5% soil relative water content, experimental group with 20% ± 5% soil relative water content), AMF inoculation (non-inoculated control vs. inoculated treatment), and planting patterns (monoculture vs. mixed planting of *T. ramosissima* and *A. sparsifolia*) on root growth and nitrogen absorption and allocation. The results demonstrated that: (1) Under drought stress, mycorrhizal infection rates in both *T. ramosissima* seedlings and *A. sparsifolia* decreased, yet mixed planting significantly increased the mycorrhizal infection rate in *T. ramosissima* seedlings ($P < 0.05$). (2) Under drought stress, mixed planting significantly increased both aboveground and belowground biomass in *T. ramosissima* seedlings. (3) Drought stress significantly increased fine root length and surface area in both species under mixed planting, while significantly decreasing the specific root length of *A. sparsifolia*. Additionally, mixed planting significantly reduced the fine root specific length of *T. ramosissima* seedlings. (4) Compared with monoculture, AMF significantly increased nitrogen uptake and aboveground nitrogen allocation ratio in *T. ramosissima* seedlings under drought stress. These findings indicate that AMF exerts a significant compensatory effect on the growth and nitrogen absorption of *T. ramosissima* seedlings when mixed with *A. sparsifolia* under drought stress, thereby facilitating the survival of *T. ramosissima* seedlings during their vulnerable growth period in the lower Tarim River region.

Keywords: arbuscular mycorrhizal fungi; drought stress; *Tamarix ramosissima*; *Alhagi sparsifolia*; nitrogen

Introduction

Plants coexisting in the same habitat engage in complex interspecific interactions, which in natural ecosystems typically manifest as competition for space and resources that directly or indirectly inhibit each other's growth. In arid environments, plant growth is suppressed by drought stress, while soil microorganisms can enhance plants' capacity to absorb and utilize water and nutrients through symbiotic relationships. Arbuscular mycorrhizal fungi (AMF), among the most closely associated soil microbes with plants, form mutualistic symbioses with two-thirds of terrestrial plant species. These fungi develop hyphal networks that can reinfect other plant roots through infection points, creating common mycorrhizal networks (CMNs) that distribute water and nutrients among different individuals and promote plant growth under adverse conditions.

The lower reaches of the Tarim River constitute an extremely arid region harboring diverse plant life forms. Soil moisture and nitrogen consistently represent critical limiting factors for seed germination, seedling growth, and survival in this area. Previous research has demonstrated that AMF significantly expand plant root systems and facilitate water absorption under drought stress. Studies on common bean (*Phaseolus vulgaris*) have shown that AMF-plant root symbiosis enhances plant responses to drought, while long-term drought experiments on the perennial grass *Themeda triandra* revealed that inoculated plants exhibited substantially greater growth recovery than non-inoculated counterparts. AMF can also increase the activity of key nitrogen assimilation enzymes, thereby enhancing nitrogen absorption capacity. In nitrogen-limited regions, plants may compete for nitrogen resources, and AMF can directly or indirectly influence interspecific nitrogen uptake patterns.

The lower Tarim River region supports a degraded desert riparian forest where *Tamarix ramosissima* (Tamaricaceae) serves as a dominant constructive species with strong drought resistance and broad ecological adaptability. *Alhagi sparsifolia* (Leguminosae), a typical perennial subshrub in this region, plays an important role in sand fixation and commonly co-occurs with *T. ramosissima* populations, together maintaining the ecological stability of the desert area. Research has documented significant associations between AMF and desert riparian forest constructive species, with 84.62% of plants in natural and artificial communities in the lower Tarim River identified as mycorrhizal. Yang et al. isolated and identified *Glomus mosseae* as the dominant AMF species in the rhizosphere of *Populus euphratica* in this extreme arid region. Wang et al. similarly isolated multiple AMF species from the rhizosphere of *A. sparsifolia*, with *G. mosseae* as the dominant species. For *T. ramosissima* to fulfill its keystone role in promoting other herbaceous plants, it must survive the vulnerable seed-to-seedling transition stage while resisting drought stress and overcoming nutrient limitations, particularly nitrogen deficiency. Studies on inland rivers in arid regions have indicated that synchronization between flooding periods and *T. ramosissima* seed dispersal significantly promotes seedling establishment, highlighting the critical importance of water availability during this vulnerable growth phase.

