Evolution of Agro-Ecosystems in Differently Managed Research Plots in an Arid Loess Area in the Northern Negev

Thesis submitted in partial fulfillment
of the requirements for the degree of
“DOCTOR OF PHILOSOPHY”

By:
Amir Mor-Mussery

Submitted to the Senate of Ben-Gurion University
of the Negev

Date: 26/12/2018
Beer-Sheva
Evolution of Agro-Ecosystems in Differently Managed Research Plots in an Arid Loess Area in the Northern Negev

Thesis submitted in partial fulfillment of the requirements for the degree of “DOCTOR OF PHILOSOPHY”

By:

Amir Mor-Mussery

Submitted to the Senate of Ben-Gurion University of the Negev

Date: 26/12/2018

Beer-Sheva

Approved by the advisor

Approved by the Dean of the Kreitman School of Advanced Graduate Studies
This study was carried out under the supervision of:

Prof. Jonathan B. Laronne

In the Department of: Geography and Environmental Development

Faculty of: Humanities and Social Sciences

Date: 26/12/2018

and

Dr. Stefan Leu

In the Department: The French Associates Institute for Agriculture and Biotechnology of Drylands

Faculty: Jacob Blaustein Institute for Desert Studies

Date: 26/12/2018
I Amir Mor-Mussery, whose signature appears below, hereby declare that

Yes. I have written this Thesis by myself, except for the help and guidance offered by my Thesis Advisors.

Yes. The scientific materials included in this Thesis are products of my own research, culled from the period during which I was a research student.

No. This Thesis incorporates research materials produced in cooperation with others, excluding the technical help commonly received during experimental work. Therefore, I am attaching another affidavit stating the contributions made by myself and the other participants in this research, which has been approved by them and submitted with their approval.

The text was proof edited by Mr. Shmuel Oliven, Thechiya Hafakot®

Date: 26/12/2018
Name: Amir Mor-Mussery    Signature: 

[Signature]
Dedication:

This thesis is dedicated to my mother Ms. Shulamit (Shula) Mussery
Acknowledgments:

My supervisor, Dr. Stefan Leu (Ben Gurion Univ, Sde Boqer), on more than 10 years of friendship and collaboration, whom his notes guided me in this study.

Second but not least, my supervisor, Prof. Jonathan B. Laronne (Ben Gurion University) a friend and an expert in geomorphology that encourage me along the study, mostly in the difficult periods.

Dr. Michael Ben Eli (The Sustainability Lab USA) and Dr. Moohamad Nabary (the mayor of Hura) both the project supervisor and coordinators. Mr. Amran Amrani, the manager of PWA visitors' center and all Project wadi Attir stuff on their assistance along the study.

Prof. Amit Gross (Ben Gurion Univ, Sde Boqer) who opened is Lab and heart to all of the chemical analyses.

Ms. Rachel Zimerman the secretary of the Geography and Environmental Development' department and Mr. Oron Guy the department computerization' manager on their assistance.

The members of the Department of Soil and Water Sciences in the Faculty of agriculture- Rehovot (Hebrew university), and their students.

Dr. Eli Zaadye on his helpful guidelines and encouragement along the study.

The cute school pupil and their teachers from El-Farduase(Rahat), Elsalam (Rahat), Abed el Raba (Laqiya), ElSalam (Cseife) and the other school pupil who helped me collecting part of the field' data.

Mr. Yehoshua Ratzon (Ben Gurion University) on his friendship and technical assistance.

Mr. Edi Toch (Ben Gurion Univ, Sde Boqer) who welded all the field analysis' tools.
# Table of contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of figures</td>
<td>III</td>
</tr>
<tr>
<td>List of tables</td>
<td>VI</td>
</tr>
<tr>
<td>Abbreviations</td>
<td>VIII</td>
</tr>
<tr>
<td>Abstract</td>
<td>IX</td>
</tr>
<tr>
<td>Key words</td>
<td>XII</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Rational</td>
<td>1</td>
</tr>
<tr>
<td>1.2 The interrelations between biotic and abiotic soil properties</td>
<td>1</td>
</tr>
<tr>
<td>and their influence on the rehabilitation state Negev</td>
<td>1</td>
</tr>
<tr>
<td>1.2.1 Global and local effects of desertification</td>
<td>1</td>
</tr>
<tr>
<td>1.2.2 Parameters indicating the rehabilitation state</td>
<td>2</td>
</tr>
<tr>
<td>1.3 Summary</td>
<td>8</td>
</tr>
<tr>
<td>2. Site’s description</td>
<td>12</td>
</tr>
<tr>
<td>2.1 Site history</td>
<td>12</td>
</tr>
<tr>
<td>2.2 Geography and topography</td>
<td>12</td>
</tr>
<tr>
<td>2.3 Climate</td>
<td>14</td>
</tr>
<tr>
<td>2.4 Parent material</td>
<td>15</td>
</tr>
<tr>
<td>2.5 Agricultural exploitation of the area</td>
<td>15</td>
</tr>
<tr>
<td>2.5.1 Cultivation practices characteristics in study initiation (2014)</td>
<td>17</td>
</tr>
<tr>
<td>2.6 The initial rehabilitation state of PWA</td>
<td>20</td>
</tr>
<tr>
<td>2.7 Hypothesis and research objectives</td>
<td>22</td>
</tr>
<tr>
<td>3. Tools and methods</td>
<td>24</td>
</tr>
<tr>
<td>3.1 Soil quality properties</td>
<td>24</td>
</tr>
<tr>
<td>3.1.1 Soil water use efficiency</td>
<td>25</td>
</tr>
<tr>
<td>3.1.2 Soil physical properties</td>
<td>26</td>
</tr>
<tr>
<td>3.1.3 Soil fertility properties</td>
<td>28</td>
</tr>
<tr>
<td>3.1.4 Biological activity properties</td>
<td>28</td>
</tr>
<tr>
<td>3.2 Statistical analyses</td>
<td>30</td>
</tr>
<tr>
<td>3.3 Landscape patterns’ analysis</td>
<td>31</td>
</tr>
<tr>
<td>4. Results</td>
<td>33</td>
</tr>
<tr>
<td>4.1 Soil quality properties of the different treatments</td>
<td>33</td>
</tr>
<tr>
<td>4.1.1 Loess deposit treatments</td>
<td>33</td>
</tr>
<tr>
<td>4.1.2 Rocky slope treatments</td>
<td>40</td>
</tr>
<tr>
<td>4.1.3 Tilled treatments</td>
<td>50</td>
</tr>
<tr>
<td>4.1.4 Dammed limans</td>
<td>57</td>
</tr>
<tr>
<td>4.2 Data’ normalization of the soil quality properties and RS change</td>
<td>65</td>
</tr>
<tr>
<td>4.2.1 Inside loess deposit</td>
<td>65</td>
</tr>
<tr>
<td>4.2.2 Inside Rocky slope</td>
<td>68</td>
</tr>
<tr>
<td>4.2.3 Tilled treatments</td>
<td>70</td>
</tr>
<tr>
<td>4.2.4 Unprocessed limans</td>
<td>73</td>
</tr>
<tr>
<td>4.3 The effects of harvester ants’ on rehabilitation of cultivated areas</td>
<td>76</td>
</tr>
</tbody>
</table>
4.3.1 Harvester ants' nests functioning as nutrients pools
4.3.2 Changes in nested area as tool to determine rehabilitation
4.3.3 The influence of harvester ants on the soil fertility of their surrounding

5. Discussion
5.1 General findings and rehabilitation mechanisms of arid cultivated areas
  5.1.1 Core rehabilitation mechanisms of arid areas in PWA study
  5.1.2 The correlation between the different soil quality properties and rehabilitation
5.2 The main mechanisms of ecosystem rehabilitation in PWA
  5.2.1 Rehabilitation mechanism of conservation
  5.2.2 Rehabilitation mechanism in the tilled fields of PWA
  5.2.2.1 Rehabilitation mechanism of field abandonment
  5.2.3 Patchy mechanism of ecosystem engineers
  5.2.3.1 Rehabilitation mechanism of harvester ants
  5.2.4 Sloped expansion mechanism of rehabilitation
  5.2.5 Limans mechanism of rehabilitation
5.3 Normalizing the soil quality data by rainfall parameters vs. reference plots
5.4 Agriculture utilization efficiency of PWA cultivations
5.5 The influence of PWA' cultivations on carbon sequestration and nutrients enrichment from natural substrates

6. Conclusion
7. References
8. Appendix1. The limans in PWA
9. Appendix 2. The initial rehabilitation state of PWA
List of figures

1.1 The influence of improper design and management of limans, Chiran area. 03/2016 7
1.2 Schematic representation of the major degradation and rehabilitation mechanisms in arid lands (based on Mor-Mussery et al., 2014b) 10

2.1 Air photograph of Project Wadi Attir in the initial state, 2012 13
2.2 Site of study before farm construction (2012), view westwards 16
2.3 Aerial photograph with the locations of the different treatments in PWA area, Israel Mapping Services (2014) 19
2.4 Spatial analysis of the Herbaceous biomass weight (HBW) over the site of study in 2011 20
2.5 The soil fertility of the abandoned ruminants enclosure compared to the adjacent area 21
2.6 Distribution of shrubs in PWA before site establishment (2012) 22

3.1 The rockiness coverage measurement 27
3.2 The vegetal measurements 29
3.3 Determination of the harvester ants' nest size 30
3.4 Manual water level tool for slightly inclined slopes 32

4.1 The mean soil moisture contents of the loess deposit treatments between 2013 and 2017 35
4.2 The mean soil organic matter contents of the loess deposit' treatments between 2013 and 2017 37
4.3 The mean biological activity properties of the loess deposit' treatments between 2012 and 2017 39
4.4 The rocky slope treatments of PWA in 2012 and 2016 40
4.5 The mean soil moisture contents of the rocky slope units between 2013 and 2017 44
4.6 The mean soil organic matter contents of the rocky slope' units between 2013 and 2017 46
4.7 The mean herbaceous biomass weights of the rocky slopes units between 2012 and 2017 48
4.8 The mean external ants activity coverage (AAC) of the rocky slopes between 2012 and 2017 49
4.9 The correlations between the soil properties of the shrub patches and the matrices of the rocky slopes 50
4.10 The mean soil moisture contents of the tilled treatments between 2013 and 2017 52
4.11 The mean soil organic matter contents of the tilled treatments between 2013 and 2017 54
4.12 The mean biological activity properties of the tilled treatments between 2013 and 2017 56
4.13 The sampling units of Liman 2 58
4.14 The areal portions of the different units of the unprocessed limans trapezoid' shaped (2-3 and 4-5) 59
4.15 The mean herbaceous biomass weights of the different units of liman 2 in 4/2017
4.16 The mean soil moisture contents of the unprocessed limans between 2013 and 2017
4.17 The mean soil organic matter contents of the unprocessed limans between 2013 and 2017
4.18 The mean biological activity properties of the unprocessed limans between 2012 and 2017
4.19 The outside loess deposit and the inside abandoned ruminants enclosure, March 2014
4.20 The normalized soil quality properties of the inside loess deposits between 2012 and 2017
4.21 The normalized soil quality properties of the inside rocky slope between 2012 and 2017
4.22 The normalized soil quality properties of the tilled cultivations between 2012 and 2017
4.23 The normalized soil quality properties of the unprocessed limans between 2012 and 2017
4.24 The sampling scheme of the rocky slopes
4.25 The mean nitrate (N-NO₃) content of the rocky slopes units, 7/2016
4.26 The mean ammonia content of the rocky slopes units, 7/2016
4.27 The mean phosphate content of the rocky slopes' units 7/2016
4.28 The mean potassium content of the rocky slopes' units 7/2016
4.29 The mean soil organic matter content of the rocky slopes' units 7/2016
4.30 The influence of nests on soil fertility
4.31 The yearly normalized growth rate of the herbaceous biomass weighs (HBW) and the External ants activity coverage (AAC) of the different PWA treatments
4.32 The interactions between the External ants activity coverage (AAC) in 2015 and the soil fertility properties in 2016 of the loess deposits treatments
4.33 The interactions between the External ants activity coverage in 2015 and the soil nutrient contents in 2016 of the loess deposits' treatments
4.34 The interactions between the External ants activity coverage in 2015 and the soil fertility properties in 2016 of the rocky slopes
4.35 The correlations of the External ants activity coverage and the active nests density of the inside tilled plots (7/2017)

5.1 A schematic representation of the major degradation and rehabilitation mechanisms in arid lands
5.2 The influences of abandoned field on soil erosion in PWA
5.3 The influence of conservation on the patchy rehabilitation mechanism
5.4 The relative SOM content in Anabasis sp. patches and harvester ants' nests
5.5 The sloped expansion mechanism of rehabilitation in the inside rocky slope, June 2016
5.6 The SOM content and herbaceous biomass weighs in the upper and lower parts of the inside and outside rocky slopes in 2016 and 2017
5.7 The influence of savanna trees on the vegetation coverage in limans
5.8 The influence of planted limans on their surrounding
5.9 The limans remodeling influence of rehabilitation
5.10 The herbaceous biomass (HBW) of limans 19:26 in 2/2018
5.11 The yearly rehabilitation state change (RS) of the different limans groups during the study deducted from herbaceous biomass values
5.12 Browsing utilization of savanna trees
5.13 The net additive nutrients content for the different cultivations in the fifth year of PWA study deduced by the differences to the reference plot

6.1 Schematic representation of the combined influence of leftover biological patches and different agriculture practices in cultivated lands on their rehabilitation or degradation state. Novel approach that is based on PWA study finding.

Ap.1 The limans locations and groups in PWA
Ap.3 The re-modelled/filled limans (3/2016)
VI

List of tables

2.1 The different plots, their correlated treatments and sizes 18

3.1 Timings and frequencies the soil quality measurements in PWA 25

4.1 Statistical data for the differences between the soil quality properties of the loess deposit treatments 33

4.2 The mean infiltrability of the loess deposits treatments at 7/2014 and 7/2016 36

4.3 The nutrient contents of the loess deposit treatments in 2012, 2014 and 2016 38

4.4 The mean seedlings densities and shape patterns in the loess deposit treatments 40

4.5 The mean landscape and soil properties of the rocky slopes 41

4.6 Statistical data for the differences between the soil quality properties of the rocky slopes 42

4.7 The mean infiltrability of the rocky slopes in 7/2014 and 7/2016 45

4.8 The nutrient contents of the rocky slopes in 2012, 2014 and 2016 47

4.9 The correlations between the soil properties of the shrub patches and matrices of the rocky slopes 49

4.10 Statistical data for the differences between the soil quality properties of the tilled treatments 51

4.11 The mean infiltrability of the tilled treatments in 7/2014 and 7/2016 53

4.12 The nutrients content of the tilled treatments in 2012, 2014 and 2016 55

4.13 The mean seedlings densities and shape patterns of the tilled treatments in 1/2015 57

4.14 The mean infiltrability of the unprocessed limans in 7/2014 and 7/2016 61

4.15 The mean soil organic matter contents of the unprocessed limans between 2013 and 2017 63

4.16 The inside loess deposit normalization data 68

4.17 The inside rocky slope normalization data 70

4.18 The tilled treatments normalization data 72

4.19 The unprocessed limans normalization data 75

4.20 The mean salinity and acidity of nests and bare areas in PWA, 12/2017 83

5.1 Summary of the influences of harvester ants on the area rehabilitation state 102

5.2 The correlations of different rainfall parameters and the herbaceous biomass weighs of the outside loess deposit and the inside abandoned enclosure 112

5.3 The principles for locating reference plots and calculations for determination of the yearly rehabilitation rate and the duration until restoration 114

5.4 The soil organic matter and nutrients content per hectare in the top 15 cm of soil of the common cultivations: outside loess deposit and the outside rocky slope of PWA in 2016 and 2017. 117

5.5 Nutrients pools of PWA soil 121
Ap.1  The limans' groups  142
Ap.2  Nutrients content in different soil depth in PWA 12/2012  146
Abbreviations

PWA - Project Wadi Attir
SOM - Soil organic matter
SMC - Soil moisture montent
RhS - Rehabilitation state
AAC - External ants activity coverage
HBW - Herbaceous biomass weight
Abstract

The current state of many semi-arid to arid cultivated lands, based on their fertility and productivity rates can be termed ‘degraded’ due to long-term overgrazing or unsustainable farming practices. Continuation of these cultivation methods at similar intensities will lead to un-changed or small further decrease of the land Rehabilitation State, a term describing the potential for sustainable further agricultural use. Implementation of conservation management will induce a steady recovery process leading to increased vegetation cover and enhanced soil fertility. The increased vegetation, in turn, enhances litter production, soil fertility, ecosystem engineer activity and landform stabilization, factors that collectively permit achieving appropriate productivity for sustainable agricultural utilization. In contrast, massive soil disturbance, such as improper landform re-modelling or deep tillage, will damage the function of ecosystem engineers, leading to instability, a state where spontaneous recovery becomes impossible. Taking this data and translating it to practical guidelines for the farmer arise four problems: what is the starting point in long-term degraded area, what is the optional (maximal possible) state and what is the most suitable practice to use for reaching the optimal state, relating parameters as climate and erosion. Moreover, how can one represents rehabilitation or degradation processes relying on soil properties with different temporal changes? Therefore, the hypothesis is that only comparison of the soil properties in controlled cultivation to the common long-term used one, will enable to define the rehabilitation rate of the cultivation. In order to determine the rehabilitation state of different cultivations and the specific mechanisms affecting its value, a comprehensive study was carried out on different cultivated arid loess areas in Project Wadi Attir, the northern Negev, Israel. Soil fertility, productivity, landform stability and biological activity of conserved and heavily grazed rangelands, loess deposits, rocky slopes and agriculture terraces were analyzed before project implementation and during the following five years. Arid environments are characterized not only by low precipitation, but also by high yearly and inter-seasonal heterogeneity. Therefore, in order to calculate the net rehabilitation trend from changes in soil fertility, their values were normalized. A scheme based on two sets of reference plots was used. One control plot resembles the common cultivation in the studied plots, heavily grazed and intensely tilled. Separate plots were defined for the treatments of loess deposit and rocky slope. The second type of reference plots resembles the
maximal fertility state achieved in the studied cultivations. The plot chosen in the Project Wadi Attir area was conserved from grazing and located on an abandoned ruminants enclosure overlaid with an ageing manure layer. The ratios between the soil fertility parameters of the studied treatments and their values in the reference plots reflect their net change.

