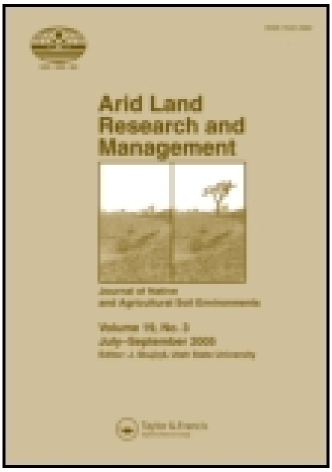
This article was downloaded by: [Erciyes University]
On: 08 January 2015, At: 01:27
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Click for updates

Arid Land Research and Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uasr20

Plant-Soil Interactions and Desertification: A Case Study in the Northern Negev, Israel

Amir Mor-Mussery [a], Stefan Leu [b], Arie Budovsky [c] & Itamar Lensky [d]

[a] Department of Geography & Environmental Development, Ben Gurion University of the Negev, Beer-Sheva, Israel

[b] The Jacob Blaustein Institutes for Desert Research, Sde Boqer, Israel

[c] Judea Regional Research and Development Center, Carmel, Israel

[d] Department of Geography and Environment, Bar Ilan University, Ramat Gan, Israel

Published online: 05 Sep 2014.

To cite this article: Amir Mor-Mussery, Stefan Leu, Arie Budovsky & Itamar Lensky (2015) Plant-Soil Interactions and Desertification: A Case Study in the Northern Negev, Israel, Arid Land Research and Management, 29:1, 85-97, DOI: 10.1080/15324982.2014.933455

To link to this article: http://dx.doi.org/10.1080/15324982.2014.933455

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms &

Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

Downloaded by [Erciyes University] at 01:27 08 January 2015

Arid Land Research and Management, 29:85–97, 2015
Copyright © Taylor & Francis Group, LLC
ISSN: 1532-4982 print/1532-4990 online
DOI: 10.1080/15324982.2014.933455

Downloaded by [Erciyes University] at 01:27 08 January 2015

Plant-Soil Interactions and Desertification: A Case Study in the Northern Negev, Israel

Amir Mor-Mussery[1], Stefan Leu[2], Arie Budovsky[3], and
Itamar Lensky[4]

[1]Department of Geography & Environmental Development,
Ben Gurion University of the Negev, Beer-Sheva, Israel
[2]The Jacob Blaustein Institutes for Desert Research, Sde Boqer, Israel
[3]Judea Regional Research and Development Center, Carmel, Israel
[4]Department of Geography and Environment, Bar Ilan University,
Ramat Gan, Israel

The impact of grazing, tilling, soil movement, among others on ecosystem health is often examined in well-defined separate experimental plots and protocols. The purpose of this project was identification of the mechanisms of soil degradation and rehabilitation in drylands. We analyzed the gradual changes in biotic and soil characteristics at the interface between strongly degraded and conserved arid shrubland restored by 20 years of conservation grazing. We defined a soil transect of 60 m crossing the border between conserved and long term degraded shrubland. Soil moisture content, water infiltration, soil organic matter (SOM), soil nitrate content, and biological activity (germination frequency, biomass productivity, patch frequency, and insect activity) were determined in equally spaced plots along the degradation gradient. Productivity expressed by the amount of herbaceous above ground biomass at the end of the growing season was one third in the degraded area compared to the conserved area. This is caused by reduced germination rates and poorer seedling growth due to lower nitrate and soil moisture content in the degraded soil. Biological productivity was enhanced in the conserved area by exponentially increasing density of perennials and shrub patches. Our results indicate that severe depletion of SOM is a leading cause for long-term soil degradation in drylands with the sparse annual vegetation incapable of restoring the SOM pool.

Keywords biological productivity, conservation, dryland degradation, plant density, soil organic carbon

Introduction

Soil degradation, vegetation depletion, and loss of biological productivity due to mismanagement are problems of global dimensions. In dryland environments, these are the key processes catalyzing desertification (Dregne, 1978; Kassas, 1995; Kéfi

Received 29 August 2013; accepted 8 June 2014.

Address correspondence to Amir Mor-Mussery, Department of Geography & Environmental Development, Ben Gurion University of the Negev, P.O.B. 653, Beer-Sheva 84105, Israel. E-mail: amir.mussery@gmail.com

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/uasr.

et al., 2007), further accelerated by continued, uncontrolled grazing (Holland, 2004), and tilling or mechanical soil movement (Kassas, 1995; Helman et al., 2014a). While reduced biological productivity and plant cover, increased soil erosion, and water runoff are the primary signs of desertification, the key physical parameter affected is soil quality (Diacono and Montemurro, 2010; Helman et al., 2014a) and landscape patterns (Boeken and Shachak, 1994; Kéfi et al., 2007; Shachak et al., 2008). Degraded soils are characterized by loss of soil organic carbon resulting in reduced nitrogen assimilation (Lal, 2004), reduced water infiltration (Eldridge et al., 2000), and the reduced capability of soils to bind water (Sharma, 1998; Zheng et al., 1996; Mor-Mussery et al., 2013a). Often closure of degraded areas for several years is sufficient for ecosystem recovery, whereby the soil organic matter is being replenished by plant life (Shachak et al., 1998). However, more profound degradation may become irreversible, especially if grazing activities continue (Zhao et al., 2003). Such desertification processes not only cause loss of productivity with serious impacts on food production, future food security, and economic development (Hussein, 2008), but also lead to increase in carbon dioxide emissions (Lal, 2004; Ruddimann, 2003).