While previous research has focused on AMF classification and interactions with single species, natural *T. ramosissima* communities are surrounded by numerous *A. sparsifolia* individuals, yet how these different species interact through

AMF networks to affect individual plant growth remains poorly understood. This study investigates the effects of AMF on root morphology and nitrogen absorption and allocation in *T. ramosissima* seedlings and *A. sparsifolia* under drought stress. We examine the ecological role of AMF during the vulnerable growth period of *T. ramosissima* seedlings, providing theoretical foundations for vegetation restoration and species diversity maintenance in the desert riparian forest of the lower Tarim River.

Materials and Methods

Experimental Apparatus

This study employed a Y-shaped pot system [Figure 1: see original paper]. Each 48 cm × 17 cm × 25 cm pot was divided into three compartments using nylon mesh barriers. The mesh was fixed to the pot walls with screws, where 20 m nylon mesh permitted hyphal passage while blocking plant roots, and 0.45 m mesh allowed only soil ions to pass while blocking both hyphae and roots. In this system, the donor compartment inoculated with AMF enabled hyphae to penetrate the 20 m mesh into receptor compartments, infecting plant roots and forming a mycorrhizal network among different individuals within the microcosm apparatus. This design allowed investigation of hyphal network effects between the two plant species.

Experimental Materials and Treatments

The experimental plants, *T. ramosissima* and *A. sparsifolia*, were sourced from the lower Tarim River region. Uniform, plump seeds of both species were selected and sown in pots for outdoor germination at the greenhouse cultivation base of Xinjiang Normal University. The experimental substrate consisted of sieved sandy soil that underwent continuous moist heat sterilization at 0.14 MPa and 121°C for 2 hours. The AMF inoculum comprised a 1:1 mixture of *Glomus etunicatum* and *G. mosseae* obtained from the Institute of Microbial Application, Xinjiang Academy of Agricultural Sciences, with a spore density of 400 per 10 kg soil. Healthy, uniformly growing seedlings approximately 10 cm tall were retained after thinning, with three seedlings per compartment.

The experiment employed a three-factor, two-level factorial design: soil moisture (70% ± 5% relative water content as control, 20% ± 5% as drought stress), inoculation treatment (non-inoculated vs. inoculated), and planting pattern (monoculture vs. mixed planting). This yielded eight treatment combinations (Table 1). Soil moisture was monitored using a WET-2 portable moisture meter and maintained through gravimetric water supplementation. After 120 days of drought stress treatment, during which normal seedling growth was ensured, 10 mL of 15N-labeled ammonium nitrate was uniformly injected at ten symmetrically distributed points in the soil for tracer analysis. Plants were harvested after 15 days for index determination.

Index Determination and Methods

Plant height, basal diameter, and crown width were measured directly using rulers. Aboveground and belowground biomass were harvested separately and dried at 80°C to constant weight. Dried samples were ground, and at least 0.5 g was sealed in centrifuge tubes for total nitrogen content and nitrogen allocation ratio determination at the Isotope Analysis and Testing Center of the Institute of Botany, Chinese Academy of Sciences. Root morphology parameters were analyzed by scanning graded root systems using an Epson V700 scanner and Japan Rhizo software. Mycorrhizal infection status was assessed using trypan blue staining and microscopic observation.

The following formulas were used for basic data analysis:

- Ndff = (15N abundance in sample - natural abundance) / (15N abundance in fertilizer - natural abundance) × 100
- This represents the contribution rate of 15N-labeled fertilizer to plant total nitrogen content (natural abundance of 15N-labeled ammonium nitrate used: 0.365%)
- Nitrogen uptake from 15N = Dry mass × Total nitrogen percentage × Ndff
- Nitrogen allocation ratio = Nitrogen uptake in aboveground or belowground parts / Total nitrogen uptake × 100

Data Analysis

All experimental data were processed using Excel for mean and standard error calculations and graphing. SPSS 19.0 was used for multi-factor ANOVA and multiple comparison analysis to determine significant differences among treatment indicators ($\alpha = 0.05$).