The net sustainable changes of the outside plots with respect to soil fertility, soil organic matter, soil moisture and nutrient content were minimal and achieved at most 5%, whereas vegetal cover increased up to 30%. These rates are comparable to other studies in the northern Negev and other arid areas worldwide, reflecting the effect of the continuation of common cultivation in degraded areas.

The second group of treatments represents the conserved plots inside the farm. Changes in their yearly soil fertility reached 10% and the herbaceous biomass weight up to 100% per year, even in the tilled treatments. Increased infiltrability, enhanced harvester ants activity and landform stability were also observed. These treatments represent a continuous rehabilitation mechanism. Further degradation was observed in un-planted and re-modelled limans outside the farm and expressed by a 15% annual decrease of the herbaceous biomass, compared to the common degraded loess cultivation.

The specific mechanisms of rehabilitation inside the farm were analyzed by separating the influence of conservation and tillage, as found in the study site. Conservation increased the herbaceous biomass weight by 100% per year in the loess deposits and by 47% in the rocky slope, leading to annual fertility changes as high as 10%. This mechanism is correlated to the lack of flora harvesting and trampling by the grazed animals, resulting in restoration of biogenic crust and litter supply. The proposed mechanism is based on a combination of the conservation influence of reduced tillage and litter management.

Three additional rehabilitation mechanisms were defined as affected by the existence of ecosystem engineers, the sloped outlines of the plots, the 3-dimentional liman shape and the implemented soil practices.

The rehabilitation mechanism of the ecosystem engineers was found to be characterized by an initially patchy landform surrounding the ecosystem engineers. This patchy concentric form expanded to a state of whole area recovery, indicating a possible
transformation from shrublands into grasslands by proper management. The rehabilitation efficiency of shrubs and harvester ants is high, thereby rehabilitating these cultivated lands under proper practices, higher than the rehabilitation of the local shrub species.

The rehabilitation mechanism of the sloping area combines the influence of conservation, existence of ecosystem engineers and the sloped outlines of plots. Altogether these influences enhanced the downslope accumulation of fertile sediments, thereby enhancing areal recovery.

The rehabilitation mechanism of the limans was found to be influenced by their unique landform design in addition to that of the conservation, sloped shape of their sides and the influence of ecosystem engineers on the planted savanna trees. These influences were expressed by low herbaceous biomass inside the limans followed by enhanced growth. In further stages the liman recovery mechanism expanded and influenced the surroundings. This study indicates that pasture utilization increased from less than 1 ruminant/ha year under conserved cultivation to fourfold. Five years of conservation increased the Nitrogen sequestration by 35%, Phosphate by 15%, Potassium by 20% and soil organic content by 30%. The principles used in this study can be used in other cultivated arid areas leading to sustainable dryland management.
Key words

Rehabilitation state, Agriculture utilization, Nutrient enrichment, Project Wadi Attir,
Sustainable dryland management
1. Introduction

1.1 Rationale

The North-Eastern Negev, as most of the areas in the strip between 20° and 30° of both hemispheres, is a heavily degraded, arid to semi-arid area. The area has been desertified due to continued mismanagement, thereby reducing agricultural (Mainguet, 2012), by repeated tilling and grazing without fertilizer inputs, fertility or grazing management (Lado et al., 2007; Helman et al., 2014a). In these areas most of the natural trees have been removed, possibly thousands of years ago. Consequently, the area displays a profound loss of soil fertility and massive soil loss due to wind and water erosion and to intensive incisional phenomena as documented e.g. in the northern Negev (Mor-Mussery and Leu, 2012) and in Spain (Zuazo et al., 2008). Project Wadi Attir (www.sustainabilitylabs.org/ecosystem-restoration) is a groundbreaking initiative of the Hura Bedouin community and the US based Sustainability laboratory to establish a sustainable agricultural operation model on heavily degraded abandoned farmland near Hura, Israel. Previously evaluated, designed and tested rehabilitation technologies aiming at maximizing environmental and economic benefits have been applied to 40 hectares of the project’s heavily degraded farmland, based on extensive previous scientific studies in similar areas (Abu Rabia et al., 2008; Helman et al., 2014a; Leu et al., 2014). This study was designed and implemented with the aim to scientifically document the parameters relevant for the rehabilitation rates and mechanisms of the restored agro-ecosystem, and to identify and test the hypotheses on underlying mechanisms contributing to eventual ecosystem restoration.

1.2. The interrelations between biotic and abiotic soil properties and their influence on the rehabilitation state

1.2.1 Global and local effects of desertification

Soil degradation is defined as "change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries" (www.fao.org/soils-portal/soil-degradation-restoration). Degradation of drylands is commonly called ‘desertification’ (Safriel and Adeel, 2008). This process ongoing worldwide annually affecting about 30,000 – 120,000 km² (Nneji, 2013) with dramatic
economic global costs. Telles et al. (2011) claim that the desertification processes cause a yearly loss of 45.5 billion dollar only for the European Union! Historical desertification processes increased atmospheric CO$_2$ by 450-500 GT of carbon due to decomposition of biomass and soil organic matter (Lal, 2004b).

In the drylands of the Middle East and the Mediterranean basin degradation occurred gradually during the last 10,000 years. In general, degradation is recognized by a profound loss of biological productivity, perennial plant cover with loss of shrubs and trees and consecutive loss of Soil Organic Matter (SOM) and soil fertility. This degradation is mostly induced by continuous unsustainable farming and wood gathering (Lal, 2004a). Recent publications (Helman et al., 2014a; Leu et al., 2014 and Mor-Mussery et al., 2014a) helped clarify this state in the Northern Negev, supported by productivity data from artificial dryland afforestation (Rotenberg and Yakir, 2010). These analyses indicate that restored dry ecosystems in the area have 3 to 10 times higher biological productivity, and 10–100 times higher standing biomass cover than nearby degraded plots, which comprise more than 90% of the Eastern parts of the Northern Negev. Based on these studies, several parameters can indicate the desertification or rehabilitation state in the Northern Negev including changes in vegetation patterns, biological productivity, biodiversity, SOM, geomorphology and agriculture utilization. The importance of adequate conserved and fully degraded control areas for normalization of the desertification or rehabilitation state and its GIS-based large scale application have been elaborated and demonstrated (Helman et al., 2014). The term Rehabilitation State (RhS) is used to describe changes in rehabilitation states on the rehabilitation- degradation scale, negative values- degredation, positive- rehabilitation and '0'- no change.

1.2.2 Parameters indicating the rehabilitation state

The following parameters will be reviewed: vegetation, SOM, state of Ecosystem engineers (with a subsection on Afforestation as artificial ecosystem engineering), geomorphological state (with two sub-sections on artificial landscape design).

Vegetation

The most observable and affecting factor on the RhS is the change in vegetation patterns (Lin et al., 2010). Most of the semiarid and arid northern Negev is comprised of patchy
shrublands. In such areas, most of the organisms (insects, perennial plants and annual vegetation) are concentrated in niches or biological patches with defined outlines, separated from each other by matrix areas characterized by distinct microbial soil crusts (Golodets and Boeken, 2006; Zaady, 2005). Natural changes, such as differences in rainfall or anthropogenic causes such as cultivation changes (Helman et al., 2014) or afforestation (Rotenberg and Yakir, 2010) have crucial influence on soil health and the RhS. In the Northern Negev, these changes are mainly expressed by the vegetation patterns of the shrubland patches such as vegetation composition and canopy size, which are affected by harvesting and trampling of animal flora (Sarah et al. 2018). The processes occurring in these patches influence the fertility of their surrounding matrix according to the Sink-Source theory (Boeken and Orenstein, 2001; Golodets and Boeken, 2006; Leu et al., 2014; Mor-Mussery et al., 2014a) and as result, influence herbaceous biomass patterns (Leu et al., 2014; Mor-Mussery et al., 2014a). These vegetation changes are correlated with soil organic matter (SOM) content and soil water holding capacity. These influences are demonstrated in the soil properties and biological productivity in six differently treated plots in Chiran, the northern Negev area by Helman et al. (2014a) and in other arid areas all over the globe by Aguiar and Sala (1999).

**Soil Organic Matter**

The central factor affecting plant growth, soil physical patterns and water holding capacity is often the Soil Organic Matter content (Dexter, 2004; Helman et al., 2014a; Mor-Mussery et al., 2014b). Increasing SOM is therefore the “key issue” for successive RhS change, mainly so in arid areas (Lal, 2004b). Improper soil management such as intensive tillage (Rasmussen and Collins, 1991), improper terrace designing (Mor-Mussery et al., 2013a) and overgrazing (Leu et al., 2014) reduce SOM by 25-50% compared to high productivity areas (Helman et al., 2014). Practices such as litter spreading (Mor-Mussery et al., 2013b; Novara et al., 2015) and conservation promote productivity of annual vegetation, whose root biomass enhance the SOM and soil nutrient pools in the soil (Chappin et al., 1990). In addition, adequate afforestation (Grünzweig et al., 2003) can increase SOM content.
**Ecosystem engineers**

Analyzing the reciprocal effects of organisms and their surrounding ecosystem is crucial for assessing their potential to rehabilitate degraded arid areas (Byers et al., 2006). A candidate for rehabilitation of ecosystems can be defined as “ecosystem engineer”, or as Jones et al. (1994) defines "Organisms that directly or indirectly modulate the availability of resources to other species, by causing physical state changes in biotic or abiotic materials". In long-term highly degraded lands the selected organisms for this purpose require “pioneering abilities” (Reynolds et al., 1999), in addition to having high “engineering efficiency” (Bouma et al., 2010). The foremost and most studied group of ecosystem engineers in arid (and semi-arid) environments are shrubs (termed ultimately, "woody perennials"). Shrubs provide to their surrounding environment litter, organic matter, soil loosening, conservation of soil moisture and create micro-ecosystems (Sarah, 2002; Eldrige et al., 2011). These enable enhanced establishment and growth of other organisms such as annuals. In the field it is easily recognized by patches with shrubs inside, a landform, which is ecologically defined as ‘shrubland’ (Golodets and Boeken, 2006). Factors such as the shrub species, density and their spatial location affect patch size and pattern (Leu et al., 2014; Mor-Mussery et al., 2015). The northern Negev has been continuously cultivated using intense tillage, which harmed the patchy outlines of the areas. Nevertheless, these areas are defined as 'shrublands'. Further studies include, in addition to the shrubs, other biogenic patch forming groups such as trees, geophytes, invertebrates and harvester ants (Eldridge et al., 2000; Jouquet et al., 2006; Mor-Mussery et al., 2014a). The patches function as “islands of fertility” to their surrounding ecosystem (Aguir and Sella, 1999) by several mechanisms as follows:

a. Sink for nutrients and SOM. The patches absorb litter, organic matter and water from the surrounded area. The organic matter is composted by micro-organisms existing in the soil patches, due to the unique micro-climate of the patch. Thereafter, soluble nutrients infiltrate from the patches to the surrounding underground area (Gravel et al., 2010).

b. The enhanced development of bio-organisms in the patches enables spreading reproductive material to the surrounding ecosystem, studied mainly with regard to annual species (Donahue et al., 2003).
c. The patches host organisms that enrich the soil by organic matter and nutrients. This mechanism is still poorly studied, but evidence is available with regard to harvester ants (Nkem et al., 2000; Mor-Mussery et al., 2017).

Several studies in the Northern Negev aimed to accumulate the biological activity of “ecosystem engineers” in the field and correlate it to ecosystem RhS. Studies conducted during 2008-2009 on intersect between conserved and heavily grazed rangelands. Parallel to these soil fertility changes, a gradual change observed in shrubs densities and the biological activity of isopods expressed by their density. The biological activity of these organisms has been correlated to the rehabilitation state of the whole area (Mor-Mussery et al., 2014a).

Additional studies demonstrated the tight correlation between the ratio of External Ants Activity Coverage (Biological activity property of harvester ants, important ecosystem engineers in arid areas, Mor Mussery and Budovsky, 2017) and soil quality properties of different cultivated areas (Leu et al., 2014).

**Afforestation as artificial ecosystem engineering tool**

Afforestation has become the primary tool for ecological restoration in the northern Negev as in other degraded arid and semi-arid regions having common sandy and loamy soils (Zhu and Wang, 1993; Malagnoux et al., 2007). The planted trees function as artificial ecosystem engineer by providing litter, moisture, and shading, which accelerate (or facilitate) ecosystem functioning and as result the area RhS (Evans et al., 2016; Helman et al., 2017). In contrast to natural ‘ecosystem engineers’ that accelerate the ecosystem functioning and increase the RS by using adequate management, those artificially added require more caution, taking into account three aspects, as follows:

a. Tree species. Tree species can accelerate the RhS by encouraging annuals growth or settlement of local ecosystem engineers under their canopy (Kaye et al., 2000; Helman et al., 2017) or enhance its degradation by opposite effects as documented on Sierra Nevada forests (Gómez-Aparicio et al., 2004).

b. Planting technique. A planting scheme based on massive soil disturbance and re-modelling (contour trenching) can decelerate the tree and its root system growth, resulting in landform degradation as shown in the Negev (Helman et
al., 2014) and in the Chinese loess plateau (Cao, 2008). However, pits plantings will not damage the ecosystem integrity (Mor-Mussery et al., 2013a).

c. Planting density. Dense planting, as a woodland type, has different influences compared to sparse planting, with regard to influences on SOM, nutrients pools and annuals species diversity (Kaye et al., 2000; Mor- Mussery et al., 2013a).

**Geomorphological state**

The influences of vegetation depletion and reduction of soil nutrient pools are widely expressed by landform changes. In arid areas with loess soils, the common sign is incision and gully formation. Avni (2005) described it as follows: "gully incision is a key factor in desertification in arid environments". In general, incision starts by overland flow in an anastomosing network (Wilkin and Hebel, 1982). The deeper parts of the anastomosing network develop due to several environmental circumstances into ephemeral rills, as Zhang et al. (2007) describes: "Small, concentrated flow channel, which is routinely obliterated by normal tillage, but reoccur at the same location year after year". From this state, environmental circumstances such as heavy and intense rainfall events (Olson, 2006) can lead to the formation of permanent gullies (Wijdenes et al., 1999). Initially, the gullies have patterns expressed by massive increase of gully length, depth and area but occupying a limited area (Sidorchuk, 1999). The gully enlarges and widens until reaching a plan shape, which halts incision. Thereafter, lateral erosion from the surrounding areas continues: "once gullies develop, they increase the connectivity in the landscape" (Poesen et al., 2003) and have an impact on a wider area as a gully static state (Sidorchuk, 1999).