Rehabilitation of degraded drylands can restore essential ecosystem services such as biodiversity and sustainable supplies of fodder, food, and renewable energy (Leu, 2005; Abu Rabia et al., 2008; Leu, 2010; Mor-Mussery et al., 2013b), essential commodities in a world running out of quality farm land and water. Additionally, dryland rehabilitation by soil restoration or afforestation can contribute significantly to mitigation of global warming by sequestering carbon into soil and biomass (Grainger et al., 2000; Lal, 2001, 2004; Leu, 2010).

Understanding the processes responsible for desertification is crucial for establishing efficient rehabilitation methods. Often physical processes such as soil erosion, tilling, or excessive vegetation removal cause desertification associated with loss of biological productivity (Safriel and Adeel, 2005; Helman et al., 2014a). In order to explore these processes, we located a plot containing a transition from conserved shrubland to severely degraded land situated between a sustainably managed private farm and publicly accessible overgrazed rangeland. This transition gradient was characterized by analyzing soil properties and biological productivity.

Downloaded by [Erciyes University] at 01:27 08 January 2015

Materials and Methods

Survey Design

The data presented here were collected North-East of Beer Sheva, Israel, near the municipalities of Meitar and Hura, geographical coordinates N 31°19′25″, E 34°59′05″ (Figure 1), at an elevation of 460 m. For the years 2001 to 2010, mean annual precipitation at the site was 232 mm as determined by averaging the data from the two nearest observation stations of the Israeli Meteorological Service (IMS, www.ims.gov.il), Beer Sheva (185 mm, 18 km south west, elevation 300 m), and Yattir Forest (279 mm, 8 km north-east, elevation 680 m). During the rainy season of this study (October 2009–May 2010) calculated annual rainfall was 237 mm.

Winter temperatures (DJF) were 8.1–19.2°C, and average summer temperatures (JJA) were 21–34.6°C, data from IMS.

The study area was selected crossing a clearly visible vegetation gradient across the border of a privately owned sustainably grazed farm, and publicly accessible rangeland. The transect (*Degradation gradient*) was placed perpendicular to the farm's

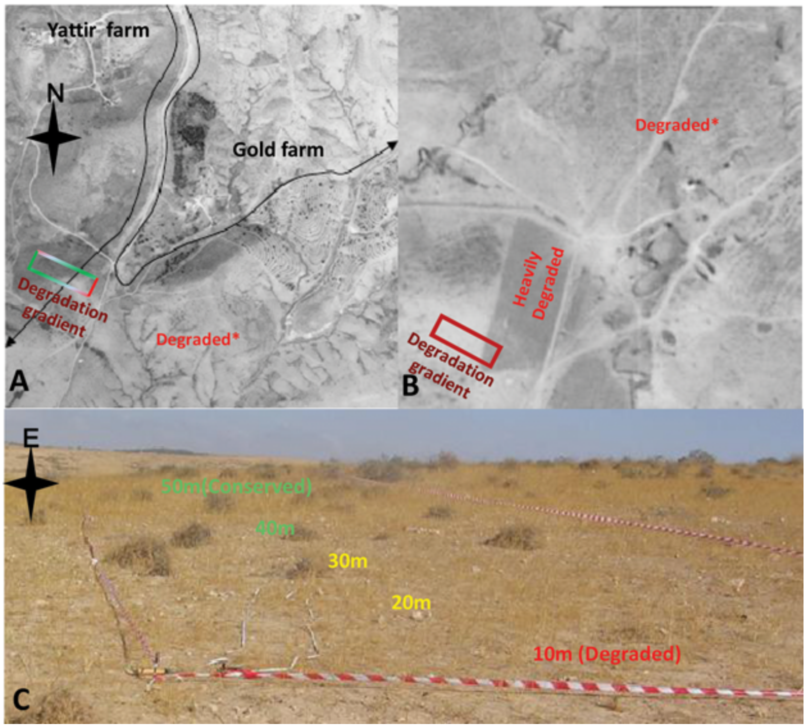


Figure 1. Graphic description of the research area; degraded plots are marked in red, intermediate states in yellow, and conserved plots in green. (A) Aerial photo of the *Degradation gradient* from *Long time degraded* to *Conserved* shrubland, 2007. The research area is indicated by a black rectangle, the border of Noam Farm is indicated by a thin black line. (B) Aerial photo of the research area from 1990 showing the degradation gradient's location as a black frame. Part of the highly degraded area was apparently under cultivation and tilled 20 years ago, while the now conserved shrubland to the left appears to have been used for grazing. (C) Photographic view of the *Degradation gradient* from the degraded toward the conserved area.

border (Figure 1A) and marked with red/white tape (Figure 1C). The distances from 10 to 50 m were marked by color-coded rocks placed every ten meters and are defined as "distance points." The 0–20 m area was defined as *Long time degradation*, the area starting with 40 m was considered as *Conserved* shrubland, as identified from aerial photographs and visual assessment (Figure 1C). All data were collected every 10 m from the 10 m to the 50 m mark. All data replicates were collected within 25 m^2 squares centered on the corresponding 'distance point.' Three pictures each (February 2008) were analyzed for the germination analysis. Infiltration analyses was performed in January 2010 determining three values per distance point. Four samples were collected at each point for soil moisture and SOM in April 2010. Isopod holes were quantified in February and June 2010. Four soil samples from each distance point were collected, mixed carefully, and submitted for nutrient analysis.

