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Special topic on Management of degraded watersheds in mountain areas

Evaluation of rainwater harvesting and shrub establishment methods for sustainable watershed management in northern Afghanistan

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Abstract: Watershed rangelands in Northern Afghanistan provide various ecosystem services that support the local people's livelihoods, but they are now highly degraded essentially due to the continuous high grazing pressure and recurrent droughts. Effects of shrub establishment method enhanced by water harvesting techniques to rehabilitate degraded rangelands have not been well addressed. The main goal of this study was to evaluate the impact of direct seeding and transplanting of seedlings in combination with semi-circular bunds on growth, yield, and survival rate of four shrub species (*Atriplex halimus, Atriplex nummularia, Atriplex lentiformis,* and *Maireana brevifolia*) under semi- arid conditions of Sayyad village, Khulm watershed. Survival rate (%), plant height, width, and plant length (cm) and plant cover (%) were measured for each plant over five occasions. A non-destructive reference unit was used to estimate biomass production. The results showed that growth attributes and biomass production of shrubs were consistently greater in the transplanting compared to direct seeding. On average, the plant length, width, height, volume, cover, and biomass production of transplanted shrubs were greater than direct-seeded shrubs by 24.3%, 8.6%, 8.7%, 121.5%, 13.8% and 34.1%, respectively. Biomass production of transplanted seedlings was the highest for *A. nummularia* (1313.5 g DM/plant) and *A. halimus* (800 g DM/plant). There was a strong correlation between plant biomass production and plant volume ($R^2_{\text{Plant volume}}$ = 0.88) for the shrub *A. nummularia*, indicating that plant volume is a key variable for assessing biomass production for this species. Additionally, the survival rate of *M. brevifolia* was 100% in both planting methods, suggesting that based on better survival this halophytic plant has great potential when restoring degraded rangelands.

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Collectively, on the basis of better growth rates, yield, and survival, transplanting *A. nummularia* and *A. halimus* may enhance shrub establishment and contribute to the rehabilitation of sloping semi-arid degraded areas of Northern Afghanistan.

Keywords: Biomass production; Land degradation; Rangeland rehabilitation; Seed germination; Shrub survival; Vegetation cover; Water harvesting

1 Introduction

Rangelands cover approximately 45% of geographical area in Afghanistan and play an essential role in providing ecosystem services and economic support to the people living on them (Ates et al. 2018). Forages from these natural grazing lands are the main source of feed for livestock that are the basis for the livelihood of over 17 million resource-poor rural communities (Robinett et al. 2008; Islam et al. 2018). Despite their vital importance, rangeland resources are under severe threat of mismanagement and unrelenting exploitation. Nearly 28% of Afghanistan's rangelands have succumbed to heavy degradation due to decades-long overgrazing, recurrent droughts, and erosion (Favre and Kamal 2004). The denuding of vegetation cover and declining supply of rangelands forages are increasing at an alarming rate as the prevailing causes of degradation (e.g. excessive grazing, fuel wood collection and encroachment of pasture lands for farming) have been intensifying. The loss of productivity during drought years has been the cause of collapses in the livestock population, causing vulnerable agropastoralists to fall into extreme poverty (Bedunah and Angerer 2012; Jacobs et al. 2015; Ates et al. 2016).

A substantial portion of these rangelands are in watersheds located in five major river basins across the country (Reddy 2019). Rangeland watersheds are highly susceptible to landslides, activation of runoff and wind erosion affected by steep slope topographical factors and arid climatic conditions in Afghanistan (Margottini 2004). Sustainable management of pastures is crucial in watersheds where the conservation of limited water sources originates mainly from snowmelt and depends on maintaining aboveground vegetation cover and well-established belowground root systems (Favre and Kamal 2004). The conservation of water is not only vital for pasture production but also crucial for high crop yields in arable lands within watersheds (Adgo et al. 2013). Increasing probability of extreme precipitation events, prolonged droughts and the changing socio-spatial landscape have been aggravating the fragility of watershed rangeland ecosystems (Reddy 2019; Garg et al. 2021). Widespread overgrazing has been accelerating this process by exposing the soil surface (Mohibbi 2018). Thus, holistic approaches involving the sound rehabilitation techniques and sustainable agricultural management practices should be applied in watershed rangelands to reverse these negative trends (Hao 2018).

Rangeland rehabilitation, conservation of soil and water and protection of rivers and reservoirs have been highlighted as country-specific priorities in watershed management in Afghanistan (Reddy 2019). Direct seeding, soil surface scarification, water conservation and planting shrubs have been common rehabilitation practices in many degraded rangelands in the world. These practices are considered key interventions to rehabilitate degraded watershed rangelands and have been found highly effective in similar arid agroecological conditions in the Central Asia, Middle East, and North Africa regions (Louhaichi et al. 2014; Louhaichi et al. 2018; Slim et al. 2021). Seeds of some species can be directly seeded to eliminate the cost of raising nursery (Singh et al. 2016). Despite being cost effective and less labor intensive, the success of direct seeding can be limited due to poor emergence of seedlings particularly in arid conditions (Palma and Laurance 2015). In contrast, the survival rate of transplanted seedlings is greater albeit with notable variations depending on the plant species, age and agroecological conditions (Grossnickle 2012; Perumal et al. 2021).

In watershed rangelands, pasture rehabilitation efforts should be coupled with water conservation and harvesting techniques such as establishing contour bunds (Birhanu et al. 2019; Stavi et al. 2020). Harvesting and preserving runoff helps conserving moisture and distribution into the root zone for seedling survival and establishment, while reducing the water stress and water erosion (Tadele et al. 2018). Contour bunds are important in conserving soil nutrients and have a potential to promote the rehabilitation process of degraded land (Tadele et al. 2018). In arid and semi-arid areas, semi-circular bunds are commonly used for rainwater harvesting for tree and shrub seedling for fodder production and rangeland rehabilitation (Mosleh and Khankahdani 2020; Owino et al. 2021). Abaker and Daldoum (2014) showed that the growth of transplanted seedling was better in semi-circular bund on the establishment of *Faidherbia albida* compared with other techniques. This technique has positive effects on vegetation structure and diversity of rangelands and soil properties (Khosrvi et al 2016; Heshmati et al. 2018). On the other hand, constructing semi-circular bunds can improve rangelands condition through natural direct seeding as well (Mousavi et al. 2019).