**Artificial landscape design for changing rehabilitation state in the northern Negev**

In order to change gullied areas RhS by using artificial landform designs the main method used is agricultural terraces (Arnáez et al., 2015). Beyond the differences between their shape and size they are aimed to store runoff water and reduce soil erosion. In the northern Negev two methods have been widely used: contour trenching and limans. Local contour trenching comprises 5-10 m wide soil contours separated by 1 m high, 2 m wide mounds planted at about 80–100 trees per hectare. The contours are designed to have moderate slopes, enabling water drainage into their lowest parts containing the planted trees (Critchley et al., 1991). The second method is the limans, which have a triangular or rectangular shape with sloped edges, planned to absorb
runoff water. Water accumulation in the limans enables growth of trees and shrubs without additive irrigation (Cohen et al. 1997).

Improper management practices of contour trenching or liman technologies, such as annuals removal (caused by herbicide application, grazing or soil exposure), deep tillage, or soil disturbance leads to enhanced incision, loss of soil fertility and decreased SOM content by as much as 50% in comparison to well treated areas (Mor-Mussery et al., 2013a; Helman et al., 2014). Examples to degradation caused by improper landform designing were found in Chiran area limans. These liman chains were constructed by Keren Kayemet Leisrael (KKL) without taking into account the flooding patterns of the area and without enhancing the activity of natural ecosystem engineers. Intense herbicide use and vegetation suppressing tree species enhanced soil salinization and tree deaths due to lack of annual vegetation and aeration of tree roots (Fig. 1.1A). Together with massive landform remodeling this resulted in enhanced incision and a net of dense rills and terrace collapse (Fig. 1.1B).

![Figure 1.1 The influence of improper design and management of limans, Chiran area. 03/2016](image)

- A- Liman terrace collapse; B- Dense rills net on liman surface
Geomorphological state of rocky slope as rehabilitation state indicator

Large parts of land in the northern Negev are defined as 'Rocky slopes' (RS), hillslope areas with high rock cover. In most cases, their upper parts are characterized by large amounts of exposed bedrock outcrops and the lower ones by colluvium (Yair et al., 1983). The thickness of the soil layer depends on the ratio between the accumulated soil, formed by bedrock weathering and leaching and windblown sediment accumulation (Yaalon and Ganor, 1973) and the eroded area, caused by overland flow (Yair, 1990). In long-term exploited areas such as the northern Negev (Deshe, 2006), the rocky material from antique ruins as found at the Wadi Attir site accelerated the rocky slope formation (Yaalon and Arnold, 2000).

During the Holocene era, the rocky slopes formation and bedrock exposure enhanced even to more temperate zones of the globe due to intensive agriculture utilization, thereby accelerating soil erosion (Yair, 1990). These continued practices reached the point when further cultivation became impracticable. The most discussed techniques for rehabilitation of these rocky slopes are based on conservation from grazing combined with afforestation (Wang et al., 2004). The increase in rocky slopes area is accompanied by drastic ecological changes, mainly expressed ecologically by patchy biogenic forms (Ludwig et al., 2005). In these situations patch parameters such as size, soil depth and organisms' composition can be representative of the rehabilitation state of these areas.

1.3 Summary

The factors involved in the rehabilitation state of the northern Negev rangelands and other open land is schematically represented in Fig. 1.2 (Mor-Mussery et al., 2014b). The dark color represents further degradation (negative change in RhS), bright grey-intermediate change and dark grey a represent steady rehabilitation.

The starting point is degradation caused by tillage and over-grazing. The common terms for the grazing state of degraded areas are "heavy grazing" and "over grazing"; both are somewhat vaguely defined "depending on management objectives" (Mysterud, 2006). Here, because the similarity between the state of PWA lands and the ones described by Mysterud (2006): "forage species are not able to maintain themselves over time due to an excess of herbivory or related processes". I will also use the term "over-
grazing" defined for the Northern Negev as a state where all above-ground biomass including shrubs is removed by grazing livestock (Mor-Mussery et al., 2014a).

The first mechanism of rehabilitation, which is expressed by no change (or minor change) in the RhS, is caused by continuation of the used cultivations (Helman et al., 2014a; Leu et al., 2014).

The second mechanism involves implementation of conservation cultivation, which induces steady recovery processes leading to establishment of increasing amounts of vegetation and creation of more conserved ecosystems, the latter with enhanced litter, SOM and nutrient pools (Helman et al., 2014b). The functioning of biological engineers is enhanced and species biodiversity increases (Leu et al., 2014). This leads to ecosystem stabilization, permitting sustainable agriculture utilization.

Another possibility is further soil disturbance by intensive tillage or landform design, dramatically reducing SOM and nutrient pools. Ultimately, this will lead to irreversible degradation and a state where spontaneous recovery becomes impossible.
Figure 1.2 Schematic representations of the major degradation and rehabilitation mechanisms in arid lands (based on Mor-Mussery et al., 2014b)

Two questions arise from this review. The first is whether changes in cultivation practices can raise the RhS of the Northern Negev open lands? and second, will these practices be economic to the farmers of the Northern Negev?

An economic analysis found that desertification in the Middle East and North Africa cause a yearly decrease of 2.7-8.8% in the gross domestic product, while the decrease due to land degradation is 0.45% (Hussein, 2008). This situation results in reduced food security, unemployment, sickness and additional negative social impacts, predicted to grow rapidly. Any solution must, therefore, affect all the defined factors and enable sustainable agriculture utilization by adequate cultivation practices (McKenzie et al.,
An economic assessment for the indigenous farmers was performed on Bedouin family farms in the foothills of Judean Mountains 7 Km east of PWA (Abu Rabia et al., 2008). These farms contain 60 ha of hilly rangelands and 60 ha loess soils used for rainfed *Triticum aestivium* and small agroforestry groves. It was found that planting of 10,000 fodder trees may raise the total vegetal biomass up to three fold, compared to the uncultivated area. This state will enable breeding of 300 small ruminants on 100 hectares with an expected income of $800 – 1600 per hectare, based on recent prices (based on data from the Israel small ruminants breeding association, www.isb.org.il). In addition, this strategy is expected to increase dramatically the soil fertility, water balance, SOM content, carbon sequestration and decrease erosion.
2 Site description

2.1 Site history

The size of Project Wadi Attir-PWA is 40 hectare (North-East corner of the Negev-N°19.54', 31°, 16 E°26.26', 34°, 56). PWA was the only plot defined as belonging to the Israel Lands Authority. Most of the area was used by neighboring farmers for wheat breeding and grazing, while the rocky slope was used only for grazing. In 2011, the land was privatized to the Project Wadi Attir Association (www.sustainabilitylabs.org/wadiattir/home) for rehabilitation and establishment of a sustainable farming development scheme. Parallel to land privatization and implementations for cultivation, a grant from Yad Hanadiv - the Rothschild Foundation (www.yadhanadiv.org.il/he) was obtained to analyze the Rehabilitation State (RhS) of the area before and after establishment of treatments. The first step in the ecosystem restoration program was the remodeling of the topography by limans to reduce runoff and to decrease soil erosion. The limans were constructed by filling soil in the gullies and remodeling agroforestry terraces to curb destructive runoff, while collecting water onsite for tree growth. Trees were planted in the terraces and limans for agricultural use and for soil restoration, erosion control and windbreaks. The carefully selected mix of mostly native dryland tree species* are expected to provide a wide range of hydrological, nutritional and physical services (Belsky, 1994; Honda and Durigan, 2016), many of them essential for soil conservation and improvement.

* The species: Acacia raddiana, A. victoriae, Albizia lebbeck, Morus sp., Pistacia lentiscus, Pistacia atlantica, Balanites aegyptiaca, Retama raetam, Spartium sp., Ziziphus spina-christi, Ceratonia siliqua, Punica granatum, Prosopis juliflora and various exotic agroforestry species

2.2 Geography and topography

Project Wadi Attir (PWA) area is located south of the town of Hura, on the right bank of Wadi Attir, in the southern edge of the Hebron Mountains, entering the Loess plains of the Beer Sheva Valley downstream of the Yattir-Eshtemoa confluence and upstream of the Beer Sheva Valley (Deshe, 2006). The topography of PWA is hilly with light slopes composed mainly of loess deposits and rocky slope on the north-east. The loess
area was characterized by a dense network of gullies in the northeast. The rocky slope of PWA was likely caused by the massive overland erosion as found in other areas in the Negev with additional physical and anthropological processes (Yair and De Ploey, 1979). The rocky slope in PWA is characterized by a thin soil layer embedded with local bedrock exposure plots and ancient rock terraces, as demonstrated in Fig. 2.1.

Figure 2.1 Air photograph of Project Wadi Attir in the initial state, 2012 (Israel Mapping Services)
2.3 Climate

The climate in the Northern Negev for the past 5,000 years has been rather constant: a semi-arid to arid Mediterranean type with cool, wet winters and hot, dry summers (Goldreich, 2003). Rainfall averages 200 mm year⁻¹, based on analyzed data from the Beer Sheva meteorological station during 2008-2017. In spite of interchanging weather and drought periods, the steep West-East and North-South rainfall gradient in the area likely means that the critical 200 mm yr⁻¹ isohyet never shifted by more than 10–20 km north or south (Ziv et al., 2014). This left the Judean Mountain foothills and the PWA area always within rainfall ranges acceptable for human subsistence. This allowed simple field crops, grazing, and the cultivation of dryland tree crops. Nevertheless, fluctuations in rainfall may have provided the necessary incentives for developing more resilient and sustainable dryland agroforestry systems, reliant on terraces, floodwater harvesting, simple irrigation systems and adequate dryland tree and crop species. Rainfall in the area consists of winter rains (common during the winter season: December-February) caused by Cyprus barometric depression systems (Prezerakos et al., 1990) or by rainstorms more common in autumn (September-November) and spring (March-May) due to convective instability, caused by a Red sea trough which is part of the Sudan barometric depression (Goldreich, 2003). Rain intensities of 58.9 and 74.8 mm hour⁻¹ have been detected once in 50 years during measurements in the adjacent Eshtemoa-Yattir basin (Halevi and Arbel, 2016), demonstrating the Intensity-Duration-Frequencies (IDF) rainfall character in this area. An additive manner to represent these extremes is given by the IDF equation, \( I_{1\%} = 2019.6T^{-0.85} \) (I representing the maximal rain intensity with 1% probability and T is duration). This equation describes relative high rainfall storms with high intensities for short durations. For comparison in the Galilee, a more temperate climate in Israel - the IDF equation is, \( I_{1\%} = 354T^{-0.53} \) (Halevi and Arbel, 2016).

For the recent ten years (data from temperatures during the cold season (December-February) are 8.1 -19.2°C, minimal and maximal day temperatures, respectively, with partial aerial moisture (day: 12-100%, night: 18- 100%) while those of the hot season (June-August) are 21- 34°C with partial aerial moisture (day: 12-97%, night: 16-100%), have been summarized from the Beer Sheva meteorological station for the recent 10 years, Israel Meteorological Services. Evaporation by type A pan (Data from Sde Hail
Measurement station), measured in the cold season: 2.1-2.6 mm day$^{-1}$ and calculated: 1.8-2.1 mm day$^{-1}$ (Penman-Montif) in the hot season: 7.8-8.6 mm day$^{-1}$ and calculated 5.6-6.2 mm day$^{-1}$, Israel Meteorological Services.

2.4 Parent material

The area is underlain by late Cretaceous limestones, covered by quaternary aeolian loess, terrestrial clastic sediment, which was formed from wind-blown dust and containing mainly fine particles of silt and clay with about 40% sand (Pye, 1995; Catt, 2011; Mor-Mussery et al., 2014a). Crouvi et al. (2008) claim that the source of loess in this area is mainly the sand dunes in the southwest side of the Mediterranean (Israel and Egypt). In the area two loess layers can be identified, L1 (surface until 1.5m depth, accumulated mainly during 19-11ka) and L2 (1.5-3 m depth, accumulated mainly in 42-78ka). L1 contains 2% of grains sized 3-8 µm and ~6% grain sized 20-200 µm, while L2 has these grains sizes in 2.5 and 4% ratios (Crouvi et al., 2008).

2.5 Agricultural exploitation of the area

The North Eastern Negev has been continuously exploited for agriculture at least since 6000 BC as deduced from many remnants of terraces, water cisterns and dams, dated to the byzantine age, Stone Age relics, and the proximity of the major antique towns of Beer Sheba and Arad existing for at least 6000-8000 years (www.sustainabilitylabs.org/ecosystem-restoration/history-geography/#archeological-sites). The local farmers in the study site and its surrounded areas are mostly Bedouin from different tribes, using traditional practices and cultivating schemes. The main cultivated crop is rain-fed wheat (*Triticum aestivum*), combined with small ruminant grazing. Camels and cattle grazing were commonly observed. Olive trees and other dryland agroforestry trees also are planted across the Northern Negev in appropriate locations and water catchments. In general, the agricultural utilization scheme of these areas can be defined as combined rangeland-cereals fields (Perevolotsky and Seligman, 1998). Specifically, the practices are mostly as follows: tilling in September-October, sowing in October-November. Hay as animal feed is produced from green wheat or barely normally in April after the end of the rainy season. This practice is mostly implemented in drought years. In rainy years, the grains are harvested between May and June. During the fallow season, the animal herds are brought to the field for grazing.
In drought years such as 2017, the grazing starts earlier, in February-March, without grain harvesting (Ingram and Hunt, 2015). The final decision for implemented practices is based on the observed rainfall patterns or short-term meteorological forecasts and not on multiyear plans (Roncoli, et al., 2002). PWA area has been continuously cultivated with rainfed wheat or barely (except during drought) and grazed. This utilization leads to severe degradation, which was enhanced by the absence of any soil fertility management. PWA area, before site construction, was characterized by minor agriculture utilization and suffered from intense incision, expressed by a dense net of gullies (Fig. 2.2).

![Site of study before farm construction (2012), view westwards](image)

Except the Bedouin cereals breeding scheme, Kibutz farming is in common use (as Kibutz Dvira, Kramim, Bet Qama). This is based on monoculture of rainfed cereals using intense tillage, use of fertilizers, herbicides and insecticides. After the grains harvesting the straw left is used or sold for livestock feed, or is grazed by migrating Bedouin herds. The cultivation of the rangelands of private family is diverse and affected by many factors (Abu Rabia et al., 2008). Only two properties in the Northern Negev have made efforts of land restoration by sustainable land management, Yattir Farm (Helman et al., 2014) and Abu Rabia Farm (Abu Rabia et al., 2008), where
farmers applied manure, restricted grazing and agroforestry technologies to achieve significant ecosystem restoration and agricultural benefits.

2.5.1 Cultivation practices characteristics in study initiation (2014)

The PWA area was designed for several cultivations, including crop-livestock, service areas, un-processed plots and landscape design limans construction. **The Crop-Livestock cultivated areas**

The crop-livestock cultivated areas occupy 70% of the area. As opposed to the surrounding areas that are yearly and continuously tilled, the crop fields of the site of study were rotational tilled in 2011, 2013 and 2015 (Mor-Mussery et al., 2016).

**Services area**

The services area is located at the top of the Wadi Attir area close to transportation paths. It includes small ruminant enclosures, a dairy product factory, offices and classes for schoolchildren.

**Unprocessed plots**

Along the tilled part of Wadi Attir several plots were left unprocessed for several reasons:

a. Conservation of items with Archeological value (dams, agricultural terraces and farms from the Byzantine era)
b. Potential habitats for rare organisms and ecosystem engineers (Mitsch and Jørgensen, 2004);
c. Ecological monitoring of the rehabilitation state (Crisp, 2008);
d. Analysis of the cultivated-conserved feedback loops with regard to soil fertility and stability (Médiène et al., 2011).

The conserved plots were divided based on the common landforms, Loess Deposits (LD) and Rocky slope (RS), Inside the farm (In) and outside (Out).

**Landscape design - liman construction**

The soil conservation and water harvesting efforts required the formation of 67 terraces/limans along former gullies and streambeds of PWA. The limans were
designed and constructed in different manners. Some were built solely by damming using imported soil ('unprocessed limans') and the others were based on damming gullies, remodeling the soil and creating chains of limans ('remodeled/filled limans'). In this study we analyzed the unprocessed group (outside and inside the farm).

The location of the different cultivation plots in PWA area

The whole area was enclosed and managed as fallow land for enhanced rehabilitation, though under repeated tilling of the main farmland plots. The different plots, their correlated treatments and sizes are summarized in Table 2.1.

