TECHNICAL STRATEGY TO IMPROVE APPLICATION POTENTIAL OF EPHEMERAL PLANTS IN ECOLOGICAL RESTORATION OF MINING AREAS

LIU, X. H.[1,2,3*] – YAN, Y. J.[4] – LI, Q.[5]

[1]*China Coal Technology & Engineering Group Co., Ltd., Beijing 100013, China*

[2]*China Coal Science & Technology Ecological Environment Technology Co. Ltd., Beijing 100013, China*

[3]*CCTEG Beijing Research Institute of Land Renovation and Ecological Restoration Technology Co., Ltd., Beijing 100013, China*

[4]*Powerchina Beijing Engineering Corporation Limited, Beijing 100024, China*

[5]*Shaanxi Key Laboratory of Ecological Restoration in Shaanbei Mining Area, Yulin University, Yulin 719000, China*

[*]*Corresponding author*
e-mail: xicheng516@126.com

(Received 4th Feb 2025; accepted 14th Apr 2025)

Abstract. Establishing suitable vegetation cover is important in restoring mining areas. Ephemeral plants, which exhibit short growth cycles, high photosynthetic efficiency, large numbers of seeds, and two-season germination, exert positive effects in desert ecological restoration and as pioneer species, making them potentially valuable in restoring mining areas. To examine their benefits, we systematically reviewed the literature on the use of ephemerals in such restoration, examining vegetation selection, planting, ecological restoration management, and methods to regulate ephemeral plant growth. Damaged mining areas provide the conditions for ephemerals to play an early role in ecological restoration. Few studies have examined the application of ephemerals in mining areas, with most examining the use of existing plant resources. Technical models for applying ephemerals are discussed, considering plant selection and pretreatment, plant combinations, the application of functional microbial agents, planting parameters, maintenance of conditions such as water supply and salinity after planting, and research prospects. This review provides new direction in realizing the resource value and ecological effects of ephemerals, supporting both research and the engineering-based application of ephemerals in mining areas. These advances could improve the quality and efficiency of ecological restoration in mining areas, especially in arid regions.
Keywords: *short-lived plant, ecological effect, plant rehabilitation, damaged land*

Introduction

Damaged surfaces formed by excavation, occupation, and subsidence in mining areas can be extremely difficult to restore ecologically, owing to soil shortages, nutrient deficiencies, and poor capacities for water retention and supply. Ecological restoration in mining areas often requires additional financial and material resources, and the process is lengthy. Plant restoration is an important goal in such restoration. The use of plants for such restoration has been extensively studied in terms of vegetation selection and combination, planting methods, support measures, and post-planting maintenance. The restoration of mining areas is effectively promoted by methods such as edge mining and restoration based on the planting of suitable vegetation (Hu et al., 2020), artificially guided natural restoration (Lei et al., 2022), and functional bacterial-assisted restoration

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849

(Bi and Xie, 2021). Plant adaptability provides an important foundation for the early and long-term restoration of mining areas. Exploring the plant resources suitable for the adverse conditions of mining areas has significant practical relevance, especially in ecologically fragile regions.

Ephemeral plants (also known as low-nutrient or short-lived plants) grow in arid desert areas or deciduous forests and exhibit a short annual growth period or aboveground life cycle (Iwanami et al., 2017). Ephemerals can survive drought and shade, and their growth cycles are not matched with those of nonephemeral plants; by occupying a particular niche, they are able to reduce competition for the resources, including space, that support survival and reproduction (Iwanami et al., 2017). These characteristics make ephemerals potentially valuable for in restoring degraded mining areas.

This review examines novel technological approaches for applying ephemerals in the ecological restoration of mining areas, summarizes their growth and application in such areas, and explores their application potential. This synthesis may be useful for improving the efficiency and effectiveness of ecological restoration in mining areas, especially in arid regions such as Western China and Africa.

Methods

A literature search was conducted using the China National Knowledge Infrastructure (CNKI) and Web of Science, using keywords such as “ephemeral plants,” “short lived plants,” and “ecological restoration.” The resulting list of sources was then simplified using the keyword “mining area,” to focus on the ecological restoration of mining areas (Which include 73 articles, 36 in English and 37 in Chinese). Research on ecological restoration in mining areas, including that on ecological restoration concepts and methods, was included. Finally, a framework for vegetation restoration was constructed, incorporating vegetation selection, planting, and maintenance.

Ecological effects of ephemerals

Ephemerals can be divided into desert ephemerals (Yuan and Tang, 2010) and understory ephemerals (Gutjahr and Lapointe, 2008; Kim et al., 2015; Dion et al., 2017; Greco et al., 2019). Given their short life cycle (ca. 2–3 months) (Lapointe, 2001; Zhang and Tan, 2007; Qiu et al., 2018; Zhao et al., 2021), high photosynthetic efficiency (Lapointe, 2001; Yuan et al., 2009; Tu et al., 2012), and rapid material accumulation (Yuan and Tang, 2010), ephemerals can efficiently utilize resources such as early spring precipitation and snow melt (Qiu et al., 2018). Ephemerals regulate their growth and adapt to the environment through biomass allocation (Kim et al., 2015; Ding et al., 2016; Zhang et al., 2021a, 2022a) and allometric growth (Zhou et al., 2014; Ding et al., 2016). They can achieve effective propagation via strategies such as heteromorphism (El-Keblawy, 2003), producing large numbers of seeds (Ma et al., 2010), producing mucilage (Zhang et al., 2014; Zhao et al., 2021), contributing to the future seed bank (Li and Zhao, 2005), and germinating in both spring and autumn (Wang et al., 2006; Chen et al., 2019; Yang et al., 2019a; Li et al., 2020; Mu et al., 2021).

