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Effects of Amendments on Morphological Traits, Survival, and Establishment of *Artemisia sieberi* in Heavy Metal-Contaminated Soils

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Abstract

Mining activities severely degrade vegetation and soil quality, highlighting the need for effective restoration strategies for heavy metal-contaminated lands. This study evaluated the effects of arbuscular mycorrhiza (*Glomus intraradices*), zeolite, and superabsorbent polymer on the morphological performance and field establishment of *Artemisia sieberi* in contaminated mine soils. Seedlings were inoculated under greenhouse conditions and transplanted to the Mashhad East Cement Factory mining area using a randomized complete block design with four replications. Morphological traits, plant height, biomass, mycorrhizal colonization, and establishment percentage were assessed over two years. All amendments significantly improved plant performance compared with the control ($P < 0.01$). Under greenhouse conditions, superabsorbent application increased root dry weight from 0.27 to 1.78 g, shoot dry weight from 0.43 to 2.93 g, total dry weight from 0.70 to 4.70 g, and plant height from 9.75 to 48.75 cm. Under field conditions, mycorrhizal inoculation achieved the highest establishment (87%) compared with the control (21%) after two years, while total dry weight increased from 0.27 to 0.87 g, root dry weight from 0.11 to 0.43 g, shoot dry weight from 0.16 to 0.44 g, and plant height from 4.5 to 12.5 cm ($P < 0.01$). Overall, mycorrhiza and zeolite were the most effective amendments for improving the performance of *A. sieberi* under heavy metal stress. These amendments can therefore be recommended for ecological restoration and revegetation of degraded mine lands in semi-arid regions.

Keywords: Biological fertilizer, Vegetation, Rangelands, Planting, *Artemisia sieberi*

Introduction

Mining is a critical economic sector for many countries; however, mines have a finite operational lifespan and are often abandoned after ore extraction (Venkateswarlu et al., 2016). Post-abandonment, heavy metal-contaminated soil can disperse into rivers and nearby urban areas through water and wind erosion (Kim et al., 2016; Yenilmez et al., 2011). Without proper vegetation restoration and soil stabilization, these contaminants pose significant risks to air, water, soil, and

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groundwater quality (Bacchetta et al., 2015; Farjad Tehrani et al., 2023; Laurence, 2011). Primary vegetation re-establishment is a crucial step in ecological restoration (Azimi et al., 2014, 2016, 2018a). Over the past two decades, various biological, physical, and chemical methods have been employed to rehabilitate vegetation in heavy metal-contaminated areas (Mahar et al., 2016; Sheoran et al., 2011; Wuana & Okieimen, 2011). One notable species for such restoration efforts is *Artemisia sieberi* Besser, locally known as «Terkh» among desert communities. This aromatic plant, a dominant species in arid and semi-arid steppes in Iran, belongs to the family Compositae . It typically grows to a height of 30–50 cm in, forming dense, mound-shaped branches. All aerial parts of the plant, including stems, leaves, flowers, fruits, and seedsemit a strong fragrance. *Artemisia sieberi* thrives in regions with annual precipitation exceeding 100 mm and adapts well to loamy, sandy, and clayey soils. Its resilience to harsh desert conditions and effectiveness in preventing wind erosion make it invaluable for soil conservation (Rasouli et al., 2023). Propagation occurs exclusively through seeds (Amirkhani et al., 2023).

Zeolites, both natural and synthetic crystalline aluminosilicates, are widely used in heavy metal remediation because of their high surface area and adsorption capacity (Restiawaty et al., 2024). They immobilize metal ions through ion exchange, absorption, surface precipitation, and dissolution (Mozgawa et al., 2005; Doula et al., 2012; Valadabadi & Yousefi, 2022). As effective adsorbents for both anions and cations (Conversa et al., 2024; Kumpiene et al., 2008; Cataldo et al., 2024), zeolites can retain up to 70% of their weight in moisture without disrupting the soil structure (Mahmoud et al., 2023; Ruíz-Baltazar & Pérez, 2015). By reducing heavy metal uptake in plants, zeolites mitigate toxicity and enhance plant growth (Conversa et al., 2024; Akbar Nakhli et al., 2017).

Superabsorbent polymers (SAPs) represent another innovative solution for revegetation in arid-region. These hydrophilic polymer networks improve soil water retention, reduce nutrient leaching, minimize evaporation, thereby promoting aeration, thereby promoting plant growth under both normal and stressed conditions (Amirkhani et al., 2023; Abedi Koupaee & Mesforoush, 2009; Fang et al., 2019; Zhang et al., 2020). Hydrogels, a subset of SAPs, can alsosequester essential nutrients (e.g., nitrates, phosphates, potassium, and micronutrients), thereby preventing nutriet losses (Besharati et al., 2022; Kabiri, 2005; Sharma & Sharma, 2013). For instance, a study on *Haloxylon* spp. in Birjand demonstrated that the application of 0.3% hydrogel significantly increased seedling height and root biomass compared to the control (Ismail et al., 2022; Zangoui Nasab et al., 2012; Ginocchio et al., 2004; Mench et al., 2010).

Mycorrhizal biofertilizers further support plant establishment in degraded soils by enhancing nutrient uptake and stress tolerance (Wang et al., 2023; Liu et al., 2021; Begum et al., 2021). Their use in mined land restoration has proven effective (Geisler et al., 2023; Kumar et al., 2010; Wahab et al., 2023), although comprehensive studies remain limited.

Recent advances have highlighted the potential of soil amendments, such as zeolites, superabsorbent polymers, and arbuscular mycorrhizal fungi, to improve soil quality, enhance nutrient and water uptake, and increase plant tolerance to abiotic stresses, including heavy metal contamination. Despite documented benefits of these amendments when applied individually, comprehensive field-based studies evaluating in improving the growth, establishment, and survival of *A. sieberi* under actual mining conditions remain limited. Addressing this knowledge gap is essential for developing efficient and sustainable strategies for the ecological restoration of heavy metal–contaminated mine lands in semi-arid environments.

The main objective of this study was to evaluate the effects of zeolite, superabsorbent polymer, and arbuscular mycorrhizal inoculation with*G. intraradices* on the growth, establishment, and survival of *A. sieberi* under both greenhouse and field conditions in heavy metal–contaminated soils.

The specific objectives were to assess the effects of different soil amendments on the morphological traits of *A. sieberi*, including plant height and biomass allocation (shoot, root, and total dry weight, and to evaluation the influence of zeolite, superabsorbent polymer, and mycorrhizal inoculation on the plant establishment rate and survival over two growing seasons. In addition the study aimed to etermine the extent of mycorrhizal root colonization and its relationship with plant growth performance under heavy metal stress; as well as identification of the most effective soil amendment(s) for enhancing vegetation restoration in abandoned mining lands of semi-arid regions.