Table 2.1 The different plots, their correlated treatments and sizes

<table>
<thead>
<tr>
<th>Analyzed treatment</th>
<th>plot</th>
<th>Size [m²]</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncultivated plots (Loess deposit)</td>
<td>I.LD*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>I.LD.A6</td>
<td>1209</td>
<td>Inside PWA farm surrounds byzantine ruins</td>
</tr>
<tr>
<td></td>
<td>I.LD.A7</td>
<td>751</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I.LD.A8</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td></td>
<td>O.LD</td>
<td>370</td>
<td>Outside PWA farm surrounds byzantine dam</td>
</tr>
<tr>
<td></td>
<td>O.LD.Enc</td>
<td>115</td>
<td>Located on abandoned seasonal enclosure</td>
</tr>
<tr>
<td>Uncultivated plots (Rocky slope)</td>
<td>I.RS</td>
<td>600</td>
<td>Have similar landscape patterns</td>
</tr>
<tr>
<td></td>
<td>O.RS</td>
<td>800</td>
<td>before cultivations implementation</td>
</tr>
<tr>
<td>Tilled plots</td>
<td>O.Tl</td>
<td>35,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>O.Tl.Ab</td>
<td>13,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I.Tl.WsSt</td>
<td>11,111</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I.Tl.EsNt</td>
<td>12,098</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I.Tl.Fld</td>
<td>13,830</td>
<td></td>
</tr>
<tr>
<td>Unprocessed limans (dammed' limans)</td>
<td>I.L2</td>
<td>781</td>
<td>Planted, Inside farm, embedded in un-cultivated area</td>
</tr>
<tr>
<td></td>
<td>I.L3</td>
<td>911</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I.L4</td>
<td>481</td>
<td>Bare, outside farm, embedded in un-cultivated area</td>
</tr>
<tr>
<td></td>
<td>I.L5</td>
<td>584</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I.L14</td>
<td>437</td>
<td>Planted, Inside farm, embedded in tilled area</td>
</tr>
<tr>
<td></td>
<td>I.L15</td>
<td>536</td>
<td></td>
</tr>
</tbody>
</table>

*plots values were averaged to get their cultivation representative value

The location of all plots and cultivations is presented in Fig. 2.3.
Figure 2.3 Aerial photograph with the locations of the different treatments in PWA area, Israel Mapping Services (2014)

Tilled area treatments: Filled green- Inside tilled (I.Tl), Unfilled green- Outside tilled (O.Tl), Unfilled dashed green- Outside abandoned (O.Ab),

Loess deposit treatments: Filled red- Inside loess deposit (I.LD), Unfilled red- Outside loess deposit (O.LD), Dotted red- Inside abandoned enclosure (I.En)

Rocky slope treatments: Filled orange- Inside rocky slope (I.RS), Unfilled orange- Outside rocky slope (O.RS)

Unprocessed limans: Filled yellow- limans 2-3, Unfilled yellow- limans 4-5, Dotted yellow- Limans 14-15
2.6 The initial rehabilitation state of PWA

A preliminary study implemented in 2007-2011 aimed to define the RS of the area. Analyses of SOM, SMC and HBW were undertaken with regard to vegetation patterns, SOM and nutrients, ecosystem engineers’ distribution, landform and agriculture utilization properties.

Vegetation RhS

Generally, before 2014, the area was characterized by a homogenous low (0.004-0.01 Kg m$^{-2}$) vegetal cover (Fig. 2.4), except several plots characterized by significant higher values. These plots were located in the abandoned seasonal ruminant enclosure, circled area, and along the gullies, shown as arrows.

The uniqueness of the abandoned seasonal ruminant enclosure lead to study more carefully its vegetal patterns in order to define its RhS. This plot was located in the middle of the farm area. The difference in vegetation weight of the abandoned ruminants enclosure (the area was abandoned before 2011 (S. Leu, pers. comm. 2019) relative to the adjacent untreated area, are easily observed. There was a ten-fold annual biomass in the enclosure area, and up to a three-fold litter biomass showing the true rainfed productivity of the area (Fig. 2.5). The preliminary observations of the abandoned ruminants' enclosure displayed maximum productivity of herbaceous

Figure 2.4 Spatial analysis of the herbaceous biomass weighs over the site of study in 2011 [Kg m$^{-2}$]
biomass and litter (Fig. 2.5, left), in contrast to the exposed soil to the left, after 200 mm year\(^{-1}\) rainfall, 1/2012.

![Figure 2.5 The soil fertility of the abandoned ruminants enclosure compared to the adjacent area](image)

### Nutrient content

Nutrient content was determined in June 2012 by taking soil samples from 30 drilled boreholes from the surface to bedrock. The drilling scheme enabled to differentiate between soil horizons (a 35-50 cm layer thick was chosen, documenting the location of each bore hole using GPS). The samples were taken to Gilat Field services laboratory for soil nutrient analysis. The nitrate was determined using 1:5 nitrate:water solution, reading in MS-Spectrometer; ammonia- using KCl reading in MS-Spectrometer; phosphate by using Olsen scheme, reading in MS-Spectrometer; potassium using CaCl\(_2\) reading with flame photometer (Mulvaney and Sparks, 1996). In the preliminary analysis, the findings indicate that most of the area had homogenous and low nitrate content, except the North Eastern part (Appendix 2).

### Ecosystem engineers Rehabilitation state (RhS)

In general, the area was bare of shrubs and other potential ecosystem engineers such as ants (Mor-Mussery and Budovsky, 2017). Shrubs were found on gully slopes (Fig. 2.6A), in the rocky slope and nearby the antique remains in plots that were not accessible to tillage. Most of these shrubs did not construct patches (Fig. 2.6B). The External Ants Activity Coverage was 0.1%.
Figure 2.6 Distribution of shrubs in PWA before site establishment (2012)

A- Shrub cover on gully slopes, with their absence in the surrounding area; B- Example of a shrub, which did not create patch due to the high degradation state of the site.

Summary

The state of agriculture utilization, vegetation, geomorphology, nutrient content and ecosystem engineers of the PWA site in 2011 represents an area with very low RS. The site managers therefore decided to build a holistic scheme for rehabilitation, including land stabilization, different cultivation implementation and savanna tree plantation, the effects of which on the ecosystem were periodically analyzed.

2.7 Hypothesis and Research objectives

The core assumption in this study, which relies on former observations in the Northern Negev together with previous publications of the author and others, is that the continuation of the common practices for the traditional rainfed cultivations (grazing and winter cereals) and removal of woody perennials in these areas has resulted in soil erosion and degradation, nutrient leakage, and low herbaceous productivity and biodiversity. Addition of artificial topographic structures, planned properly to reduce runoff; reduced grazing and planting suitable dryland trees together with adequate management were predicted to enhance RhS by enriching soil organic matter and nutrient pools. The resulting increase in the natural ecosystem engineers function,
together with erosion control and water conservation on site, is hypothesized to result in restoration of critical ecosystem functions such as biomass production, soil carbon sequestration, and biodiversity.

Based on this hypothesis the following research objectives were defined:

a. Analyzing the soil quality changes of a given cultivation, before project establishment and during ecosystem development, in comparison to the state of untreated plots of the area, in order to define rehabilitation state recovery rate and mechanisms.

b. Parallel comparison of soil quality factors and changes in biological productivity in differently managed plots to identify mechanisms contributing to rehabilitation;

c. Defining landform changes parallel to fertility changes with the objective to identify the mechanisms contributing to rehabilitation.
3 Tools and methods

3.1 Soil quality properties

The comprehensive variable 'Soil quality' was defined by the Crop Science Society of America as follow: “the capacity (of soil) to function” one term for many properties with relation to ecology such as nutrients, water balance and geomorphology (Karlen et al., 1997). Many soil properties were analyzed and are divided into four groups: (i) water holding capacity, (ii) physical properties, (iii) fertility properties and (iv) biological properties. The timing and the frequency measurements is given in Table 3.1.
Table 3.1 Timings and frequencies the soil quality measurements in PWA

<table>
<thead>
<tr>
<th>The parameter</th>
<th>frequency</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Water holding capacity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Moisture Content (SMC)</td>
<td>Once every 2-3 months throughout the year*</td>
<td>Measured in the time, which the SMC is in its lowest and equal among treatments (Leu et al., 2014)</td>
</tr>
<tr>
<td>Infiltration rate</td>
<td>July-August, once a year</td>
<td></td>
</tr>
<tr>
<td>(ii) Physical properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine particles content</td>
<td></td>
<td>Measured in July 2016m based on Leu et al. (2014).</td>
</tr>
<tr>
<td>Soil Organic Matter (SOM)</td>
<td>Once every 2-3 months throughout the year*</td>
<td>Measured after reaching the maximal micro-organisms activity (Juan et al., 2008)</td>
</tr>
<tr>
<td>Nutrients</td>
<td>July-August</td>
<td></td>
</tr>
<tr>
<td>(iii) Fertility properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbaceous cover</td>
<td>April-May, once a year*</td>
<td>Measured when the annuals starting to dry to obtain the maximal value (Helman et al., 2014)</td>
</tr>
<tr>
<td>Germination</td>
<td>January-February, once a year</td>
<td>Measured at the start of germination period (Leu et al., 2014).</td>
</tr>
<tr>
<td>Ants' activity</td>
<td>August*</td>
<td>Measured when most of the herbaceous biomass dried (the ants feed), and the mostly observed (Jouquet et al., 2006; Mor-Mussery et al., 2017).</td>
</tr>
</tbody>
</table>

* This scheme was chosen to represent the wide variations during a year (Morin, and Benyamini, 1977).

3.1.1 Soil water holding capacity

Two parameters belong to the soil water holding capacity were measured: the Soil Moisture Content (SMC) and infiltrability.

Soil moisture content- The SMC was determined gravimetrically by drying the soil samples overnight at 105°C and comparisons of the weighs before and after the drying (Mulvaney and Sparks, 1996). The SMC value for each treatment was determined periodically each three months from 2012 (At project start) until 2017 based on six replicates per treatment.
Soil infiltration and infiltrability- The infiltration rates were measured by a disk tension infiltrometer (Decagon Devices, Inc®: www.decagon.com/en/hydrology/hydraulic-conductivity/mini-disk-portable-tension-infiltrometer). The height of the water column in the infiltrometer was measured continuously in 1min intervals for up to 6 min (four replicates). The infiltration rates were calculated as described by Eldrige et al., (2000). The soil infiltrability was determined by fitting a power equation to the measured data and integrating the infiltration values for duration of 6 minutes (Liu et al., 2011).

3.1.2 Soil physical properties

Several measurements were undertaken to determine the long-term effects of the different management practices on soil physical properties. These measurements include the Soil organic matter and grain size distribution, pH, EC, soil depth, rockiness and the soil bulk density.

Soil Organic Matter- Determination of SOM was performed using dry samples after the SMC analyses, by burning them in 500°C for 4 hours and measuring the mass differences of the dry versus the burnt samples, 6 replicates (Mulvaney and Sparks, 1996).

Grain size distribution - The soil grain size distribution was determined according to Stokes Law, by suspending 5 g of dry soil from the plot of study in 1 L of distilled water in a glass cylinder and comparison of the floating heights of ASTM 151H calibrated soil hydrometer after predefined time durations. The hydrometer values were used to define the sand, silt and clay fractions (Simuenek et al., 1995).

pH and EC- The pH and EC were determined using a Lutron pH-207 sensor. Altogether, 30 g of soil samples were mixed with distilled water (1:1 ratio). After the soil grains sink, the pH and EC were measured (10 replicates). Parallel to this analysis parts of the core samples were dried overnight in 105°C for calculating the moisture content. The moisture content values were used to calibrate the EC and pH of the sample dry matter. This methodology was used to prevent evaporation of acidic compounds by the conventional drying process.
**Soil depth and Rockiness coverage** - The soil depth for the loess plots was determined by the maximal depth of drilled boreholes (30 replicates). This was undertaken by Windex Co. in 2012 for the nutrient content analysis before the start of this study. For the rocky slope the soil depth was determined by sticking narrow and long iron nails in the soil and measuring the soil depth to bedrock. This was done by averaging 30 replicates per each area. A correlative parameter resembling soil thickness is the rockiness (van Wesemael et al., 2000).

The rockiness coverage of the rocky slope plots was determined by photographing a randomly thrown 0.5 X 0.5 m scaled iron frame. In the lab, the rockiness was determined from the photos by measuring stone sizes; those larger than 5 cm and their accumulated area were used to determine the coverage (Mulvaney and Sparks, 1996). Ten replicates were used per each area (Fig. 3.1).

![Figure 3.1 The rockiness coverage measurement](image)

A- Inside rocky slope (I.RS), B-Outside rocky slope (O.RS)

**Soil bulk density** - The soil bulk density was determined based on clod analysis. Three soil clods were aerially dried during one month and weighed. The clods were covered with melted paraffin and laid in a 1 L calibrated glass cylinder filled with 500 mm³ water. The new water level represented the clod volume (Tan, 2005).
3.1.3 Soil fertility properties

Four fertility parameters were determined as follows: Nitrate: N-NO₃, Ammonium: N-NH₄, Phosphate: P-PO₄ and Potassium: K. All the analyses are based on a mixture of four soil samples from the annuals root zone layer (0-20 cm) (1 sample mixed from 4 plots). The mixed samples were dried overnight at 105°C (Sava, 1994) and submitted for analysis to Gilat field services Laboratory for soil nutrient analysis based on standard procedures (Mulvaney and Sparks, 1996) procedures.

3.1.4 Biological activity properties

In order to determine the biological activity of ecosystem engineers in a given area, several measurements were performed: woody perennials cover, germination rates and patterns, total annual herbaceous biomass and the External Ants Activity Coverage (AAC).

**Woody perennials** - Perennials were manually counted in 100 m² squares on each plot of interest (8 replicates). Their average patch size was determined by measuring the longitudinal and lateral axes of the different patches and expressing their size based on the ellipse equation (Mor-Mussery et al., 2014a).

**Seedling densities and shape patterns** - The seedlings and their shape patterns were determined by photographing iron frames of 0.5 X 0.5 m thrown randomly in the plots of interest. Cereals (monocotyledonous) and broad leaves (dicotyledonous) seedlings were counted separately (Mor-Mussery et al., 2014b). Their shape patterns were visually determined from the photos as follows:

- cereal groups: a- seedlings with one stem less than 2 cm; b- seedlings with 2-3 stems less than 2 cm; c- seedlings with more than 3 stems between 2-5 cm; and d-seedlings higher than 5 cm.
- broad leaf groups (forbs and legumes): a- seedlings with one-two leaves with width less than 1cm; b- seedlings with 2-4 leaves between 1-3 cm; c- seedlings with more than 4 stems less than 5 cm; and d-larger than the former group (Fig. 3.2A).

**Annuals herbaceous biomass weight** - Annual herbaceous biomass was determined by randomly collecting six samples for each treatment. The annual herbaceous biomass was harvested using an iron frame of 20 X 30 cm in April-May when the amount of annual herbaceous biomass reached its maximum (Fig 3.2 B). The collected samples
were dried for 48 hours at 60°C, weighed and values were expressed in Kg m⁻² units (Sava, 1994).

![Figure 3.2 The vegetal measurements](image)

**Figure 3.2 The vegetal measurements**

A- analysis of germination properties of a given plot using high resolution photos of an 0.5 X 0.5 m iron frame; B- Collecting annual herbaceous plant biomass using a 20 X 30 cm iron frame.

**Harvester ants’ activity** - The term harvester ants relates to a group of species that consume seeds as their main feeding resource. The ants collect the seeds and store them in nests, which they built at the communal chambers (Mor-Mussery and Budovsky, 2017). Most of the previous studies on this group focused on the ant life cycle and the effects of the climate on their activity (Arnan et al., 2012; Rosado et al., 2013), fewer studies deal with their capacity to indicate on the rehabilitation states (De Bruyn, 1999). In order to determine the harvester ants activity, mostly from the species *Messor arrhenius, M.abenesis*; Mor-Mussery and Budovsky, 2017), in a given area, an analysis of External Ants Activity Coverage was done (AAC). This analysis refers to the area, which is covered by the external spatial signs and not the actual nest size, which is wider and located underground (Tschinkel, 2004). These external spatial signs include nests, soil and litter dumps and entrance holes. The AAC was calculated mainly by selecting a representative area of 15 X 15 m (or other based on area patterns) in the tested plot and measuring the longitudinal and lateral axes of the different signs of ant activities. The area of each spatial sign was calculated based on the elliptic shape form (Maillieux et al., 2003) and documented with its type as nest and dump, and observed activity. The AAC was calculated as the portion of all ants external spatial signs relative to the measured area (Mor-Mussery et al., 2017), Fig. 3.3. The analysis was conducted in summer.
3.2 Statistical analyses

In order to determine the differences among the defined treatments and the analyzed properties several analyses were used, as follows.

**Stand-alone properties**- In order to analyze the differences between treatments at a given time, or for the same treatments at different dates, the statistical confidence was analyzed by Analysis of Variance (ANOVA) using JMP® ver. 13 ($\alpha=0.1$).

