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Sustainable Rangeland Management Practices for Arid and Semi-Arid Ecosystems Restoration

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Introduction

Nearly 10–20% of rangelands worldwide have been seriously degraded, with over 12 million ha deteriorating each year with serious consequence for people and livelihoods (Millennium Ecosystem Assessment 2005; Reynolds et al. 2007; James et al. 2013). Arid rangelands are more damaged in relation to other areas and, due to mismanagement, their situation is deteriorating from bad to worse almost on a yearly basis and so they are becoming less productive. Rangeland productivity in arid areas is affected by a myriad of factors that are often interconnected, including overgrazing, low rainfall distribution, overcutting for firewood, expansion of irrigated agriculture, expansion of tree planting, road development, urban development, mining activities, and climate change. All these factors cause decreases in vegetation cover, loss of biodiversity, accelerated soil erosion, and encroaching desertification. Once severely damaged, restoration of arid rangeland is difficult even if grazing and other disturbances related to human activities are halted.

Jordan's Badia rangelands are the most degraded of the Jordanian rangelands, due to the vulnerability of perennial shrubs and soil degradation that reflects the historical use of rangelands. In the Badia rangelands, severe degradation occurred under drought conditions in the mid-1980s, and a survey in 1991 indicated that up to 90% of the potential of rangeland productivity had been lost (FAO 1991; Al-Tabini et al. 2012).

These arid rangelands were mainly supporting sheep and were among the first Jordanian rangelands to be occupied by pastoralists, from about 1800 onwards. However, the continued grazing pressure led to decreases of rangeland productivity which made pastoralists more vulnerable and less resilient; by 2011, only 1% of pastoralists were still using the rangeland resources for grazing for just three months of the year, mainly between spring and summer. For the rest of the year, livestock is highly dependent on feed. The other 99% of pastoralists provide feed for their livestock all year round; however, their sheep are still present on the large steppe of rangelands, preventing potential regeneration processes (Zoghib 2014). Ultimately, rangelands are likely to remain as the open core-space for pastoralists of the Badia even if the productivity potential is lost (Figure 1). Most of the rangelands have been reduced to barren stretches of dust and rock with little economic value and, at this critical juncture, there are calls for decisive human intervention.

Our experiment, in maintaining and improving Badia rangeland and assessment of the methods and means being applied, brings new hope for greater success for arid rangeland restoration. The present work provides a good overview of activities of rangeland restoration projects, based on recent information and results provided by ICARDA, using different methods and means. The intention of this experiment is to help arid rangeland managers around the world and prove that restoration is possible. Managers need to believe that the challenges facing drylands may be daunting but are not insurmountable.

We will use the example primarily from the Jordanian Badia, because the Majidya area from Badia is a target area for rangeland restoration using a package of practices such as direct seeding, shrub planting, soil scarification, and water harvesting.

Site description

The Hashemite Kingdom of Jordan is a small Middle Eastern country located to the northwest of the Arabian Peninsula. Jordan has a total area of 92,300 km^2, and 1,619 km total boundary length, with the longest being that with Saudi Arabia (728 km). The highest point on the mainland is at Jabal Ramm (1,734 m) and the lowest point on land is at the Dead Sea (408 m below sea level). Jordan's climate is Mediterranean, with hot, dry summers and cool winters. Average temperatures in Amman are 18–32°C in August and 4–12°C in January. Most rain falls

Figure 1. Even if the rangelands lose their main role in providing forage to livestock, they will be places of safety for pastoralist accommodation

between November and April, with an average ranging from less than 100 mm in the south to around 500 mm in the northwest near the Jordan River. Jordan's land is generally arid, and the eastern four-fifths of Jordan is an extended desert bordering Saudi Arabia, Iraq, and Syria. These drylands that occupy 80% of the country's area represent the Badia zone in Jordan.