Soil Analyses

The soil texture in the area is classified by the United States Department of Agriculture (USDA) as Sandy clay loam type (USDA, 1999). Minimal difference in mechanical

Downloaded by [Erciyes University] at 01:27 08 January 2015

composition between the *Long time degraded* and *Conserved* areas of the transect were observed. Soil moisture and Soil Organic Matter (SOM) contents were determined as follows: four soil samples from the top 20 cm were collected randomly at each distance point (20 cm is considered as root zone of annual vegetation in arid areas, Fischer and Turner, 1978). Soil moisture content was determined gravimetrically by drying the soil overnight at 105°C. SOM was determined by burning the dry soil for four hours at 400°C (Sparks, 2003) and measuring the mass difference of burnt versus dried samples. SOM and moisture content were calculated as percentages of dry soil and averaged for the number of independent subsamples.

For determination of soil nitrate content, the samples were carefully mixed (Sava, 1994) and submitted for analysis to the Gilat Service Laboratory of the Ministry of Agriculture (Gilat Field Services Laboratory, Ministry of Agriculture and Rural Development, Israel; http://www.agri.gov.il/en/departments/109.aspx).

Infiltration was measured using a disk tension infiltrometer (Decagon Devices, Inc.). The height of the water column in the infiltrometer was measured in one-minute intervals up to six minutes in three replicates centered on each "distance point." The infiltration rate was calculated as described by Eldridge et al. (2000).

Quantification of Biomass Productivity

Woody perennials were manually counted in 100 m^2 squares centered on each distance point.

Annual herbaceous biomass was determined by randomly collecting four samples in 25 m^2 squares centered on each distance point along the transect. Annual herbaceous vegetation was collected in iron wire rectangles of 20 × 30 cm in April when the amount of annual herbaceous biomass reached its maximum. The collected samples were dried for 48 h at 60°C, weighed, and expressed in g per m^2 units (Sava, 1994).

Germination Frequency

Germination was evaluated by taking 4 MB resolution digital photographs of 50 × 50 cm sized areas with a ruler added as internal scale. The photos were adjusted and printed on A-4 paper to give areas of defined size. Seedlings were marked on the prints, counted manually and divided into size classes. Three random replicates surrounding each distance point were chosen, counted, normalized to 1 m^2 and averaged (Dell'Aquila, 2009).

Invertebrate Activity

We quantified isopod activity as a measure for invertebrate activity, which is an important factor in determining the extent of desertification (Whitford, 1993). The isopod *Hemilepistus reaumuri* (H. Milne-Edwards)- dig frequencies (Shachak et al., 1976) were counted using an iron frame of 20 × 30 cm. The measurements were done in four random locations centered on each distance point. The counts were taken once in February and once in June.

Statistical Analysis

Analysis was performed using JMP ver. 5.0 SAS Institutes co software. ANOVA analysis was performed to 90% confidence ($\alpha = 0.1$), differences were considered

Downloaded by [Erciyes University] at 01:27 08 January 2015

Downloaded by [Erciyes University] at 01:27 08 January 2015

significant between values marked as "a" (lowest), "b" (intermediate), and "c" (highest). Mixed letters ("ab" or "bc") reflect differences between values with less than 90% confidence (Sall and Lehman, 1996).

Results

SOM and Nutrients Content

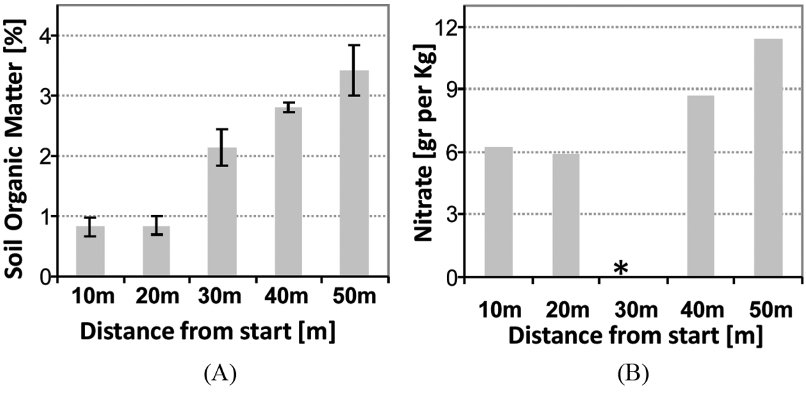
Mechanic content analysis of the soil at the study site in June 2009 was: Sand: 19–23%, Silt: 52–58%, Clay:19–27%, and Rockiness 9–18%. The SOM content in matrix soil (defined as exposed soil between shrub patches, Golodets and Boeken, 2004) of the *Long time degraded* area was profoundly depleted to less than one percent of the soil weight. This is only 25% of SOM content of the matrix soil in the conserved area (90% statistical confidence) (Figure 2A). Nitrate concentration was significantly increased in the conserved versus the degraded soil samples (Figure 2B).