The yearly changes of soil moisture content and organic matter in different treatments, characterized by seasonally changes, were determined according to a three phase analysis (Ussiri and Lal, 2009): (i) demonstration of their seasonal changes, (ii) Determination of seasonal trends (maximal and minimal values), and (iii) using season sets to determine the yearly changes for each treatments and for comparison between treatments.

**Continuant soil property**- Analyzing continuous property changes, as infiltrability was performed by integration of the values along the analyzed period. In practice, the integration was performed as follows (Shao and Horton, 1998):

a. The analyzed property values were located in a scattered graph vs. the period since start.

b. A correlation graph (linear or exponential) was fitted and integration of the values between the analyzed periods was performed.

c. The integration values of the tested plots were analyzed by ANOVA.
Seasonal changes- Detecting seasonal changes was implemented by cross-referencing the mean value of soil property per each treatment of interest to the number of months passed from the study start. For all soil quality properties a detailed significance analysis table was added in order to clarify the sets in which the differences between the treatments became consistently significant.

Correlation between properties- The significance of the correlations between properties was analyzed using EXCEL (with linear or exponential correlation schemes), based on their $r^2$.

Data normalization for RhS calculation- The Wadi Attir area as other arid, heavily and long-term loess cultivated areas is affected by three main processes: cultivation schemes, rainfall patterns and erosion processes (Fu and Gulinck, 1994). In order to determine the real RS change of a given area and cultivation, one has to normalize the soil quality properties with the change caused by the remaining factors. Two methods were used for normalization. The first was done by correlating different rainfall patterns and soil quality properties. The second was done by comparison of the measured soil quality properties of a given treatment to the ones of the reference plots (Spellerberg, 2005; Aronson et al., 1993). For the most representative view for each treatment, references plots were chosen to represent the lowest or maximal RS soil quality property values. These were normalized by the annual changes of sample location compared to control locations.

3.3 Landscape patterns

Due to the massive erosion state and dense incised phenomena, characterizing the study site was undertaken, by two manners to define the landscape: before and along the rehabilitation processes, manually and by aerial photography.

Manual analyses- Before plot establishment the incised phenomena of the site of study were mapped using manual tools as meter bands, angled ruler for high inclines and water level for light inclined slopes, constructed solely for this propose based on Castillo et al., (2012) guidelines (Fig. 3.4). The collected data are graphically presented
for further use, such as treatment design and terraces location. Incision phenomena were documented manually to define the land rehabilitation state (Pellant et al., 2000).

Figure 3.4 Manual water level tool for slightly inclined slopes

**Aerial photography analyses**- Aerial photographs of the site of study from 2000 until 2015 were purchased from MAPI Israel ([www.mapi.gov.il](http://www.mapi.gov.il)). All the aerial photos were taken in spring or early the summer, enabling to define landform changes and the recognition of ecological phenomena (Fenshman et al., 2005; Stein et al., 2010). The analyses were implemented by comparisons of recognizable landform patterns (Turner and Ruscher, 1988; Marzolff and Poesen, 2009).
4. Results

4.1 Soil quality properties of the different treatments

4.1.1 Loess deposit treatments

Field measurements
The group of loess deposits includes three types of treatments, three inside PWA farm (I.LD1-3), one treatment located outside the farm, outside loess deposit (O.LD) and one located on the abandoned ruminant enclosure inside PWA (I.En). For the treatments of loess deposits, three types of analyses were implemented: ‘water holding capacity’, ‘soil fertility’ and ‘biological activity’. The number of rainy days, possibly the most influential rainfall pattern that affect soil quality properties is shown as a secondary vertical axis. In order to determine consistent significant changes among the treatments, each set of measurement was analyzed. Summary of the significance analyses data is given in Table 4.1.

Table 4.1 Statistical data for the differences between the soil quality properties of loess deposits by treatment

<table>
<thead>
<tr>
<th>Factor</th>
<th>Date</th>
<th>Differences</th>
<th>F(Ratio)</th>
<th>Prob&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBW</td>
<td>4(2014)</td>
<td>O.LD&lt;sub&gt;a,b&lt;/sub&gt;, I.LD&lt;sub&gt;b&lt;/sub&gt;, I.En&lt;sub&gt;a&lt;/sub&gt;</td>
<td>16.0</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>4(2015)</td>
<td>O.LD&lt;sub&gt;b&lt;/sub&gt;, I.LD&lt;sub&gt;a,b&lt;/sub&gt;, I.En&lt;sub&gt;a&lt;/sub&gt;</td>
<td>4.4</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>4(2016)</td>
<td>O.LD&lt;sub&gt;c&lt;/sub&gt;, I.LD&lt;sub&gt;b&lt;/sub&gt;, I.En&lt;sub&gt;a&lt;/sub&gt;</td>
<td>23.8</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>4(2017)</td>
<td>O.LD&lt;sub&gt;b&lt;/sub&gt;, I.LD&lt;sub&gt;a,b&lt;/sub&gt;, I.En&lt;sub&gt;a&lt;/sub&gt;</td>
<td>6.9</td>
<td>0.01</td>
</tr>
<tr>
<td>SMC</td>
<td>4(2014)</td>
<td>I.En&lt;sub&gt;a&lt;/sub&gt;, I.LD&lt;sub&gt;a,b&lt;/sub&gt;, O.LD&lt;sub&gt;b&lt;/sub&gt;</td>
<td>2.9</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td>6(2014)</td>
<td>I.LD&lt;sub&gt;a&lt;/sub&gt;, I.En&lt;sub&gt;b&lt;/sub&gt;, O.LD&lt;sub&gt;b&lt;/sub&gt;</td>
<td>7.6</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td>10(2014)</td>
<td>I.LD&lt;sub&gt;a&lt;/sub&gt;, I.En&lt;sub&gt;b&lt;/sub&gt;, O.LD&lt;sub&gt;b&lt;/sub&gt;</td>
<td>4.1</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>12(2014)</td>
<td>I.LD&lt;sub&gt;a&lt;/sub&gt;, I.En&lt;sub&gt;b&lt;/sub&gt;, O.LD&lt;sub&gt;b&lt;/sub&gt;</td>
<td>3.3</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>March and June 2015 sets are not available due to technical reasons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9(2015)</td>
<td>I.LD&lt;sub&gt;a&lt;/sub&gt;, I.En&lt;sub&gt;b&lt;/sub&gt;, O.LD&lt;sub&gt;b&lt;/sub&gt;</td>
<td>9.7</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>2(2016)</td>
<td>I.LD&lt;sub&gt;a&lt;/sub&gt;, I.En&lt;sub&gt;b&lt;/sub&gt;, O.LD&lt;sub&gt;b&lt;/sub&gt;</td>
<td>5.5</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>5(2016)</td>
<td>O.LD&lt;sub&gt;c&lt;/sub&gt;, I.LD&lt;sub&gt;b&lt;/sub&gt;, I.En&lt;sub&gt;a&lt;/sub&gt;</td>
<td>5.5</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>9(2016)</td>
<td>O.LD&lt;sub&gt;a,b&lt;/sub&gt;, I.LD&lt;sub&gt;a&lt;/sub&gt;, I.En&lt;sub&gt;b&lt;/sub&gt;</td>
<td>2.8</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>2(2017)</td>
<td>O.LD&lt;sub&gt;b&lt;/sub&gt;, I.LD&lt;sub&gt;a&lt;/sub&gt;, I.En&lt;sub&gt;b&lt;/sub&gt;</td>
<td>20.2</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>7(2017)</td>
<td>O.LD&lt;sub&gt;b&lt;/sub&gt;, I.LD&lt;sub&gt;a&lt;/sub&gt;, I.En&lt;sub&gt;b&lt;/sub&gt;</td>
<td>7</td>
<td>0.009</td>
</tr>
<tr>
<td>SOM</td>
<td>4(2014)</td>
<td>I.En&lt;sub&gt;a&lt;/sub&gt;, I.LD&lt;sub&gt;b&lt;/sub&gt;, O.LD&lt;sub&gt;b&lt;/sub&gt;</td>
<td>18.2</td>
<td>0.0002</td>
</tr>
<tr>
<td></td>
<td>6(2014)</td>
<td>I.En&lt;sub&gt;a&lt;/sub&gt;, I.LD&lt;sub&gt;b&lt;/sub&gt;, O.LD&lt;sub&gt;b&lt;/sub&gt;</td>
<td>3.3</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>10(2014)</td>
<td>I.En&lt;sub&gt;a&lt;/sub&gt;, I.LD&lt;sub&gt;b&lt;/sub&gt;, O.LD&lt;sub&gt;b&lt;/sub&gt;</td>
<td>2.9</td>
<td>0.09</td>
</tr>
</tbody>
</table>
March and June 2015 sets are not available due to technical reasons

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>O.LD</th>
<th>I.LD</th>
<th>I.En</th>
<th>Significant Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>a/b</td>
<td>2.9</td>
<td>0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>b</td>
<td>9.1</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>a/b</td>
<td>10.8</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>b</td>
<td>5.5</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>a/b</td>
<td>63.7</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>b</td>
<td>63.7</td>
<td>0.0001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>O.LD</th>
<th>I.LD</th>
<th>I.En</th>
<th>Significant Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>b, a/a</td>
<td>10.6</td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>b</td>
<td>9.8</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>O.LD</th>
<th>I.LD</th>
<th>I.En</th>
<th>Significant Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>a, b/a</td>
<td>5.5</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>a/a</td>
<td>0.8</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>a</td>
<td>7.1</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(O.LD- Outside loess deposits, I.LD- Inside loess deposits, I.En- Inside abandoned enclosure), 6 replicates per each measurement

Significant differences are greyed- 'a'- highest significant grade, 'b'- moderate, 'c'- lowest grade, a/b and b/c non-significant differences. P<0.1

**Soil water holding capacity**

The analyzed soil water holding capacity properties were the soil moisture content (SMC) and the infiltrability.

**Soil moisture content**

The soil moisture content of the loess deposits treatments was measured every 3 months between 2014 and 2017 (Fig. 4.1). Error bars represent SE. The O.LD and I.En values were calculated by averaging the values of six replicates randomly selected for each treatment. The I.LD was calculated by averaging the average values of the loess deposit plots inside the farm. The values were calculated as % water of dry mixed soil from the surface to 15 cm.
The Soil Moisture Content (SMC) of all treatments has similar seasonal parabolic shapes, as expected characterized by high values in winter and low in the summer. The summer values were similar for all the treatments and during the years (Fig. 4.1). In the winter sets a similarity was found between the I.LD and the I.En SMC values, both were higher compared to the outside values. From June 2014 set, the values of the I.LD plots were about 6% above the O.LD with significant difference (Table 4.1).

Infiltratibility
The second analyzed soil water use efficiency property was the Infiltratibility. The findings for the loess deposit treatments are presented in Table 4.2
Table 4.2 The mean infiltrability of the loess deposits treatments at 7/2014 and 7/2016

<table>
<thead>
<tr>
<th></th>
<th>I.LD</th>
<th>O.LD</th>
<th>I.En</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/2014</td>
<td>17.2(0.9)</td>
<td>10.9(1.35)</td>
<td>32.1(2.4)</td>
</tr>
<tr>
<td>7/2016</td>
<td>11.2(1.4)</td>
<td>7.1(0.6)</td>
<td>23.0(4.6)</td>
</tr>
</tbody>
</table>

(I.LD- Inside loess Deposit, O.LD- Outside loess deposit, I.En- Inside abandoned enclosure), 4 replicates per each measurement

The values inside brackets represent the ±SE. Two sets were implemented at July 2014 and July 2016

The highest infiltrability was in the ruminant enclosure (I.En) compared to the Inside loess deposits (I.LD) and the lowest in the outside one (O.LD) for both dates (Table 4.2). Importantly, the infiltration rates in the conserved plots inside (I.LD) were 50% higher compared to the outside plot (O.LD), and the enclosure infiltrability was about double compare to the I.LD. These differences were significant for 2014 and 2017. Nevertheless, the ratios between the three treatments remained constant; the rates were reduced by 50% in 2016 compared to 2014 for unknown reasons.

Soil fertility

Two soil fertility properties were measured in the loess deposits plots, SOM and nutrients content.

SOM analysis- The soil samples for the SOM determination were the same as those taken for the SMC. The findings are presented in Fig. 4.2.
Figure 4.2 The mean soil organic matter content of the loess deposit treatments between 2013 and 2017

Error bars represent ±SE. The horizontal axis represents the year and calendar month, No. of rainy days represents the entire rainy season

(O.LD- Outside loess deposits, I.LD- Inside loess deposits, I.En- Inside abandoned enclosure), 6 replicates per each measurement.

Until 2014, the SOM values of the I.LD and O.LD were identical. In the following years, the difference increased to 0.5-1%. The differences were significant, except for two data points in winter 2015/2016. From spring 2016 onwards, the I.LD values were consistently 1% higher than those in the O.LD. The SOM of the enclosure plot fluctuated, whereas in the other treatments values were less variable. SOM in the I.En reached 7-10% in spring and summer vs. 3.5-5% in fall (Table 4.1). This area was difficult to sample precisely due to a closed overlaying layer of decomposing manure.

**Nutrient content analyses:** Three sets of nutrient analyses (one replicate based on mix from 4 plots) were implemented: in 2012 (before site construction), 2014 and 2016 (Table 4.3).

The nutrient contents of the I.En were much higher in comparison to the other loess deposits treatments. The Nitrate values in 2012 were similar for the I.LD and the O.LD, while in 2016 the nitrate values were two-fold higher in the I.LD compared to the O.LD. As nitrate, similar values of the other analyzed nutrients (Ammonia, Phosphorus and
Potassium) measured in 2012 in the I.LD and O.LD treatments, while in 2016 these nutrients values were 50% higher for the I.LD. Interestingly the Potassium content was much higher in 2012 than in the other sets in the I.LD and O.LD. The most likely explanation for this observation is that in 2012 a mixed soil profile from 0 - 50 cm depth was analyzed, while in the two following samples soil between 0-20 cm was sampled, may indicate higher K content in deeper soil layers.

Table 4.3 The nutrient contents of the loess deposit treatments in 2012, 2014 and 2016 [mg Kg$^{-1}$], 1 sample mix of 4 plots

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kg</td>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>N-NO$_3$</td>
<td>7.2</td>
<td>4.2</td>
<td>5.6</td>
<td>7.6</td>
<td>7.7</td>
<td>2.3</td>
<td>N</td>
<td>30.8</td>
<td>29.5</td>
</tr>
<tr>
<td>N-NH$_4$</td>
<td>3.12</td>
<td>6.3</td>
<td>18.9</td>
<td>1.4</td>
<td>5.0</td>
<td>12.2</td>
<td>N</td>
<td>46.2</td>
<td>33.3</td>
</tr>
<tr>
<td>N-Total</td>
<td>10.4</td>
<td>13.6</td>
<td>23.1</td>
<td>9.0</td>
<td>12.7</td>
<td>14.5</td>
<td>N</td>
<td>77.0</td>
<td>64.1</td>
</tr>
<tr>
<td>P-PO$_3$</td>
<td>3.0</td>
<td>6.3</td>
<td>12.3</td>
<td>3.9</td>
<td>9.7</td>
<td>7.2</td>
<td>N</td>
<td>243</td>
<td>212</td>
</tr>
<tr>
<td>K(CaCl$_2$)</td>
<td>53.0</td>
<td>20.9</td>
<td>23.8</td>
<td>37.9</td>
<td>10.2</td>
<td>16.5</td>
<td>N</td>
<td>117.5</td>
<td>93.6</td>
</tr>
</tbody>
</table>

(I.LD- Inside loess deposit, O.LD- Outside loess deposit, I.En- Inside abandoned enclosure)
N- Not measured

Biological activity

Biological activity was determined by three parameters: the herbaceous biomass weight (HBW) at the end of winter (April each year), the monocotyledons and dicotyledons seedling densities and shape patterns, and external ant activity coverage in each studied treatment.

_Herbaceous biomass:_ The highest herbaceous biomass weight was in the abandoned ruminants enclosure (I.En) - significant in all years (from 2012 until 2017). The lowest values were found in the outside loess deposit plot and the I.LD plot in 2012. The HBW values of the I.LD increased constantly and became significantly higher than the O.LD values in 2016 and 2017, but were significantly lower than in the enclosure (I.En). In 2017 the HBW of the I.LD reached over 50% of the I.En plot, indicating a 50% recovery of maximal possible recovery within 5 years of conservation. The HBW values of
treatments for all sets show some correlation to the number of rainy days of the present winter.