The Badia land is generally arid, receiving less than 200 mm/year. Livestock production is the main Bedouin livelihood in this region. However, these rural households face major challenges including climate change and steady rangeland degradation. Furthermore, land use changes through expansion of barley cultivation and urban-based economic development are marginalizing Badia users. The deteriorated status of the natural resource base poses challenges for rural households to sustain their livestock and vital social, cultural, economic, and ecological assets. The Badia is essential to rural life, as it provides a home to pastoralists and their animals, and provides feed forage, food, fuel, and medicinal plants.

Direct seeding, shrub planting, soil scarification, and water harvesting are all very useful in tackling rangeland degradation, lack of feed, and climate change and protecting biodiversity, but the wrong methods in the wrong areas can do more harm than good. The rules include restoring existing rangelands first, selecting and using appropriate methods, and involving local communities.

Rehabilitation intervention must be a top priority in areas that have become degraded. In this context, the Majidya region was selected as the target area. Although it is only a small area, it is crucial and plays a key role in pastoralism. Despite its small area, the methods and activities used in the restoration program have wide application.

Majidya covers approximately 10 ha, and is located 32 km southeast of Amman (31°43′04″N 36°07′36″E) (Figures 2 and 3) at an elevation of 855 m and receives 100–150 mm of annual precipitation (126 mm for 2018/2019 and 200 mm for 2019/2020). The soil is characterized as silty loam and silty clay loam. The site is situated on two hill slopes separated by a small wadi. Perpendicular to the slope, intermittent contour lines were made using a Vallerani machine and shrubs were planted in 2016 to consolidate the contours, reduce erosion, and restore vegetation cover.

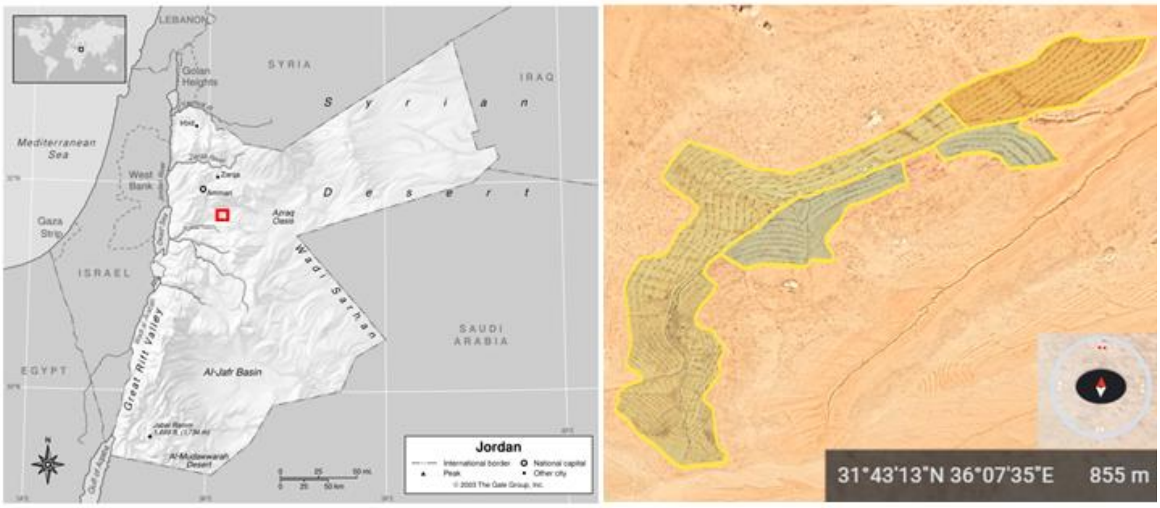

Figure 2. Location map of the target areas in Jordan

Figure 3. Land cover change maps of target area April 2011 to September 2019

Rangeland restoration techniques

Active and appropriate intervention is necessary to rehabilitate degraded arid and semi-arid rangeland. Intervention is required when the ecosystem cannot naturally recover its functions, and sometimes, even if possible, it may take many years to achieve the ultimate goal of restoration (Bainbridge 1990; Dregne 2002). Natural recovery is highly dependent on the ecological condition of rangeland and climatic conditions. If the state of rangelands does not reach the threshold of irreversibility and climate conditions are favorable, a short period of resting is effective for rangeland regeneration, if not, regeneration can be very slow or impossible. Rangeland restoration and revegetation are carried out using suitable tools on ecosystems where degradation has advanced. The current practices executed on degraded land of the Jordanian Badia are summarized below.