Material and methods

This study evaluated the effects of mycorrhizal inoculation (*Glomus intraradices*), superabsorbent polymer (A200), and zeolite (clinoptilolite) on the establishment and productivity of *A. sieberi* in a semi-arid post-mining area at the East Mashhad Cement Factory (36°28′96″N, 59°44′46.99″E; 1,120–1,130 m a.s.l.). The region has a semi-arid climate with an average annual rainfall of 225 mm, mainly occurring as short, intense events in the cold season. A randomized complete block design (RCBD) with four replicates was applied, including four treatments: mycorrhizal inoculation, zeolite amendment, superabsorbent polymer, and an untreated control. The experiment was conducted on a 720 m² plot. Composite soil samples (0–30 cm) were collected prior to transplantation to assess physicochemical properties, including pH, electrical conductivity, texture, and heavy metal content (Table 1).

Seedling production, transplantation, and field cultivation of A. sieberi

Seeds of *A. sieberi* were cultivated in 160 trays under controlled greenhouse conditions. After one month, the seedlings were transplanted into paper pots (7 × 9 cm) filled with soil collected from the excavated mine site of the Mashhad Cement Factory. Each pot contained approximately 160 g of soil. Once the seedlings reached a height of 3–5 cm, the pots were transferred outside the greenhouse for acclimatization To ambient environmental conditions.

The selection of treatments was based on

Table 1. Soil properties of the study site

Parameter	EC (dS/m)	pH	Texture	Cd	Co	Ni	Zn	Cu	Cr	Mn	As	Pb
Value	2.6	8.16	Silty loam	1.1	18.46	58	88.23	45	45.7	287.5	6.7	12
Permissible Range (mg/kg)				0–0.7	1–10	2–50	3–50	1–20	2–50	15–150	0–4.5	0.5–5

manufacturer recommendations, previous experimental findings, and published literatures. At the time of field transplantation, the following treatments were applied to the planting pits,each containing approximately2 kg of soil:The *Glomus intraradices* inoculum was incorporated into the soil at an inoculum-to-soil ratio of 1:10 by distributing the inoculum in layers throughout the planting pit (Azimi et al., 2014, 2016; Sharma & Sharma, 2013). Zeolite was applied at a rate of 2% (40 g per 2 kg of soil) according to the method described by Yari et al. (2013). In addition, the superabsorbent polymer was incorporated into the soil at a rate of 0.4% (8 g per 2 kg of soil) following the recommendations of Abedi Koupaee and Mesforoush (2009). The mycorrhizal inoculum, procured from a biotechnology company, contained at least 50 viable spores g^{-1}, together with colonized root fragments, and fungal hyphae. Zeolite was sourced from Alvand Agricultural Development Company (Mahdishahr, Semnan, Iran), whereas the superabsorbent polymer was supplied by the Iran Polymer Research Institute.

Field transplanation was conducted using a randomized complete block design with four replicates. To minimize the decline in mycorrhizal colonization associated with leaf senescence, seedlings were transplanted prior to the onset of leaf yellowing and abscission. Following transplantation, the seedlings received a single irrigation. For wubwequent measurements, two plants from each treatment within each plot were randomly selected and carefully excavated. The measured parameters included plant establishment percentage, plant height, mycorrhizal colonization percentage, and dry biomass components, including leaf, root, stem, and total dry weights. Plant samples were oven-dried at 70°C for 48 h, and their dry weights were determined using a digital balance with a precision of 0.01 g (Azimi et al., 2013). Mycorrhizal colonization was evaluated through two separate experiments. The first experiment was conducted under greenhouse conditions prior to field transplantation to assess the compatibility of the mycorrhizal inoculum with the mine soil. For this purpose, four mycorrhiza-inoculated seedlings were maintained in the greenhouse until March, after which their roots were harvested and the colonization percentage was determined. The second experiment was carried out under field conditions, in which the colonization percentage of inoculated seedlings was assessed at the time of harvest at the end of July.For the quantification of mycorrhizal colonization, fresh root samples (0.2 g) were thoroughly washed and cut into (1 cm) segments before beingstained according to a modified Phillips and Hayman (1970) protocol. Root segments were cleared in 10% KOH for 60 h and subsequently acidified in 0.1 M HCl for 2 min prior to staining. The intensity of mycorrhizal symbiosis was then determined using the method described by Giovannetti and Mosse (1980)..*Statistical Analysis*

Data were initially organized using microsof Excel, and subsequent statistical analyses, including analysis of variance ANOVA, and mean comparisons were performed using SPSS version 18 and Minitab version 16. Percentage data were subjected to angular (arcsine square-root) transformation prior to analysis, and treatment means were compared using Duncan's multiple range test at significance levels of $\alpha = 0.05$, 0.01. Figure 1 illustrates the roots of *A. sieberi* exhibiting extensive vesicular and hyphal colonization.

Results and Discussion

Effects of treatments on morphological characteristics and establishment of A. sieberi in greenhouse conditions

Analysis of variance revealed that zeolite, mycorrhiza, and superabsorbent treatments significantly influenced ($p \leq 0.01$ or $p \leq 0.05$) the dry weight of the whole plant, shoot dry weight, root dry weight, and plant height of *A. sieberi* under greenhouse conditions (Table 2). Specifically, these treatments had a highly significant effect ($p \leq 0.01$) on root dry weight (Table 2). Mean comparisons indicated that plants treated

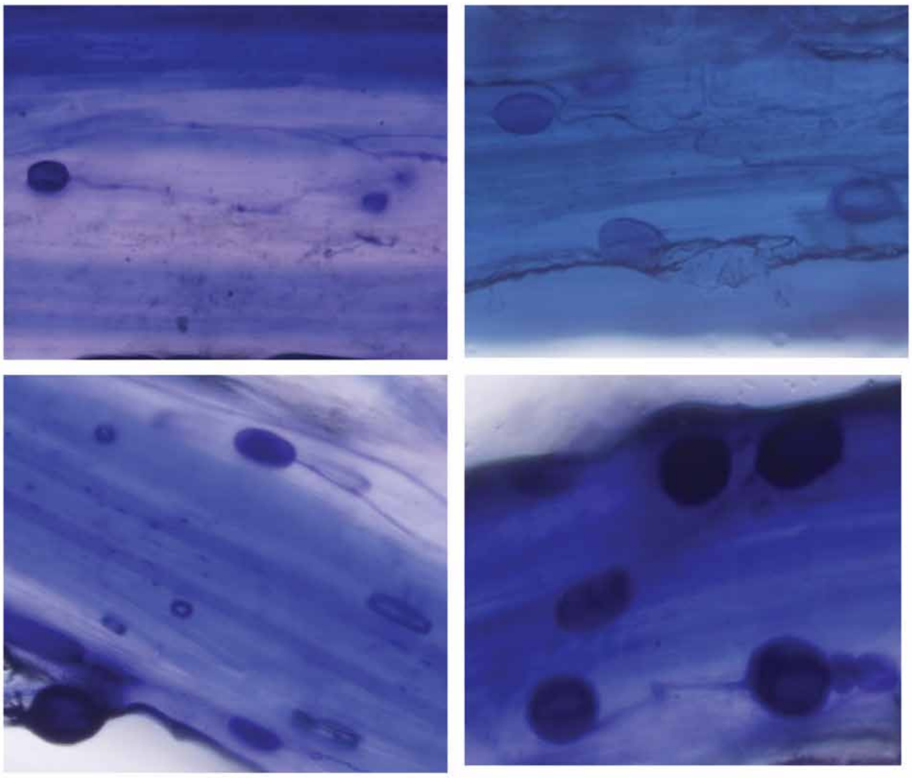


Fig. 1. the contaminated roots of *A. sieberi* by numerous vesicles and hypha of *G. intraradices*

with mycorrhiza, zeolite, and superabsorbent exhibited the highest root dry weight (Table 3), which is consistent with previous studies (Amirkhani et al., 2023; Sedaghat et al., 2021; Dowarah et al., 2022) (Table 3).