![Figure 4.3 Mean properties of the biological activity of loess deposit treatments between 2012 and 2017](image)

**Figure 4.3 Mean properties of the biological activity of loess deposit treatments between 2012 and 2017**

A- Herbecous Biomass Weighs (HBW); B- External Ants Activity Coverage (AAC), 6 replicates per each measurement

Error bars represent ±SE, Rainy days is the total amount for the whole rainy season

The External Ants Activity Coverage (AAC)
The AAC of the enclosure was the highest in this the study, followed by the Inside plot ILD and the lowest values in the outside plot.

Seedlings: patterns analysis
The third analyzed property of the biological activity. The seedlings densities and categories were determined in January 2015 and are summarized in in Table 4.3B.
The highest dicotyledonous seedlings density was found in the enclosure (I.EN), followed by the Inside plots I.LD and the lowest value was found outside OLD (Table 4.4). The monocotyledons demonstrate opposite trend, in which the highest values were measured in the outside plot OLD, followed by the enclosure I.En and last was in the Inside plot I.LD. The highest density of both seedlings types was in the inside treatments.
Table 4.4 The seedlings densities and shape patterns in the loess deposit treatments, determined in 1/2015

<table>
<thead>
<tr>
<th>Dicotyledons</th>
<th>Monocotyledons</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. m²</td>
<td>shape patterns</td>
<td>No. m²</td>
</tr>
<tr>
<td>I.LD</td>
<td>164(78)</td>
<td>a-d</td>
</tr>
<tr>
<td>O.LD</td>
<td>7(3.4)</td>
<td>a</td>
</tr>
<tr>
<td>I.En</td>
<td>413.6(116.2)</td>
<td>a</td>
</tr>
</tbody>
</table>

(I.TI- Inside tilled, O.TI- Outside tilled, O.Ab- Outside abandoned)

densities (No. per m²), shape patterns: a- low developed state and d high developed seedlings (Tools and methods)

In brackets-±SE.

4.1.2 Rocky slope treatments

Background findings
Before the establishment of the PWA, both rocky slopes were one unit as demonstrated in an aerial photograph dated 2012 (Fig. 4.4A), with similar shrub density and rockiness patterns. After 2012 changes were gradually emerged (Fig. 4.4B1 and 4.4B2).

![Figure 4.4 The rocky slope treatments of PWA in 2012 and 2016](image)

A- An aerial photo of the rocky slope in 2012, B1- photo of the inside unit, B2- photo of the outside unit, both in 2016

The black arrow represents an expansion of vegetation coverage along the years (B2), while the outside sustained homogenous with low coverage.
In order to analyze property changes of soil quality, a background database was collected (Table 4.5). Data is based on comparisons of aerial photographs between 2000-2014.

Table 4.5 The mean landscape and soil properties of the rocky slopes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Date</th>
<th>O.RS</th>
<th>I.RS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrub's patches coverage [%]</td>
<td>07(2016)</td>
<td>23.19</td>
<td>23.01</td>
</tr>
<tr>
<td>Patch size (m²)</td>
<td></td>
<td>0.32 (0.1)</td>
<td>1.04 (0.15)</td>
</tr>
<tr>
<td>Patches number</td>
<td></td>
<td>7900</td>
<td>2205</td>
</tr>
<tr>
<td>Soil depth (cm)</td>
<td>11(2017)</td>
<td>5.2 (0.65)</td>
<td>6.4 (0.72)</td>
</tr>
<tr>
<td>Rockiness (%)</td>
<td>11(2017)</td>
<td>46.3 (8.1)*</td>
<td>18.9 (4.0)</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>11(2017)</td>
<td>17.1 (0.95)</td>
<td>16.9 (0.9)</td>
</tr>
<tr>
<td>Clay (%)</td>
<td></td>
<td>22.2 (0.5)</td>
<td>21.0 (0.4)</td>
</tr>
<tr>
<td>Sand (%)</td>
<td></td>
<td>60.7 (1.3)</td>
<td>62.01 (1.2)</td>
</tr>
<tr>
<td>pH</td>
<td>12(2017)</td>
<td>6.26 (0.13)</td>
<td>6.18 (0.04)</td>
</tr>
<tr>
<td>EC (mv)</td>
<td></td>
<td>130 (4.6)</td>
<td>124.4 (4.6)</td>
</tr>
</tbody>
</table>

(I.RS- Inside rocky slope, O.RS-Outside rocky slope), 6 replicates per each measurement
In brackets±SE *- significant difference (Alpha=0.1)

Field measurements

From the study start, we noticed that the rocky slopes are characterized by high geomorphology and floristic heterogeneity, as opposed to the tilled and loess deposits groups. The rocky slope in PWA and outside can be described as puzzle of micro-topographical units, mainly shrub patches and ant nests that are surrounded by matrix and various sizes of rocks of mixed origin. In order to study functional interrelations between the parts and isolate the most indicating topographic unit for the RS of the rocky slopes, the rocky slope units, the nests, shrub patches and matrix were measured and separately sampled. In general, for most soil quality properties the rocky slopes matrixes were analyzed in six replicates, while the nests and shrubs patches, in four replicates, due to their relative small coverage from the total area. From 2016 two distinct parts were observed on the inside farm rocky slope, expressed by dense vegetal cover in the lower part compared to the upper one. Therefore, all soil quality
measurements from then onwards were done separately on both parts in 2016 and 2017. In order to determine consistent significant changes among the treatments, each set of measurement was analyzed. Summary of the significance analyses data is given in Table 4.6.

Table 4.6 Statistical data for the differences between the soil quality properties of the rocky slopes

<table>
<thead>
<tr>
<th>Factor</th>
<th>Date</th>
<th>Differences</th>
<th>F(Ratio)</th>
<th>Prob&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBW</td>
<td>4(2014)</td>
<td>I.RS&gt;O.RS</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>4(2015)</td>
<td>I.RS&gt;O.RS</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>4(2016)</td>
<td>I.RS&gt;O.RS</td>
<td>2.4</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>4(2017)</td>
<td>I.RS&gt;O.RS</td>
<td>1.9</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.RS(UP) b  I.RS(Dn) a</td>
<td>15.1</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.RS(UP) b  I.RS(Dn) a</td>
<td>21</td>
<td>0.002</td>
</tr>
<tr>
<td>SMC</td>
<td>4(2014)</td>
<td>O.RS&gt;I.RS</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>6(2014)</td>
<td>I.RS&gt;O.RS</td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>10(2014)</td>
<td>I.RS&gt;O.RS</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>12(2014)</td>
<td>Not implemented</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>March and June 2015 sets are not available due to technical reasons</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9(2015)</td>
<td>I.RS a, O.RS b</td>
<td>10.4</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>2(2016)</td>
<td>I.RS&gt;O.RS</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>5(2016)</td>
<td>I.RS&gt;O.RS</td>
<td>0.08</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.RS(UP)&gt;O.RS(DN)</td>
<td>1.4</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>9(2016)</td>
<td>I.RS&lt;O.RS</td>
<td>0.1</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.RG(UP)&gt;I.RS(Dn)</td>
<td>0.04</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>2(2017)</td>
<td>I.RS a O.RS b</td>
<td>4.6</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.RS(UP)&gt;I.RS(Dn)</td>
<td>3.2</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>7(2017)</td>
<td>I.RS a O.RGS b</td>
<td>2.8</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.RS(UP)&gt;I.RS(Dn)</td>
<td>2.9</td>
<td>0.14</td>
</tr>
<tr>
<td>SOM</td>
<td>4(2014)</td>
<td>I.RS&gt;O.RS</td>
<td>2.5</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>6(2014)</td>
<td>I.RS&gt;O.RS</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>10(2014)</td>
<td>I.RS&gt;O.RS</td>
<td>0.04</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>March and June 2015 sets are not available due to technical reasons</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9(2015)</td>
<td>Not implemented</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2(2016)</td>
<td>I.RS&gt;O.RS</td>
<td>1.9</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.RS(UP) b  I.RS(Dn) a</td>
<td>21</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>5(2016)</td>
<td>I.RS&lt;O.RS</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.RS(UP)&gt;I.RS(Dn)</td>
<td>1.3</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>9(2016)</td>
<td>I.RS&lt;O.RS</td>
<td>0.06</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.RS(UP) b  I.RS(Dn) a</td>
<td>6.3</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>2(2017)</td>
<td>I.RS a O.RS b</td>
<td>15.7</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.RS(UP)&lt;I.RS(Dn)</td>
<td>1.5</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>7(2017)</td>
<td>I.RS a O.RS b</td>
<td>28.4</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.RS(UP)&lt;I.RS(Dn)</td>
<td>1.6</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Infiltrability

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>Value1</th>
<th>Value2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>I.RS&gt;O.RS</td>
<td>1.9</td>
<td>0.3</td>
</tr>
<tr>
<td>2016</td>
<td>I.RS&gt;O.RS</td>
<td>0.15</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>I.RS(UP)(^b)</td>
<td>5.2</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>I.RS(Dn)(^a)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dicotyledons

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>Value1</th>
<th>Value2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>I.RS&gt;O.RS</td>
<td>2.8</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Monocotyledons

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Value1</th>
<th>Value2</th>
</tr>
</thead>
<tbody>
<tr>
<td>O.RS&gt;I.RS</td>
<td>0.3</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Total

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Value1</th>
<th>Value2</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.RS&gt;O.RS</td>
<td>0.6</td>
<td>0.4</td>
</tr>
</tbody>
</table>

(I.RS- Inside rocky slope, O.RS- Outside rocky slope, UP- Upper part, Dn- Down part), 6 replicates per each measurement

Significant differences are greyed: a- high significant grade, b- low significant grade, a/b non-significant differences. P<0.1

Soil water holding capacity

Two soil water efficiency properties were analyzed, the soil moisture content and infiltrability.

Soil moisture content

The soil moisture content (SMC) of the rocky slopes analysis is based on measurements every 3 months between 2014 and 2017. The measurements were carried out separately on the matrix and the shrub patches. The findings are presented in Fig. 4.5
Figure 4.5 The mean soil moisture contents of the rocky slope units between 2013 and 2017

(I.RS- Inside rocky slope (Matrix), O.RS- Outside rocky slope (Matrix), I.RS (Pt)- Inside rocky slope (Shrubs patches), O.RS(Pt)- Outside rocky slope shrubs patches), 6 replicates per each measurement

Error bars±S.Er. The horizontal axis represents the year and calendar month, Rainy days represents the total amount for the entire rainy season

Similar to the loess deposits group, the SMC demonstrate parabolic shape along the years with similar content of 2-2.5% in the summer sets. The SMC of O.RS and I.RS were similar also in winter until 2015. Thereafter the SMC of the I.RS was higher than in the O.RS. In 2016 and 2017 the difference between I.RS and O.RS was significant (Table 4.6). Similar to the matrix parts (O.RS and I.RS) the SMC of the shrub patches demonstrated a parabolic shape during the year. Interestingly, the difference between the winter and summer sets became even higher in 2017 although the number of rainy days decreased drastically. The SMC of the shrub patches between 2015 and 2017 are similar for the I.RS (Pt) and the O.RS (Pt) units during the study (14- 16%), while the matrix SMC values in O.RS remained significantly lower compared to the I.RS. In 2017 no significant difference of the SMC was found among the patches of the rocky slopes. Nevertheless, the significant difference of the SMC in the I.RS compared to the O.RS was maintained.
In conclusion, a very rapid response of conservation leading to increased SMC in the I.RS matrix plot was observed, confirming the key role of soil hydrology in desertification and rehabilitation processes.

**Infiltrability**

The second analyzed water holding capacity property was the infiltrability. Two sets of infiltrability measurements were carried out in 2014 for both rocky slopes (4 replicates) and in 2016 4 replicates for the O.RS and 8 for the I.RS (4 from the upper part I.RS(Up) and 4 from down part (I.RS(Dn))*

*For the I.RS the values of the I.RS(Up) and I.RS(Dn) were averaged. The findings are presented in Table 4.7

**Table 4.7 The mean infiltrability of the rocky slopes in 7/2014 and 7/2016**

<table>
<thead>
<tr>
<th></th>
<th>I.RS</th>
<th>O.RS</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/2014</td>
<td>10.2(1.55)</td>
<td>7.3(0.7)</td>
</tr>
<tr>
<td>7/2016</td>
<td>11.8(1.6)*</td>
<td>9.6(1.25)</td>
</tr>
<tr>
<td>I.RS(Up)</td>
<td>8.03(1.05)</td>
<td>I.RS(Dn)</td>
</tr>
</tbody>
</table>

*I.average of I.RS(Up) and I.RS(Dn)*

(I.RS- Inside rocky slope (Matrix), O.RS- Outside rocky slope (Matrix), 6 replicates per each measurement

In brackets-±SE

For both sets of infiltrability (2014 and 2016), the integration demonstrates higher values of 2.5 mm³ per 6 min. for both sets to the I.RS, compared to O.RS (Table 4.6). In 2016 an increased volume of 7 mm³ per 6 min was found in the lower part (I.RS(Dn)) compared to the upper part (I.RS(Up)), (Table 4.7).

**Soil fertility properties of the rocky slopes**

Two soil fertility properties were analyzed- the Soil organic matter (SOM) and the nutrients content.

**Soil Organic Matter**

The SOM values were calculated based on six replicates per each treatment, taken every 3 months between 2014 and 2017. The findings are presented in Fig. 4.6
Figure 4.6 The mean soil organic matter contents (SOM) of the rocky slope units between 2013 and 2017

(I.RS- Inside Rocky slope (Matrix), O.RS- Outside Rocky slope (Matrix), I.RS (Pt)- Inside Rocky slope (Shrubs patches), O.RS(Pt)- Outside Rocky slope (shrubs patches), 6 replicates per each measurement

Error bars± S.Er., The horizontal axis represents the year and calendar month, Rainy days is the total amount in the entire rainy season

Until winter 2015 the SOM content of both plots (I.RS and O.RS) was similar among the shrublands. In the summer of 2015 the SOM of the I.RS became gradually significantly higher when a difference of 0.25% higher in I.RS than O.RS 2015 increased to 1% higher in 2016 and 2017 during all seasons maintaining the annual parabolic pattern for the I.RS and the O.RS. The difference between I.RS and O.RS was significant with (F(Ratio)=15.7, Prob>F=0.03, Table 4.7). The SOM of the I.RS and O.RS shrub patches were very similar, and not significantly different from the matrix values of the I.RS, but significantly higher than the O.RS values, with a steadily growing difference from 2015 onwards.

**Nutrient analysis**

Three sets of nutrient analyses were carried out in the rocky slope area, in 2012, before site construction, in 2014 and 2016 (Table 4.8).
Table 4.8 Nutrients content of the rocky slopes’ matrices in 2012, 2014 and 2016

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N-NO₃</td>
<td>7.0</td>
<td>5.4</td>
<td>4.2</td>
<td>7.0</td>
<td>4.4</td>
<td>4.9</td>
</tr>
<tr>
<td>N-NH₄</td>
<td>1.7</td>
<td>6.0</td>
<td>15.4</td>
<td>1.7</td>
<td>N</td>
<td>13.1</td>
</tr>
<tr>
<td>N-Total</td>
<td>8.7</td>
<td>11.4</td>
<td>19.6</td>
<td>8.7</td>
<td>N</td>
<td>17.5</td>
</tr>
<tr>
<td>P-PO₃</td>
<td>3.2</td>
<td>9.5</td>
<td>8.5</td>
<td>3.2</td>
<td>8.9</td>
<td>8.2</td>
</tr>
<tr>
<td>K(CaCl₂)</td>
<td>45.8</td>
<td>16.9</td>
<td>17.2</td>
<td>45.8</td>
<td>15.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

(I.RS- Inside rocky slope (matrix), O.RS- Outside rocky slope (matrix))

one sample mix of 4 plots.

The Nitrogen compounds (Nitrate and Ammonium) and the Phosphate had similar content for both rocky slopes with a slightly higher value of Ammonium in the I.RS compared to the O.RS, 15.4 vs. 13.1 mg Kg⁻¹ (Table 4.8). The Potassium value was 70% higher in the Inside rocky slope (17.2 vs. 10 mg Kg⁻¹). The dramatic changes between the Potassium values in 2012 and the ones of 2014 and 2016 sets can be explained by differences in sampling methodologies. In 2012 a mixture of the top 50 cm was analyzed and in the other samples a mixture from surface until 15cm depth was analyzed.

**Biological activity**

The biological activity is expressed by the herbaceous biomass at the end of winter (April each year), the germination densities and their shape patterns, and the measured ant activity in each research plot.

The values of the herbaceous biomass weighs (HBW) of the rocky slopes matrices and shrub patches are demonstrated in Fig. 4.7
Figure 4.7 The mean herbaceous biomass weights of the rocky slopes units between 2012 and 2017

A- Comparisons of the inside and outside rocky slope matrix values; B- Comparisons between the inside and outside rocky slope shrub patch values.