1.1. Water-harvesting techniques

Water is an important resource in arid and semi-arid rangelands, but often it is wasted or allowed to erode the landscape. One way to address this is through simple, cost-effective water-harvesting techniques that can be easily adopted by pastoral and agro-pastoral communities. This practice has been used for thousands of years in arid and semi-arid regions of the world to supplement scarce water resources. In general, the interventions are used to increase soil moisture content and vegetation cover, and so improve the productivity of rainwater, and maintain productive and sustainable agro-pastoral systems in marginal environments.

Continuous contour furrows

Contour furrows are small soil banks that run along a contour. A furrow is established next to each bank on the upper side of the slope (Figure 4). The distance between ridges varies depending on rainfall and slope. Contour furrows aim to concentrate moisture into the ridge and furrow area (where the plants are placed) by trapping runoff water from the catchment area. This also reduces the erosion risk. To maximize the runoff between the two ridges, the catchment area should be left uncultivated and clear of vegetation.

Figure 4. The minimum tools for an arid rangeland restoration project: using a tractor with two-furrow plow to make a Vallerani micro water-harvesting catchment

Intermittent contours

To prevent destruction of the contour bunds, it is advisable to establish intermittent contours especially for steep slopes (Figure 5).

Figure 5. Intermittent contour ridges for capturing excess rainwater runoff on slopes

Semi-circular bunds

The sizes of these bunds vary from small (2 m) to very large structures (30 m) used for rangeland rehabilitation (Figure 6). Bunds are constructed by digging out soil from within the area to be enclosed and supporting it up to form the bund. They are easy to construct and reduce soil erosion and catch water to ensure good storage for shrubs. The bunds should be established along a contour line in a matched arrangement so that water will be caught and collected by the two main tips. Semi-circular bunds are suitable for gentle sloping areas. One or two shallow holes are dug in the lowest part to help concentrate moisture, and shrubs are usually placed in these holes.

Figure 6. Preparation of semi-circular bunds for forage shrubs

V-shaped micro-catchments

These are diamond-shaped basins surrounded by small earth bunds with an infiltration pit in the lowest corner (Figure 7). Although V-shaped micro-catchments are well suited for hand construction, they cannot easily be mechanized. These micro-catchments are mainly used for growing trees or shrubs in arid and semi-arid areas.

Figure 7. Preparation of V-shaped micro-catchments for forage shrubs

1.2. Soil surface scarification

Crusted or capped soils are common in arid or semi-arid degraded rangelands, either occurring naturally or as a result of poor management. Without measures to improve soil conditions, rangeland rehabilitation efforts often result in unacceptably low seed germination and/or seedling performance. Success rates may be improved by human intervention, using methods such as soil surface scarification to promote physical and chemical processes within the soil that enhance plant survival and growth.

Soil surface scarification breaks up the compacted/crusted surface soil to enhance ecosystem processes. Soil respiration is improved, water can penetrate faster, germination and emergence of seeds are facilitated, and succession can proceed more quickly. Scarification is commonly used to ensure successful regeneration of vegetation either through natural rehabilitation or direct seeding.

Procedure

Different soil surface treatments can be used to improve degraded rangelands, with surface disturbance being achieved either naturally or mechanically. These actions may have different impacts on mixed plant communities and can significantly affect biodiversity and rangeland structure.