Similarly, shoot dry weight increased significantly (p ≤ 0.01) in response to zeolite, mycorrhiza, and superabsorbent applications (Table 2). Plants treated with zeolite and superabsorbent produces the greatest shoot dry weight among all treatments (Table 3). Furthermore, total dry weight was significantly enhanced (p ≤ 0.01) by these treatments, with zeolite and superabsorbent yielding the highest whole-plant dry weight (Table 2).

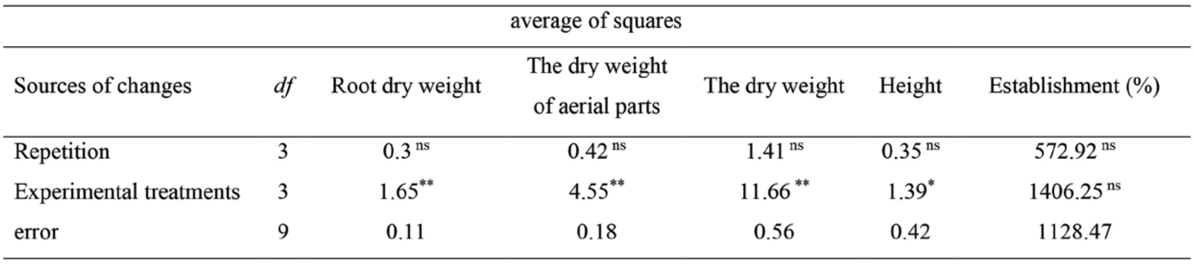
Plant height was also significantly affected (p ≤ 0.01) by zeolite, mycorrhiza, and superabsorbent applications (Table 2). Mean comparisons demonstrated that plants were significantly taller than the control plants (Amirkhani et al., 2023; Sedaghat et al., 2021; Dowarah et al., 2022) (Table 3).

Effects of treatments on morphological traits and field establishment of A. sieberi

Analysis of variance revealed that zeolite, mycorrhizal, and superabsorbent treatments exerted a statistically significant influence (p ≤ 0.01) on multiple growth parameters, including whole-plant dry weight, shoot dry weight, root dry weight, plant height, and field establishment rate (Wahab et al., 2023) (Table 4).

The application of zeolite, mycorrhiza, and superabsorbent significantly influenced root dry weight under field conditions (*p* ≤ 0.01) (Table 4). Time also exerted a significant effect on root dry weight (Table 4). Comparative analysis revealed that across both experimental years, plants treated with

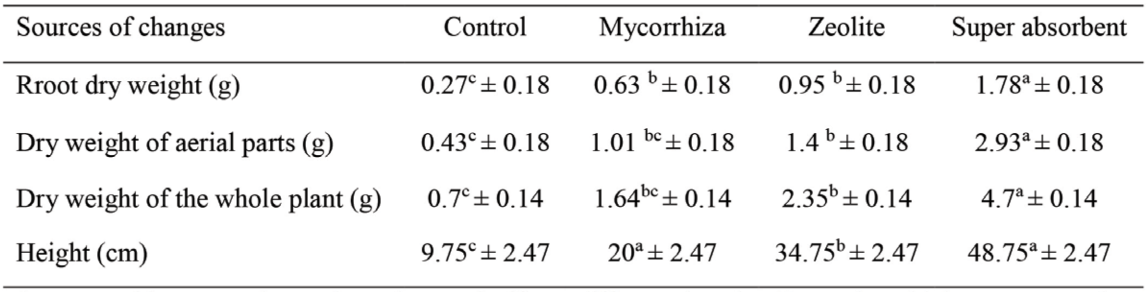
Table 2. The variance analysis of the treatment effects on the morphological characteristics and the initial establishment of *A. sieberi* in the greenhouse



		average of squares				
Sources of changes	*df*	Root dry weight	The dry weight of aerial parts	The dry weight	Height	Establishment (%)
Repetition	3	0.3^{ns}	0.42^{ns}	1.41^{ns}	0.35^{ns}	572.92^{ns}
Experimental treatments	3	1.65^{**}	4.55^{**}	11.66^{**}	1.39^{*}	1406.25^{ns}
error	9	0.11	0.18	0.56	0.42	1128.47

*, **, and ns: respectively significant at the level of 0.01, 0.05, and non-significance.

Table 3. The average comparison effect of the treatments on morphological characteristics and establishment of *A. sieberi* in the greenhouse



Sources of changes	Control	Mycorrhiza	Zeolite	Super absorbent
Rroot dry weight (g)	0.27^{c} ± 0.18	0.63^{b} ± 0.18	0.95^{b} ± 0.18	1.78^{a} ± 0.18
Dry weight of aerial parts (g)	0.43^{c} ± 0.18	1.01^{bc} ± 0.18	1.4^{b} ± 0.18	2.93^{a} ± 0.18
Dry weight of the whole plant (g)	0.7^{c} ± 0.14	1.64^{bc} ± 0.14	2.35^{b} ± 0.14	4.7^{a} ± 0.14
Height (cm)	9.75^{c} ± 2.47	20^{a} ± 2.47	34.75^{b} ± 2.47	48.75^{a} ± 2.47

Averages with common letters do not have a significant difference based on Duncan's multiple range test at the 5% probability level mycorrhiza and zeolite exhibited the highest root dry weight among all treatments (Amirkhani et al., 2023; Sedaghat et al., 2021; Dowarah et al., 2022) (Table 5).

Similarly, these treatments significantly enhanced shoot dry weight compared to the control ($p \leq 0.01$) (Table 4), with time also playing a significant role (Table 4). Mean comparisons indicated that mycorrhiza-inoculated plants in the first year and zeolite-mycorrhiza-treated plants in the second year yielded the highest shoot dry weight (Table 5).

Furthermore, zeolite, mycorrhiza, and superabsorbent significantly affected total plant dry weight ($p \leq 0.01$) (Table 4). Year also exerted a significant effect on this trait (Table 4). Across both experimental years,plants treated with mycorrhiza and zeolite consistently demonstrated the highest total dry weight compared with the other treatments (Amirkhani et al., 2023; Sedaghat et al., 2021; Dowarah et al., 2022) (Table 5).