There is a paucity of information on the watershed-scale impacts of establishment method, plant species and rainwater harvesting techniques worldwide. The scarcity of information on the effect of interventions to improve watershed rangelands is even wider for conflict-ridden countries such as Afghanistan. In order to put this issue into a broader perspective, this research aimed to determine the effectiveness of planting methods through semi-circular bunds used as rainwater harvesting techniques in rangeland rehabilitation and to compare studied species performance to appraise the species greatly adaptable to the ecosystem. Thus, the main objective of this study was to evaluate rehabilitation of 5%-10% sloping semi-arid degraded rangelands at watershed scale of Northern Afghanistan using different shrub species and methods of planting. Findings will assist decision-makers to develop effective strategies for rehabilitating degraded rangelands in the country.

2 Materials and Methods

2.1 Experimental site

The study was conducted at Sayyad village, Khulm district of Balkh province located in Northern Afghanistan (36°34'31.97"N; 67°46'06.73"E) and about 75 km from the west Mazar-e-Sharif (Fig. 1). The land belongs to the village community that consists of 250 households whose livelihoods depend on forest/fruit trees, livestock, and pasture. Livestock

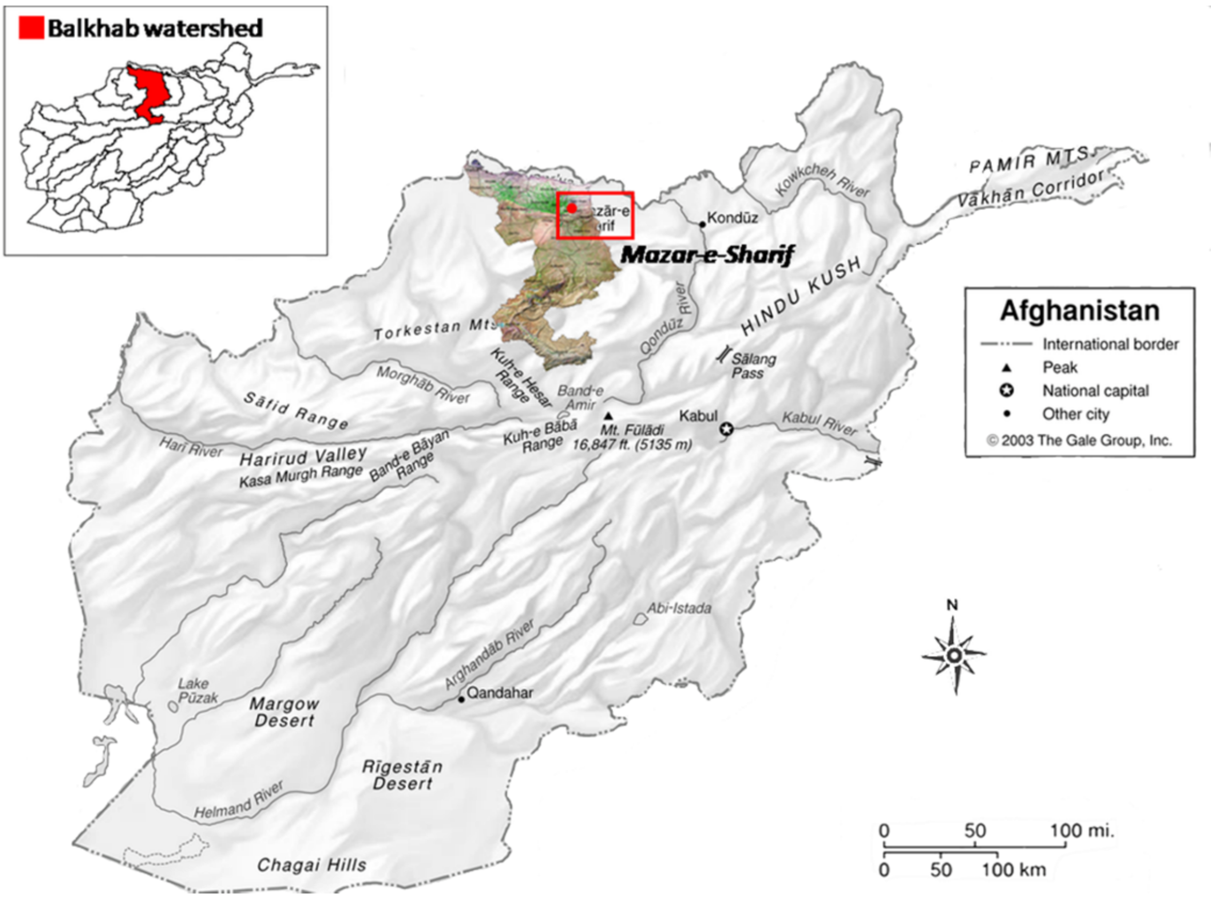

Fig. 1 Geographical location of Mazar-e-Sharif in Afghanistan and Balkhab watershed (Ellicott and Gall 2003; Favre and Kamal 2004).

products are an important source of food and clothing and provide income through the sale of meat, hides, and wool (Sexton 2012). The site is characterized by semi-arid mountainous rangelands with an elevation of 1,481 m above sea level.