Mechanical scarification (machinery)

Mechanical scratching or plowing are the most common scarification techniques. The choice of field cultivator or ripper is based on how compacted the soil is, how hard the crusted layer is, and whether rocks are present. Usually a tractor is fitted with a tool bar that carries tines, rippers, or other devices capable of disturbing the upper 5–10 cm of the crusty soil. Cultivators consist of a frame, tines with reversible shovels, and heavy-duty springs. The teeth work on the soil surface to loosen the soil without inversion.

This treatment was implemented to measure the effect of soil surface scarification on the production of barley strips (Figure 8). Each catchment between two contour ridges was divided randomly into two parts, one was left without scarification while the second part was scarified (5 cm depth) using a field cultivator. The planted barley strips were 1 m wide.

Figure 8. Mechanical soil surface scarification

Natural scarification (herd effect)

Ideally, soil surface scarification can be achieved naturally through the action of the hooves of grazing animals. In the past, this was facilitated by the behavior of grazing wildlife which, when chased by predators, would stampede, and break up the soil surface. However, nowadays, with domestic livestock grazing calmly at a slow pace, the impact of the herd is negligible, especially when the soil surface is already capped or crusted. There are certain practices that can mimic predator-induced behavior such as the use of a mobile watering facility or additional feeding and/or mineral supplementation (for example, salt in a granular form).

Effective implementation

Soil scarification is recommended for bare (denuded) and crusted soil depending on the geographic location; scarification should be implemented in advance of the early fall rainfall (usually 1–2 weeks before the first rain is expected). If the soil seed bank is depleted, scarification should be combined with direct seeding. Scarified areas should be protected to allow seeds to emerge and seedlings to establish. The established plants should be lightly grazed initially, with moderate grazing permitted thereafter. Cautionary note—there could be limitations according to soil depth or the risk of wind erosion.

1.3. Shrub planting

The degradation of rangelands is induced by overgrazing, over-gathering of firewood, and conversion of the best rangelands into cropping land. Over-exploitation has negative effects leading to soil erosion and the reduction of forage biomass for livestock. To alleviate the spread of rangeland degradation, planting shrubs provides a large amount of fodder for livestock, combats desertification, and plays a key role in natural resource conservation.

Importance of fodder shrubs/trees

Shrubs reduce solar radiation and soil temperature, conserve moisture, and enrich the soil nutrient content. In providing ecosystem goods (especially forage for livestock and carbon sequestration), shrubs in arid zones boost poverty alleviation strategies and contribute to reducing food insecurity. The integration of shrubs through alley cropping has the potential to improve both the sustainability and profitability of utilizing a piece of land, thus improving the livelihoods of smallholder farmers.

Species and site selection

Select shrubs well-adapted to conditions of individual planting sites. The choice of species will depend on the annual rainfall amount, soil, topography, runoff, water-harvesting potential of the site, and the likelihood of environmental stresses such as drought, salinity, and cold. Species selection is also guided by rangeland development objectives, such as fodder production, wood production, dune fixation, or erosion control.

Ideal species for arid environments

In arid and semi-arid areas, common fodder shrubs include *A. halimus* (Mediterranean saltbush), *A. leucoclada* (Orache), *A. nummularia* (old man saltbush), *Bassia prostrata* (desert bush), *Salsola vermiculata* (Mediterranean saltwort), and *Haloxylon aphyllum* (saxaul).

Certain shrubs/trees contain anti-nutritional factors (secondary chemical compounds or toxins) which reduce the overall digestibility and palatability of their forage quality. Care must be taken to select highly adaptable species suited to the low rainfall and salt conditions of arid environments (Figure 9).

Figure 9. Rangeland rehabilitation using Atriplex halimus seedlings in the Jordanian Badia

Challenges during shrub planting

The high cost related to the establishment and maintenance of shrubs is the main challenge for smallholder farmers with low incomes. Another common issue faced by most shrub planting programs is availability of suitable species for the target ecosystem at the appropriate time. In most cases, supplementary irrigation is needed immediately after planting to secure strong roots and soil contact. Alternative feed resources to supplement livestock are most often in high demand in dry areas. This increases the risk of predation on transplanted shrubs because animals prefer the young succulent seedlings to the older and more mature plants.

