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Direct seeding of *Salsola vermiculata* for rehabilitation of degraded arid and semi-arid rangelands

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Abstract
Proper soil preparation provides the basis for good seed germination and establishment of steppe vegetation in the arid and semi-arid areas of West Asia and North Africa. *Salsola vermiculata* is a key shrub species of the region and contributes to rangeland and livestock productivity. The aim of this study was to evaluate the establishment of *S. vermiculata* using three different soil preparation techniques since transplanting is often cost prohibitive. This study also aims to assess the establishment in different gradients of gentle landscape depressions for scarification and furrowing; at the top, on slope and at the core. The experiment was conducted in the semi-arid steppe of the Hama District in Syria with three establishment treatments *viz*., scarification (SC), pitting machine (PM) and furrowing (FR). Our results indicated that the density of *S. vermiculata* under scarification treatment is 10 folds higher ($P < 0.05$) than the other two techniques. The results suggest that direct seeding with superficial soil surface scarification may provide a significant remedy for the rehabilitation of degraded arid rangelands. Seeding densities tested on different gradients of landscape depressions were highest on the top, followed by on slope for both furrowing and scarification.

Keywords: Arid environment, Plant density, Seed germination, Soil moisture, Transplanting seedlings, Water infiltration

Introduction

Arid and semi-arid rangelands correspond to fragile zones, typically dominated by harsh environmental conditions in terms of low and erratic rainfall, shallow and poor soils, extreme temperatures, and high evaporation rates (Allison, 1998). The Syrian rangeland locally referred as badia, covers more than 10 million hectares, *i.e.*, approximately 55% of the country's landmass (Louhaichi and Tastad, 2010). These lands have been extensively used over time to support livestock production, in particular small ruminants (Lewis, 1987). However, these rangelands are suffering from anthropogenic and environmental disturbances (Louhaichi *et al*., 2012; Ouled Belgacem and Louhaichi, 2013) and are gradually losing their inherent soil fertility and are subject to erosion due to over-exploitation and inappropriate management practices. As a result, the grazing area is shrinking, available biomass is reduced and species biodiversity is being eroded (Enne *et al*., 2004). There is an urgent need to reverse the trend of rangeland degradation through appropriate rehabilitation techniques.

The most common and often most reliable method of rehabilitating arid and semi-arid rangelands are to transplant native plants to a variety of sites (Akroush *et al*., 2011). However, direct seeding is an alternative to transplanting and its cost is one-tenth that of shrub transplanting (Osman and Shalla, 1994). Given the vast areas, large scale range improvement will require the development of more cost effective approaches.

The main advantage of direct seeding is the ability to sow large areas rapidly at a lower cost compared to transplanting (Douglas *et al*., 2007). Furthermore, direct seeding is considered to produce a more natural appearance and improved successional pathway compared to spaced-planting (Douglas *et al*., 2007). However, direct seeding also has a number of potential disadvantages, including; difficulty in sourcing large quantities of viable seed, lack of information on optimum sowing times for many species, variability in commencement and duration of germination, less flexibility to control conditions for seed germination and early seedling growth, predation of seed and seedlings, and the need to control intense competition from existing vegetation, particularly grasses (Douglas *et al*., 2007).

One of the principal ways to improve the success of any direct seeding operation is thorough soil surface prepa-

-aration. In arid and semi-arid pastoral ecosystems of West Asia and North Africa (WANA), lack of soil moisture is probably the greatest limitation for satisfactory establishment of sown species (Karrou and Oweis, 2011). Historically, brittle rangelands, such as those in WANA, rely on soil and plant disturbance by hooved wild animals for presentation of water and seeds into the soil (Savory, 1988). Soil surface scarification and furrowing with direct seeding attempts mimic these natural processes. In arid and semi-arid regions of WANA, where water availability is the critical limiting factor, techniques which involve the scarification and ripping of substantial amounts of soil to maximize rainfall catchment and improve the infiltration of water have proven to be the most effective (Louhaichi, 2011).

Direct seeding of native Mediterranean shrub species is rarely successful in rangelands of the WANA region, except for *S. vermiculata* (Gintzburger *et al*., 2006). Although *Salsola vermiculata* is successful in direct seeding, seeds have a short storage life compared to other range species (Kay *et al*., 1988). The seed of *S. vermiculata* loses its viability within 6-9 months under ambient storage conditions (Tadros *et al*., 2000). Even though the storatolity can be extended by reducing storage temperature (Zaman *et al*., 2010). It is not always available in many developing countries. Thus, investigating the best direct seeding soil preparation methods is important to improve the success rate and establishment for restoration projects.