Plant height was significantly influenced by the application of zeolite, mycorrhiza, and superabsorbent treatments ($p \leq 0.01$), while year also had a significant effect on this trait (Table 4). . Mean comparisons revealed that plants treated with mycorrhiza, zeolite, and superabsorbent exhibited greater height (Amirkhani et al., 2023; Sedaghat et al., 2021; Dowarah et al., 2022) (Table 5). Among all treatment-year combinations, mycorrhiza-inoculated plants in the second year exhibited the greates plant height (Geisler et al., 2023) (Table 5).

The application of zeolite, mycorrhiza, and superabsorbent significantly improved the initial establishment of herbaceous plants under field conditions ($p \leq 0.01$) (Table 4). Year had no significant effect on plant establishment (Table 4). Comparative analysis revealed that mycorrhiza and zeolite treatments improved both establishment and survival rates of the medicinal plant over other treatments in both years (Amirkhani et al., 2023; Sedaghat et al., 2021; Dowarah et al., 2022) (Table 5).

Greenhouse vs. field conditions

In greenhouse trials, zeolite, mycorrhiza, and superabsorbent treatments increased root dry weight and plant height relative to the control. Additionally, superabsorbent application enhanced the dry weight of ae-

Table 4. Variance analysis of treatments effects on morphological characteristics and establishment *A. sieberi* in the field

		Average of squares				
Sources of changes	*df*	Root dry weight	The dry weight of aerial parts	The dry weight	Height	Establishment (%)
Repetition	3	0.003	0.003	0.008	5.29	277.78^{ns}
Experimental treatments	3	0.06^{**}	0.16^{**}	0.41^{**}	74.19^{**}	4606.48^{ns}
Original error	9	0.001	0.001	0.003	1.49	331.79
Time	1	0.28^{**}	0.02^{**}	0.44^{**}	20.99^{**}	138.89^{ns}
Time × treatments	3	0.009^{**}	0.001^{**}	0.014^{**}	1.07^{ns}	69.44^{ns}
Minor error	12	0.001	0.001	0.001	0.37	63.66

*, **, and ns: respectively significant at the level of 0.01, 0.05, and non-significance

Table 5. Comparison of treatments' mutual effects and time on morphological characteristics and establishment of *A. sieberi* in the field

Year	Treatment	Sources of changes				
		Dry weight (g)	Dry weight of aerial parts (g)	Root dry weight (g)	Height (cm	Establishment (%)
First year	Control	$0.14^{f} \pm 0.03$	$0.09^{e} \pm 0.02$	$0.05^{f} \pm 0.02$	$3.5^{e} \pm 0.59$	$37^{d} \pm 5.03$
	Mycorrhiza	$0.56^{c} \pm 0.03$	$0.39^{ab} \pm 0.02$	$0.17^{d} \pm 0.02$	$9.8^{bc} \pm 0.59$	$83^{a} \pm 5.03$
	Zeolite	$0.43^{d} \pm 0.03$	$0.3^{c} \pm 0.02$	$0.13^{de} \pm 0.02$	$8.5^{bcd} \pm 0.59$	$79^{a} \pm 5.03$
	Super absorbent	$0.26^{e} \pm 0.03$	$0.17^{d} \pm 0.02$	$0.09^{ef} \pm 0.02$	$6.8^{d} \pm 0.59$	$62^{bc} \pm 5.03$
Second year	Control	$0.27^{e} \pm 0.03$	$0.16^{d} \pm 0.02$	$0.11^{ef} \pm 0.02$	$4.5^{e} \pm 0.59$	$21^{e} \pm 5.03$
	Mycorrhiza	$0.87^{a} \pm 0.03$	$0.44^{a} \pm 0.02$	$0.43^{a} \pm 0.02$	$12.5^{a} \pm 0.59$	$87^{a} \pm 5.03$
	Zeolite	$0.72^{a} \pm 0.03$	$0.37^{b} \pm 0.02$	$0.35^{b} \pm 0.02$	$10^{b} \pm 0.59$	$75^{ab} \pm 5.03$
	Super absorbent	$0.46^{d} \pm 0.0S$	$0.21^{d} \pm 0.02$	$0.25^{c} \pm 0.02$	$8.1^{cd} \pm 0.59$	$50^{cd} \pm 5.03$

Averages with common letters do not have a significant difference based on Duncan's multiple range test at the 5% probability level

rial organs and total plant biomass. Under field conditions, these treatments improved shoot dry weight, root dry weight, total dry weight, plant height, and establishment percentage compared to the control, with zeolite and mycorrhiza yielding the most favorable outcomes.

Mechanisms Underlying Treatment Effects

These findings align with prior research indicating that mycorrhizal inoculation enhances vegetative growth by improving nutrient and water uptake (Dowarah et al., 2022; Ahmad Khan et al., 2007). Mycorrhizal symbiosis, particularly with *G. intraradices*, facilitates phosphorus absorption, thereby increasing photosynthetic activity, CO_2 fixation, and biomass production (Chowdhury et al., 2024; Johnson et al., 2002; Swift, 2004). For instance, Dowarah et al. (2022) reported elevated phosphorus concentration and photosynthetic rates in mycorrhiza-inoculated olive and thistle seedlings, leading to higher yields. Similarly, Rezvani et al. (2008) observed that *Medicago sativa* colonized by *G. mosseae* and *G. intraradices* exhibited greater phosphorus, zinc, and potassium uptake, resulting in increased shoot biomass. Zeolite application mitigates nitrogen leaching, enhancing nitrogen availability during growth and subsequently increasing shoot dry weight (Gholamhosseini et al., 2017). Clinoptilolite zeolite also improves potassium and nitrogen retention in sandy soils (Conversa et al., 2024; Hershey, 1980). Mahmoud et al. (2023) further demonstrated that zeolites reduce nutrient leaching, particularly nitrogen, thereby optimizing root-zone nutrient availability.

Superabsorbent polymers improved soil moisture retention, leading to enhanced growth and dry matter accumulation in fodder corn (Zhang et al., 2020; Mozen Qaysari et al., 2008). However, their effect on plant height was inconsistent; for example, Rafiei et al. (2018) found no significant impact on *Haloxylon aphyllum* (Minkw.) Iljin seedling height.

Plant Establishment and Stress Tolerance

In field conditions, mycorrhiza and zeolite treatments significantly improved the establishment and survival of *A. sieberi* over two years, outperforming superabsorbent

(Conversa et al., 2024; Bahador & Tadayon, 2018). Mycorrhizal fungi enhance plant resilience in heavy metal-contaminated soils by expanding nutrient absorption zones and immobilizing toxic metals (Paszkowski et al., 2024; Azimi et al., 2018b). Adeyemi et al. (2021) highlighted the role of *G. intraradices* and *G. mosseae* in restoring degraded habitats via improved water-use efficiency and stress tolerance (Miller & Jastrow, 2000).