The area receives about 189 mm average rainfall and temperature interval during a year of -5°C to 37°C (ICARDA weather station at Mazar Sharif). Sayyad village is characterized by a large area of rangeland, which is part of Khulm watershed 1,0230.3 km² (Fig. 2). Rangelands represent 58% of Khulm watershed. Rainfed land is 16%, sand-covered areas represent 13%, and 4.8% of the watershed is irrigated land (Favre and Kamal 2004). The soils are Mountain Entisols with silty loam texture. The vegetation is poor and the ephemerophytes were the dominant species.

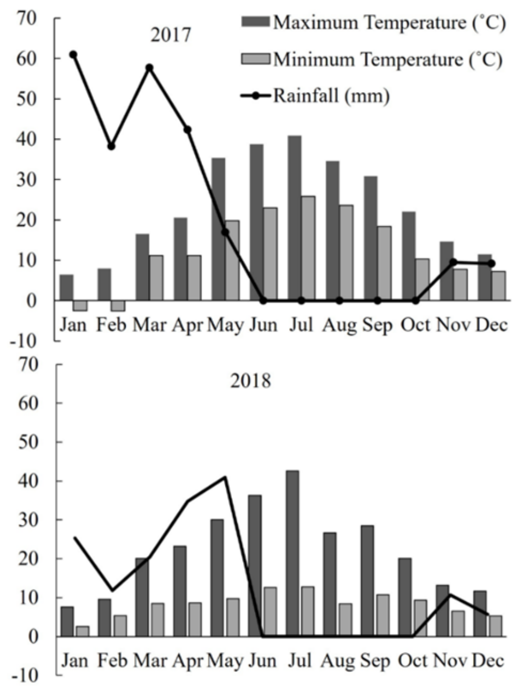

Fig. 2 Monthly mean rainfall (mm) and air temperature (°C) in Sayyad village recorded during the experimental period (February 2017 to September 2018). Source: ICARDA weather station at Mazar Sharif.

2.2 Experimental procedure

2.2.1 Plant materials

Four Amaranthaceae (Phenopodiaceae) forage shrubs were selected, *Atriplex halimus* L., *Atriplex nummularia* Lindl., *Atriplex lentiformis* (Torr.) S. Wats., and *Maireana brevifolia* (R.Br.) Paul G. Wilson. These introduced species are important for rangeland rehabilitation in arid and semi-arid areas because they are drought and frost tolerant, adapted to a wide range of soil types, grazing tolerant, and represent alternatives for remediation of saltlands. In addition, these fodder shrubs can provide forage reserve during the dry season.

Atriplex halimus L. commonly called Mediterranean saltbush, is a perennial halophytic and nitrophilous C4 shrub. *Atriplex halimus* have a wide distribution in the arid and semi-arid regions, with high tolerance to salinity and drought (Walker and Lutts 2014; Calone et al. 2021). *Atriplex halimus*, also known as *Guettaf*, is a shrub or woody herb, much-branched, procumbent or sprawling thickened to suberect, 0.5-3 m high with smooth white bark, 40 cm long. It grows in areas with annual rainfall ranging from 100 to 400 mm but can survive between one and several years without rainfall on a variety of soils, from fine to coarse texture, with varying degrees of salinity (Le Houérou 1992).

Atriplex nummularia Lindl., commonly called old man saltbush, is a perennial C4 shrub that reaches 3 m in height and 3 m in diameter native to the arid and semi-arid areas of Australia. It has one of the highest crude protein content and digestibility values of the chenopods. Globally, *A. nummularia* is one of the most important species selected for the rehabilitation of degraded dry rangeland (Melo et al. 2016) and widely used in commercial grazing systems (Norman et al. 2008). *Atriplex nummularia* is very adaptable and can tolerate severe droughts as well as soil salinity (Melo et al. 2016).

Atriplex lentiformis (Torr.) S. Wats., commonly called Quailbush, is a halophytic and phreatophytic C4 shrub with numerous erect branches 40-80 cm high and densely covered with hairs. *Atriplex lentiformis* blooms from August to October. It provides forage for livestock, wildlife habitat and has been used in revegetation and rangeland rehabilitation projects around the world. The species has higher drought resistance and recovery ability, which could be explained by its increased activities of antioxidant enzymes (Sadeghi and Delaviz 2016).

Maireana brevifolia (R.Br.) Paul G. Wilson, commonly known as Small Leaf Bluebush, is a perennial succulent-leaved shrub with an erect stem to 1 m high. It is native to the arid areas of Australia and used to ameliorate salt-laden pastures (Barrett-

Lennard et al. 2003; Dagar 2018). In other parts of the world, it has been introduced for saline soil improvement and dry-season fodder production (Danin 2000). Flowering time is from August to April and produces many seeds.

2.2.2 Shrub establishment methods

Based on the site topography and according to land slope, semi-circle bunds were manually constructed with diameter varying from 1 to 2 m along the contour lines spaced between 5 to 7 m apart, whereas the depth of the bunds was 0.5 m. Transplanting and direct seeding methods were used for growing forage shrubs. Seeds of selected shrub species were collected from 3 years old shrubs planted in a nursery established at research station in Mazar-e-Sharif. In February 2017, seeds were planted using two distinct methods*:* direct seeding and seedlings in the nursery.

(1) Direct seeding Five seeds from each shrub species were sown at 2 cm depth directly in each assigned semi-circle bund based on the experimental layout. The bunds were watered once right after the seed sowing. After germination and when the seedlings reached 3 cm long, thinning was done and the seedling with the best growth performance was left in the bund to mimic the plant's natural habitat.

(2) Production of Seedlings Three plastic bags filled with a mixture of clay loam soil (50%), sand (30%), and manure (20%) were assigned to each shrub species. In each bag, 5 seeds were sown at 2 cm depth and watered right after the seed sowing. The bags were randomly distributed in the nursery and were maintained and irrigated as needed. Emerged seedlings were thinned when they reached 3 cm long, and the strongest seedling was kept in each bag. Two-month-old and equal sized seedlings were then transplanted into their assigned bund in the experimental site.