Salsola vermiculata L. is a member of the Chenopodiaceae family and is perhaps the most valuable browse species in arid rangelands of WANA. This plant provides a drought reserve for livestock and provides green feed with protein and other nutrients at a time of low nutritional value of other grasses and forbs (Pengelly *et al*., 2003). It is grazing resistant, self-reseeding and as a result used in many rangeland rehabilitation projects in Jordan and Syria (Gintzburger *et al*., 2006).The aim of this study was to evaluate the establishment of *S. vermiculata* using direct seeding in different gradients (at top, on slope and at the core) of gentle landscape depressions using scarification and furrowing soil preparation techniques, as well as evaluate the use of pitting machines on flat land in the semi-arid steppe of the Hama district in Northern Syria. The focus is on denuded rangelands, which avoids the more complex biological interactions that occur adjacent to and within shrub ruminants.

Materials and Methods

Study area

The study was conducted in the semi-arid steppe of the Hama district in Northern Syria. The climate in this area is Mediterranean arid, exhibiting highly variable and extreme precipitation and temperature patterns. The average annual precipitation (1996-2010) was 187.22 mm at the nearest weather station in Maragha, with the highest amounts occurring between December and March (Fig. 1). The average annual temperature is 17.6°C, with a range of 2.4°C in January to 39°C in August. During the study period the annual rainfall was 124.8mm and the average temperature was 13.8°C. Gentle landscape depressions are characteristic of the area. The study site areas were historically degraded from long-term barley encroachment until ban on its cultivation in 1995. Soils are derived from gypsiferous deposits and calcareous gypsic materials that accumulate in topographic depressions throughout the region.

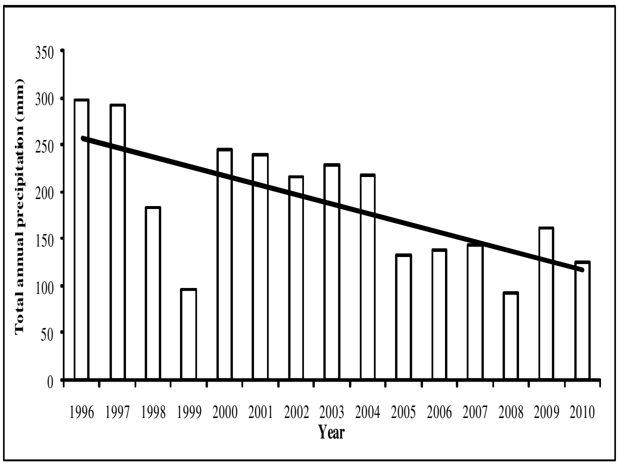

Fig 1. Annual precipitation (1996 to 2010) at Maragha in Northern Syria

Soil preparation and direct seeding

Seeds of *Salsola vermiculata* were collected from the Syrian rangelands in autumn of 2010. Before seed broadcasting the soil was prepared using three establishment techniques: 1) scarification (SC) using shallow cultivation of the whole surface area; 2) furrowing (FR) by opening 15 furrows per ha spaced 6 m apart and having 30 cm width each and 3) pitting (PM) using a pitting machine generated approximately 1,000 pits per ha. The seeding rate was set at 8 kg/ha for each technique. Seeds were sown in three landscape depressions (top, slope, and the core) for scarification and furrowing. The landscape depressions had a slope less than 10% and a maximum depth around 1 meter (Fig. 2). The pitting machine was tested on relatively flat surfaces only, as it was pulled by a pickup.

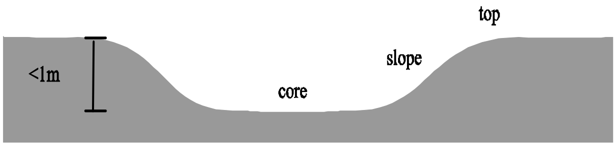

Fig 2. Landscape depression gradient locations and maximum depth

The soil preparation including scarification, furrowing, and pitting occurred in September/October, just prior to the rainy season. Assaeed (2001) reported that late autumn and early winter sowings should be recommended, when salinity and temperature stresses are reduced after the first rains of the season. Therefore, seeds were broadcasted in November taking advantage of the fall rain in order to improve the germination rate.

Plant density

In order to estimate the density of *Salsola* seedlings, ten randomized quadrats of 1m x 1m were chosen during the spring season. Quadrats were placed at the top, on the slope, and at the core of each landscape depression. Plant density was expressed as the number of individuals that occurred within a designated surface unit (m^2). The average density was calculated for each treatment at the different gradient positions.