Results

Effects of AMF on Mycorrhizal Infection Rates Under Drought Stress

AMF effects on mycorrhizal infection rates differed between the two species under varying water treatments (Table 2). In control groups, a few arbuscules and vesicles were observed in *A. sparsifolia* roots, possibly associated with legume rhizobium symbiosis. No mycorrhizal infection, hyphal fragments, or arbuscule/vesicle structures were detected in *T. ramosissima* under non-inoculated conditions. Under drought stress, mycorrhizal infection rates decreased significantly in both species under monoculture ($P < 0.05$), with a more pronounced reduction in *T. ramosissima*. Although drought stress also reduced infection rates under mixed planting, *T. ramosissima* exhibited significantly higher infection rates than *A. sparsifolia*.

Effects of AMF on Plant Biomass and Root-Shoot Ratio Under Drought Stress

Drought stress significantly reduced aboveground and belowground dry weight in both species (Table 3). However, AMF inoculation promoted growth in both plants. Under monoculture, inoculation significantly increased *A. sparsifolia* biomass ($P < 0.05$). Under mixed planting, inoculation enhanced biomass in both species and particularly increased *T. ramosissima* aboveground and belowground biomass by 47.5% and 21.0%, respectively.

AMF also affected root-shoot ratios (Figure 2). Under drought stress, inoculation significantly increased the root-shoot ratio of *T. ramosissima* seedlings under mixed planting. The root-shoot ratio of *T. ramosissima* seedlings showed an increasing trend under inoculation, while that of *A. sparsifolia* increased initially then decreased. Under monoculture, inoculation significantly increased the root-shoot ratio of *A. sparsifolia* but not *T. ramosissima*. Under mixed planting, inoculation significantly increased root-shoot ratios in both species.

Effects of AMF on Root Morphology Under Drought Stress

AMF effects on root morphology were most direct (Tables 4-6). Drought stress decreased root length and surface area in both species, while AMF increased these parameters and reduced specific root length. Under drought stress, monoculture inoculation significantly increased fine root length (<2 mm) in both species ($P < 0.05$) but not coarse root length (>2 mm). Inoculation significantly increased fine root surface area in *A. sparsifolia* but not in *T. ramosissima*. Mixed planting with inoculation significantly increased coarse root length and fine root surface area in *T. ramosissima* seedlings.

Under drought stress, both monoculture and mixed planting with inoculation significantly reduced coarse root specific length in *A. sparsifolia*, while mixed planting significantly reduced fine root specific length in *T. ramosissima* seedlings. This suggests that mycorrhizal hyphae may substitute for some root absorption functions.

Effects of AMF on Nitrogen Uptake and Distribution Under Drought Stress

AMF affected total nitrogen uptake differently in the two species under drought stress (Figure 3). Inoculation increased total nitrogen content in *T. ramosissima* seedlings but decreased it in *A. sparsifolia*. Mixed planting under drought stress significantly increased total nitrogen in *T. ramosissima* ($P < 0.05$), indicating that mixed planting with AMF promotes nitrogen uptake in *T. ramosissima* seedlings and regulates nutrient deficiency.

AMF also influenced above- and belowground nitrogen allocation ratios (Figure 4). Under drought stress, *T. ramosissima* seedlings showed reduced nitrogen allocation to both above- and belowground parts, but mixed planting with inoculation significantly increased aboveground nitrogen allocation ($P < 0.05$), enabling *T. ramosissima* seedlings in mixed culture to absorb more nitrogen.