Effect of Degradation on Soil Moisture Content

Soil moisture content along the *Degradation gradient* was determined underneath shrub canopies (where applicable) and in open matrix soil. Similar trends in water content along the transect were observed, both under shrub canopies and in the matrix, with soil moisture content steadily increasing by about 25% from the *Long time degraded* to the *Conserved* soil, or by over 1% of gravimetrically measured soil moisture content (Figure 3). About one percent higher water content was observed in soil under shrub canopies compared to the exposed matrix soil in all plots tested.

Water Infiltration

The water infiltration rates in matrix soil increased four-fold from the *Long time degraded* to *Conserved* soil along the transect (Figure 4A). As demonstrated at the



(A) (B)

Figure 2. Soil quality assessment in samples collected along the *Degradation gradient* from the *Long time degraded* plots (0–10 m) towards the *Conserved* area (40–50 m). (A) Soil Organic Matter (SOM) content (in % of soil dry weight, $n = 4$). (B) Nitrate content in a mix of four samples from each distance. *Missing sample (due to technical reasons). Thin lines on columns represent the Standard Error; Letters above columns represent significant differences between plot averages ($\alpha < 0.1$, see tools and methods, statistical analysis).

Downloaded by [Erciyes University] at 01:27 08 January 2015

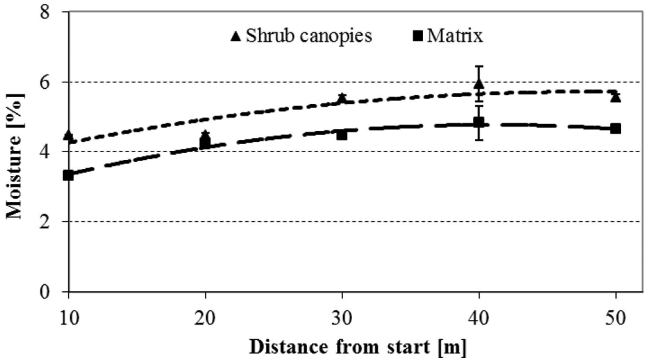
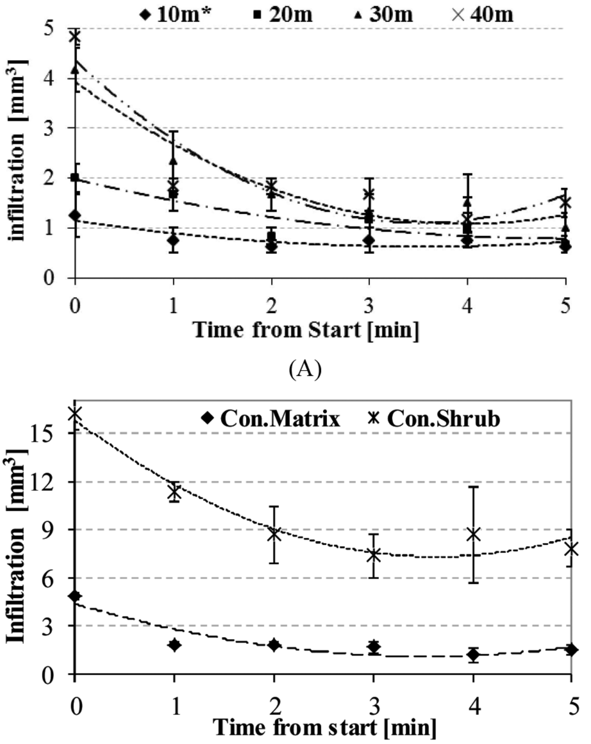


Figure 3. Soil moisture (in % of soil dry weight) in soil samples collected along the *Degradation gradient*, from 10 m (*Long time degraded*) to 50 m (*Conserved*), separately determined in matrix soil (squares) or underneath shrub canopies (triangles) in April 2010. Thin lines above and beyond data points represent the Standard Error ($n = 4$).



(A)

(B)

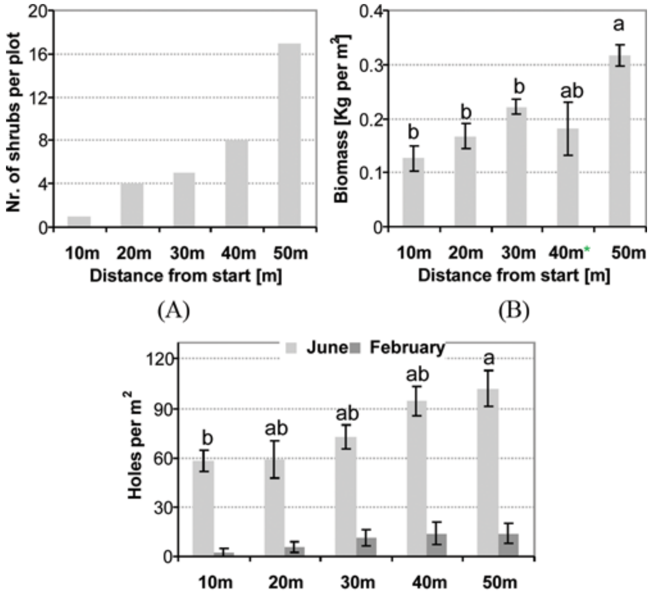
Figure 4. Water infiltration rates in soil along the *degradation gradient* from *Long time degraded* (10 m) to *Conserved* (40 m) soil. (A) infiltration rates in exposed matrix soil ($n = 3$); (B) comparison of infiltration rates in *Conserved* matrix soil (at 40 m distance in the *Degradation gradient*) to infiltration in shrub patches at the same distance ($n = 3$). Thin lines above and beyond data points represent the Standard Error.