The value of ephemerals is reflected in their use as forage feed (Lv and Tan, 2005) and in traditional Chinese medicine (Cong et al., 2011), in creating floral landscapes (Ecseri et al., 2015; Tong et al., 2022), and in their ecological effects (Yuan and Tang, 2010; Zhang et al., 2022a). Ecologically, they play an important role in stabilizing desert

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849

ecosystems and improving desert ecological health (Wang et al., 2003; Lv and Tan, 2005; Yuan and Tang, 2010; Zhang et al., 2011; Qiu et al., 2018; Zhao et al., 2021; Peng et al., 2022; Tao et al., 2022). Ephemerals are therefore pioneer plants in succession processes (Wang et al., 2003; Yuan and Tang, 2010). They can improve utilization of light and enhance ecosystem productivity, thus accelerating ecosystem material cycles and energy flows (Rothstein, 2000). Their growth and ecological effects be influenced by temperature (Dion et al., 2017), the supply of water (Zhou et al., 2010; Dion et al., 2017), nutrients (Zhou et al., 2010), and light (Zhang and Tan, 2007), and by terrain-related factors including slope and orientation (Zhang et al., 2021a). Climatic factors, including annual average temperature and winter precipitation, are often the most important influencing factors (Wang et al., 2021a).

In Africa, which experiences worse drought than other parts of the world, ephemerals have been studied (Rosch et al., 1997; Milton and Dean, 2000). Studies have examined the types of ephemerals present (Liang et al., 2019; Singh et al., 2023), their seed characteristics (El-Keblawy, 2003), growth status on saline soils (de Villiers et al., 1999), and the relationship between precipitation and flowering time (Steyn et al., 1996; Hegazy, 2001). Seed production of ephemeral species was reduced under low-salinity conditions, whereas that of perennial species was not significantly affected by low salinity (de Villiers et al., 1999). Steyn et al. (1996) found that the flowering time of ephemeral species in Namaqualand (South Africa) depends on the timing of the first substantial winter rain event. In Egypt, the additional rainfall received in wet years causes some ephemerals to live longer (Hegazy, 2001).

The exposed surfaces and harsh habitat of mining areas provide sufficient lighting for the growth of ephemerals. The rough surfaces formed by mining are conducive to seed interception and can create favorable conditions for their establishment and growth. Ecologically, ephemerals increase vegetation cover, improve soil texture, and increase overall biodiversity, giving them application value and advantages in restoring mining areas.

Current research on ephemerals in mining areas

Relatively little research has been conducted on ephemerals in mining areas. Surveys of vegetation resources in mining areas have shown that ephemerals are distributed throughout arid and desert mining areas (Li et al., 2015, 2018). Disturbance due to large-scale and high-intensity engineering activity such as mining can sharply reduce the number of ephemeral species in deserts (Yuan et al., 2014). Ephemerals are often used as pioneer plant species to restore mining areas. Xu et al. (2019) found that the plants growing in the Wucaiwan mining area (Xinjiang, China) exhibited the typical phenological growth characteristics of desert ephemerals. Ouyang (2017) speculated that ephemerals such as *Vicia hirsuta* and *Vicia sepium* could effectively intercept dust pollution in Mn mining areas. In an on-site mining-area study, Yang (2017) found that subsidence-induced cracks can be occupied by ephemerals, and Norman et al. (2006) found that ephemerals dominate in terms of vegetation density (rather than vegetation coverage) during mining-area restoration. The seed bank in the surface soil retained during mining excavation comprises mostly ephemerals, with ephemerals constituting a high proportion of the species present after restoration using this surface soil (Flores-Alvarez et al., 2018).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849

Strategies for using ephemerals in restoring mining areas

For mining-area restoration, this review systematically examines the planting of ephemerals, methods to regulate their growth, factors influencing their growth, the construction of the plant community, and post-planting management. For ephemerals that function as pioneer species in mining areas, it is necessary to support their ability to overcome adverse factors during their early growth and to provide some assistance to support their later growth. We present a technical strategy for applying ephemerals in mining areas, addressing seed-source selection and treatment, planting, and post-planting management the supply of water and nutrient (*Figure 1*).

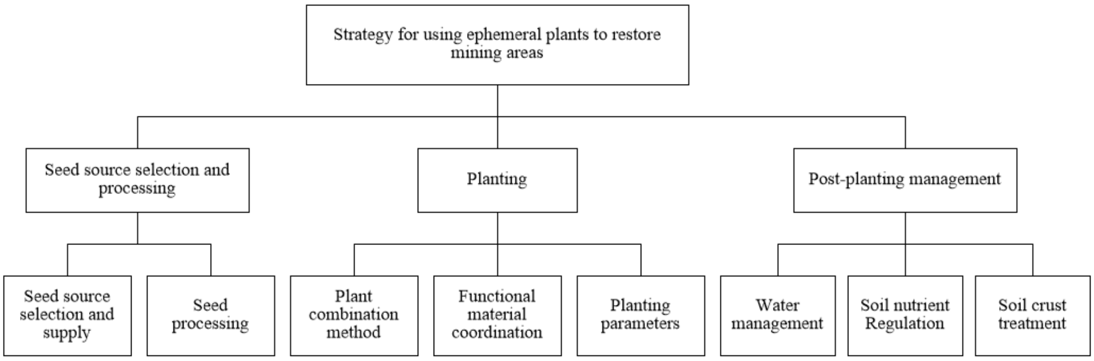

Figure 1. *Strategy for using ephemeral plants to restore mining areas*

Seed source selection and processing

Seed source selection and supply

Choosing a suitable ephemeral plant species for cultivation is crucial for ecological restoration (Peng et al., 2022). Although some ephemeral plant species are recommended for urban landscaping, shortcomings persist regarding their establishment and the application of seed banks. Various hardy ephemerals that are available for landscaping and greening can be used for restoring mining areas. However, further research is required into their application in mining environments and to discover other ephemerals that can be widely applied in mining areas. Multiseason-germinating and perennial ephemerals may perform better under adverse conditions in mining areas and should receive more attention.