Discussion

Mycorrhizal infection rate represents the fundamental condition for plant root-AMF interactions, and different symbiotic relationships with various hosts affect host growth characteristics differently. Wang et al. isolated multiple AMF species from the rhizosphere of *A. sparsifolia*, with *G. mosseae* as the dominant species. Our experimental inoculum comprised a mixture of *G. etunicatum* and *G. mosseae*, which may explain the higher infection rate in *A. sparsifolia* compared to *T. ramosissima*. However, under drought stress with mixed planting, *T. ramosissima* exhibited significantly higher infection rates than *A. sparsifolia*, suggesting that under mixed growth conditions, AMF may preferentially promote *T. ramosissima* seedling growth by transferring more water and nutrients to this species, thereby helping it survive the vulnerable seedling stage.

Our findings show that inoculated plants had higher total biomass than non-inoculated plants, consistent with Merrild et al.'s conclusion that mycorrhizal networks can increase average plant size. However, Weremijewicz et al. found that mycorrhizal networks promote growth of larger plants while inhibiting smaller ones. In our study, AMF effects on above- and belowground biomass differed between species and water treatments. Under drought stress, mixed planting with inoculation significantly increased *T. ramosissima* seedling biomass, while monoculture inoculation significantly increased *A. sparsifolia* biomass. This indicates that AMF may enhance water retention capacity in *A. sparsifolia* under drought, but in mixed culture, AMF more strongly promotes *T. ramosissima* root development.

Under drought stress, mixed planting significantly promoted coarse root length and fine root surface area in *T. ramosissima* seedlings, suggesting that AMF favor root development in this species. This enables deeper soil penetration by coarse roots and expanded absorption area by fine roots, enhancing water and nutrient acquisition. Han et al. demonstrated that roots with diameters <2 mm perform the primary absorption function, and Veiga et al. showed that AMF colonization induces finer root systems that facilitate water and nutrient uptake. Our results indicate that AMF hyphae may substitute for some root absorption functions, as evidenced by reduced specific root length in colonized plants. The differential growth rates between *T. ramosissima* (a constructive shrub species) and *A. sparsifolia* (a subshrub) create competition, and AMF appear to preferentially promote *T. ramosissima* seedling root development while having less pronounced effects on *A. sparsifolia*, thereby balancing the competitive relationship under drought stress.

Using 15N isotopic tracing provides convenient comparison of nitrogen allocation patterns between species. Liu et al. detected 15N in tobacco roots, stems, and leaves after AMF inoculation, and we similarly detected 15N in both study species, with differential distribution between above- and belowground parts. Ma et al. found reduced rhizosphere soil nitrogen in drought-stressed *Bombax ceiba* inoculated with AMF, confirming that nitrogen can be supplied to plants via hyphal networks. Our results show that under normal water conditions (70% soil relative water content), AMF effects on both species were not significant, likely because adequate soil moisture facilitates nitrogen mobility, reducing plant dependence on mycorrhizae. However, under drought stress, *T. ramosissima* seedlings stored most AMF-acquired nitrogen in aboveground tissues, creating a nitrogen “sink” that accelerates seedling growth and helps them rapidly pass through the vulnerable establishment phase.

Conclusions

1. Drought stress reduces AMF colonization in seedlings of both desert plant species in the lower Tarim River, while mixed planting enables drought-stressed *T. ramosissima* seedlings to maintain higher mycorrhizal infection rates than *A. sparsifolia*.
2. Under drought stress, AMF inoculation significantly increases biomass and promotes growth of both desert plant seedlings. Specifically, when mixed with *A. sparsifolia*, AMF markedly enhances *T. ramosissima* seedling root development by significantly increasing coarse root length and fine root surface area, substantially improving water and nutrient acquisition capacity.
3. Under drought stress, AMF differentially affects total nitrogen uptake between monocultured species, increasing total nitrogen in *T. ramosissima* while decreasing it in *A. sparsifolia*. Mixed planting with AMF significantly enhances nutrient absorption, particularly aboveground nitrogen content, in *T. ramosissima* seedlings.

References

[1] Lei Yao, Hao Zhipeng, Chen Baodong. Effects of indigenous AM fungi and neighboring plants on the growth and phosphorus nutrition of *Leymus chinensis* [J]. *Acta Ecologica Sinica*, 2013, 33(4): 1071-1079.

[2] Li Junshuai. Studying on the Relationship Between Hyphal Infection Characteristic of AMF and Phylogeny of Plant [D]. Lanzhou: Lanzhou University, 2016.