2.3 Measurements and data collection

Survival rate (%), plant height (cm) width (cm) and plant length (cm) were measured for each plant over five occasions: 6th December 2017, 18th March 2018, 11th May 2018, 28th August 2018, and 20th September 2018. The plant height was measured as the distance from the plant base to the top of the highest vegetation part, while the plant width and plant length were recorded by measuring the long axis

Fig. 3 Data collection of shrub height, width, and length of rangelands species in Sayyad village, Afghanistan.

and the short axis for each respectively (Fig. 3). The plant volume (m^3) (assumed spherical canopy shape) was calculated using equation 1(Aranha et al. 2020):

$$\text{Volume} = 1/6\ \pi \times L \times W \times H \qquad (1)$$

where L = plant length (m), W = plant width (m), H = plant height (m).

Shrub cover (%) was estimated using the VegMeasure®, an image processing software, through using supervised classifications of captured pictures (Louhaichi et al. 2010; 2022). Vertical pictures were taken for each shrub plant using a digital camera from a height of 135 cm. To estimate the biomass production, a non-destructive reference unit was used to estimate biomass production (Carpenter and West 1987). A standard unit (branch) is selected as a biomass comparison for other plants during sampling. A reference unit reflecting 20% of the foliage on an average sized shrub was sampled, usually consisting of a shrub branch. This unit was cut and used to approximately estimate the number of units per shrub. Then, the edible materials in the reference units were separated, dried (60°C for 48h) and weighed to estimate the total biomass of each shrub by multiplying their weights by the number of branches of each shrub species.

2.4 Statistical analysis

The trial was conducted as a factorial randomized complete block design with two factors: two establishment treatments (direct seeding and transplanting) and four rangeland species (*A. halimus*, *A. nummularia, A. lentiformis* and *M. brevifolia*). The trial was replicated three times. The data analysis was carried out using the SAS statistical package (SAS 2009; Version 9.2, Cary, NC, USA: SAS Institute) and the mean comparisons were carried out using Duncan's multiple range test at $P < 0.05$ level of probability to test the differences between the treatments. Univariate correlation and regression model were applied to evaluate the relationship between the biomass production (as the dependent variables) and shrub growth measurements. The regression model is defined by the following (Eq. 2):

$$y = \alpha + \beta x \tag{2}$$

where y = dependent variable; x = independent variable; α = the intercept and β = slope.

3 Results

The main effects of species and planting method and their interaction had significant effects ($P < 0.01$) on the plant survival rate, plant height, width, length, volume, plant cover and biomass production. However, there was no significant effect of data collection date and its interaction with species, planting method treatment and their interaction.

3.1 Variations in shrub species

Shrub heights varied considerably among species ($P < 0.05$), with *A. nummularia* and *A. halimus* being more than 51% and 28% taller ($P < 0.01$) than *A. lentiformis* and *M. brevifolia,* respectively (Fig. 4). The width of the shrub species ranged from 73.3 to 126.6 cm. Although the growth of *A. nummularia*, *A. halimus,* and *M. brevifolia* did not differ (P=0.155) in the length, *A. nummularia* showed the longest plant length, reaching about 100 cm. Among all species, *A. lentiformis* recorded the lowest values of plant width and length (73 cm) (Fig. 4).

The plant volume, plant cover, and biomass yield varied ($P < 0.05$) by shrubs species (Fig. 5). The plant volume, plant cover, and biomass yield were highest in the shrub species *A. nummularia* (volume: 1.08 m^3, cover: 84.7%, biomass: 1,079.2 g). Among all species, *A. lentiformis* had the lowest plant volume, cover, and biomass production of 0.28 m^3, 64.8%, and 464.5 g, respectively.

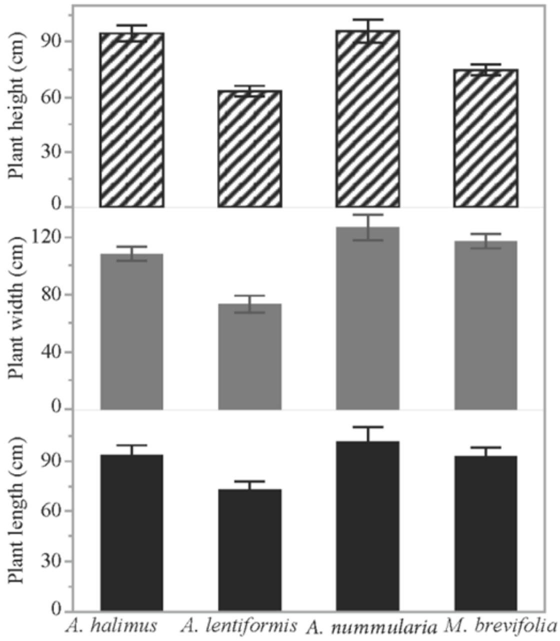

Fig. 4 Plant height, width, and length (cm) of four rangelands shrub species established in Sayyad village, Afghanistan. Bars represent standard error (n=3).

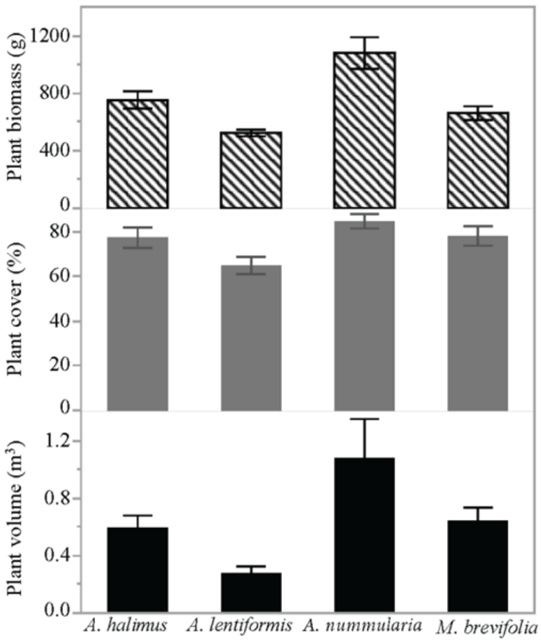

Fig. 5 Plant volume (cm^3), plant cover (%), and plant biomass production (g) of four rangelands shrub species established in Sayyad village, Afghanistan. Bars represent standard error (n=3).