Statistical analysis

The experiment design consisted of a randomized block design based on three blocks (sites) and eight replications per treatment. Treatments consisted of a factorial combination of three establishment methods and three landscape depressions features. ANOVA with the general linear model procedure was performed (SAS, 2009). If differences were significant, the separation of means was done with Duncan's Multiple Range Test, and a probability level < 0.05 was considered significant.

Results and Discussion

The WANA rangelands are deteriorating as a result of mismanagement and climate change resulting in recurrent droughts and increased temperatures. Direct seeding is considered to be one of the most economical and effective methods for restoring degraded rangelands, particularly where the seed bank is depleted (Porto, 2001). Our results indicated that the density of *S. vermiculata* under scarification treatment was 10 fold higher ($P<0.05$) than the other two techniques (Fig. 3). There was no significant difference between furrowing and pitting machine.

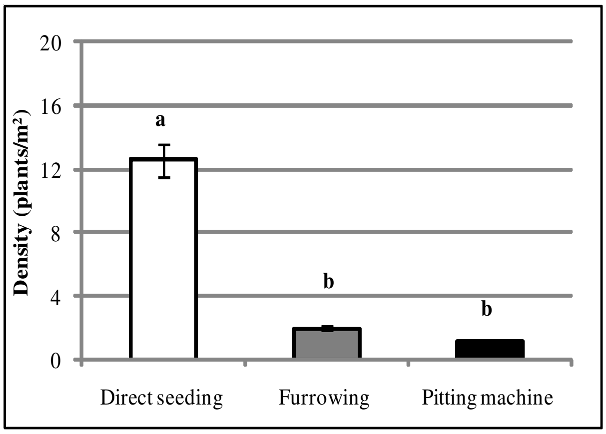

Fig 3. Density (number of *Salsola* plants/m^2) in all sites (bars that have different letters are significantly $P < 0.05$ different from one another).

When applying the soil scarification technique, the density of *S. vermiculata* was higher at the top and on the slope compared to the core of the landscape depressions ($p = 0.039$) for all sites (Fig. 4). However when comparing within individual sites; sites 1 and 2 did not record any significant differences in density, site 3 had higher density at the top of the landscape depressions compared to the slope and the core ($P = 0.004$) (Fig. 5). The reason for the lower density at the core of the landscape depressions than the top could be attributed to water that is collected at the core (bottom). The persistence of such a ponded area would limit the germination of the seed because of asphyxia (anaerobic conditions).

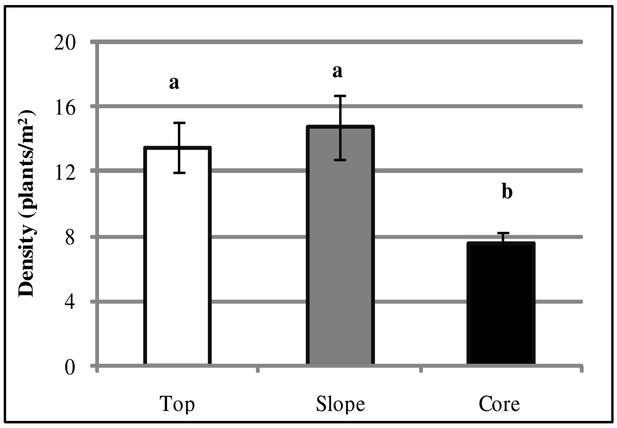

Fig 4. Density (number of *Salsola* plants/m^2) when using soil surface scarification for all sites (bars that have different letters are significantly $P < 0.05$ different from one another).

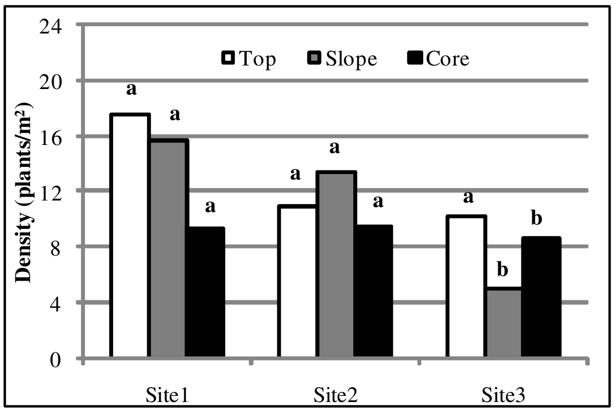

Fig 5. Density (number of *Salsola* plants/m²) in each site when using soil surface scarification (In each site, bars that have different letters are significantly *P < 0.05* different from one another).