To promote the cultivation of ephemerals, methods such as tissue culture and plant regeneration (Xu et al., 2010) can be used to increase germplasm resources and improve strategies for utilizing ephemerals in mining areas. Seedling nurseries and supply systems should be constructed to ensure a sufficient supply of ephemeral plant seedlings for restoring mining areas (Broadhurst et al., 2016).

Seed processing

In ephemerals, seed dormancy can reduce the germination rate (Zhang et al., 2018). Improving germination rates is important in promoting restoration of mining areas. Methods to achieve this include seed soaking, mechanical treatment, biochemical reagent treatment, hormone treatment, low/high-temperature treatment, and combination treatments (Yang et al., 2006).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849

Mechanical-damage treatment can cause the seed coat to relax or become breathable (Zhang et al., 2007), breaking seed dormancy (Long, 2012; Li et al., 2020) and reducing mechanical resistance to embryo growth (Fan et al., 2010), thus improving germination rates in natural habitats (Zhang et al., 2007). *Astragalus apilobus* seeds could germinate rapidly after the seed coat was artificially cut (Long, 2012). Li et al. (2020) found that cutting through the seed coat of *Erodium oxyrhinchum* effectively broke the physical dormancy of spring- and autumn-sprouting seeds, increasing seed germination from <20% to ca. 90%; Yang et al. (2016) examined seed germination in *Gagea nigra*, finding that removing the seed coat effectively promoted germination (which reached 88%); in contrast, treatment at room temperature (25°C) with acid/alkali application did not achieve this. For *Malcolmia scopioides* and *Tetracme quadricornis*, Fan et al. (2010) found that puncturing the seed coat increased seed germination to >90%.

Zhang et al. (2018) examined the effects of sand burial of the seeds of various ephemerals, finding significant differences in seed germination characteristics and dormancy release after burial. They divided the plant species into three categories, based on their germination patterns: burial-promoted, burial-inhibited, and burial-invariant. Sand burial promoted the germination of ephemerals such as *Eremopyrum orientale*, *Alyssum desertorum*, and *Neotoriria korolkovii* (Zhang et al., 2018).

Seed soaking is commonly used to promote germination, and the effects of different soaking conditions vary. Long (2012) found that soaking in concentrated sulfuric acid was one of the best methods for breaking seed dormancy in *Astragalus apilobus*. In contrast, soaking *Gagea nigra* seeds in warm water at 50°C did not significantly affect seed germination (Yang et al., 2016). Zhang et al. (2007) found that gibberellin effectively promoted seed germination (by >50%) in *Arabidopsis pumila*, by enhancing embryonic activity. For *Malcolmia scopioides* and *Tetracme quadricornis*, gibberellin treatment increased seed germination from <15% (their natural germination rate) to >90% (Fan et al., 2010). For *Gagea nigra*, gibberellin alone at 200 mg/L did not significantly affect seed germination, whereas 200 mg/L gibberellin plus seed-coat puncturing and 500 mg/L gibberellin plus 15% H_2O_2 treatment effectively promoted seed germination, achieving germination rates of 84% and 82%, respectively (Yang et al., 2016).

In summary, treatments targeting specific ephemerals should be implemented to break seed dormancy and promote seed germination and plant growth when restoring mining areas. Seed coat puncture and gibberellin treatment, alone or in combination, are the primary methods.

Planting

The planting method affects planting efficiency and the stability of the resulting vegetation. The models for applying ephemerals in mining areas include early restoration methods (including sowing alone or together with the seeds of nonephemerals) and later supplementary sowing (targeting areas exhibiting poor greening and early restoration). Supplementary sowing can avoid weakening the impact of ephemerals in early-spring greening and can promote soil improvement after the loss of single plants. To achieve efficient and sustainable cultivation of ephemerals in mining areas, it is necessary to increase research on planting methods, including plant combinations and functional-material coordination.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849

Plant combinations

Although ephemerals grow vigorously and are highly important in certain seasons, their short life cycles can cause instability in plant communities (Li, 2015). Therefore, during restoration, it is necessary to balance these negative effects by planting nonephemeral plants. In the constructed composite system, ephemerals function mainly as pioneer plants, achieving short-term greening and improving soil structure and organic matter conditions before the mining area is fully vegetated, thereby creating conditions for the establishment and restoration of nonephemeral plant communities.

For *Haloxylon ammodendron*, Tian (2014) found that during the early growth stage, its seedlings compete for water with the surrounding ephemerals and are usually at a disadvantage. Specifically, under good water conditions, its seedling survival was not necessarily high, whereas when water was limited, its survival was higher because the germination rate and water consumption of other ephemerals was reduced. Therefore, it is necessary to consider the competitive relationship between ephemerals and related vegetation in vegetation combinations as well as artificial regulation and mitigation measures.

Functional microbial agents

In mining areas, the growth of ephemerals can be promoted using organic and inorganic fertilizers. Arbuscular mycorrhizal (AM) fungi often have a symbiotic relationship with ephemerals, and this can promote growth. The role of AM fungi in soil improvement and ecological restoration in mining areas has been extensively studied (Li et al., 2013; Bi, 2017), and their positive effects are widely recognized (Zhang et al., 2020, 2021b; Bi et al., 2022). Therefore, when planting ephemerals for ecological restoration of mining areas, appropriate microbial agents can be applied to promote the growth of both the planted ephemerals and other plants.