Establishment and management

Shrub establishment and growth often suffer heavily due to intense lack of soil moisture. Several techniques are used to aid seed germination, such as seed pretreatment through scarification, or soaking in hot water. To improve overall productivity once established, rotational browsing/grazing of the rangeland will aid in reducing soil erosion, depletion of soil nutrients, and prevalence of weeds/invasive species, and raise uniformity of soil fertility levels. Before establishment, shrubs should not be browsed as this reduces their growth and survival potential.

Combining shrub planting with water-harvesting techniques

When seedlings are planted on steep slopes, water-harvesting techniques that enhance efficient use of soil moisture should be implemented first. When combined with water-harvesting techniques such as semi-circular structures or intermittent contours, shrub planting improves erosion control, forage quality and availability, and plant and animal micro-habitat conditions.

Effective establishment and maintenance

Select a suitable site for the introduction of new shrubs where precipitation usually exceeds 250 mm. In low rainfall areas, rainwater harvesting structures such as intermittent bunds or semi-circular bunds are needed. Transport seedlings to the site of transplanting with extra care. Harden young seedlings by gradually introducing them to their new environment. Right after transplantation, irrigate seedling to ensure good root contact with soil and avoid browsing during the establishment phase. Allow enough recovery time after browsing/harvesting and replace missing and/or dead seedlings during the following season. Prune shrubs every other year to induce regeneration of new growth.

1.4. Direct seeding

Rangeland degradation resulting from unsustainable human activities and climate change is a serious threat to natural resources in arid and semi-arid areas. Changes in rangelands use and management practices are urgently required to slow and even reverse degradation. There are several solutions available to tackle rangeland degradation. One of the most rapid and cost-effective options is direct seeding, which involves sowing seeds directly into their final growing location rather than transplanting seedlings nurtured elsewhere. Due to its low cost, direct seeding can be applied to large-scale degraded rangeland in many areas of the world. In choosing whether to restore rangelands with native or exotic species, suitable species should be chosen based on their responses to specific site characteristics to ensure success of the restoration project.

Direct seeding and its merits as a Badia restoration option

Direct seeding is currently receiving much attention as a method of rangeland improvement. Direct seeding is suitable for small or large areas where the terrain and cost of transplanting seedlings prevent natural regeneration or planting. It is an age-old practice that has regained favor due to the high costs associated with alternative methods of planting and transporting seedlings from nurseries for transplanting. Direct seeding reduces the time and labor required, increasing resource efficiency and preserving soil structure through reduced tillage. It is a method recommended in the lowlands and landscape depressions (Marab) that receive additional amounts of rainwater from runoff because the extra soil moisture improves seedling emergence and establishment. Furthermore, under intensifying climate change and increasing soil degradation rates, direct seeding without disturbing the soil (no-tillage) is becoming more appealing. Such practice helps the soil retain moisture and maintain more organisms that break down organic matter into vital nutrients, increasing the potential for nutrient recycling and leading to healthy soil.

Improving the impact of direct seeding

The constraints to successful direct seeding in drylands include drought, soil surface crusting and compaction, slow permeability, low available water capacity, and seed mortality due to heat and predation by birds or insects. Direct seeding is feasible on drylands if well-adapted species and recommended seeding methods are used. Outcomes can be improved through better site selection and ground preparation through drilling and pitting seeds to enhance germination and survival. Drills and pits can be created by hand or machine, and they contribute to protecting the seeds and improving moisture capture in arid areas.

Choosing species for direct seeding

Choosing seed species depends on the restoration's objective and the biophysical and socio-economic conditions of the target site and its community. In general, plants that grow naturally in the same habitat have the greatest chance of success. Exotic species such as fodder shrubs may also perform well under direct seeding once their ecological demands in the target site are met.