3.2 Variations in planting method

Plant measurements of shrub species were significantly ($P < 0.05$) affected by planting methods (Fig. 6). The length of the transplanted shrubs was 24% greater than direct-seeded shrubs. Likewise, as observed for shrub length, the transplanting method resulted in higher shrub width (111 cm) compared to the direct seeding method (102 cm). The heights of shrubs established by transplanting were significantly taller than direct-seeded shrubs. Transplanted plants recorded higher plant volume which were 2 times more than that of direct seeded plants. Transplanting resulted in a significantly higher plant cover of 100% compared to direct seeding, which achieved 70%. In addition, there was a significant ($P < 0.05$) variation in biomass production between the two planting methods. On average, the biomass yield of transplanted shrubs was 634 g higher as compared to direct seeded shrubs (Fig. 6).

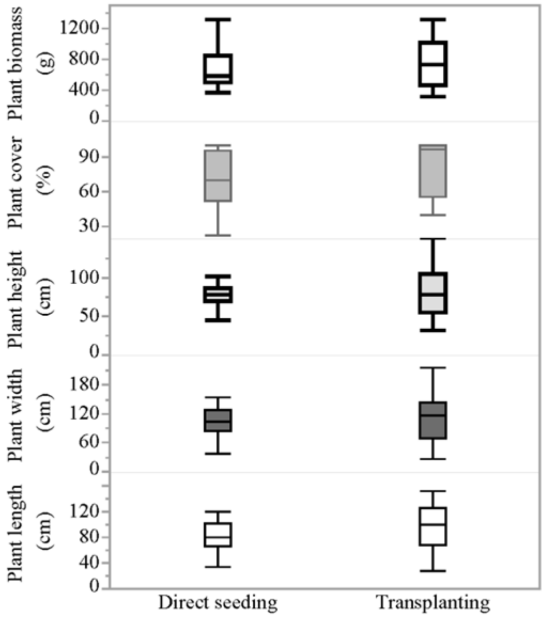

Fig. 6 Plant measurements and biomass of four rangelands shrub species under different planting methods in Sayyad village, Afghanistan.

3.3 Shrub species and planting methods interaction

The interaction effect of species and planting methods was significant (all $P > 0.05$) on the plant height, width, volume, plant cover and biomass production. There was no interaction ($P = 0.079$) between shrub species and planting method for plant length (Fig. 7). Transplantation of seedlings enhanced the biomass production and plant growth attributes of both *A. nummularia* and *A. halimus* as compared to direct seeding method. The plant height, width, volume, plant cover and biomass production of *A. halimus* plants were greater when established as seedlings than direct seeding by 34.1, 40.1, 199.3, 59.8 and 54.6, respectively. In contrast, growth and biomass production of *A. lentiformis* were positively affected by direct seeding method. The establishment method with seedling transplantation enhanced *M. brevifolia* height, width, volume and plant cover, however, the biomass production of transplanted and direct seeded *M. brevifolia* did not differ (Fig. 7).

3.4 Relationships between plant measurements and biomass

Positive and strong correlations existed between plant cover and plant length ($R^2_{\text{plant length}} = 0.75$), and plant width ($R^2_{\text{plant width}} = 0.78$, $P < 0.005$) (Fig. 8). There was strong correlation trend between plant biomass production and volume ($R^2_{\text{Plant volume}} = 0.86$, $P < 0.005$). For the *A. nummularia*, there was strong linear relationship between the biomass and the plant volume, plant width, plant height and plant cover variables with R-squared (R^2) ranging from 0.78 to 0.88. The same strong relationships were observed between the biomass and the plant cover of *A. lentiformis* ($R^2 = 0.78$). However, the relationship between the biomass production, plant length, width, and volume in *M. brevifolia* showed the same trend with (R^2) ranging from 0.77 to 0.91 (Table 1).

3.5 Classification of shrubs

Classification of shrubs performance based on their interaction with planting methods resulted from the hierarchical dendrogram identified three major clusters (Fig. 9). The first cluster included *A. halimus* and *A. nummularia* transplanting treatment. The second cluster included shrub species: *M. brevifolia* direct seeding and transplanting, and *A. nummularia* direct seeding. The last cluster included: *A. halimus* direct seeding, and *A. lentiformis* direct seeding and transplanting (Fig. 9).

3.6 Survival rate

Survival rate of transplanted and direct-seeded shrubs was significantly different ($P < 0.05$) between methods and species. Survival rate of transplanted seedlings of all shrub species was 100%. However, except for *M. brevifolia*, survival rate of the other shrub species was 67% under direct seeding. Around 33% of *A. nummularia*, *A. halimus* and *A. lentiformis* seedlings died when they were seeded directly (Fig. 10). The survival rate of *M. brevifolia* was 100% in both transplanting and direct seeding methods.