In contrast, inhibiting AM fungi or preventing mycelial growth can adversely affect plant growth. Wu et al. (2018) showed that preventing the development of the hyphal network of AM fungi reduced seedling leaf traits, plant height, and above- and below-ground biomass in *Erodium oxyrhinchum*, an ephemeral. When growing ephemerals in combination with AM fungi, efforts should be made to minimize soil disturbance and to avoid the adverse effects of hyphal damage.

Planting parameters

Yuan et al. (2014) showed that ephemerals in desert areas exhibit a clustered and patchy distribution. The microterrain formed by moderate- and low-level interference (such as rutting and rolling) can provide favorable conditions for the germination and growth of ephemerals by redistributing resources such as water and soil and altering temperature patterns. Ephemerals exhibit habitat-specific adaptations, and their growth is affected by differences in the microterrain, soil quality, and in other environmental conditions. Therefore, combinations of ephemerals can be used in the restoration of mining areas and in their post-planting management. Microterrain features such as waterlogging can be preserved or constructed to facilitate ephemeral germination, growth, and seed fall.

A seedling-excavation experiment (Long, 2012) revealed that the most suitable sand-burial depth for the ephemeral plant *Astragalus apilobus* was 1–2 cm, with no seedlings appearing at depths ≥6 cm. For ephemerals in the Gurbantunggut Desert, plant seeds were concentrated mainly in the 0–5 cm soil layer, with very few of the seeds at depths >5 cm being viable (Zhang et al., 2006). A bulb-planting study on the ephemeral *Erythronium japonicum* (Yang et al., 2019b) revealed significant differences in survival rates between soil-cover depths: survival was highest (88%) at 15 cm depth. Therefore, in mining areas, the seeds of ephemerals should be sown in the appropriate soil layers, avoiding deep burial, while bulbs should be planted according to their specific growth characteristics to facilitate normal emergence and growth.

Plants that germinate at different times of the year exhibit significant differences in cold resistance (Li, 2014). Ephemerals exhibit multiseason germination, influenced by regional precipitation and other factors (Li, 2014). Therefore, it is necessary to consider the sowing time-points for ephemerals. To fully utilize early-spring precipitation in mining areas, ephemerals should be sown as early as possible in spring.

Post-planting management

The pioneer efficacy of ephemerals and their preliminary treatment during planting can ensure their effective use in mine-land restoration. However, to further explore the growth potential and restorative effects of ephemerals, field management practices can be implemented after planting and establishment. For annual ephemerals, early maintenance is applied, primarily to help the plants to complete their growth cycle and achieve fruiting, seed drop, and regermination the following year. In perennial ephemerals, early maintenance promotes sufficient belowground growth, promoting normal germination and subsequent growth. In mining areas, the primary field-management measures include the regulation of water and soil-nutrient levels and surface-crust treatment.

Water supply management

Water plays an important role in the growth of ephemerals, and water supply management is an important regulatory method in plant establishment. Few studies have examined how altering the water supply regulates the growth of ephemerals. For the ephemeral *Astragalus apilobus*, watering caused the phenological period to shift slightly later (Long, 2012). In mining areas, the supply of water to ephemerals can be managed based on their response to precipitation; specifically, they should be watered as early as possible, timed according to the post-sowing phenological period (Yuan et al., 2015; Rominger et al., 2019; Zhang et al., 2022b). Considering that precipitation is the dominant factor regulating germination, leaf expansion, flowering, and withering (Zhang and Tan, 2007), ephemerals require timely and moderate watering at key points in their later growth, especially during their first year.

In arid regions, such as parts of Western China and Africa, water shortages limit early irrigation activities. In these regions, targeted measures, including water-saving and zoning irrigation, should be considered.

Soil nutrient regulation

Rosch et al. (1997) studied competition among ten pioneer plant species at two nutrient levels in Namaqualand (South Africa); they found that ephemerals face intense intraspecific competition in nutrient-deficient environments, and that competition intensity is higher at low nutrient levels, features that are not conducive to the establishment of plant communities for restoring mining areas. Nitrogen and phosphorus,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849

the two main nutrient elements, are related to the growth and biomass of ephemerals (Wang et al., 2021b). Although adding nitrogen and phosphorus promotes their growth, adverse effects can arise from single-nutrient, excessive, or continuous application of nutrients. In managing ecological restoration of ephemerals in mining areas, especially during the initial stages, attention should be paid to the application of nutrient elements, and water replenishment should be combined with other measures to eliminate adverse effects and increase the benefits.

Soil crust treatment

Soil surface crust can affect plant growth and natural seed-based reproduction (Eldridge and Greene, 1994; Beyschlag et al., 2008). *Grubovia dasyphylla* seedlings survived better on moss crust than on sand, and seedling survival was positively correlated with surface-soil water content (Long and Li, 2003). Chen et al. (2008) found that soils with crusts had relatively high nutrient levels, thus supporting the growth and survival of annual ephemerals. Moderate disturbance of the soil crust promotes plant diversity, whereas severe disturbance can lead to nutrient deficiencies in the soil and reduce plant diversity. Therefore, in managing ephemerals in mining areas, soil crusts should be moderately disturbed to further improve the growth of ephemerals and other plants.