Superabsorbents marginally aided plant establishment in mining lands by increasing soil water-holding capacity (Zhang et al., 2020; Wu et al., 2008). Rafiei et al. (2019) reported improved *Haloxylon* seedling establishment due to reduced water evaporation and enhanced moisture availability.

The study underscores the efficacy of zeolite and mycorrhiza in promoting plant growth, nutrient uptake, and stress tolerance, while superabsorbents primarily improve water retention. These treatments collectively enhance plant establishment in both greenhouse and field settings, with mycorrhiza and zeolite offering the most consistent benefits.One of the primary sources of heavy metal contamination in soil is mining activities, particularly metal extraction processes. In arid and semi-arid regions, the initial establishment of seedlings in mined lands is a critical yet challenging stage due to adverse environmental conditions, including low rainfall, high evaporation and transpiration rates, nutrient-deficient soils, soil layer disruption, and substrate instability. These factors often lead to poor plant survival and growth.

This study evaluated the effectivenessof soil amendments, including zeolite, superabsorbent polymers, and the arbuscular mycorrhizal fungus *G. intraradices*, in improving the establishment and growth of the medicinal plant *Artemisia sieberi* under both greenhouse and field conditions in the reclaimed mining area of the Mashhad East Cement Factory.

Under greenhouse conditions, root colonization by *G. intraradices* was significantly higher compared to field conditions throughout the two-year study. Additionally, the application of zeolite, superabsorbent polymers, and mycorrhizal inoculation significantly enhanced seedling growth and early establishment compared with the untreated control.Field trials demonstrated that all three amendments improved the stablishment and survival of *A. sieberi*. However, mycorrhizal inoculation and zeolite application were the most effective treatments, resulting in the highest establishment and survival rate. Overall, these findings suggest that ntegrating mycorrhizal fungi and zeolite into restoration practices can substantially improve vegetation establishment and accelerate ecological rehabilitation in degraded mining landscape. Furthermore, arbuscular mycorrhizal symbiosis plays a crucial role in enhancing plant tolerance to heavy metal stress by improving nutrient acquisition. The results indicate that *A. sieberi* exhibits a high capacity to tolerate heavy metal-contaminated soils and adapt to the harsh climatic conditions of the study area, resulting in successful establishment and long-term survival. These results the considerable potential of *A. siberi*, particularly when combined with mycorrhizal inoculation and suitable soil amendments, as an effective species for the ecological restoration of heavy metal-contaminated mine lands in semi-arid mined regions, such as the Mashhad East Cement Factory.

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References

Abedi Kopaee, J. and Mesforosh, M., 2018. Evaluation of the use of superabsorbent polymer on yield, water consumption efficiency, and nutrient storage in greenhouse cucumber. *Iran Irrigation and Drainage Journal,* 3(2), pp.100-111.

Adeyemi, N.O., Atayese, M.O., Sakariyawo, O.S., Azeez, J.O. and Ridwan, M., 2021. *Arbuscular mycorrhizal* fungi species differentially regulate plant growth, phosphorus uptake, and stress tolerance of soybeans in lead-contaminated soil. *Journal of Plant Nutrition,* 44 (11), pp.1633–1648. Doi:https://doi.org/10.1080/01904167.2021.1871742.

Ahmadi Azar, F., Hassanlou, F., Imani, A. and Feizi Asl, V., 2014. Drought stress and application of mineral zeolite on growth and some physiological parameters of *Malva sylvestris*. *Plant Research Journal (Iranian Biology Journal),* 8(3), pp. 459-474.

Ahmad Khan, I., Ahmad, S., Sarvat, N., Moazzam, N., Athar, M. and Shabir, S., 2007. Growth response of Buffel Grass (*Cenchrus ciliaris*) to phosphorus and mycorrhizal inoculation. *Journal of Agriculturae Conspectus Scientificus,* 72(2), pp. 129-132.

Akbar Nakhli, S.A., Delkash, M., Ebrazi Bakhshayesh, B. and Kazemian, H., 2017. Application of Zeolites for Sustainable Agriculture: A Review on Water and Nutrient Retention. *Water, Air and Soil Pollution,* 228(464), pp. 1- 34. Doi:https://doi.org/10.1007/s11270-017-3649-1.

Amirkhani, M., Mayton, H., Loos, M. and Taylor, A.G., 2023. Development of Superabsorbent Polymer (SAP) Seed Coating Technology to Enhance Germination and Stand Establishment in Red Clover Cover Crop. *Agronomy,* 13 (2), Article 438. Doi:https://doi.org/10.3390/agronomy13020438.

Azimi, R., Heshmati, G.A., Farzam, M. and Goldani, M., 2018a. The Effect of Mycorrhiza, Zeolite, and Superabsorbent on Growth and Initial Establishment of Medicinal Rangeland Species *Achillea millefolium* in Abandoned Cement Mines Soils (Case Study: Mashhad East Cement Factory, Iran). *Journal of Agroecology,* 10(2), pp. 565- 579.

Azimi, R., Farzam, M., Pessarakli, M. and Kianian, M.K., 2018b. Mycorrhiza inoculation effects on seedling establishment, survival, and morphological properties of *Ziziphora clinopodioides* Lam. *Journal of Plant Nutrition,* 41(20), pp. 2698-2704. Doi:https://doi.org/10.1080/01904167.2018.1510518.

Azimi, R., Hossein Jafari, S., Kianian, M.K., Khaksarzade, V. and Amini, A., 2016. Studying Arbuscular Mycorrhiza Symbiotic Effects on Establishment and Morphological Characteristics of *Bromus kopetdaghensis* on Cadmium Contaminated Soil. *Taiwan Water Conservancy,* 64(3), pp. 82-91.

Azimi, R., Heshmati, G.A., Farzam, M. and Goldani, M., 2018c. Effect of Mycorrhiza, Zeolite, and Superabsorbent on Growth and Primary Establishment of *Agropyron desertorum* in Mining Field (Case Study: Mashhad East Cement Factory, Iran*). Journal of Rangeland Science,* 9, pp.172-183.

Azimi, R., Heshmati, G.A., Farzam, M. and Goldani, M., 2018d. Effect of Mycorrhiza, Zeolite and Superabsorbent on Early Growth and Seedling Establishment of *Agropyron elongatum* in Mining lands (Case Study: Mashhad East Cement Factory, Iran). *Applied Research in Field Crops,* 31(2), pp. 1-20.

Azimi, R., Heshmati, G.A. and Kianian, M.K., 2017. Effects of Drought Stress and Mycorrhiza Inoculation on the Viability and Vegetative Growth Characteristics of *Ziziphora clinopodioides* Lam. *Journal of Rangeland Science,* 8(3), pp. 253-263.

Azimi, R., Jangju, M. and Asghari, H.R., 2014. Effects of mycorrhizal fungi Inoculation on seedling establishment and growth morphological characteristics *Bromus kopetdaghensis* in rangelands. *Journal of Range and Watershed Management*, 67(4), pp. 559-570.