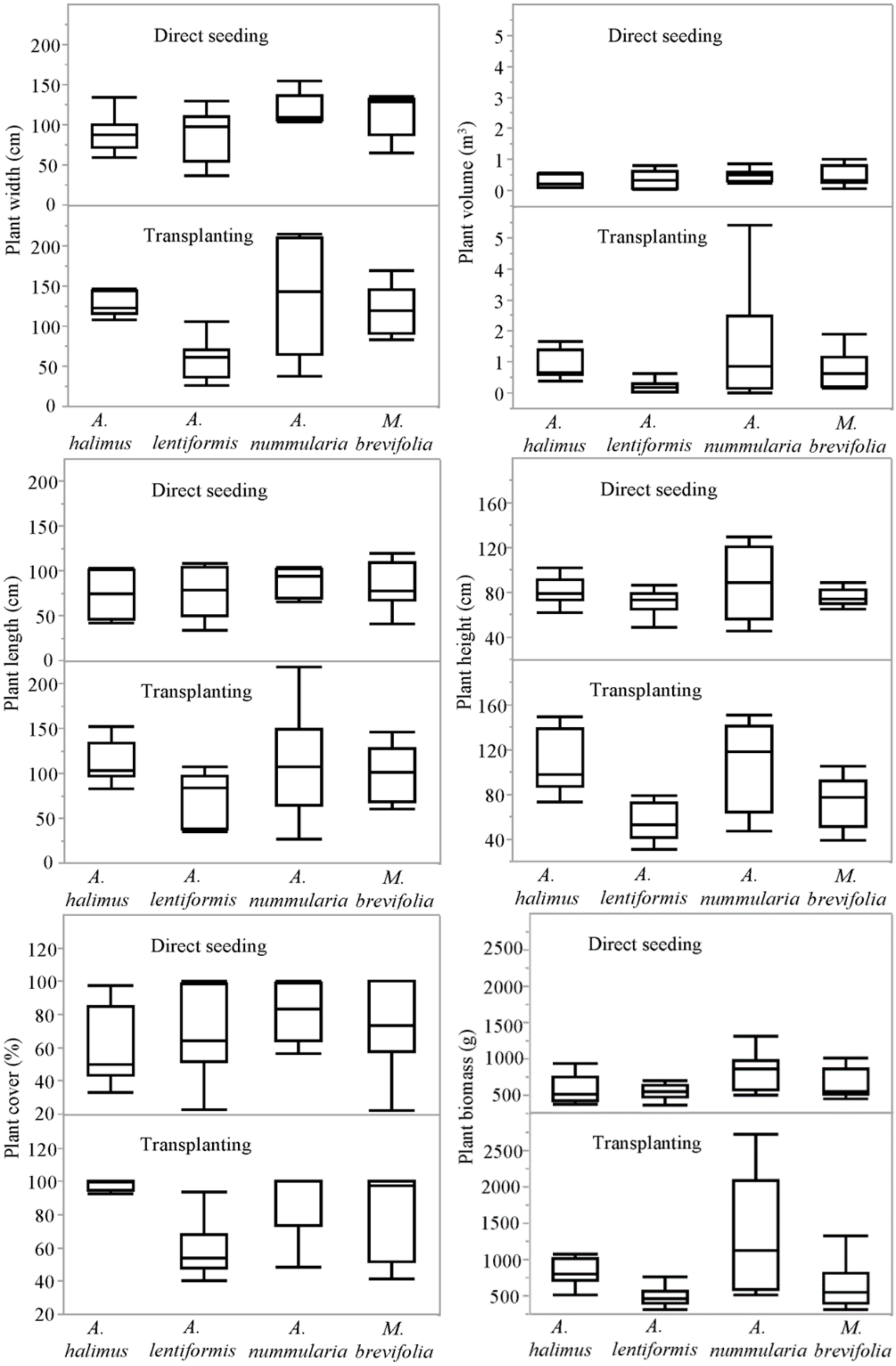

Fig. 7 Plant measurements and biomass of four different rangelands shrub species under different planting methods in Sayyad village, Afghanistan. Bars represent standard error (n=3).

