Improving Revegetation of Degraded Dryland Using Zeolitic Tuff and Saltbush Species

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Summary

Drought is considered one of the major problems that renders the success of rehabilitation activities in arid and semi rangeland. Promoting survival and growth, using zeolitic tuff added to planting holes is suggested as possible solution. An experiment was conducted using a factorial design. Two shrub species (*Atriplex halimus* L., *Atriplex nummularia* Lindl.) were transplanted into holes prepared with three levels of tuff treatments (mulching, mixing and control) under rainfed condition. The result showed no significant effect of tuff on seedling survival percentage, when mixing tuff with plantation soil or adding tuff as mulch. Also, the two species showed similar survival percentages over two measured dates. However, mixing tuff with soil during hole preparation significantly enhanced seedling heights. The Australian Atriplex (*Atriplex nummularia*) species significantly grew higher than the Mediterranean *Atriplex halimus*. Also, results revealed insignificant effect of tuff treatments (mixing, mulch and control) on recorded species richness. But, the Australian Atriplex species significantly harbors more diverse species than the local *Atriplex*. The study concluded using zeolitic tuff had the potential to enhance seedling growth, thus improving the success of rangeland rehabilitation in dry areas.

Key words

zeolite, tuff, rangeland, atriplex, rehabilitation, species richness

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Introduction

Land degradation currently causes serious complex environmental problems affecting more than 20% of rangelands in the world (Hassan et al.2005). Land degradation combines both natural and social in a cause-effect cycle (Wiesmeier 2015). Major drivers for land degradation include unsustainable use of land resources, harsh climatic conditions (prolonged or frequent droughts), overgrazing (Alhamad and Alrababah 2008, Alrababah et al. 2007, Angassa 2014), and high population growth rate (Oudenhoven et al. 2015). Aber (1987) pointed the need to understand the requirements and positive traits of various species and planting patterns to maximize the productivity and stability of restored degraded areas. Call and Roundy (1991) pointed out the benefits of using shrubs in revegetation program including enhancing soil productivity and seed banks for plant regrowth; trapping wind-blown soil and seeds. Also, its canopies affect understory temperature conditions, which may reduce evapotranspiration, increase nutrient cycling and provide resting places for animals. Shrubs were found to act as nurse plants that increased the establishment of understory species (Sanjereheia et al. 2006) and significantly enhanced the productivity of associated herbs (Frost and McDougald 1989). These processes induce local spatial heterogeneity in soil moisture and nutrients around the shrubs and can lead to the development of 'fertile micro islands' thus adding to the complexity and biodiversity of the system. (Alhamad and Alrababah 2013).

Saltbush species (*Atriplex* spp.) have been recommended for use in rehabilitation of degraded lands (Le Houreou 1992), for animal feed (Otal et al., 2010) and to control erosion (Le Houerou, 2000). The saltbush (*Atriplex halimus* L.) is less sensitive to grazing (Ruiz-Mirazo and Robles 2011) and thus can be recommended as good source of fodder production in arid areas (Le Houérou 2006), to meet the nutritional requirements of non-productive animals during the periods with lower grass production (Correal and Sotomayor 1999). Larbi et al., (2009) reported that Mediterranean saltbush (*A. halimus*) was a successful shrub species in terms of establishment and biomass production. In Jordan the Atriplex saltbush species (*A. halimus* and *A. nummularia* Lindl.) are of potential for rehabilitation of degraded Badia and steppe rangeland (Abu-Zanat et al. 2004).

Rangeland revegetation faces a serious challenge due to the low survival rate of transplanted seedlings. Finding out novel approaches to assure successful establishment of seedling is a big challenge to rehabilitation programs in dry areas. Drought is a major problem in rehabilitation of degraded rangeland. Boosting survival and growth, using zeolitic tuff added to planting holes is proposed to be a possible solution. Natural Zeolite is a mineral found in volcanic rocks. Zeolites can accommodate a wide variety of cations, such as Na^+, K^+, Ca^{2+}, Mg^{2+}, water and/or other molecules within their pores. Zeolites are good alternatives to traditional potting media used for plant growing, seedling production (Manolov et al., 2005). Mulches, surface applied materials, have been extensively used in restoration of degraded land to control soil erosion (Li et al. 2020), and to enhance seedling survival and growth (García-Moreno et al., 2013; Jiménez et al., 2016). Different mulch materials have been inspected, including organic materials (Ives et al 2012, Hueso-González et al 2018) gravel mulches, volcanic rocks, or small stones in arid areas (Jafari et al., 2012, Lv et al 2017). The overall objective of this experiment was to find out the possible effect of adding tuff at the bottom of planting seedling hole or using tuff as a surface mulch on the (a) survival, growth and biomass of two rangeland species namely; *A. halimus* and *A. nummularia*, and (b) species richness.