Enhancing seedling emergence and establishment

Seed pretreatment methods such as mechanical and chemical scarification or soaking seeds in hot water can improve direct seeding efficiency by breaking dormancy and overcoming field stress factors. Seed pretreatment also speeds up seedling emergence and enhances seed survival. Sowing at the appropriate time and depth is critical to the success of direct seeding.

Methods of direct seeding

Given the nature of rangeland landscapes, the most common method of direct seeding is hand broadcasting—sprinkling the seeds by hand. This is the easiest and cheapest method, requiring less labor compared to seedling transplantation. In most cases, this intervention is usually combined first with seedbed preparation through light soil surface scarification. After broadcasting, the seeds should be covered to protect against birds and other predators.

Another direct seeding technique is drilling—dropping seeds at a fixed depth and covering them with soil. In this method, sowing tools are used to place the seeds in the soil. Several options are available, such as mechanical seed drillers and pitting machines. The latter is towed by an ordinary two-wheel-drive pickup making it popular and achievable for small-scale farmers. Small shallow "pits" are scooped out by the action of inclined metal disks just before the rainy season. Seeds are placed in each pit either by hand or through a seed hopper mounted on top of the pitting machine. Seeds that germinate in the pits find favorable conditions for emergence and growth.

Main achievements

Using a strip plot design, an experiment was implemented in December 2015 to evaluate and compare the effect of different water-harvesting techniques on *A. halimus* survival rate and productivity. Three different water-harvesting techniques were used: contour ridges (continuous and intermittent), V-shaped bunds, and semi-circular bunds. The contour ridges were formed using a Vallerani machine, while the 3-m V-shaped and semi-circular bunds were established manually. Data on *A. halimus* survival rate, growth performance, plant height, and stem thickness were monitored during the peak standing crop in spring and fall of 2017 (Figure 10).

There were no differences in plant cover and survival rate; however, thickness and plant height were affected by the water-harvesting techniques. The tallest plants and the thickest stems were found for the Vallerani contours (Figures 11 and 12).

Figure 10. Three different water-harvesting techniques: (a) semi-circular bunds, (b) V-shaped bunds, and (c) intermittent contours implemented in Majidya

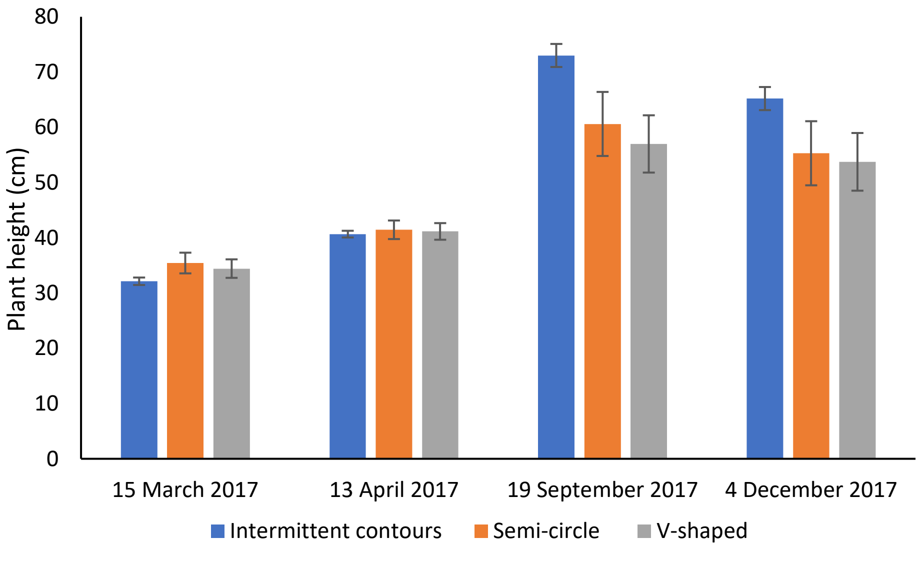

Figure 11. Effect of three different water harvesting techniques on Atriplex halimus plant height