[3] Xiang Dan, Xu Tianle, Li Huan, et al. Ecological distribution of arbuscular mycorrhizal fungi and the influencing factors [J]. *Acta Ecologica Sinica*, 2017, 37(11): 3597-3606.

[4] HE X H, Critchley C, Bledsoe C. Nitrogen transfer within and between plants through common mycorrhizal networks (CMNs) [J]. *Critical Reviews in Plant Sciences*, 2003, 22(6): 531-567.

[5] Booth M G. Mycorrhizal networks mediate overstorey-understorey competition in a temperate forest [J]. *Ecology Letters*, 2004, 7(7): 539-556.

[6] Meng Xiaoyan, Yin Linke, Chen Li. Arbuscular mycorrhizaes of common plants infection at the lower reaches of Tarim River [J]. *Arid Land Geography*, 2008, 31(1): 102-108.

[7] Zhong Xiaoli, Ma Xiaodong, Lyu Haohao, et al. Effect of nitrogen on growth and photosynthesis of *Populus euphratica* seedlings under drought stress [J]. *Chinese Journal of Ecology*, 2017, 36(10): 2777-2786.

[8] Ali Ganjeali, Elham Ashiani, Maryam Zare, et al. Influences of the arbuscular mycorrhizal fungus *Glomus mosseae* on morphophysiological traits and biochemical compounds of common bean (*Phaseolus vulgaris*) under drought stress [J]. *South African Journal of Plant and Soil*, 2018, 35(2): 121-127.

[9] Renee H P, Jonathan B G, Todd M P, et al. Habitat specific AMF symbioses enhance drought tolerance of a native Kenyan grass [J]. *Acta Oecologica*, 2017, 78: 71-78.

[10] Ruiz Lozano J M, Azcón R. Mycorrhizal colonization and drought stress as factors affecting nitrate reductase activity in lettuce plants [J]. *Agriculture, Ecosystems and Environment*, 1996, 60(2-3): 175-181.

[11] Suri V K, Kumar A, Choudhary A. AM fungi lead to better plant nutrient acquisition and drought tolerance in agricultural crops: A review [J]. *Current Advances in Agricultural Sciences*, 2017, 9(1): 17-26.

[12] Ingraffia R, Amato G, Frenda A S, et al. Impacts of arbuscular mycorrhizal fungi on nutrient uptake, N2 fixation, N transfer, and growth in a wheat/faba bean intercropping system [J]. *PLoS ONE*, 2019, 14(3): 103116.

[13] Wahbi S, Maghraoui T, Hafidi M, et al. Enhanced transfer of biologically fixed N from faba bean to intercropped wheat through mycorrhizal symbiosis [J]. *Applied Soil Ecology*, 2016, 107: 91-98.

[14] Liu Huan. Effect of Various Arbuscular Mycorrhizal Fungi on Plant Growth Characteristics [D]. Lanzhou: Gansu Agricultural University, 2016.

[15] Zhang Ruiqun, Ma Xiaodong, Lyu Haohao. Response of growth and anatomical structure of roots of *Tamarix ramosissima* seedlings to salinity and water stress [J]. *Pratacultural Science*, 2016, 33(6): 1164-1173.

[16] Merrild M P, Ambus P, Rosendahl S. Common arbuscular mycorrhizal networks amplify competition for phosphorus between seedlings and established plants [J]. *New Phytologist*, 2013, 200(1): 229-240.

[17] Weremijewicz J, Sternberg L D, Janos D P. Common mycorrhizal networks amplify competition by preferential mineral nutrient allocation to large host plants [J]. *New Phytologist*, 2016, 212(2): 461-471.

[18] Han Yanying, Ye Yanhui, Wang Zhenhong, et al. Root biomass, specific root length and root length density of *Sophora moorcroftian* in Tibet [J]. *Journal of Northeast Forestry University*, 2014, 42(2): 39-41.