Downloaded by [Erciyes University] at 01:27 08 January 2015

40 m location, water infiltration under shrub canopies was three times higher than in matrix soil (Figure 4B). Higher infiltration in conserved matrix soil and further threefold increase of infiltration in the frequent shrub patches results in much higher water infiltration capacity in the conserved area compared to the *Long time degraded* area, explaining the significantly higher soil moisture observed in the conserved soil (Figure 3).

Plant Biomass Measurements

The density of patches formed by perennial plants or shrubs in the *Conserved* area was about 15 times higher than in the *Long time degraded* area (Figure 5A). A 2.5 fold higher productivity of annual herbaceous biomass was observed in matrix soil in the *Conserved area* compared to the long term degraded plots (statistical confidence of 90%), with a gradual increase along the transect (Figure 5B). In turn, the increased patch density significantly contributed to higher soil quality and productivity in the conserved area. The patches were more complex in the conserved area with higher amounts of plant species and higher seedling density per patch observed (data not shown).



(A) (B)

(C)

Figure 5. Biological activity along the *Degradation gradient*. (A) Standing annual herbaceous above ground biomass along the gradient from 10 m (*Long time degraded*) to 50 m (*Conserved*), determined in April 2010 ($n = 4$); (B) Frequency of perennial plant patches (patches per 100 m^2) along the gradient from 10 m (*Long time degraded*) to 50 m (*Conserved*) shrubland. March 2010; *Result may be the result of a very shallow soil layer. (C) Isopod holes in February and June 2010. Thin lines on columns represent the Standard Error; Letters above columns represent significant differences between plots averages ($\alpha < 0.1$ see tools and methods, statistical analysis).

Downloaded by [Erciyes University] at 01:27 08 January 2015

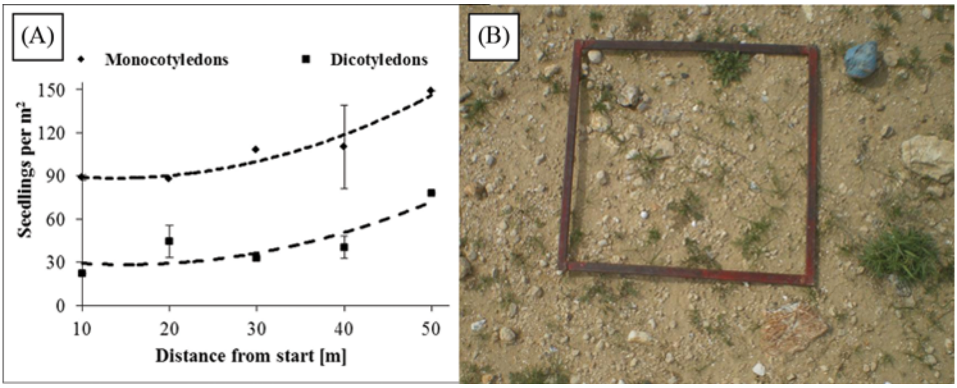


Figure 6. Germination rate along the *Degradation gradient* from *Long time degraded* (10 m) to *Conserved* (50 m), determined in matrix ground (A). (B) represents one of the pictures used for data collection. Thin lines above and below data points represent the Standard Error ($n = 3$); *Note*: Polynomials trendlines for germination.

Germination Analysis

A gradual increase in seedlings density was observed in matrix soil from long-term degraded to conserved areas, with seedling density increasing from 115 to about 220 seedlings per m^2, with the threefold increase in dicotyledon-seedlings in the conserved areas especially remarkable (Figure 6). The most abundant species in the area was the annual grass *Stipa capensis* (Thunb). Larger forms of this species with at least five leaves with length of 3–5 cm and more were much more abundant in the *Conserved* area than in the *Long time degraded* area indicating more vigorous seedling growth in conserved soil in addition to the higher rates of germination.

Number of Isopods Digs

The number of isopods digs was up to 60% times higher in summer in the *Conserved* compared to the open area, and five times higher in winter (Figure 5C). Similarly, the amount of snail excrements found in the conserved area was significantly higher than in the *Long time degraded* area (not shown).

Discussion

The research site described herein is unique in featuring an irreversibly degraded plot near a diverse, functional shrubland ecosystem, separated by a few dozen meters of transition zone (Figure 1 A). This is in contrast to recent similar reports that compare plots kilometers apart or more (Leu et al., 2014; Helman et al., 2014a), where effects other than human influence and management, such as local differences in rainfall, topography, soil composition, soil management history, and so forth may interfere with the interpretation of research results. As deduced from aerial photographs, the long term degraded area has been subject to agricultural use and tilling 20 years ago (Figure 1B), while the now restored shrubland suffered of overgrazing only and was left to recover by conservation management after its incorporation into a private farm in 1992 (Figure 1A; Leu et al., 2014). The direct neighborhood of the

Downloaded by [Erciyes University] at 01:27 08 January 2015

conserved and degraded areas within the transect analyzed guarantee that any differences in soil quality, plant life, and visual ecosystem assessment observed across the gradient are the direct result of soil degradation or rehabilitation processes. All physical, chemical, and biological measurements performed in this work thus reflect the transition from severely degraded to conserved shrubland. Though covering only a small experimental area, the high density of data points in the area and the direct correlation of all parameters assessed together with the visual assessment of degradation provide an excellent degree of confidence for the accuracy of our observations.