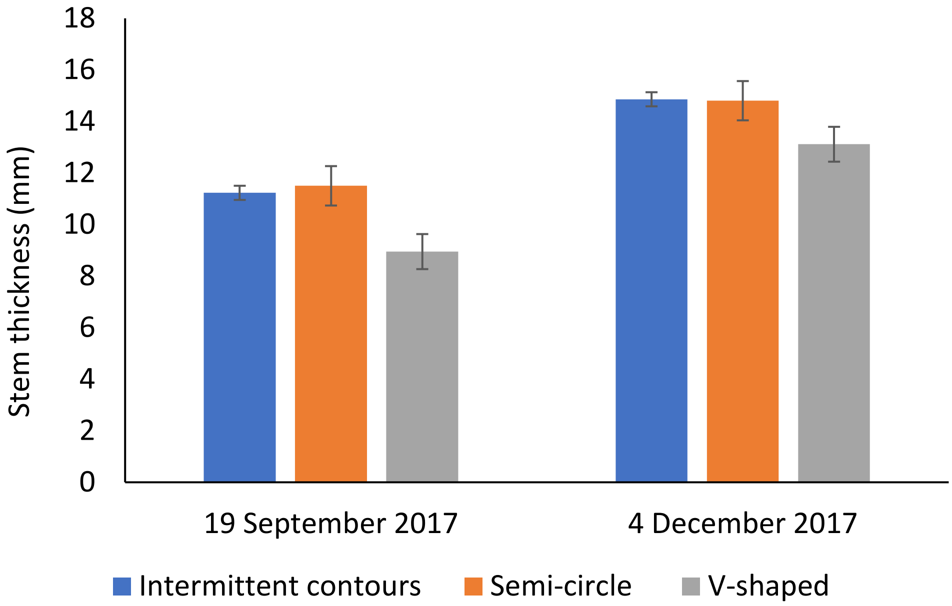

Figure 12. Effect of three different water-harvesting techniques on Atriplex nummularia stem thickness

To assess the effect of direct seeding of native species under three different water-harvesting techniques (V-shaped, semi-circular, and Vallerani contours), *Salsola vermiculata* was planted (manually spread) in December 2017 before the rain. Each plot of each water-harvesting technique was divided into two parts: control and *S. vermiculata* direct seeding. Mechanical soil scarification was applied for the parts that were assigned to *S. vermiculata* direct seeding (Figure 13).

Figure 13. Manual Salsola vermiculata seeding

In this site, ridges at least 50 cm high and about 1 m apart were plowed using a tractor. These ridges were constructed to reduce runoff and allow water to collect and settle in the strips, where barley was then planted. This approach was taken to slow runoff and trap eroding soil (Figures 14 and 15).

Figure 14. Barley seeding

Figure 15. Barley strip cultivation in the Badia rangelands

Conclusion

The key to achieving large-scale restoration of degraded rangeland is integrating suitable practices into rangeland management and that would assist rangeland managers and users to develop the appropriate strategies and help make the links with government policy and program. This can be done by implementing appropriate methods of restoration such as water harvesting, shrub plantation, direct seeding, and soil surface scarification. Successful restoration can be ensured once we demonstrate that restoration work will improve the livelihood of local communities, increase incomes, keep rural communities vital, limit soil erosion, and protect livestock production. This is the ultimate reason for this project on land restoration. The advantages of Badia rangeland restoration are apparent and the potential for restoration is real. In arid areas, when water resources are scarce, the successful reintroduction of fodder shrubs can increase yield, but it can only be done using rainwater harvesting techniques to secure water supplies. These practices could be valuable in halting and reversing desertification processes of other drylands worldwide.

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