Azimi, R., M. Jangju, and Asghari. H. R., 2013. Effects of mycorrhizal fungi Inoculation on initial establishment and morphologic characteristics of *Thymus vulgaris* L. in natural areas. *Iranian Journal of Field Crops Research,* 11(4), pp. 666-676.

Bacchetta, G., Cappai, G., Carucci, A. and Tamburini, E., 2015. Use of native plants for the remediation of abandoned mine sites in Mediterranean semiarid environments. *Bulletin of Environmental Contamination and Toxicology,* 94 (3), pp. 326–333. Doi:https://doi.org/10.1007/s00128-015-1474-3.

Baghodrat, G., Ahmadi, K. and Valizadeh, B., 2021. The effect of sulfur, wollastonite, biotite, zeolite, graphite, perlite, and feldspar on oviposition and egg hatching of common pistachio psylla (*Agonoscena pistaciae*) under orchard conditions. *Pistachio and Health Journal,* 4 (2), pp. 56-74.

Bahador, M. and Tadayon, M.R., 2018. Effect of deficit irrigation and zeolite levels on phenology, oil yield, and water use efficiency of hemp. *Iranian Journal of Field Crop Science,* 49(3), pp. 25-38.

Bano, S.A. and Ashfaq, D., 2013. Role of mycorrhiza to reduce heavy metal stress. *Natural Science,* 5(12A), pp. 16-20.

Barea, J.M., Palenzuela, J., Cornejo, P., Sánchez-Castro, I., Navarro-Fernández, A., López-García, A., Estrada, B., Azcón, R., Ferrol, N. and Azcón-Aguilar, C., 2013. Ecological and functional roles of mycorrhizas in semi-arid ecosystems of Southeast Spain. *Journal of arid environments,* 75, pp. 1292-1301. Doi:https://doi.org/10.1016/j.jaridenv.2011.06.001.

Begum, N., Akhtar, K., Ahanger, M.A., Iqbal, M., Wang, P. and Mustafa, N.S., 2021. Arbuscular mycorrhizal fungi improve growth, essential oil, secondary metabolism, and yield of tobacco (*Nicotiana tabacum*) under drought-stress conditions. *Environmental Science and Pollution Research*, 28, pp. 45276–45295. Doi:https://doi.org/10.1007/s11356-021-13669-2

Besharati, J., Shirmardi, M., Meftahizadeh, H., Ardakani, M.D. and Ghorbanpour, M., 2022. Changes in growth and quality performance of Roselle (*Hibiscus sabdariffa* L.) in response to soil amendments with hydrogel and compost under drought stress. *South African Journal of Botany, 145*, 334–347. Doi:https://doi.org/10.1016/j.sajb.2021.11.016.

Cataldo, E., Puccioni, S., Pacifico, S., La Rotonda, P., Lazzizera, C., Bonasia, A. and Elia, A., 2024. Prevention of drought damage through zeolite treatments on Vitis vinifera: A promising sustainable solution for soil management. Soil Use and Management, 40 (1), e13036. Doi:https://doi.org/10.1111/sum.13036.

Chowdhury, M.S.N., Sani, M.N.H., Siddique, A.B., Hossain, M.S. and Yong, J.W.H., 2024. Synergistic effects of biochar and potassium co-application on growth, physiological attributes, and antioxidant defense mechanisms of wheat under water deficit conditions. *Plant Stress*, 12, 100452. Doi:https://doi.org/10.1016/j.stress.2024.100452.

Conversa, G., Pacifico, S., La Rotonda, P., Lazzizera, C., Bonasia, A. and Elia, A., 2024. The foliar application of natural zeolites affects the growth and productivity of processing tomatoes. *European Journal of Agronomy*, 154, 127100. Doi:https://doi.org/10.1016/j.eja.2024.127100.

Doula, M.K., Elaiopoulos, K., Kavvadias, V.A. and Mavraganis, V., 2012. Use of clinoptilolite to improve and protect soil quality from the disposal of oil mill wastes. *Journal of Hazardous Materials*, 207-208, pp. 103-110. Doi:https:// doi.org/10.1016/j.jhazmat.2011.04.014.

Dowarah, B., Gill, S.S. and Agarwala, N., 2022. *Arbuscular mycorrhizal* fungi in conferring tolerance to biotic stresses in plants. *Journal of Plant Growth Regulation,* 41, pp. 1429–1444. Doi:https://doi.org/10.1007/s00344-021-10340-z.

Ekebafe, L.O., Ogbeifun, D.E. and Okieimen, F.E., 2011. Polymer applications in agriculture. *Biokemistri,* 23 (2), 81-89.

Fang, S., Wang, G., Xing, R., Chen, X., Liu, S., Li, Y., Qin, K., Wang, X., Li, R. and Li, P., 2019. Synthesis of superabsorbent polymers based on chitosan derivative graft acrylic acid-co-acrylamide and its property testing. *International Journal of Biological Macromolecules*, 132, pp. 575–584.

Farjad Tehrani, S., Bernard, F. and Soleimani, H., 2023. Accumulation of cadmium in Narcissus tazetta L. ornamental plant and its effect on growth character and zinc uptake under in vitro condition. *Plant Process and Function*, 11 (47), pp. 145-158.

Geisler, M., Buerki, S. and Serpe, M.D., 2023. *Arbuscular Mycorrhizae* Alter Photosynthetic Responses to Drought in Seedlings of *Artemisia tridentate*. Plants, 12(16), 2990. Doi:https://doi.org/10.3390/plants12162990.

Gholamhosseini, M., Agha Alikhani, M. and Malkuti, M., 2018. The effect of different levels of nitrogen and zeolite on the quantitative and qualitative performance of autumn rapeseed fodder. *Agricultural Sciences and Techniques and Natural Resources*, 45, 537-548.

Ginocchio, R., Carvallo, G., Toro, I., Bustamante, E., Silva, Y. and Sepúlveda, N., 2004. Micro-spatial variation of soil metal pollution and plant recruitment near a copper smelter in Central Chile. *Environmental Pollution*, 127(3), pp. 343-352. Doi:https://doi.org/10.1016/j.envpol.2003.08.005.

Hershey, D.R., Paul, J.L. and Carlson, R.M., 1980. Evaluation of potassium-enriched clinoptilolite as a potassium source of putting media. *HortScience,* 15 (2), pp. 87-89.

Hosseini, F. and Afrousheh, M., 2022. The impact of zeolite in the planting medium and seed priming on some vegetative parameters of pistachio (*Pistachio Vera* L.) under drought stress conditions. *Pistachio and Health Journal*, 5(1), pp. 30-38.

Ismail, L.M., Soliman, M.I., Abd El-Aziz, M.H. and Abdel-Aziz, H.M.M., 2022. Impact of Silica Ions and Nano Silica on Growth and Productivity of Pea Plants under Salinity Stress. *Plants,* 11 (4), 494. Doi:https://doi.org/10.3390/plants11040494.