Materials and Methods

Jordan is a small country with arid and semi-arid climate conditions. Natural rangelands cover more than 90% of total land area of Jordan (MOA, 2003). The majority of rangeland areas are located within the arid zone of the country (Alhamad 2006). Poor grazing management practices such as uncontrolled grazing and yearlong grazing in addition to plowing of rangeland and gathering of wild plants and cutting of range trees for wood have resulted in severe rangeland degradation in Jordan. Rangeland degradation is represented by the decrease in the most palatable and nutritious plants, soil degradation and by lower vegetation cover. (Alrababah et al. 2007, Alhamad and Alrababah. 2008).

The study was conducted at Jordan University of Science and Technology (JUST) campus in northern Jordan (32° 13' 40" N; 36° 10' 10" E; and 520m altitude). The site is characterized by an arid climate of mild rainy winters and dry hot summers. The mean annual rainfall for the last 10 years has been 211 mm. The soil of the study area is fine-loamy with a pH of 8.03 and EC of 0.78 dS m^{-1}.

The experiment was conducted using a factorial arrangement within a randomized complete block design (RCBD). Two shrub species (*A. halimus* and *A. nummularia*) were transplanted into holes prepared with three levels of tuff treatments (mulching, mixing and control) under rainfed condition. The first factor represents the use of tuff in planting hole with three levels (mulching, mixing and control). The second factor represents species with two levels: *A. halimus*, and *A. nummularia*. The experiment was conducted in three blocks, each block consisting of 240 seedlings. The seedlings were transplanted on January 2012 at JUST with a spacing of 3 m between rows and 2 m between shrubs within a row. The following data were collected:

(1) Survival on two dates (April 2013 and November 2013), (2) Height which was collected on April 2013, (3) Biomass which was collected on November 2013 using the unit reference method, and (4) Species richness measured around the Atriplex plants.

The data were analyzed using JMP 8 (SAS 2009) using GLM. ANOVA was first run with the following sources of variation (Replicates, Tuff treatments, Atriplex, Interaction between tuff and Atriplex, and Error). For the significant treatments, means were separated using least square mean LSD with probability level of 0.05.

Results

Seedling Survival

The analysis of the effect of tuff treatments on seedling survival of two Atriplex species (*A. halimus*; *A. nummularia*) and the species*treatment interaction are presented in Table 1. The effect of tuff did not show a significant effect on Atriplex seedling survival, when mixing tuff with plantation soil or adding tuff as

Table 1. ANOVA results for the effect of tuff treatments (mulch, mix and control), tow Atriplex spp. (*Atriplex halimus* L. and *Atriplex nummularia* Lindl.) and the interaction between treatment and shrub species on seedling survival measured at two dates (n=720)

Source of variation	DF	April 2013			Nov 2013		
		MS	F Ratio	Prob > F	MS	F Ratio	Prob > F
Block	2	0.517	4.40	0.013	0.635	5.37	0.005
Tuff	2	0.117	0.99	0.369	0.100	0.85	0.429
Species	1	0.405	3.45	0.063	0.320	2.71	0.100
Tuff* Species	2	0.056	0.48	0.619	0.089	0.75	0.471
Error	712	0.117			0.118		
R^2			0.02			0.023	

mulch. The transplanted seedlings reached good survival rate and were averaged around 80% of the two shrubs over all treatment for the measured periods.

Seedling Height

The ANOVA results on plant height measurements in response to tuff treatments on two Atriplex species (*A. halimus* and *A. nummularia*) and the species*treatment interaction are presented in Table (2). The result was significant regarding the effect of treatment and species responses. However, an insignificant interaction was detected between treatment and species. Mixing tuff with soil plantation exhibited the highest significant plant height over adding tuff as mulch or the control (Fig. 1a). The Australian Atriplex (*A. nummularia*) species significantly grew higher than the Mediterranean Atriplex (*A. halimus*) (Fig. 1b)

Biomass

The ANOVA results showed significant effect of tuff treatments on two Atriplex species (*A. halimus* and *A. nummularia*) and the species*treatment interaction (Table 3). Mixing tuff with soil plantation exhibited the highest significant biomass production over adding tuff as mulch or the control (Fig. 2a). However, a significant difference was found between using tuff as mulch and the control on biomass production (Fig. 2a).