[19] Veiga R S, Faccio A, Genre A. Arbuscular mycorrhizal fungi reduce growth and infect roots of the non-host plant *Arabidopsis thaliana* [J]. *Plant Cell & Environment*, 2013, 36(11): 1926-1937.

[20] Liu Q, Parsons A J, Xue H, et al. Functional characterization and transcript analysis of an alkaline phosphatase from the arbuscular mycorrhizal fungus *Funneliformis mosseae* [J]. *Fungal Genetics and Biology*, 2013, 54: 52-59.

[21] Chen K, Shi S M, Yang X H. Contribution of arbuscular mycorrhizal inoculation to the growth and photosynthesis of mulberry in karst rocky desertification area [J]. *Applied Mechanics and Materials*, 2014, 488(8): 769-773.

[22] Barto E K, Hilker M, Müller F, et al. The fungal fast lane: Common mycorrhizal networks extend bioactive zones of allelochemicals in soils [J]. *PLoS ONE*, 2011, 6(11): e27195.

[23] Leiyao, Wu Songlin, Hao Zhipeng, et al. Development of arbuscular mycorrhizal hyphal networks mediated by different plants and the time effects [J]. *Acta Botanica Boreali-Occidentalia Sinica*, 2013, 33(1): 154-161.

[24] Lai Jinli, Li Xinxin, Xue Lei, et al. Research progress of plant drought resistance [J]. *Jiangsu Agricultural Sciences*, 2018, 46(17): 23-27.

[25] Wen Zhe. Application of isotope dilution technique and tracer technique in the study of N element in forest soil [J]. *South China Agriculture*, 2016, 10(30): 102-103, 109.

[26] Liu Bei, Gao Yuan, Song Wenjun, et al. Effects of AMF on nitrogen metabolism and osmotic regulators in tobacco [J]. *Journal of Fungal Research*, 2017, 15(1): 14-20.

[27] Ma Kun, Yang Jianjun, Li Lu, et al. Drought stress effects of nutrients of the *Bombax ceiba* at the root soil and plants body after inoculation of AMF [J]. *Journal of Central South University of Forestry Technology*, 2017, 37(11): 90-95, 102.

[28] Walder F, Niemann H, Natarajan M, et al. Mycorrhizal networks: Common goods of plants shared under unequal terms of trade [J]. *Plant Physiology*, 2012, 159: 789-797.

[29] He Shubin, Guo Lixiang, Li Jing, et al. Advances in arbuscular mycorrhizal fungi and legumes symbiosis research [J]. *Acta Prataculturae Sinica*, 2017, 26(1): 187-194.

[30] Wang Youshan, Chen Li, Zhang Shubin, et al. Biodiversity of arbuscular mycorrhizal fungi in the natural forests of *Populus euphratica* and *Alhagi sparsifolia* in Xinjiang [J]. *Arid Zone Research*, 2010, 27(6): 927-932.

[31] Yang Yuhai, Chen Yaning, Li Weihong. Fungal infection of arbuscular mycorrhizal fungi and environmental impact factors in desert riparitic forests: A case study of the lower Tarim River [J]. *Progress in Natural Science*, 2008, 18(4): 397-405.

[32] Yang Yuhai, Chen Yaning, Cai Boyan, et al. Arbuscular mycorrhizal infection in *Populus euphratica* roots of in the lower reaches of Tarim River in the extreme arid area [J]. *Arid Land Geography*, 2012, 35(2): 260-266.

[33] Ma Jiaqi. Effects of arbuscular mycorrhizal fungi on plant drought tolerance: Research progress [J]. *Biotech World*, 2016(3): 63-63.

[34] Zou Yingning, Wu Qiangsheng, Li Yan, et al. Effects of arbuscular mycorrhizal fungi on root system morphology and sucrose and glucose contents of *Poncirus trifoliata* [J]. *Chinese Journal of Applied Ecology*, 2014, 25(4): 1125-1129.

[35] Yang H, Zang Y, Yuan Y. Selectivity by host plants affects the distribution of arbuscular mycorrhizal fungi: Evidence from ITS rDNA sequence metadata [J]. *BMC Evolutionary Biology*, 2012, 2(1): 1-14.

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