Conclusions

Owing to their positive roles as pioneer plants and their impacts in desert restoration, ephemerals have good application prospects in restoring disturbed mining areas. This review examined the distribution, growth, and technical application of ephemerals in the restoration of mining areas, as well as methods to control their growth. A technical model for the application of ephemerals in mining areas was constructed, including the selection and treatment of ephemeral species, planting, and post-construction maintenance.

To better leverage the role of ephemerals in such restoration and to promote the efficiency of ecological restoration, the following recommendations for strengthening research and application are proposed:

(1) To effectively achieve both short- and long-term restoration of mining areas, ephemerals should be applied along with other restoration models such as assisted regeneration and ecological reconstruction.

(2) Synergistic measures are required to support the growth of ephemerals and other plants for mining land restoration, including planting leguminous plants as well as both annuals and perennials, and applying the principles of growth-cycle displacement and niche complementarity; this will strengthen the positive role of ephemerals in such restoration.

(3) Further research is required into methods to efficiently regulate the germination and early-growth of ephemerals in restoring mining land, including methods to promote early greening and to examine the effects of improving the substrate.

(4) Research is required to support large-scale engineering-based applications of ephemerals in such restoration; this requires examination of the growth process of major ephemerals under specific climatic conditions (especially arid conditions), succession rules, and exit timing. Further, the development of technical specifications and regulations requires research.

(5) The market-oriented and large-scale breeding of ephemerals should be promoted, to ensure sufficient seed resources for the restoration of mining areas.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849

Acknowledgements and funding. We would like to send our gratitude for the support from the National Key R&D Program of China (2023YFF1306003), the Key Research and Development Program of Shaanxi (2024CY2-GJHX-39), the Tiandi Science and Technology Co., Ltd. Science and Technology Innovation Venture Capital Special Project (2023-TD-ZD004-004), and the Engineering Research Center of Coal-based Ecological Carbon Sequestration Technology of the Ministry of Education (MJST 2022-03). We are grateful for the valuable comments of the editors and the three anonymous reviewers, which help to improve the manuscript greatly.

REFERENCES

[1] Beyschlag, W., Wittland, M., Jentsch, A., Steinlein, T. (2008): Soil crusts and disturbance benefit plant germination, establishment and growth on nutrient deficient sand. – Basic and Applied Ecology 9: 243-252.

[2] Bi, Y. (2017): Research advance of application of arbuscular mycorrhizal fungi to ecological remediation in subsided land of coal mining areas. – Mycosystema 36: 800-806. (In Chinese with English Abstract).

[3] Bi, Y., Xie, L. (2021): Functions of arbuscular mycorrhizal fungi and dark septate endophytes in ecological restoration. – Acta Microbiologica Sinica 61: 58-67. (In Chinese with English Abstract).

[4] Bi, Y., Wu, C., Wang, S., Gao, X., Xue, C., Yang, W., Li, M., Xiao, L., Christie, P. (2022): Combined arbuscular mycorrhizal inoculation and loess amendment improve rooting and revegetation post-mining. – Rhizosphere 23(2): 100560.

[5] Broadhurst, L. M., Jones, T. A., Smith, F. S., North, T., Guja, L. (2016): Maximizing seed resources for restoration in an uncertain future. – Bioscience 66: 73-79.

[6] Chen, R., Wei, W., Zhang, Y., Wu, N., Zhang, J. (2008): Effect of biological soil crust on plant diversity in arid area. – Journal of Desert Research, pp. 868-873. (In Chinese with English Abstract).

[7] Chen, Y. F., Zhang, L. W., Shi, X., Ban, Y., Liu, H. L., Zhang, D. Y. (2019): Life history responses of spring-and autumn-germinated ephemeral plants to increased nitrogen and precipitation in the Gurbantunggut Desert. – Science of the Total Environment 659: 756-763.

[8] Cong, X., Cao, W., Wang, J. (2011): Research on spring ephemerals in the Baishilazi Nature Reserve, Liaoning. – Ecological Science 30: 525-530. (In Chinese with English Abstract).

[9] de Villiers, A. J., van Rooyen, M. W., Theron, G. K. (1999): Seed production of four Namaqualand pioneer plant species grown on saline soil. – South African Journal of Botany 65: 110-112.

[10] Ding, J., Fan, L., Li, Y., Tang, L. (2016): Biomass allocation and allometric relationships of six desert herbaceous plants in the Gurbantunggut Desert. – Journal of Desert Research 36: 1323-1330. (In Chinese with English Abstract).

[11] Dion, P. P., Bussieres, J., Lapointe, L. (2017): Late canopy closure delays senescence and promotes growth of the spring ephemeral wild leek (*Allium tricoccum*). – Botany 95: 457-467.

[12] Ecseri, I., Mosonyi, I. D., Tillyne Mandy, A. T., Honfi, P. (2015): Decoration value and herbicide sensibility of some ephemeral annual ornamental plants. – Scientific Papers-Series B-Horticulture 59: 341-346.

[13] El-Keblawy, A. (2003): Effects of achene dimorphism on dormancy and progeny traits in the two ephemerals Hedypnois cretica and *Crepis aspera* (Asteraceae). – Canadian Journal of Botany-Revue Canadienne De Botanique 81: 550-559.