The results of our studies, including a diverse range of floral, faunal, and soil chemical parameters, all showing with high confidence significant changes from the *long term degraded* toward the *Conserved* area in tight correlation with transect distance.

The significant reduction in biological productivity of annual vegetation together with much lower patch density observed in the persistently degraded area (Figure 5) is a clear sign for degradation or desertification as defined by Safriel and Adeel (2005). The almost complete absence of shrub patches in the persistently degraded plot (10 m) confirms the importance of those patches for resource conservation and recovery in arid shrublands (Reid et al., 1999; Shachak et al., 2008). Our recent observations (Leu et al., 2014) presented a clear picture on the impact of patch density on soil quality, annual plant productivity, and rangeland quality. However, those observations found a six-fold difference in patch frequency between conserved and overgrazed plots only, while across the gradient described here patch frequency in the long term degraded area is 15 times lower than in the conserved area. Absence of shrub patches together with sparse annual vegetation causes excessive soil crusting (Boeken and Shachak, 1994; Li et al., 2006; Shachak et al., 2008) and increases runoff intensity, leading to seed and soil loss by wind- and water erosion. Analysis of germination frequency (Figure 6) provides an additional, clear indication as to the impact of soil degradation on biological productivity. Reduced germination rates, probably by seed loss and lower soil moisture lead to reduced seedling numbers, while the simultaneously observed poorer growth on degraded soil is apparently the result of reduced soil nutrient and moisture content as well.

With respect to soil quality, the most evident difference and apparently the key explanation for persistent long term degradation at the 10 m distance points is the extremely low soil organic carbon content of less than 1%, apparently the result of both soil disturbance and continued overgrazing. Previously, we compared other soils, for example, degraded by continuous overgrazing, tilling, or contour trenching, to conserved shrubland soils, but never found a higher than 50% reduction of SOM (Helman et al., 2014a; Leu et al., 2014), except in the run-on slopes prepared for tree planting by contour trenching, where annual vegetation is suppressed by herbicide application leading to similarly low SOM resulting in severe vegetation depletion (Mor-Mussery et al., 2013a). Thus the fourfold reduction of SOM observed in this study in the long-term degraded soil is likely a contributing factor for the inability of the area to recover when compared to other, less degraded plots recently observed. In support of this notion, and confirming our observation, are reports showing that low SOM results in reduced nitrogen assimilation (Lal, 2004; Zaady, 2005), lower water infiltration, higher water runoff, lower soil moisture (Sharma, 1998), and as a consequence lower biological productivity, as confirmed by the data presented here.

Downloaded by [Erciyes University] at 01:27 08 January 2015

The major contributing factor to the restoration of SOM in the conserved area seems to be annual plant root biomass left in the soil, which improves water infiltration and re-establishment of adequate soil nutrient contents, animal activity, and biological patches (Mor-Mussery et al., 2013a) as observed in the conserved plots at distances 40 and 50 m. Thus, our results clearly demonstrate a mechanism of desertification initiated by reduced plant productivity causing the loss of soil fertility. Furthermore reduced patchiness facilitates erosion of seeds and soils from exposed matrix soils, adding to further ecosystem degradation and loss of soil moisture and soil fertility to the extent permanently reducing plant growth. Those interdependencies are partly summarized in Figure 7 which is based on the present study as well as on our recent observations in the same areas (Leu et al., 2014; Helman et al., 2014a,b). As a major result of the present analysis we can postulate existence of long term, almost irreversibly degraded soils where biological productivity and soil quality have deteriorated to a state that cannot be restored based on the systems own resources, mostly as a result of both mechanical disturbance and overgrazing. Intermediate degradation as found at the 20–30 m distance points here, or in the grazed plot described by Leu et al. (2014) with higher SOM and patch density has the ability to recover spontaneously after reduction of grazing pressure. In summary, the observations described here have far reaching consequences on soil