(I.RS- Inside Rocky slope (Matrix), O.RS- Outside Rocky slope (Matrix), 6 replicates per each measurement

*Error bars- ±SE, Rainy days is the total amount of rain for the entire rainy season

Herbaceous biomass:
The weights of herbaceous cover were identical in the 2012 matrix parts, but thereafter consistently higher in the Inside plot (I.RS) compared to the outside one (O.RS) along the years with a drastic increase in 2016 and 2017 (Fig. 4.7). Little correlation was found to rainfall days.
The herbaceous biomass in the outside shrub patches of the outside rocky slope (O.RS) is similar throughout the years (0.15 Kg m⁻²), while the one of the Inside part became significantly higher in 2016 and 2017.

The External Ants Activity Coverage (AAC)
The second analyzed biological activity was the external ants activity (AAC), Fig. 4.8.
Figure 4.8 The mean external ants activity coverage (AAC) of the rocky slopes between 2012 and 2017 (I.RS- Inside Rocky slope (Matrix), O.RS- Outside Rocky slope (Matrix)), 6 replicates per each measurement. Rainy days is the total amount for the entire rainy season.

The AAC of the I.RS was higher compared to the O.RS during the entire study period. Nevertheless, both rocky slopes demonstrate a continuous increase in the AAC (Fig. 4.8).

Seedlings analysis

The third analyzed biological activity was the seedlings densities and shape' patterns. The findings are presented in Table 4.9

Table 4.9 The mean seedlings densities and their shape patterns of the rocky slopes in 1/2015

<table>
<thead>
<tr>
<th></th>
<th>Dicotyledons</th>
<th>Monocotyledons</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. m²</td>
<td>Shape patterns</td>
<td>No. m²</td>
</tr>
<tr>
<td>I.RS</td>
<td>11(0.6)</td>
<td>a-b</td>
<td>4(1.0)</td>
</tr>
<tr>
<td>O.RS</td>
<td>5(0.6)</td>
<td>a-c</td>
<td>5(0.95)</td>
</tr>
</tbody>
</table>

In brackets- ±SE. (I.RS- Inside rocky slope (matrix), O.RS- Outside rocky slope (matrix)), 6 replicates per each measurement.

Seedlings densities [No. ha⁻¹], shape patterns: 'a'- 'low developed seedling' and 'd' high developed seedling' (Tools and methods)
The seedlings densities in both rocky slopes were low, nevertheless the density of the di-cotyledons seedlings I.RS was little high compared to the O.RS.

**The correlation between the shrub patches and their surrounding matrix**

In order to analyze the correlations between the shrub patches and their surrounded matrixes of the studied rocky slopes, the SOM and SMC values of the shrub patches and the matrix between were intersected per each analyzed set and regressed (separately for the I.RS and O.RS plots). The results are shown in Fig. 4.9.

![Figure 4.9 The correlations between the soil properties of the shrub patches and matrices of the rocky slopes](image)

**Soil moisture content (SMC); B-Soil Organic Matter (SOM)**

Fig. 4.9 demonstrates the correlations between the patches fertility values and their matrices ones in the rocky slopes. Nevertheless the tightest correlation relates to soil moisture content ($r^2=0.7-0.8$). These findings strengthen the ones of Aguir and Sella (1999) on the hydrological role of patches in in other shrublands all over the globes. Nevertheless, due to the solubility of the organic matter, its flow from the patches into the matrix occurs at lower rates compared to that of water (Morales et al., 2010).

**4.1.3 Tilled treatments**

**Field measurements**

The tilled group of plots represents a number of sites with treatments strongly varying during the years. The logical variability of some of the results therefore does not yet provide consistent data sets. Nevertheless, the results confirm in part the results in the different treatments described above. The tilled group contains three plots analyzed, the Inside tilled (I.Tl) fenced areas within PWA, the Outside tilled (O.Tl) open area and a
tilled and subsequently abandoned plot outside of PWA (O.Ab). Tillage was done in
summer 2012, for all cultivations; in the summer of 2014 and 2015 (September-
October) for the Inside and the Outside tilled plots indicated by arrows in the figures.
Three types of soil properties were analyzed: water balance, soil fertility and biological
activity, all of them sampled 5 m from the plot edge, in order to prevent edge effects.
In order to determine consistent significant changes among the treatments, each set of
measurement was analyzed. Summary of the significance analyses data is given in
Table 4.10.

Table 4.10 Statistical data for the differences between the soil quality properties
of the tilled treatments

<table>
<thead>
<tr>
<th>Factor</th>
<th>Date</th>
<th>Difference</th>
<th>F(Ratio)</th>
<th>Prob&gt;F</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBW</td>
<td>4(2014)</td>
<td>I.Tl(^a) O.Ab(^{ab}), O.Tl(^a)</td>
<td>1.6</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>4(2015)</td>
<td>I.Tl(^a), O.Ab(^{ab}), O.Tl(^b)</td>
<td>3.9</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>4(2016)</td>
<td>I.Tl(^a), O.Ab(^{b}), O.Tl(^c)</td>
<td>14.3</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>4(2017)</td>
<td>I.Tl(^a), O.Ab(^{ab}), O.Tl(^b)</td>
<td>1.8</td>
<td>0.02</td>
</tr>
<tr>
<td>SMC</td>
<td>4(2014)</td>
<td>I.Tl(^a), O.Ab(^{ab}), O.Tl(^b)</td>
<td>3.2</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td>6(2014)</td>
<td>I.Tl(^a), O.Ab(^{b}), O.Tl(^b)</td>
<td>9.3</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>10(2014)</td>
<td>O.Ab(^a)&gt;I.Tl(^a)&gt;O.Tl(^b)</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>12(2014)</td>
<td>I.Tl(^a)&gt;O.Ab(^a)&gt;O.Tl(^b)</td>
<td>1.9</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>March and June 2015 sets are not available due to technical reasons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9(2015)</td>
<td>O.Ab(^a)&gt;I.Tl(^a), O.Tl(^b)</td>
<td>16.3</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>2(2016)</td>
<td>I.Tl(^a), O.Ab(^{ab}), O.Tl(^b)</td>
<td>9.7</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>5(2016)</td>
<td>I.Tl(^a), O.Ab(^{ab}), O.Tl(^b)</td>
<td>7.5</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>9(2016)</td>
<td>I.Tl(^a), O.Ab(^{b}), O.Tl(^b)</td>
<td>17.4</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td>2(2017)</td>
<td>I.Tl(^a), O.Ab(^{b}), O.Tl(^c)</td>
<td>11.9</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>7(2017)</td>
<td>I.Tl(^a), O.Ab(^{b})&gt;O.Tl(^b)</td>
<td>59.9</td>
<td>0.001</td>
</tr>
<tr>
<td>S0M</td>
<td>4(2014)</td>
<td>I.Tl(^a), O.Tl(^{ab})&gt;O.Ab(^{b})</td>
<td>3.8</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>6(2014)</td>
<td>I.Tl(^a), O.Ab(^{b})&gt;O.Tl(^b)</td>
<td>2.9</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>10(2014)</td>
<td>I.Tl(^a), O.Ab(^{b})&gt;O.Tl(^b)</td>
<td>4.8</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>March and June 2015 sets are not available due to technical reasons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9(2015)</td>
<td>I.Tl(^a), O.Ab(^{b}), O.Tl(^c)</td>
<td>35.5</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>2(2016)</td>
<td>I.Tl(^a), O.Ab(^{ab}), O.Tl(^b)</td>
<td>3.4</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>5(2016)</td>
<td>I.Tl(^{ab}), O.Ab(^{b}), O.Tl(^b)</td>
<td>2.2</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>9(2016)</td>
<td>I.Tl(^{ab}), O.Ab(^{b}), O.Tl(^b)</td>
<td>6.5</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>2(2017)</td>
<td>I.Tl(^a)&gt;O.Ab(^a)&gt;O.Tl(^b)</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>7(2017)</td>
<td>I.Tl(^{ab}) O.Ab(^{b})&gt;O.Tl(^b)</td>
<td>10.4</td>
<td>0.0015</td>
</tr>
<tr>
<td>Infiltrability</td>
<td>7(2014)</td>
<td>I.Tl(^a)&gt;O.Tl(^a)&gt;O.Ab(^a)</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>7(2014)</td>
<td>I.Tl(^a)&gt;O.Tl(^a)&gt;O.Ab(^a)</td>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Dicotyledons</td>
<td>1(2015)</td>
<td>O.Ab(^{a}) O.Tl(^{b}) I.Tl(^{e})</td>
<td>10.6</td>
<td>0.02</td>
</tr>
<tr>
<td>Monocotyledons</td>
<td></td>
<td>I.Tl(^{f})&gt;C.Ab(^{b}) O.Tl(^{b})</td>
<td>2.3</td>
<td>0.1</td>
</tr>
<tr>
<td>total</td>
<td>O.Ab(^{a})&gt;O.Tl(^a)&gt;I.Tl(^{a})</td>
<td>1.05</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

O.LD- Outside loess deposits, I.LD- Inside loess deposits, I.En- Inside abandoned
enclosure, I.Tl- Inside tilled, O.Tl- Outside tilled, O.Ab- Outside abandoned, 6
replicates per each measurement
Significant differences are greyed- 'a' - highest significant grade, 'b' - moderate significant, 'c' - lowest significant grade, a/b and b/c non-significant differences, P<0.1

**Soil water holding capacity properties**

Two soil water holding capacity properties were analyzed, the soil moisture content (SMC) and the infilterability.

**Soil water profile**

The soil moisture content of the tilled treatments was measured every 3 months between 2014 and 2017, Fig. 4.10.

---

**Fig. 4.10** The mean soil moisture content (SMC) of the tilled treatments between 2013 and 2017

(I.Tl- Inside tilled, O.Tl- Outside tilled, O.Ab- Outside abandoned), 6 replicates per each measurement

Error bars- ±S.Er., The horizontal axis represents the year and calendar month, Arrows represent the tillage events, Rainy days is the total amount for the whole rainy season

The SMC (Fig. 4.10) demonstrates for all treatments a yearly parabolic shape reaching a seasonaly maximal value during the winter months (December until March) and the minimal values in summer (July until September). Analysis of SMC of the different treatments between 2013 until 2017 in the winter season reveals an increasing difference between the I.Tl cultivation and the O.Tl, amounting to 3% SMC points in winter 2014/2015. From 7/2016 all the SMC values of the I.Tl were consistantly and
significantly higher than the O.Tl ones (Table 4.1). In the abandoned tilled field, the SMC content was about halfway between the outside and Inside tilled plots.

**Soil infiltrability**

The second analyzed soil water holding capacity property was the infiltrability. The findings of the tilled sets are presented in Table 4.1

**Table 4.11 The mean infiltrability of the tilled treatments in 7/2014 and 7/2016**

<table>
<thead>
<tr>
<th></th>
<th>I.Tl</th>
<th>O.Tl</th>
<th>O.Ab</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>7/2014</strong></td>
<td>23.4(5.6)</td>
<td>25.8(8.0)</td>
<td>14.7(1.7)</td>
</tr>
<tr>
<td><strong>7/2016</strong></td>
<td>10.4(0.7)</td>
<td>13.6(4.5)</td>
<td>14.3(2.4)</td>
</tr>
</tbody>
</table>

(I.Tl- Inside tilled, O.Tl- Outside tilled, O.Ab- Outside abandoned), 4 replicates per each measurement In brackets- ±SE

The measured values of the abandoned plot (O.Ab) were similar for both sets (~4.5 mm³ per 6 min) while for the actual tilled plots (I.Tl and O.Tl) the values of the second set were much lower compared to the first set. For the first and the second sets, the values of the I.Tl and O.Tl were similar.

**Soil fertility properties of the tilled treatments**

Two soil fertility properties were analyzed in the tilled treatments, the Soil Organic Matter (SOM) content and the nutrients content. The SOM content of the Inside tilled area (I.Tl) was calculated by averaging the tilled north, south and flooded plots values. The SOM was measured every 3 months between 2014 and 2017 (Fig. 4.11).
The SOM values (Fig. 4.11) demonstrate a yearly parabolic shape for all cultivations with the maximal values found in the summer (July until September), and the minimal values in winter. In summer 2014, the I.Tl and O.Tl plots were tilled, which caused a drastic reduction of the SOM in both areas. In 2015, a rapid increase of 1% in the SOM value was observed in I.Tl plots. A 0.5% increase was found in the out fence plot. From 2015 onwards, SOM values of all treatments in the winter sets increased, although it may be a systematic error.

In October 2015, the second tilling event on the I.Tl and O.Tl plots resulted in a decrease of 0.4% of their SOM values in both winter sets as compared to the previous winter sets. Overall, no significant differences could be identified during 2016 and 2017 between the three treatment sets, only in summer 2017 the I.Tl became again significantly higher compared to the other plots.
Soil nutrient contents:

Three sets of nutrient analyses were performed: in 2012 (before site construction), in 2014 and 2016 (Table 4.12).

Table 4.12 The nutrients content of the tilled treatments in 2012, 2014 and 2016

<table>
<thead>
<tr>
<th></th>
<th>I.Tl</th>
<th>O.Tl</th>
<th>O.Ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-NO₃</td>
<td>6.8</td>
<td>6.4</td>
<td>6.1</td>
</tr>
<tr>
<td>N-NH₄</td>
<td>1.8</td>
<td>14.7</td>
<td>14.0</td>
</tr>
<tr>
<td>N-Total</td>
<td>8.6</td>
<td>17.6</td>
<td>20.1</td>
</tr>
<tr>
<td>P-PO₃</td>
<td>3.1</td>
<td>6.6</td>
<td>8.2</td>
</tr>
<tr>
<td>K(CaCl₂)</td>
<td>49.5</td>
<td>13.3</td>
<td>15.8</td>
</tr>
</tbody>
</table>

(I.Tl- Inside tilled, O.Tl- Outside tilled, O.Ab- Outside abandoned)

1 sample, mix of 4 plots

The nitrogen compounds (Nitrate and Ammonium) demonstrated similar values in 2016 in all treatments (with total N ~20 mg Kg⁻¹). The phosphate demonstrated a steady increase in the inside plots between 2012 and 2016 in comparison to the two outside plots (8.2 vs. 5.9 mg Kg⁻¹ in 2016). In the outside plots the phosphorus contents remained about 40% lower than in the inside plots. The potassium demonstrated twice-higher values in the inside plots compared to the other treatments in 2016 (15.8 vs. 8.9 mg Kg⁻¹). The potassium contents of 2012 set were very high compared to the sets of the other years. This can be explained by the fact that this is a soil sample from the top 50 cm of soil, not from 20 cm only as in 2014 and 2016. This can also be the reason that the nitrogen and the phosphorus values in 2012 are significantly lower than in 2014 and 2016 in all plots.

Overall, the most important changes observes are a significantly higher phosphorus and potassium contents in the I.Tl compared to the outside plots in 2016 and a more rapid increase of ammonia and total nitrogen in I.Tl compared to outside, approaching 20 mg Kg⁻¹ total nitrogen already in 2014.
Properties of biological activity

The biological activity, expressed as the weight of standing annual herbaceous biomass at the end of winter (April each year), and ant activity in each research plot, were determined periodically as described in Materials and Methods. The data on HBW and AAC are summarized in Fig. 4.12. The significance data is presented in Table 4.10.

**Figure 4.12 The mean biological activity properties of the tilled treatments between 2013 and 2017**

A- Herbaceous biomass weight (HBW); B-External ants' activity coverage (AAC) (I.Tl- Inside tilled, O.Tl- Outside tilled, O.Ab- Outside abandoned), 6 replicates per each measurement

Error ± SE., Arrows represent the tillage events, Rainy days is the total amount for the whole rainy season

**Herbaceous biomass:**

The herbaceous biomass weights of all plots were similarly low in 2012. From 2014 the I.Tl group consistently had the highest annual biomass cover, followed by the abandoned plot and the lowest ones were found consistently in the out fence tilled plot O. Tl (Fig. 4.12A).

Until 2015, not all differences were judged as significant. However, from 2016 set the HBW of the I.Tl were significant higher from the other treatments (Table 4.12).

**External Ants Activity Coverage (AAC)**

The AAC was the highest in the abandoned treatments in all years measured, in accordance with nest destruction by tillage (Fig. 4.12B). Among the tilled plots (I.Tl and O.Tl) in 2015 and 2017 I.Tl had higher AAC, while in 2016 the I.Tl value was lower, apparently due to tilling in the 2015 fallow season.
Seedling analysis: The third analyzed property of the biological activity was the seedlings density. The findings are shown in Table 4.13.