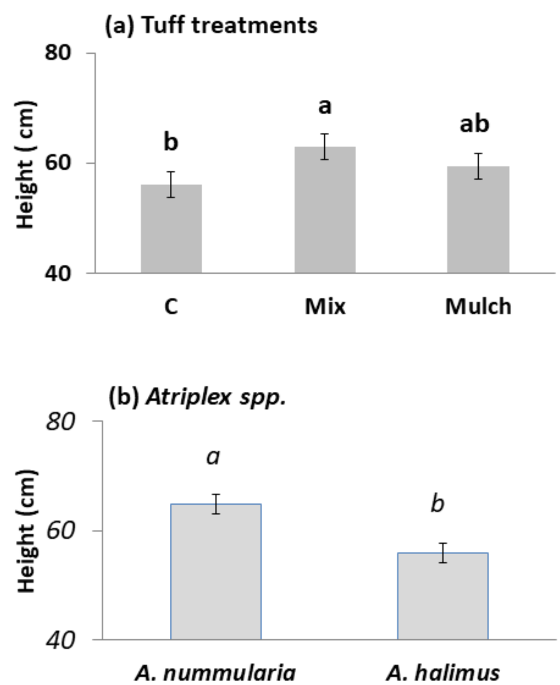

Figure 1. The average shrub heights (cm) as affected by (a) three types of tuff treatments (mixing, mulch and control) and (b) two Atriplex spp. (*A. halimus* L. and *A. nummularia* Lindl.)

Table 2. ANOVA results for the effect of tuff treatments (mulch, mixing and control), two Atriplex spp. *Atriplex halimus* L. and *Atriplex nummularia* Lindl.) and the interaction between treatment and species on seedling height (cm) (n=240)

Source	DF	Mean Square	F Ratio	Prob > F
Block	2	1724.867	5.372	0.005
Tuff	2	1005.746	3.133	0.045
Species	1	5274.735	16.430	<.0001
Tuff* Species	2	493.5792	1.537	0.217
Error	232	232	321.04	
R^2			0.33	

The results showed significant differences between *A. halimus* and *A. nummularia* in biomass production (Fig. 3a). The local species (*A. halimus*) produced significantly higher biomass than introduced species (*A. nummularia*. The treatment that was made from mixing tuff with soil and local Atriplex species (*A. halimus*) expressed the highest significant biomass production over other combinations of tuff treatment and the planted species (Fig. 3b).

Species Richness

The ANOVA results revealed insignificant effect of tuff treatments (mixing, mulch and control) on species richness measured around the planted shrubs (Table 4, Fig. 3a). The recorded species richness around the Australian atriplex (*A. nummularia* L.) showed significantly higher species richness than around the local atriplex (*A. halimus* L.) (Table 1, Fig. 3b).

Table 3. ANOVA results for the effect of three tuff treatments (mulch, mix and control) tuff on shrub biomass (g shrub^{-1}), two Atriplex spp. (*Atriplex halimus* L. and *Atriplex nummularia* Lindl.) and the interaction between treatment and shrub species (n=240)

Source	DF	Mean Square	F Ratio	Prob > F
Block	2	482207.4	5.6188	0.0041
Tuff	2	166028	1.9346	0.1468
Species	1	857300.2	9.9894	0.0018
Tuff* Species	2	159552.6	1.8591	0.1581
Error	232	85821		
R^2			0.31	

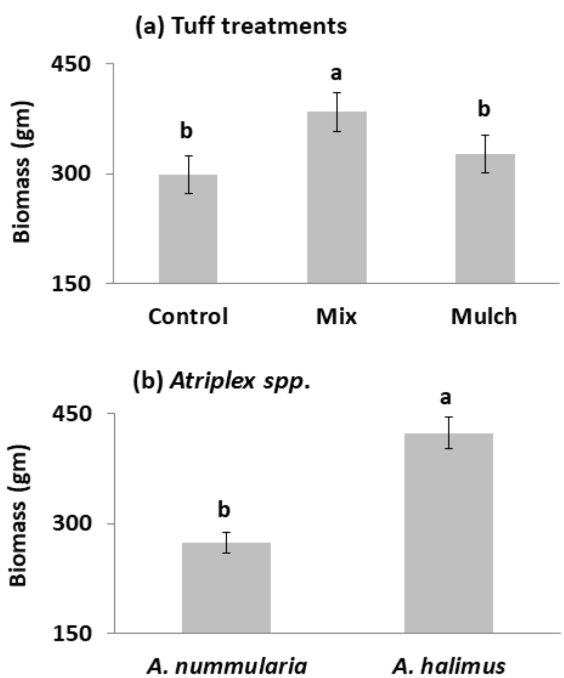

Figure 2. The average biomass (gm shrub^{-1}) as affected by (a) three types of tuff treatments (mixing, mulch and control) and (b) two Atriplex spp. (*A. halimus* L. and *A. nummularia* Lindl.)