[14] Eldridge, D. J., Greene, R. S. B. (1994): Microbiotic soil crusts: a review of their roles in soil and ecological processes in the rangelands of Australia. – Australian Journal of Soil Research 32: 389-415.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849

[15] Fan, C., Zhao, H., Gao, X., Li, Q. (2010): Study on seed germination characteristics and seedling physiological of two ephemera plants. – Seed 29: 33-37. (In Chinese with English Abstract).
[16] Flores-Alvarez, J. L., Ladd, B., Velez-Azanero, A., de Mola, U. L., Bonser, S. (2018): Using knowledge of plant persistence traits to optimize strategies for post-mine ecological restoration on the Peruvian Altiplano. – Mountain Research and Development 38: 135-142.
[17] Greco, D. A., Schamp, B. S., Mercer, K. A. (2019): Canopy effects on abundance and leaf traits of a spring ephemeral: *Erythronium americanum*. – Botany 97: 691-698.
[18] Gutjahr, S., Lapointe, L. (2008): Carbon dioxide enrichment does not reduce leaf longevity or alter accumulation of carbon reserves in the woodland spring ephemeral *Erythronium americanum*. – Annals of Botany 102: 835-843.
[19] Hegazy, A. K. (2001): Reproductive diversity and survival of the potential annual Diplotaxis harra (Forssk.) Boiss (Brassicaceae) in Egypt. – Ecography 24: 403-412.
[20] Hu, Z., Xiao, W., Zhao, Y. (2020): Re-discussion on coal mine eco-environment concurrent mining and reclamation. – Journal of China Coal Society 45: 351-359. (In Chinese with English Abstract).
[21] Iwanami, H., Takada, N., Koda, Y. (2017): Ephemerality of a spring ephemeral *Gagea lutea* (L.) is attributable to shoot senescence induced by free linolenic acid. – Plant and Cell Physiology 58: 1724-1729.
[22] Kim, H. J., Jung, J. B., Jang, Y. L., Sung, J. H., Park, P. S. (2015): Effects of experimental early canopy closure on the growth and reproduction of spring ephemeral *Erythronium japonicum* in a montane deciduous forest. – Journal of Plant Biology 58: 164-174.
[23] Lapointe, L. (2001): How phenology influences physiology in deciduous forest spring ephemerals. – Physiologia Plantarum 113: 151-157.
[24] Lei, S., Bian, Z., Yang, Y. (2022): Discussion on the guided restoration for mine ecosystem. – Journal of China Coal Society 47: 915-921. (In Chinese with English Abstract).
[25] Li, Q., Zhao, W. (2005): Advances in the soil seed bank of arid regions. – Advances in Earth Science 20(3): 350-358. (In Chinese with English Abstract).
[26] Li, S., Bi, Y., Kong, W., Wang, J., Yu, H. (2013): Effects of the arbuscular mycorrhizal fungi on environmental phytoremediation in coal mine areas. – Environmental Science 34: 4455-4459. (In Chinese with English Abstract).
[27] Li, Q. (2014): Cold resistance mechanism of autumn germination plants in Gurbantunggut Desert and its application in processing tomato autumn sowing. – Shihezi University, Shihezi. (In Chinese with English Abstract).
[28] Li, X. (2015): Distribution of rare psammophyte *Asrtragalus lehmannianus* (Fabaceae) and the effect of the cocoon-shaped calyx on sexual reproduction and seed disperal. – Xinjiang Agricultural University, Urumqi. (In Chinese with English Abstract).
[29] Li, C., Yao, F., Qi, X., Zhang, G., Li, H. (2015): Analysis of vegetation damage in area of Xinjiang Zhundong Wucaiwan open coalmine. – Journal of Henan Polytechnic University (Natural Science) 34: 124-128. (In Chinese with English Abstract).
[30] Li, Y., Zhao, N., Cao, Y., Yang, J. (2018): Effects of coal dust deposition on the physiological properties of plants in an open-pit coal mine. – Acta Ecologica Sinica 38: 8129-8138. (In Chinese with English Abstract).
[31] Li, D., Zhang, D., Zhang, L., Zhang, Q., Liu, H. (2020): Biological seed characteristics of spring-emergence and autumn-emergence *Erodium oxyrrhynchum*. – Arid Zone Research 37: 1562-1568. (In Chinese with English Abstract).
[32] Liang, Y., Phillips, S. M., Cheek, M., Larridon, I. (2019): A revision of the African genus Mesanthemum (Eriocaulaceae). – Kew Bulletin 74.
[33] Long, L., Li, X. (2003): Effects of soil microbiotic crusts on seedling survival and seedling growth of two annual plants. – Journal of Desert Research 23: 53-57. (In Chinese with English Abstract).
[34] Long, Y. (2012): Seed germination and life history traits in ephemeral *Astragalus arpilobus*. – Xinjiang Agricultural University, Urumqi. (In Chinese with English Abstract).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849