Jarosz, R., Szerement, J., Gondek, K. and Mierzwa-Hersztek, M., 2022. The use of zeolites as an addition to fertilizers – a review. *Catena*, 213, 106125. Doi:https://doi.org/10.1016/j.catena.2022.106125.

Jeffries, P., Gianinazzi, S., Perotto, S., Turnau, K. and Barea, J.M., 2003. The contribution of *arbuscular mycorrhizal* fungi in sustainable maintenance of plant health and soil fertility. *Biology and Fertility of Soils*, 37(1), pp. 1-16. Doi:https://doi.org/10.1007/s00374-002-0546-5

Johnson, D., Leake, J.R., Ostle, N., Ineson, P. and Read, D.J., 2002. In situ, 13CO_2 pulse labeling of upland grassland demonstrates a rapid pathway of carbon flux from *arbuscular mycorrhizal* mycelia to the soil. *New Phytologist,* 153(2), pp. 327-334. Doi:https://doi.org/10.1046/j.0028-646X.2001.00316.x

Jongen, M., Albadran, B., Beyschlag, W. and Unger, S., 2022. Can *arbuscular mycorrhizal* fungi mitigate drought stress in annual pasture legumes? *Plant and Soil,* 472, pp. 295–310. Doi:https://doi:10.1007/s11104-021-05233-z.

Kabiri, K., 2005. Superabsorbent Hydrogel: Introduction and Applications. In: Proceedings of 3rd specific symposium on the application of super absorbent polymer hydrogels in agriculture. Petrochemistry and Polymer Research Center, Karaj, Iran.

Khani, M., Fekri, M., Sarcheshmehpour, M. and Mohammadinejad, Q., 2014. Investigating the condition of heavy metal contamination in the soil and *Artimisia aucheri* plant in Sarcheshmeh copper mining area, the 11th national seminar on irrigation and evaporation reduction, Shahid Bahonar University, Kerman, Iran.

Kim, S.M., Suh, J., Oh, S., Son, J., Hyun, C.U., Park, H.D., Shin, S.H. and Choi, Y., 2016. Assessing and prioritizing environmental hazards associated with abandoned mines in Gangwon-do, South Korea: The Total Mine Hazards Index.

Environmental Earth Sciences, 75, 369. Doi:https://doi.org/10.1007/s12665-015-5098-9.

Kumar, A., Raghuwanshi, R. and Upadhyay, R.S., 2010. *Arbuscular mycorrhizal* technology in reclamation and revegetation of coal mine spoils under various revegetation models. *Engineering*, 2 (9), pp. 683–689. Doi:http://dx.doi.org/10.4236/eng.2010.29088.

Kumpiene, J., Lagerkvist, A. and Maurice, C., 2008. Stabilization of As, Cr, Cu, Pb and Zn in soil using amendments – A review. *Waste Management,* 28(1), 215-225. Doi:https://doi.org/10.1016/j.wasman.2006.12.012.

Laurence, D., 2011. Establishing a sustainable mining operation: an overview. *Journal of Cleaner Production* 19(2-3), pp. 278–284. Doi:https://doi.org/10.1016/j.jclepro.2010.08.019

Liu, L., Li, D., Ma, Y.L., Shen, H.T., Zhao, S.M. and Wang, Y.F., 2021. The combined application of *arbuscular mycorrhizal* fungi and exogenous melatonin alleviates drought stress and improves plant growth in tobacco seedlings. *Journal of Plant Growth Regulation,* 40, pp. 1074–1087.

Mahar, A., Wang, P., Ali, A., Awasthi, M.K., Lahori, A.H., Wang, Q., Li, R. and Zhang, Z., 2016. Challenges and opportunities in the phytoremediation of heavy metals contaminated soils: A review. *Ecotoxicology and Environmental Safety,* 126, pp. 111-121. Doi:https://doi.org/10.1016/j.ecoenv.2015.12.023.

Mench, M., Lepp, N., Bert, V., Schwitzguébel, J.P., Gawronski, S.W., Schröder, P. and Vangronsveld, J., 2010. Successes and limitations of phytotechnologies at field scale: outcomes, assessment, and outlook from COST Action 859. *Journal of Soils and Sediments,* 10(6), pp. 1039-1070. Doi:https://doi.org/10.1007/s11368-010-0190-x.

Miller, R.M. and Jastrow, J.D., 2000. The application of VA mycorrhizae to ecosystem restoration and reclamation. In: Allen MF, ed. *Mycorrhizal functioning: an integrative plant-fungal process*. New York: Chapman and Hall, pp. 438–467.

Mohammadi Turkashvand, A. and Mehboob Khomami, A., 2012. Zeolite: a suitable input to replace peat in the substrate for the cultivation of Dieffenbachia ornamental plant. *Journal of Science and Technology of Greenhouse Culture,* 4(14), pp. 81-96. Doi:https://doi.org/20.1001.1.20089082.1392.4.2.10.7.

Mahmoud, A.W.M., Rashad, H.M., Esmail, S.E., Alsamadany, H. and Abdeldaym, E.A., 2023. Application of silicon, zinc, and zeolite nanoparticles—A tool to enhance drought stress tolerance in coriander plants for better growth performance and productivity. *Plants,* 12 (15), 2838. Doi:https://doi.org/10.3390/plants12152838.

Mozgawa, W. and Bajda, T., 2005. Spectroscopic study of heavy metals sorption on *clinoptilolite. Physics and Chemistry of Minerals,* 31 (10), pp. 709–713. Doi:https://doi.org/10.1007/s00269-004-0446-3.

Moazen Ghamsari, B., Akbari, G., Zohorian, M.J. and Nikniaee, A., 2018. Investigating the performance and growth parameters of fodder corn (*Zea mays* L.) under the effect of using different amounts of superabsorbent polymer (Superb A-200) under drought stress conditions. *Journal of Agricultural Plant Sciences of Iran (Agricultural Sciences of Iran),* 4(3), pp. 1-8

Paszkowski, U., Kroken, S., Roux, C. and Briggs, S.P., 2002. Rice phosphate transporters include an evolutionarily divergent gene specifically activated in *arbuscular mycorrhizal* symbiosis. *Proceedings of the National Academy of Sciences of the United States of America*, 99 (20), pp. 13324–13329. Doi: https://doi.org/10.1073/pnas.202474599.

Rafiei, Z., Zahtabian, G., Tavili, A. and Kianirad, M., 2014. The effect of hydrogel and compost on the establishment and vegetative characteristics of *Haloxylon aphyllom*. *Khoshbom,* 1(3), pp. 24-37.

Rasouli, F., Amini, T., Skrovankova, S., Asadi, M., Hassanpouraghdam, M.B., Ercisli, S., Bockova, M., Mrazkova, M. and Mlcek, J., 2023. Influence of drought stress and mycorrhizal (Funneliformis mosseae) symbiosis on growth parameters, chlorophyll fluorescence, antioxidant activity, and essential oil composition of summer savory (*Satureja hortensis* L.) plants. *Frontiers in Plant Science*, *14*, 1151467. Doi:https://doi.org/10.3389/fpls.2023.1151467.