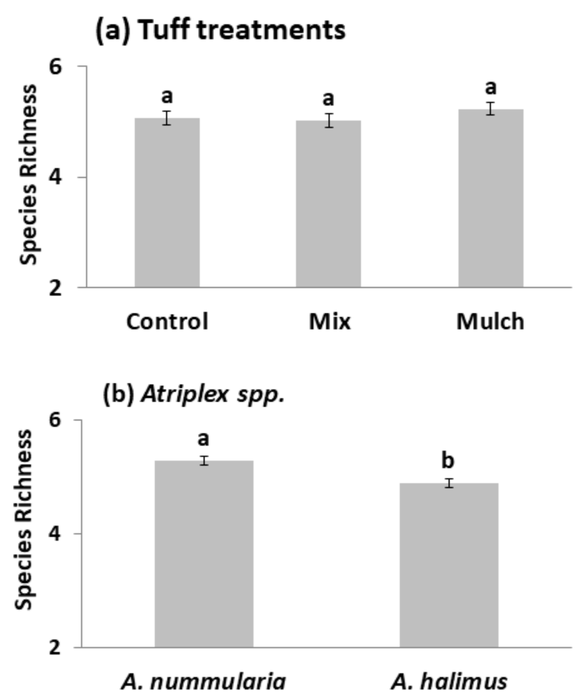

Figure 3. Species richness (no. of species per quadrate) as affected by (a) three types of tuff treatments (mixing, mulch and control) and (b) two Atriplex spp. (*A. halimus* L. and *A. nummularia* Lindl.)

Table 4. ANOVA results for the effect of tuff treatments (mulch, mix and control), tow *Atriplex* spp. (*Atriplex halimus* L. and *Atriplex nummularia* Lindl.) and the interaction between treatment and shrub species on species richness (n=720)

Source	Df	MS	F Ratio	Prob > F
Block	2	76.02	29.675	<0.001
Tuff	2	2.64	1.029	0.358
Species	1	28.63	11.174	<0.001
Tuff* Species	2	2.06	0.803	0.448
Error	712	2.562		
R^2		0.94		

Discussion

The results did not show any significant effect of tuff on seedling survival percentage when mixing tuff with plantation soil or adding tuff as mulch. Also, the two species had similar survival percentages over two measured dates. However, mixing tuff with soil during hole preparation significantly enhanced seedling heights over the control. These results can be explained by enhancing the water availability either by rendering the soil moisture by mixing or reducing water evaporation by mulching. Our findings agree with Valdecantos et al. (2009) who reported that the application of slash mulch increased soil moisture by 30%. The positive effect of soil mulching was confirmed by an enhanced soil moisture content (Qu et al., 2019). Katra et al. (2008) pointed out that the soil moisture in the topsoil under rock fragments was higher than that found for the bare soil areas. The available water under rock fragments was higher because the stones reduce the surface runoff, erosion and increase the infiltration (Martínez-Zavala & Jordán, 2008; Zhang et al., 2010. On the contrary, adding tuff to the Atriplex during planting resulted in showing a significant increase in plant biomass over mulching or the control treatment (Fig 3).

Further, the Australian Atriplex (*A. nummularia*) species significantly grew taller than the Mediterranean Atriplex (*A. halimus*). These results recorded a higher survival percentage as compared to Abu-Zanat et al. (2004) report on Atriplex species of an overall seedling survival of 67% after three growing seasons without water supplement. However, the survival was highly increased to 95% when additional harvested water of 39 mm was applied. Further, browse production of Atriplex species averaged 380 and 1151 kg DM (dry matter) per ha without and with additional water, respectively (Abu-Zanat et al. 2004).

Conclusion

Our results showed that using tuff can substitute for supplemental water in improving survival and growth of transplanted Atriplex seedlings. The study concluded that using zeoltic tuff had the potential to enhance seedling growth, thus improving the success of rangeland rehabilitation in dry areas where growth confer advantage. Also, the study clearly showed that the Australian Atriplex (*A. nummularia* L.) species significantly harbored more diverse species than the local shrub (*A. halimus* L.). The study results suggested that mixing zeolitic tuff with soil during transplantation of seedling was promising in improving the success of rangeland rehabilitation in dry areas in Jordan.

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