[35] Lv, L., Tan, D. (2005): The characteristics of fruit-set and reproductive package in four species of ephemeral plants in Eremopyrum (poaceae). – Journal of Xinjiang Agricultural University 28(3): 21-25. (In Chinese with English Abstract).
[36] Ma, S., Ma, M., Wang, G., Sun, X., Huang, S. (2010): Seed dispersal and pattern of seed bank of ephemeroid desert plant *Eremurus inderiensis*. – Journal of Shihezi University (Natural Science) 28: 11-17. (In Chinese with English Abstract).
[37] Milton, S. J., Dean, W. R. J. (2000): Disturbance, drought and dynamics of desert dune grassland, South Africa. – Plant Ecology 150: 37-51.
[38] Mu, X. H., Huang, G., Li, Y., Zheng, X. J., Xu, G. Q., Wu, X., Wang, Y. G., Liu, Y. (2021): Population dynamics and life history response to precipitation changes for a desert ephemeral plant with biseasonal germination. – Frontiers in Plant Science 12.
[39] Norman, M. A., Koch, J. M., Grant, C. D., Morald, T. K., Ward, S. C. (2006): Vegetation succession after bauxite mining in western Australia. – Restoration Ecology 14: 278-288.
[40] Ouyang, L. (2017): Phytoremediation effect of a plant community model on a manganese contaminated site. – Central South University of Forestry and Technology, Changsha. (In Chinese with English Abstract).
[41] Peng, M. W., He, H., Wang, Z. K., Li, G. F., Lv, X. H., Pu, X. Z., Zhuang, L. (2022): Responses and comprehensive evaluation of growth characteristics of ephemeral plants in the desert-oasis ecotone to soil types. – Journal of Environmental Management 316: 115288.
[42] Qiu, Y., Liu, T., Zhang, C., Liu, B., Pan, B. R., Wu, S. X., Chen, X. (2018): Mapping spring ephemeral plants in Northern Xinjiang, China. – Sustainability 10(3): 804.
[43] Rominger, K. R., Meyer, S. H., Van Buren, R., Searle, A. B. (2019): Phenological patterns in the desert spring ephemeral Astragalus holmgreniorum Barneby (Fabaceae). – Western North American Naturalist 79: 308-322.
[44] Rosch, H., vanRooyen, M. W., Theron, G. K. (1997): Competitive effect and response of ten Namaqualand ephemeral plant species at two nutrient levels. – South African Journal of Botany 63: 210-215.
[45] Rothstein, D. E. (2000): Spring ephemeral herbs and nitrogen cycling in a northern hardwood forest: an experimental test of the vernal dam hypothesis. – Oecologia 124: 446-453.
[46] Singh, J., Srivastava, P., Sharma, O., Kumar, N., Jayaraj, M., Bharti, S. D. (2023): Synergizing different control methods for sustainable management of Parthenium weed (*Parthenium hysterophorus*) (integrated pest management strategies). – Journal of Experimental Zoology, India 26: 2529-2540.
[47] Steyn, H. M., vanRooyen, N., vanRooyen, M. W., Theron, G. K. (1996): The prediction of phenological stages in four Namaqualand ephemeral species using thermal unit indices. – Israel Journal of Plant Sciences 44: 147-160.
[48] Tao, Y., Qiu, D., Gong, Y. M., Liu, H. L., Zhang, J., Yin, B. F., Lu, H. Y., Zhou, X. B. B., Zhang, Y. M. (2022): Leaf-root-soil N:P stoichiometry of ephemeral plants in a temperate desert in Central Asia. – Journal of Plant Research 135: 55-67.
[49] Tian, Y. (2014): The lethal factors and survival strategy in Haloxylon ammodendron germination and ecesis process. – Xinjiang University, Urumqi. (In Chinese with English Abstract).
[50] Tong, L., Lei, F. W., Wu, Y. M., Shen, X. L., Xia, X. F., Zhang, D. H., Mu, X. Y., Zhang, Z. X. (2022): Multiple reproductive strategies of a spring ephemeral plant, *Fritillaria maximowiczii*, enable its adaptation to harsh environments. – Plant Species Biology 37: 38-51.
[51] Tu, W. F., Li, Y., Zhang, Y. M., Zhang, L., Liu, H. Y., Liu, C., Yang, C. H. (2012): Diminished photoinhibition is involved in high photosynthetic capacities in spring ephemeral *Berteroa incana* under strong light conditions. – Journal of Plant Physiology 169: 1463-1470.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849

[52] Wang, X., Jiang, J., Lei, J., Zhang, W., Qian, Y. (2003): The distribution of ephemeral vegetation on the longitudinal dune surface and its stabilization significance in the Gurbantunggut Desert. – Acta Geographica Sinica 58(4): 598-605. (In Chinese with English Abstract).
[53] Wang, X. Q., Jiang, J., Wang, Y. C., Luo, W. L., Song, C. W., Chen, J. J. (2006): Responses of ephemeral plant germination and growth to water and heat conditions in the southern part of Gurbantunggut Desert. – Chinese Science Bulletin 51: 110-116.
[54] Wang, A., Ma, J., Gong, H., Fan, G. A., Wang, M., Zhao, H., Cheng, J. (2021a): Patterns and drivers of species richness of early spring annual ephemeral plants in northern Xinjiang. – Biodiversity Science 29: 735-745. (In Chinese with English Abstract).
[55] Wang, M., Ma, H. Y., Tan, D. Y. (2021b): Trait-abundance relationships of annual ephemerals in response to nitrogen addition in Gurbantunggut Desert. – Diversity-Basel 13(11): 569.
[56] Wu, N., Zhang, J., Wang, Y., Yin, J., Zhang, Y. (2018): Effects of snow cover and arbuscular mycorrhizal fungi network on the seedling growth of *Erodium oxyrrhynchum*. – Arid Zone Research 35: 624-632. (In Chinese with English Abstract).
[57] Xu, D., Chen, S., You, T., Lan, H. (2010): Tissue culture and plant regeneration of xinjiang ephemeral plant *Lepidium apetalum* willd. – Plant Physiology Communications 46: 1183-1184. (In Chinese with English Abstract).
[58] Xu, X., Li, J., Bao, A., Wang, B., Li, C. (2019): Disturbance analysis of desert vegetation under the development of Wucaiwan mining area in Xinjiang. – Journal of Geo-Information Science 21: 1934-1944. (In Chinese with English Abstract).
[59] Yang, Q., Yin, X., Ye, W. (2006): Dormancy mechanism and breaking methods for hard seeds. – Bulletin of Botany 23(1): 108-118. (In Chinese with English Abstract).
[60] Yang, K., Zeng, W., Zhu, C., Xie, Q. (2016): Effects of different treatments on seed germination of Gagea. – Seed 35: 97-100. (In Chinese with English Abstract).
[61] Yang, Y. (2017): Study on the resilience of land ecosystem in mining area and its measurement and regulation. – China University of Mining and Technology, Xuzhou. (In Chinese with English Abstract).
[62] Yang, S. L., Shi, X., Wang, S. M., Liu, J. S., Meng, F. X., Pang, W. (2019a): Is bi-seasonal germination an optimal choice for an ephemeral plant living in a cold desert? – Journal of Arid Land 11: 280-291.
[63] Yang, X., Liu, Y., Zhang, S., Song, M., Sun, Z., Zhang, H., Zhang, H. (2019b): A preliminary report on the cultivation experiment of early spring ephemeral plant: Erythronium. – Forest by-Product and Speciality in China, pp. 23-24. (In Chinese with English Abstract).
[64] Yuan, S. F., Tang, H. P., Yan, Y. C. (2009): Photosynthetic characteristics of spring ephemerals in the desert ecosystem of Dzungaria Basin, northwest China. – Environmental Earth Sciences 59: 501-510.
[65] Yuan, S., Tang, H. (2010): Research advances in the eco-physiological characteristics of ephemerals adaptation to habitats. – Acta Prataculturae Sinica 19: 240-247. (In Chinese with English Abstract).
[66] Yuan, S., Tang, H., Zhang, H. (2014): Response of distribution characteristics of ephemeral plants to the human disturbance in Dzungaria Desert. – Journal of Arid Land Resources and Environment 28: 122-126. (In Chinese with English Abstract).
[67] Yuan, S., Tang, H., Zhang, H. (2015): On the relationships between intra-annual variation of Ephemeral Synusia and hydrothermal conditions. – Arid Zone Research 32: 941-946. (In Chinese with English Abstract).
[68] Zhang, T., Tian, C., Sun, Y., Feng, G. (2006): Soil seed banks of ephemerals in the Gurbantunggut Desert Area. – Arid Land Geography, pp. 675-681. (In Chinese with English Abstract).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849