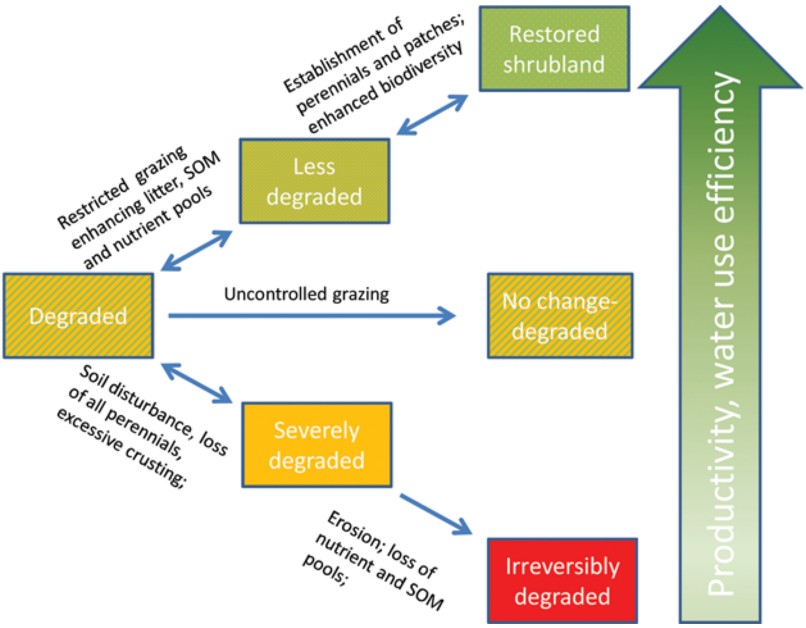


Figure 7. Schematic representation of the major degradation and rehabilitation mechanisms acting in arid–semiarid shrublands based on this work and other recent observations. Starting from an overgrazed base case, reduced grazing intensity as applied at the research site will induce steady recovery processes leading to establishment of conserved shrubland. Adding soil disturbances such as tilling, compaction, or soil movement to overgrazed areas can lead to irreversibly degraded shrubland as seen at the degraded end of the gradient (10 m plot), where spontaneous recovery becomes impossible. The same color code as in Figure 1 is used to indicate degraded (red), intermediate (yellow), and conserved states (green).

Downloaded by [Erciyes University] at 01:27 08 January 2015

rehabilitation and carbon sequestration strategies in the degraded drylands. Figure 7 shows a schematic representation of some major degradation and rehabilitation mechanisms acting in arid–semiarid shrublands based on the results described here as well as in other recent observations (Leu et al., 2014; Helman et al., 2014a). While grazing alone induces degradation levels that can be reversed by temporary enclosure, severe soil disturbances such as tilling, compaction, or contour trenching can lead to irreversibly degradation as seen at the degraded end of the gradient (10 m plot), or in a contour trenched area nearby recently described (Mor-Mussery et al., 2013a; Helman et al., 2014a,b).

Therefore, the restoration of highly degraded drylands is only possible by direct introduction of organic matter, nutrients, litter, and seeds (Diacono and Montemurro, 2010), together with active introduction of landscape features such as planted shrubs, trees, or man-made pits and mounds that act as seed traps and can induce spontaneous re-vegetation (Boeken and Shachak, 1994, 1998; Buis et al., 2010).

Acknowledgments

We thank the Oren and Eren families, Yattir Farm, for their help in implementing this research. We also thank Mr. Ben Freihoff for his technical assistance.

Funding

This project was supported in part by a grant from the Israel Ministry of Science.

References

Abu Rabia, K., E. Solowey, and S. Leu. 2008. Environmental and economic potential of Bedouin dryland agriculture: A case study in the Northern Negev, Israel. *Manage Environmental Quality* 19: 353–366.

Boeken, B., and M. Shachak. 1994. Changes in desert plant communities in human-made patches in and their implications for the management of desertified landscapes. *Ecological Applications* 4: 702–716.

Boeken, B., and M. Shachak. 1998. Colonization by annual plants of an experimentally altered desert landscape: source–sink relationships. *Journal of Ecology* 86(5): 804–814.

Buis, E., A. J. A. M. Temme, A. Veldkamp, B. Boeken, A. G. Jongmans, N. van Breemen, and J. M. Schoor. 2010. Shrub mound formation and stability on semi-arid slopes in the Northern Negev Desert of Israel: A field and simulation study. *Geoderma* 156: 363–371.

Dell' Aquila, A. 2009. Digital imaging information technology applied to seed germination testing. A review. *Agronomical Sustainable Development* 29: 213–221.

Diacono, M., and F. Montemurro. 2010. Long-term effects of organic amendments on soil fertility. A review. *Agronomical Sustainable Development* 30: 411–422.

Dregne, H. E. 1978. Desertification: Man 's abuse of the land. *Journal of Soil and Water Conservation* 33: 11–14.

Eldridge, D. J., E. Zaady, and M. Shachak. 2000. Infiltration through three contrasting biological soil crusts in patterned landscapes in the Negev, Israel. *Catena* 40: 323–336.

Fischer, R. A., and N. C. Turner. 1978. Plant productivity in the arid and semiarid zones. *Annual Review of Plant Physiology* 29: 277–317.

Golodets, C., and B. Boeken. 2004. Moderate sheep grazing in semiarid shrubland alters small-scale soil surface structure and patch properties. *Catena* 65: 285–291.

Grainger, A., M. S. Smith, V. R. Squires, and E. P. Glenn. 2000. Desertification and climate change: The case for greater convergence. *Mitigation Adapt. Strategies Global Change* 5: 361–377.

Helman, D., A. Mussery, I. M. Lensky, and S. Leu. 2014a. Detecting changes in biomass productivity in a different land management regimes in drylands using satellite-derived vegetation index. *Soil Use and Management* 30(1): 32–39.

Helman, D., I. M. Lensky, A. Mussery, and S. Leu. 2014b. Rehabilitating degraded drylands by creating woodland islets: Assessing long-term effects on aboveground productivity and soil fertility. *Agricultural and Forest Meteorology* 195–196: 52–60.