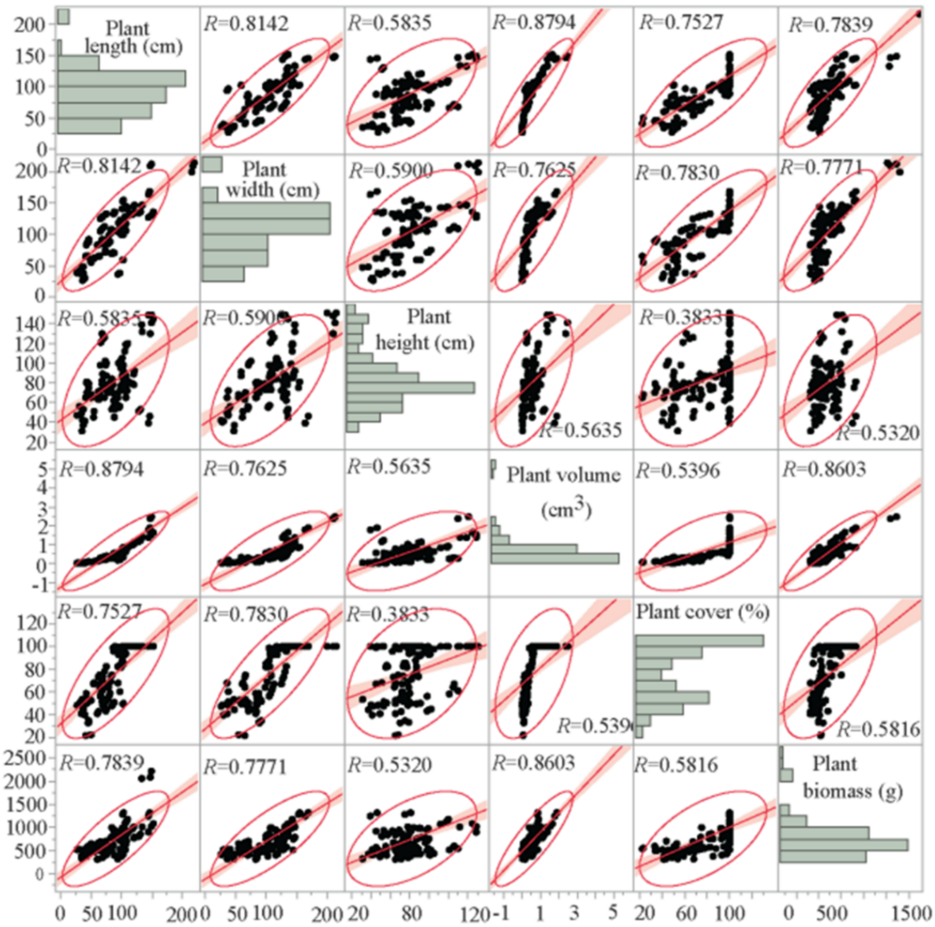

Fig. 8 Correlation coefficients between plant measurements and biomass production in shrub species in Sayyad village, Afghanistan.

Table 1 Simple linear regression parameters to establish relationships between the biomass (g/shrub) and plant measurements of four rangelands species in Sayyad village, Afghanistan.

Shrub Species	Variable	*β*	Intercept	R^2
A. lentiformis	Plant length	0.0774	31.160	0.156
	Plant width	0.1100	4.501	0.337
	Plant height	0.0008	-0.211	0.222
	Plant cover	0.0843	47.611	0.780
	Plant volume	0.0578	31.592	0.259
A. halimus	Plant length	0.0301	85.151	0.220
	Plant width	0.0136	114.79	0.127
	Plant height	0.0399	72.413	0.304
	Plant cover	0.0017	93.982	0.005
	Plant volume	0.0006	0.349	0.257
A. nummularia	Plant length	0.0545	39.476	0.766
	Plant width	0.0580	60.657	0.833
	Plant height	0.0406	49.881	0.808
	Plant cover	0.0329	14.879	0.787
	Plant volume	0.0013	-0.561	0.882
M. brevifolia	Plant length	0.0843	47.611	0.778
	Plant width	0.0819	67.322	0.815
	Plant height	-0.0449	102.831	0.433
	Plant cover	0.0499	48.891	0.405
	Plant volume	0.0017	-0.316	0.914

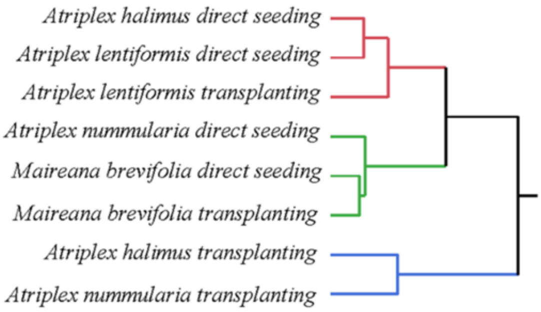

Fig. 9 Dendrogram constructed by Euclidean distance using Ward's method, to study the performance of four shrubs species (*A. halimus*, *A. nummularia*, *A. lentiformis* and *M. brevifolia*) based on their interaction with planting methods (direct seeding and seedling transplantation).

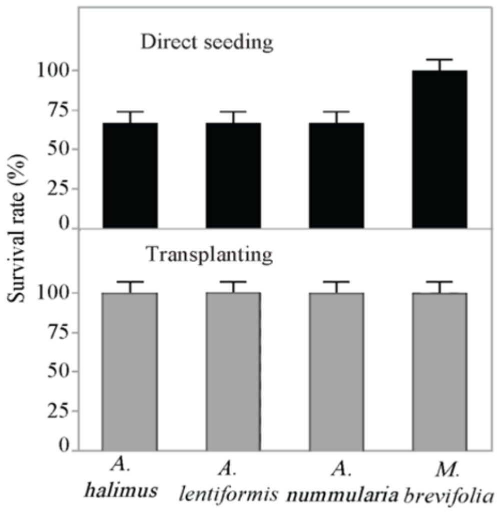

Fig. 10 Survival rates (%) of four rangelands shrub species under different planting methods in Sayyad village, Afghanistan. Bars represent standard error (n=3).

4 Discussions

The main objective of this study was to investigate the establishment success of four shrubs, that could potentially be used to rehabilitate degraded rangelands using two distinct planting methods (direct seeding and transplanting) with rainwater harvesting technique. For this purpose, the studied shrubs established by direct seeding and transplanting were compared in terms of their growth attributes including plant height, width, length, volume, and cover as well as biomass production. This study would provide local land managers more information on promising planting techniques and shrubs for future rangeland restoration.

Regardless of the planting method applied, plant trait responses varied considerably among species, with *A. nummularia* showing greater initial growth, volume, and biomass production in relation to the other shrub species. This result is in line with findings of Lemage and Tsegaye (2020) who reported changes in growth parameters among shrub species under Southern Ethiopian pastoral zone conditions. Plant species differ in numerous traits that may drive differences in rates of photosynthesis, water uptake, biomass allocation (Abdallah et al. 2018), and result in different abilities of a plant to cope with environmental stress (Gratani 2014). *Atriplex nummularia* is a very potential halophyte that is extremely hardy, thriving in particularly harsh environmental conditions such as drought and salinity which can be used as livestock fodder (Silva et al. 2016; de Melo et al. 2018). Because it has deeper roots than many *Atriplex* species, *A. nummularia* can access deep water tables (Barrett-Lennard 2003), demonstrating its significantly increased biomass.