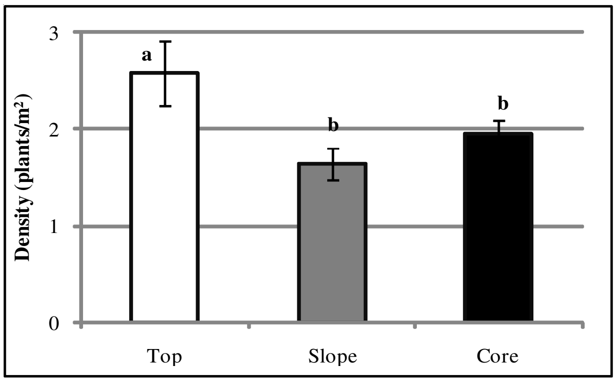

Fig 6. Density (number of *Salsola* plants/m²) in all sites when using soil surface furrowing (bars that have different letters are significantly *P < 0.05* different from one another).

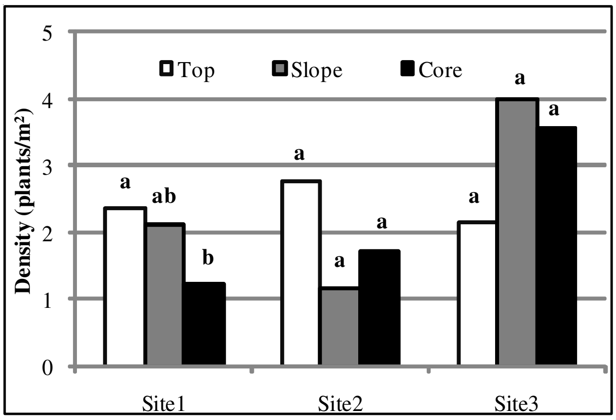

Fig 7. Density (number of *Salsola* plants/m²) in each site when using soil surface furrowing (In each site, bars that have different letters are significantly *P < 0.05* different from one another).

For the furrowing technique, density for all sites was higher at the top of the LD compared to the slope and core (P = 0.011) (Fig. 6). However, when comparing the densities within the individual sites, no significant differences were observed among the 3 landscape depression positions (Fig. 7).

Understanding the best soil preparation techniques and the best gradient for *Salsola vermiculata* is important since it is a key native forage species for restoring degraded rangeland in the WANA region. Temperature, soil moisture status and salinity are some of the most important environmental conditions that affect seed germination, seedling establishment and survival in arid areas. Episodic rather than average environmental conditions control the successful plant recruitments in arid and semi-arid regions (Call and Roundy 1991). Research is needed to improve the success rate of rehabilitation projects that plant *S. vermiculata*.

Based on climatic models, several studies show relationships between climate change and drought in the region which predict that the impacts of climate change will result in more frequent and harsher droughts, higher temperatures and lower and more unpredictable precipitation levels. The situation becomes more severe due to a steady population increase coupled with groundwater depletion. Similar to other arid ecosystems in the region, the Syrian Badia has a high resilience. Its natural vegetation is well adapted to frequent droughts and wet periods. If managed well, the system can recover after prolonged droughts.

In this study, direct seeding of *S. vermiculata* following soil surface scarification gave the best results based on the number of seedlings established in one year. This is likely due to climatic condition during the establishment phase. The precipitation was lower than the long-term average which is key for seed germination and establishment. The small pits created by the pitting machine gave a uniform seed bed and most of the seed germinated at once. When the soil moisture dropped because of prolonged drought, most of the seeds died. Though in principle the furrowing seems to mimic soil scarification, the depth at which the seeds were sown was too deep for the small seeds to germinate and rise above the soil surface. Soil surface scarification (top 5 cm) presented a more ideal situation for *S. vermiculata* to germinate and succeed. The micro topography generated by the soil surface scarification gave a mosaic of small scale niches that allowed seeds positioned at certain topographic facets to succeed fully. This assessment coincides with the view that rangeland productivity is governed by climate (temperature and precipitation), disturbance (grazing), topography, and the interaction of these (Gibson, 2009).

Conclusion

The results suggest that the superficial soil surface scarification is the best soil preparation technique for direct seeding for *S. vermiculata* when compared to furrowing or pitting machine. Direct seeding in soil scarifications may provide a significant remedy for the rehabilitation of degraded arid rangelands in WANA. Such a technique is not suggested for the core of landscape depressions as water logging may reduce plant density. While shrub transplanting makes it possible to establish plants that are not easily started from seed in the field, it is expensive and can be cost prohibitive in many contexts. Further experimentation of different methods for direct seeding soil preparation is recommended as well as the inclusion of other species.

Acknowledgements

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