[69] Zhang, X., Tan, D. (2007): Phenology of 10 ephemeral species of asteraceae in relation to the main meteorological factors. – Arid Zone Research 2007(4): 470-475. (In Chinese with English Abstract).
[70] Zhang, H., Liu, P., Liu, L., Lan, H., Zhang, F. (2007): Seed germination characteristics and ecological adaptability of Arabidopsis pumila, a Xinjiang-originated ephemeral plant species. – Acta Ecologica Sinica 2007(10): 4310-4316. (In Chinese with English Abstract).
[71] Zhang, T., Sun, Y., Song, Y. C., Tian, C. Y., Feng, G. (2011): On-site growth response of a desert ephemeral plant, *Plantago minuta*, to indigenous arbuscular mycorrhizal fungi in a central Asia desert. – Symbiosis 55: 77-84.
[72] Zhang, C. P., Wu, C. X., Song, Y. C., Tian, C. Y., Feng, G. (2014): Effects of mucilage on seed germination of the desert ephemeral plant *Plantago minuta* Pall. under osmotic stress and cycles of wet and dry conditions. – Plant Species Biology 29: 109-116.
[73] Zhang, L., Liu, H., Sheng, J. (2018): Effect of burial on seed germination traits of 10 ephemeral plant species. – Arid Zone Research 35: 633-639. (In Chinese with English Abstract).
[74] Zhang, Y., Bi, Y., Shen, H., Zhang, L. (2020): Arbuscular mycorrhizal fungi enhance sea buckthorn growth in coal mining subsidence areas in Northwest China. – Journal of Microbiology and Biotechnology 30: 848-855.
[75] Zhang, C., Zhao, W., Dang, H., Zhuang, L., Sun, H. (2021a): Effects of different slope aspect on biomass allocation and stoichiometry of ephemeral plants in the southern margin of Junggar Basin. – Acta Botanica Boreali-Occidentalia Sinica 41: 151-158. (In Chinese with English Abstract).
[76] Zhang, J., Bi, Y., Song, Z., Xiao, L., Christie, P. (2021b): Arbuscular mycorrhizal fungi alter root and foliar responses to fissure-induced root damage stress. – Ecological Indicators 127: 107800.
[77] Zhang, Y., Meng, X., Zhou, X., Yin, B., Zhou, D., Tao, Y. (2022a): Biomass allocation patterns of an ephemeral species (*Erodium oxyrhinchum*) in different habitats and germination types in the Gurbantunggut Desert, China. – Arid Zone Research 39: 541-550. (In Chinese with English Abstract).
[78] Zhang, Y., Yin, B., Tao, Y., Li, Y., Zhou, X., Zhang, Y. (2022b): Effects of the first rainfall timing and amount on morphological characteristics and chlorophyll fluorescence of two ephemeral species in the Gurbantünggüt Desert, northwestern China. – Chinese Journal of Plant Ecology 46: 428-439. (In Chinese with English Abstract).
[79] Zhao, C. X., Zheng, R. Q., Shi, X., Wang, L. (2021): Soil microbes and seed mucilage promote growth of the desert ephemeral plant *Nepeta micrantha* under different water conditions. – Flora 280: 151845.
[80] Zhou, X., Zhang, Y., Wang, S., Zhang, B. (2010): Combined effects of simulated nitrogen deposition and drought stress on growth and photosynthetic physiological responses of two annual desert plants in Junggar Basin, China. – Chinese Journal of Plant Ecology 34: 1394-1403. (In Chinese with English Abstract).
[81] Zhou, X. B., Zhang, Y. M., Niklas, K. J. (2014): Sensitivity of growth and biomass allocation patterns to increasing nitrogen: a comparison between ephemerals and annuals in the Gurbantunggut Desert, north-western China. – Annals of Botany 113: 501-511.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_68376849