Shrubs established with the transplanting method had higher height, width, length, volume, and cover as compared to shrubs established by direct seeding. The improvement of growth attributes in transplants (compared to direct seeding) also resulted in higher biomass production (843.8 g compared to 634.2 g), suggesting that transplanting method produces a more stable yield. The nonstructural carbohydrates of plant seedlings are known to be critical to survive stresses such as drought (Yang et al. 2019; Camisón et al. 2020), possibly explaining why transplanted seedlings achieved better plant growth and higher yield compared to newly germinating plants. The higher importance of establishment under the transplanting method could be mainly due to the initial plant age inherent with a two-months-old transplant that promotes lateral and basal roots growth of shrubs. Transplanting *A. nummularia* and *A. halimus*, in particular, had a high success rate demonstrated by higher biomass yield and growth attributes. Previous research reported a low germination rate of direct seeding in comparison to transplanting resulting in poor plant establishment in semi-arid and arid environments (Davies et al. 2013; Rowe et al. 2020). In these environments, evaporation from topsoil layers decreases soil water potential, negatively affecting seed germination (Volis and Bohrer 2013). Shallow seeding as in our study can lead to poor germination due to low soil moisture retention near the soil surface (Minnick and Alward 2012; Stewart et al. 2021). Nevertheless, establishment of *A. lentiformis* by direct seeding was greater than that by transplanting, which indicates that the former is a viable planting technique for this species.

The study showed a strength of correlation between some traits (including plant length and width) with plant cover. Also, increases in biomass production were associated with increases in plant volume (R^2 = 0.86). The highest values of correlation coefficients between plant volume and biomass production were 0.91 and 0.88 for *M. brevifolia* and *A. nummularia*, respectively. These values were within the ranges of (R^2 = 0.75 - 0.98) reported for other studies (Hirata et al. 2007; Greaves et al. 2015; Stovall et al. 2018). Further, the coefficients of determination for the volumes were higher than the other traits (length, width, height, and cover) in *M. brevifolia* and *A. nummularia*. Thus, it is suggested that the volumes could become the most accurate independent variable for predicting biomass production for these species. Plant volume has been demonstrated as a promising indicator of biomass (Proulx et al. 2015; Maimaitijiang et al. 2019). For *A. lentifloris*, the biomass depended mainly on plant cover, which is indicated by the high positive correlation (R^2 = 0.78).

Our findings identified three clusters. These clusters suggest that biomass yield and growth attributes (plant height, width, length, volume, and cover) could be used to identify promising shrub species for rangeland rehabilitation projects. The higher biomass yield and growth attributes in cluster 1 suggest that transplanted seedlings of the species (*A. nummularia* and *A. halimus*) in this cluster could be used in rangeland restoration efforts in Afghanistan, especially since both species have similar characteristics. These species share common characteristics such as good forage yields (Falasca et al. 2014), tolerance to drought and salinity (Orrego et al. 2020; Pérez-Romero et al. 2020), and ability to grow and accumulate high amounts of cadmium (Kahli et al. 2021), which clearly indicates their adaptation and tolerance to the presence of metal.

The survival rate of transplanted seedlings was 100%, that was greater than found in several other field experiments (Davies et al. 2013; Al-Satari et al. 2018; Abu-Zanat et al. 2020). Al-Satari et al. (2018) found that the survival rate of 4-month-old seedlings of *A. halimus* does not exceed 95%. Seedling survival rate of *A. nummularia* is estimated to be 71% (Al-Satari et al. 2013), which is 29% lower than found in the present study. The success can be attributed to the effectiveness of water harvesting techniques in conserving and storing soil moisture (Tadele et al. 2018; Strohmeier et al. 2021). For instance, Abu-Zanat et al. (2004), through field experiments conducted in arid rangeland of Jordan, showed that the survival rate from seedling transplanting of *A. halimus* and *A. nummularia* is 67% under natural conditions and increases to 95% when using rainwater harvesting systems. In this study, the most significant finding was that although transplanted seedling had higher survival than directly seeded, the establishment of seedlings from direct seeding poses a significant challenge due to their emergence in natural conditions. Survival rate of *A. nummularia, A. halimus* and *A. lentiformis* from direct seeding averaged 67%, a value that may be considered successful, given the extreme conditions that direct-seeded shrubs must tolerate in arid regions. These findings are higher than other studies that reported low survival (18%-56%) when direct seed techniques were applied (Palma and Laurance 2015; Pérez et al. 2019).

The survival rate from transplanting and direct seeding methods is considered of paramount importance in this study. Halophyte species have diversified adaptation mechanisms, which are important tools for survival, not for high productivity (Breckle 2016). However, these studied species have high productivity and used as dry-season fodder (Le Houérou 1992; Falasca et al. 2014; Dessena and Mulas 2016; Hintsa et al. 2018; Eissa and Abeed 2019). The survival rate (100%) of *M. brevifolia* in both establishment methods is exemplary, indicating that based on better survival this shrub should be a top candidate for preferential use in rangeland rehabilitation programs in Afghanistan.

5 Conclusion

In Afghanistan, watershed rangelands provide critical ecosystem services such as water regulation, wildlife habitat, and grazing for livestock, that support rural livelihood and the environment. However, these ecosystems are under threat of continued degradation driven by overgrazing and recurrent droughts leading to soil and water erosion. Revegetation is commonly practiced to enhance forage production and rehabilitate degraded rangelands. The purpose of this study was to demonstrate the best shrub revegetation methods (direct seeding vs transplanting) for degraded rangeland rehabilitation accompanied by semi-circular bunds used as a water harvesting technique. The findings of the present research reveal that transplanting method improved the growth, yield, and survival rate of the studied shrubs markedly in comparison to direct seeding. This intervention generated a positive impact especially for shrubs *A. nummularia* and *A. halimus*. However, the survival rate of direct seeding especially for the shrub *M. brevifolia* is as important as transplanted seedlings, stating that the two methods can be useful for the establishment of this shrub in rehabilitation strategy of salt affected soils. Overall, rangeland rehabilitation through the transplanting of shrubs in semi-circular bunds may be a good choice for restoring degraded rangelands of Afghanistan. Further studies are needed to identify local rangeland species that are well adapted to the local environment and provide quality fodder for the livestock.

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