Restiawaty, E., Gozali, V.A., Wibisono, T.A.S.E. and Budhi, Y.W., 2024. Utilizing modified clinoptilolite for the adsorption of heavy metal ions in acid mine drainage. *Case Studies in Chemical and Environmental Engineering*, 9, 100706. Doi:https://doi.org/10.1016/j.cscee.2024.100706.

Rezvani, M., Ardakani, M., Rejali, F., Noormohammadi, G., Zafarian, F. and Teimouri, S., 2010. The effect of different strains of mycorrhizal fungi on root characteristics and concentrations of phosphorus, potassium, zinc, and iron in alfalfa. *Journal of Modern Agricultural Science,* 15, pp. 291-301.

Ruíz-Baltazar, Á.J. and Pérez, R., 2015. Kinetic Adsorption Study of Silver Nanoparticles on Natural Zeolite: Experimental and Theoretical Models. *Applied Sciences,* 5, pp. 1869-1881. Doi:https://doi.org/10.3390/app5041869.

Sedaghat, M., Hazrati, S. and Omrani, M., 2022. Use of zeolite and salicylic acid as an adaptation strategy against drought in wheat plants. *South African Journal of Botany*, 146, pp. 111-117. Doi:https://doi.org/10.1016/j.sajb.2021.11.024

Salehi, A., Qalavand, A., Safidkon, F. and Asgharzadeh, A., 2018. The effect of using zeolite, microbial inoculant, and vermicompost on the concentration of N, P, and K elements, the amount of essential oil, and the yield of essential oil in the organic cultivation of the medicinal plant German chamomile (*Matricaria chamomilla* L.*). Iranian Medicinal and Aromatic Plants,* 27(2), pp. 188-201.

Sharma, A. and Sharma, A., 2013. Role of vesicular arbuscular mycorrhiza in the mycoremediation of heavy toxic metals from soil. *International Journal of Life Sciences Biotechnology and Pharma Research,* 2(3), pp. 418-431.

Sheoran, V., Sheoran, A.S. and Poonia, P.,

2010. Soil reclamation of abandoned mine land by revegetation: a review. *International Journal of Soil, Sediment and Water,* 3, Article 13.

Sprocati, A.R., Alisi, C., Pinto, V., Montereali, M.R., Marconi, P., Tasso, F., Turnau, K., De Giudici, G., Goralska, K., Bevilacqua, M., Marini, F. and Cremisini, C., 2014. Assessment of the applicability of a “toolbox” designed for microbially assisted phytoremediation: the case study at Ingurtosu mining site (Italy). *Environmental Science and Pollution Research,* 21(11), pp. 6939-51. Doi:https://doi.org/10.1007/s11356-014-2598-5

Swift, C.E., 2004. Mycorrhiza and soil phosphorus levels. Area Extension Agent: http://www.colostate.edu/Depts/CoopExt/ TRA/PLANTS/mycorrhiza.

Tadayon, M.R. and Karimzadeh Surehjani, H., 2019. The effect of zeolite on growth and physiological indices of. miliaceum Panicum L Under the management of a lack of irrigation. *Environmental Stresses in Crop Sciences,* 12(2), pp. 415-427.

Valadabadi, S.A. and Yousefi, M., 2023. Effect of Zeolite and Bio fertilizers on the Essential Oil Yield and Some Physiological Characteristics of *Satureja hortensis* L. under Water Deficit Stress. *Journal of Medicinal Plants and By-products*, 12(4), pp. 349-356. https://doi.org/10.22092/jmpb.2022.353488.1327.

Venkateswarlu, K., Nirola, R., Kuppusamy, S., Thavamani, P., Naidu, R. and Megharaj, M., 2016. Abandoned metalliferous mines: ecological impacts and potential approaches for reclamation. *Reviews in Environmental Science and Bio/Technology,* 15, pp. 327–354. Doi:https://doi.org/10.1007/s11157-016-9398-6.

Wahab, A., Murad, M., Asma, M., Abdi, G., Wajid, Z., Ayaz, A., Khizar, C. and Reddy, S.P.P., 2023. Role of Arbuscular Mycorrhizal Fungi in Regulating Growth, Enhancing Productivity, and Potentially Influencing Ecosystems under Abiotic and Biotic Stresses. *Plants,* 12(17), 3102. Doi:https://doi.org/10.3390/plants12173102.

Wang, M., Wang, Z., Guo, M., Qu, L. and Biere, A., 2023. Effects of *arbuscular mycorrhizal* fungi on plant growth and herbivore infestation depend on the availability of soil water and nutrients. *Frontiers in Plant Science,* 14,1101932. Doi:https://doi.org/10.3389/fpls.2023.1101932.

Wu, L., Liu, M. and Liang, R., 2008. Preparation and properties of a double-coated slow-release NPK compound fertilizer with superabsorbent and water-retention. *Bioresource Technology,* 99 (3), pp. 547-554. Doi:https://doi.org/10.1016/j.biortech.2006.12.027.

Wuana, R.A. and Okieimen, F.E., 2011. Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. *International Scholarly Research Notices*, 402647, 20 pages. Doi:https://doi.org/10.5402/2011/402647.

Yari, S., Khalighi Sigaroudi, F. and Moradi, P., 2012. The effect of different levels of zeolite on the growth and amount of gel production in the medicinal plant Aloe vera (*Aloe vera* L.) in different irrigation conditions. *Journal of Medicinal Plants*, 11(48), pp. 72-81.

Yenilmez, F., Kuter, N., Emil, M.K. and Aksoy, A., 2011. Evaluation of pollution levels at an abandoned coal mine site in Turkey with the aid of GIS. *International Journal of Coal Geology,* 86 (1), pp. 12-19. Doi:https://doi.org/10.1016/j.coal.2010.12.002.

Ying, Z., Yinqiao, X., Zheng, W. and Shengyu, L., 2019. Advances in Application of Soil Amendments in Desert Control. *Journal of Ludong University, 35*, pp. 51–58.

Zhang, W., Liu, Q., Liu, S., Chen, J., Guo, L., Wang, P. and Lei, Z., 2020. Study on Seed Emergence and Seedling Growth of *Artemisia Desertorum* with Superabsorbent Polymers. *Polymers, 12* (12), 2873. Doi:https://doi.org/10.3390/polym12122873.

Zangouei Nasab, S., Emami, H., Astaraei, A. and Yari, A., 2013. The effects of Stakozerb hydrogel and irrigation frequency on some soil characteristics and the growth of *Haloxylon* plants. *Soil management and sustainable production*, 3(1), pp. 167-182.

Zou, Y.N., Zhang, F., Srivastava, A.K. and Wu, Q.S., 2021. *Arbuscular mycorrhizal* fungi regulate polyamine homeostasis in roots of trifoliate orange for improved adaptation to soil moisture deficit stress. *Frontiers in Plant Science,* 11, 600792. https://doi.org/10.3389/fpls.2020.600792.