Holland, J. M. 2004. The environmental consequences of adopting conservation Tillage in Europe: Reviewing the evidence, a review. *Agriculture Ecosystems and Environment* 103: 1–25.

Hussein, M. A. 2008. Costs of environmental degradation: An analysis in the Middle East and North Africa region. *Management and Environmental Quality* 19: 305–317.

Kassas, M. 1995. Desertification: A general review. *Journal of Arid Environment* 30: 455–464.

Kéfi, S., M. Rietkerk, C. L. Alados, Y. Pueyo, V. P. Papanastasis, A. ElAich, and P. C. de Ruiter. 2007. Spatial vegetation patterns and imminent desertification in Mediterranean arid ecosystems. *Nature* 449: 213–217.

Lal, R. 2001. Potential of desertification control to sequester carbon and mitigate the greenhouse effect. *Climatic Change* 51: 35–72.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304: 1623.

Leu, S. 2005. Dryland agroforestry for biomass, food, carbon sequestration and desert rehabilitation. In *Proceedings of the 14th European Biomass Conference, Paris*, 341–344.

Leu, S. 2010. Forests and climate: The search for specifics. *Science* 328: 1479.

Leu, S., A. Mor-Mussery, and A. Budovsky. 2014. "The effects of long time conservation of heavily grazed shrubland: A case study in the Northern Negev, Israel." *Environmental Management*, DOI 10.1007/s00267-014-0286-y, published online 17 May 2014.

Li, X. R., X. H. Jia, and G. R. Dong. 2006. Influence of desertification on vegetation pattern variations in the cold semi-arid grasslands of Qinghai-Tibet Plateau, North-west China. *Journal of Arid Environments* 64: 505–522.

Mor-Mussery, A., S. Leu, and A. Budovsky. 2013. Modeling the optimal grazing regime of *Acacia victoriae* silvopasture in the Northern Negev, Israel. *Journal of Arid Environments* 94: 27–36.

Mor-Mussery, A., S. Leu, I. Lensky, and A. Budovsky. 2013. The effect of planting techniques on arid ecosystems in the Northern Negev. *Arid Land Research and Management* 27: 90–100.

Reid, K. D., B. P. Wilcox, D. D. Breshears, and L. MacDonald. 1999. Runoff and erosion in Pinon-Juniper woodland: Influence of vegetation patches. *Soil Science Society of America Journal* 63: 1869–1879.

Ruddimann, W. F. 2003. The anthropogenic greenhouse effect era began thousands of years ago. *Climatic Change* 61: 261–293.

Safriel, U., and Z. Adeel 2005. Dryland systems, in *Ecosystems and Human Well-Being: Current State and Trends*. Island Press Millennium Ecosystem Assessment Series, Vol. 1. Island Press, Washington DC.

Sall, J., and A. Lehmann. 1996. JMP start statistics: A guide to statistical and data analysis using JMP and JMP IN software. Duxbury Press, Belmont, CA.

Sava, R. 1994. *Guide to sampling, air, water, soil and vegetation for chemical analysis*. Environmental Protection Agency, Department of Pesticide Regulation, Environmental Monitoring and Pest Management Branch, California.

Shachak, M., B. Boeken, E. Groner, R. Kadmon, Y. Lubin, E. Meron, G. Ne'eman, A. Perevolotsky, Y. Shkedy, and E. Ungar. 2008. Woody species as landscape modulators and their effect on biodiversity patterns. *BioScience* 58: 209–221.

Downloaded by [Erciyes University] at 01:27 08 January 2015

Shachak, M., E. A. Chapman, and Y. Steinberger. 1976. Feeding, energy flow and soil turnover in the desert isopod *Hemilepistus reaumuri*. *Oecologia* 24: 57–69.

Shachak, M., M. Sachs, and I. Moshe. 1998. Ecosystem management of desertified shrublands in Israel. *Ecosystems* 1: 475–483.

Sharma, K. D. 1998. The hydrological indicators of desertification. *Journal of Arid Environments* 39: 121–132.

Sparks, D. L. 2003. *Environmental soil chemistry.* 2nd ed. Academic Press, Amsterdam and Boston.

USDA. 1999. Soil taxonomy. A basic system of soil classification for making and interpreting Soil Surveys, 2nd edition, United States Department of Agriculture Natural Resources Conservation Service, Available online at ftp://fc.sc.egov.usda.gov/NSSC/Soil_Taxonomy/tax.pdf (accessed December 2010).

Whitford, W. G. 1993. Animal feedback in desertification: An overview. *Revista Chilena de Historia Natural* 66: 243–251.

Zaady, E. 2005. Seasonal change and Nitrogen cycling in a patchy Negev desert: A review. *Arid Land Research and Management* 19: 111–124.

Zhao, H. L., X. Y. Zhao, R. L. Zhou, and D. S. Zhang. 2003. Desertification processes due to heavy grazing in sandy rangeland, inner Mongolia. *Journal of Arid Environment* 62: 309–319.

Zheng, D., E. R. Hunt, and S. W. Running. 1996. Comparison of available soil water capacity estimated from topography and soil series information. *Landscape Ecology* 11: 3–14.

Downloaded by [Erciyes University] at 01:27 08 January 2015