Table 4.13 The mean seedlings densities and shape patterns of the tilled treatments in 1/2015

<table>
<thead>
<tr>
<th></th>
<th>Dicotyledons</th>
<th>Monocotyledons</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. m⁻²</td>
<td>Shape patterns</td>
<td>No. m⁻²</td>
</tr>
<tr>
<td>I.Tl</td>
<td>10(6.2)</td>
<td>a-b</td>
<td>50.5(18.7)</td>
</tr>
<tr>
<td>O.Ab</td>
<td>54(15.4)</td>
<td>b-c</td>
<td>28(16.7)</td>
</tr>
<tr>
<td>O.Tl</td>
<td>26.4(8.6)</td>
<td>a-c</td>
<td>4.8(2.0)</td>
</tr>
</tbody>
</table>

(I.Tl- Inside tilled, O.Tl- Outside tilled, O.Ab- Outside abandoned), 6 replicates per each measurement
In brackets- ± SE.
Seedlings density [No. ha⁻¹], shape patterns: 'a'-'low developed state' and 'd' 'high developed state' (Tools and methods)

The highest density of dicotyledons seedlings was in the abandoned area (Table 4.14). In contrast, the highest density of the monocotyledons was in the I.Tl treatments, followed by the O.Tl ones with the lowest values found in the abandoned plot O.Ab. The sizes of the dicotyledonous seedlings were lower in the actual tilled plots as compared to the abandoned plot (a-b vs. b-c), while the biggest monocotyledon sizes were found in the Inside tilled (I.Tl) plots and the lowest in the abandoned plots. The total seedlings count was highest in the I.Tl plots and the lowest in the O.Tl one. The O.Tl values are significantly lower than the O.Ab and I.Tl values in all categories. Dicotyledonous seedlings were more frequent in the abandoned plot (O.Ab) while monocotyledons germinated most frequently in the conserved tilled area (I.Tl).

4.1.4 Dammed limans

Field measurements and analysis methodologies

The limans in PWA, as presented earlier (see “research site”), are characterized by high landform, shape and planting pattern heterogeneity. In order to study the effects of savanna trees planting and conservation from grazing on their fertility and productivity, we chose the 'dammed limans' group. In this group two types were defined the trapezoid shaped (2, 3, 4, 5) and the flat types (14, 15).
In order to get representative value of each soil quality property the trapezoid shaped limans were divided into six sampling units based on area stream directionality- upper and lower parts and based the limans' trapezoid shape: north slope, channel and south slope. The units are demonstrated in Fig. 4.13.

**Figure 4.13 The sampling units of Liman 2** (unprocessed type, trapezoid shaped),
February 2016
Division on the east-west axis: north slope, channel and south slope. Division on the north-south axis: upper and lower parts. This division scheme was also used for limans 2, 3, 4 and 5.

The relative area portions of the different units of the unprocessed liman 2-3 and 4-5 are given in Fig. 4.14.
In each unit, four random measurements of the analyzed soil quality property were measured. The averaged value per each unit multiplied by its aerial portion (Fig. 4.14). The resulted values were added to get the liman total value, as exemplified on the herbaceous biomass of liman 2 in 4/2017, Fig 4.15.

The measurements in Limans 14-15 were taken randomly all over the liman area (and averaged). In general, for the unprocessed limans group, three types of soil properties analyses were implemented as follows: water holding capacity, soil fertility and biological activity, all of them sampled 2 m from the liman edge, in order to avoid edge effects. For comparison, the number of rainy days is presented in the secondary vertical
axis. The following unprocessed limans were analyzed: limans 2-3 (Inside, Planted, embedded inside un-cultivated area), Limans 4-5 (Outside, not planted inside un-processed area), Limans 14-15 (Inside planted, embedded inside tilled area). The outside loess deposits (O.LD) values were used for comparison. In general, all the soil quality properties demonstrated high heterogeneity among the replicates of each limans group, therefore significance analyses were not implemented for these treatments.

**Water holding capacity properties**

Two water holding capacity properties were analyzed, the soil moisture content (SMC) and the infilterability.

*Soil Moisture Content*

The soil moisture content of the unprocessed limans was measured every 3 months between 2014 and 2017. The soil moisture content of Limans 14 and 15 determined by averaging the SMC values of 6 randomly selected plots. The SMC of limans 2-3, 4-5 was calculated by averaging 4 replicates per unit and averaging all units' values based on the scheme in Fig. 4.15. The findings are presented in Fig. 4.16

![Figure 4.16 The mean soil moisture contents (SMC) of the dammed limans between 2013 and 2017. Error±SE, The horizontal axis represents the year and calendar month. 6 replicates per each measurement](image)

In spite of high heterogeneity of the SMC values along the years in the different liman groups several trends can defined. The SMC of the winter sets of limans 14-15 was higher than limans 2-3 and limans 4-5. With time the difference between the SMC of
the conserved limans and the O.LD increased, while the difference of limans 4-5 and the O.LD decreased. The lowest values were found in the outside loess deposit O.LD. Even in the summer sets the different dammed limans groups have ~0.5% higher SMC compared to the O.LD. Visually, correlation to the number of rainy days can be observed in all the limans and the O.LD.

**Infiltrability**

The second analyzed water balance property was the infiltrability. The infiltrability of the unprocessed limans was determined by averaging the SMC values of 4 randomly selected plots per each liman. The findings are presented in Table 4.14.

**Table 4.14 The mean infiltrability of the unprocessed limans in 7/2014 and 7/2016 [mm$^3$ per 6min]**

<table>
<thead>
<tr>
<th></th>
<th>L. 2-3</th>
<th>L. 4-5</th>
<th>L. 14-15</th>
<th>O.LD</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/2016</td>
<td>16.7(5.9)</td>
<td>16.5(2.7)</td>
<td>18.0(1.2)</td>
<td>7.1(0.6)</td>
</tr>
</tbody>
</table>

(L. Limans group, O.LD- Outside loess deposit) 4 replicates per each measurement In brackets-±SE

The infiltrability in 2016 was similar for the whole limans group (around 17 mm$^3$ per 6 minutes), 2.5 fold higher compared to the O.LD (7.1 mm$^3$ per 6min), Table 4.16.

**Soil fertility properties of the dammed limans**

Two soil fertility properties were analyzed in the different unprocessed limans, the SOM and nutrients contents.

**Soil organic matter:**

The soil organic matter content (SOM) of Limans 14 and 15 was determined by averaging the SOM values of 6 randomly selected plots. The SOM of limans 2-3, 4-5 was calculated by averaging 4 replicates per unit and averaging the units' values based on the scheme in Fig. 4.16. The findings are shown in Fig. 4.17
The SOM demonstrate high variability, but several trends can be defined (Fig. 4.15). The SOM values of limans 12-13 were the highest. Until 2016 limans 2-3 and 4-5 had similar values also when compared to the O.LD, and lower than limans 12-13. In addition, until 2016 all groups present a parabolic shape. From 2016 a difference of 1% higher SOM was observed in the different limans groups, compared to the O.LD, though statistical significance could not be demonstrated. Correlation to the number of rainy days was not observed.

**Soil nutrient contents:**

Three sets of nutrient measurements were implemented in the course of the study, in 2012 (before site construction), 2014 and 2016 (Table 4.15). The 2012 analysis was performed using soil from the top 50 cm of a soil profile extracted before liman construction. In 2014 and 2016 the analysis was performed with a soil mix form the top 20 cm.
Table 4.1 The nutrient contents of the dammed limans in 2012, 2014 and 2016 [mg Kg⁻¹]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N-NO₃</td>
<td>7.4</td>
<td>5.53</td>
<td>3.9</td>
<td>7.4</td>
<td>7.35</td>
<td>9.3</td>
<td>7.4</td>
<td>7.35</td>
<td>9.3</td>
<td>7.6</td>
<td>7.7</td>
<td>2.3</td>
</tr>
<tr>
<td>N-NH₄</td>
<td>2.25</td>
<td>3.6</td>
<td>14.7</td>
<td>2.25</td>
<td>6.7</td>
<td>17.0</td>
<td>2.25</td>
<td>4.5</td>
<td>14.2</td>
<td>1.4</td>
<td>5.0</td>
<td>12.2</td>
</tr>
<tr>
<td>N-Total</td>
<td>9.7</td>
<td>9.1</td>
<td>18.6</td>
<td>9.7</td>
<td>14.0</td>
<td>26.4</td>
<td>9.7</td>
<td>11.8</td>
<td>19.1</td>
<td>9.0</td>
<td>12.7</td>
<td>14.5</td>
</tr>
<tr>
<td>P-PO₄</td>
<td>3.4</td>
<td>7.2</td>
<td>9.1</td>
<td>3.4</td>
<td>6.5</td>
<td>7.0</td>
<td>3.4</td>
<td>8.4</td>
<td>6.6</td>
<td>3.9</td>
<td>9.7</td>
<td>7.2</td>
</tr>
<tr>
<td>K(CaCl₂)</td>
<td>45.8</td>
<td>12.5</td>
<td>16.2</td>
<td>45.8</td>
<td>9.85</td>
<td>9.5</td>
<td>45.8</td>
<td>12.1</td>
<td>16.6</td>
<td>37.9</td>
<td>10.2</td>
<td>16.5</td>
</tr>
</tbody>
</table>

1 sample mix of 4 plots

The total nitrogen content is higher in the unprocessed limans. In limans 2-3 and 4-5 about 19 mg Total N Kg⁻¹ were determined, while for limans 14-15 26.4 mg total N Kg⁻¹ were determined which 50 – 80% higher than the O.L.D. The phosphorus values are similar for the dammed limans group and the O.L.D. The Potassium content in 2016 is almost twice in the Inside limans compared to limans 4-5 (16 vs. 9.5 mg Kg⁻¹) indicating K mobilization from deeper soils by the help of deep rooted vegetation in the planted limans.

The properties of the biological activity

Two biological activity properties of the limans were measured, the herbaceous biomass weights (HBW) and external ants activity coverage (AAC). The HBW of the limans was measured at the end of winter (April each year) and calculated in limans 14-15 in 6 randomly selected plots. In limans 2-3, 4-5 the value was determined by averaging 4 replicates per unit and averaging all units' values based on the scheme in Table 4.15. The AAC calculated along the limans. The HBW and the AAC values are presented in Fig. 4.18.
Figure 4.18 The mean biological activity properties of the dammed limans between 2012 and 2017
A- Herbaceous biomass weight (HBW), B- External ants activity coverage (AAC), 6 replicates per each measurement
Error bars± SE, Rainy days is the number of days with >1mm precipitation of the entire rainy season

**Herbaceous biomass:**
Until 2015 amounts of herbaceous biomass in the inside dammed limans 2-3 and 14-15) were similar and significantly higher than the outside Limans 4-5 and the O.LD that were similar (Fig. 4.16A). In 2015 and later limans 14-15 showed the highest values, followed by limans 2-3 with limans 4-5 showing the the lowest biomass values that are similar to the untreated outside control, the O.LD. An observable correlation of the biomass values to the number of rainy days was evident.

**External Ants Activity Coverage** (AAC)
In 2014, the AAC values of Limans 2-3 were higher than the O.LD, that were higher than the values of limans 4-5. In liman 14-15 in 2014 no AAC was detected. From 2015 the AAC values of the inside dammed limans (2-3 and 14-15) were higher compared to the outside plots, Limans 4-5 and O.LD. Visual correlation between the AAC and the number of rainy days could be identified. Similarly, a correlation between growing HBC and AAC was becoming evident.
4.2 Data normalization using reference plots

Since the climate and especially the rainfall patterns are highly heterogeneous in drylands. In order to determine the rehabilitation state (RhS) of analyzed cultivations for analyzed soil fertility different properties need to be normalized relative to climate, specifically to variations in rainfall. I decided to apply data collected from reference plots providing the minimal baseline values, or the maximal apparently achievable productivity values and remained untreated during the observation period. The Outside loess deposits (O.LD) is considered at a high state of degradation and served as the baseline lower value for the degraded state. The inside abandoned Enclosure (I.En) covered with manure was considered the highest productivity achievable. From 2012 until 2017 the O.LD, had continuously the lowest values in all soil quality properties, whereas the I.En has the highest ones, compared to the other loess cultivations with ratios of 3-8 fold difference during the study (section 4.1.1). These differences may be caused by different mineralization rates of the solid manure (Chang and Janzen, 1996). Nevertheless, because all during the study period solid manure existed, we used the yearly average difference from the O.LD to determine the rehabilitation duration for all the treatments. For the soil quality properties normalization we used the O.LD soil quality property values as the lower base-line, while the I.En values were considered the target values achievable under given climatic conditions. The crusted loess plateau west of the wadi Attir channel was chosen as baseline for an undisturbed but grazed plot outside of the project (O.LD) and its soil properties were used as baseline in our productivity normalization approach. The inside abandoned ruminant enclosure (I.En) consistently provided about 5-fold productivity compared to the surrounding areas and to O.LD, and was used to define the target values indicating full soil quality recovery.
4.2.1 Inside loess deposit

The soil quality properties normalized in order to determine the RhS change of the Inside loess deposit (I.LD) treatment were as follows: herbaceous biomass weights- HBW (based on the finding in Fig. 4.3A), soil moisture content – SMC (based on the findings in Fig. 4.1), soil organic matter of the summer and winter sets - SOM_{summer} and SOM_{winter} (based on the findings in Fig. 4.2) and the External ants activity coverage- AAC (based on the findings in Fig. 4.3). The soil quality properties were referenced to the O.LD soil quality properties values, taken as 100% for each data set. The normalized % increases and the resulting restoration functions for the different properties are presented in Fig. 4.20.
Figure 4.20 The normalized soil quality properties of the Inside loess deposits (I.LD) between 2012 and 2017, relative to the initially observed values (in 2012 = 100%)

A- Herbaceous Biomass Weigh (HBW); B- Soil Moisture Content (SMC); C- Soil Organic Matter of the summer sets (SOM\text{summer}); D- Soil Organic Matter of the winter sets (SOM\text{winter}); E- External ants activity coverage (AAC).

The highest observed increase of soil fertility property during the study with high significance ($R^2$ value) was the herbaceous biomass weigh (HBW). The normalized HBW of the inside loess deposit increased steadily along the years and was 92% of the initially observed value per year (Fig. 4.20A).

The SMC demonstrated a steady increase of average 13.8% per year until reaching a constant value (plateau) in the third year, which was equal to the value found in the abandoned enclosure, Fig. 4.20B. The SOM values of both winter and summer sets
demonstrated constant linear increase by 7-8% of the baseline value per year, Fig. 4.20C and D. The AAC showed a continuous annual increase with strongly fluctuating rates (Fig. 4.20E).

An important parameter derived from this normalization procedure is the deduced number of years needed to change different soil fertility properties from the O.LD degraded state to the I.En maximal achievable value based on the rehabilitation intensity of the studied landform (Table 4.16). The results indicate that under the conservation regime applied, assuming maximal biomass productivity and SMC can be achieved within a few years, while full restoration of topsoil SOM will happen in 20 – 30 years. Deep soil SOM representing a much bigger reservoir was not assessed in this study but must be considered for a full and rapid restoration.

<table>
<thead>
<tr>
<th>change[%]</th>
<th>$R^2$</th>
<th>Duration estimation [years]</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBW</td>
<td>97.4</td>
<td>6-7 years</td>
</tr>
<tr>
<td>SMC*</td>
<td>25</td>
<td>2 years</td>
</tr>
<tr>
<td>SOM (summer)</td>
<td>8.8</td>
<td>28-29 years</td>
</tr>
<tr>
<td>SOM (winter)</td>
<td>7.2</td>
<td>20-21 years</td>
</tr>
<tr>
<td>AAC</td>
<td>59.9</td>
<td>16-17 years</td>
</tr>
</tbody>
</table>

* Assessment due to plateau state from the second year.

HBW- Herbaceous biomass weigh; SMC- Soil moisture content (SMC); SOM- Soil organic matter of the summer sets (SOMsummer) or winter sets (SOMwinter); AAC- External ants' activity coverage (AAC)

4.2.2 Inside Rocky slope

The soil quality properties were normalized in order to determine the RS in the Inside rocky slope (I.RS) were: Herbaceous biomass weighs- HBW (based on the data in Fig. 4.7A), soil moisture content - SMC (based on the data in Fig. 4.7), soil organic matter of the summer and winter sets- SOMsummer and SOMwinter (based on the data in Fig. 4.5) and the External ants activity coverage- AAC (based on the data in Fig. 4.6). The soil
quality properties were normalized in reference to the O.LD soil quality properties are presented in Fig. 4.21.

Figure 4.21 The normalized soil quality properties of the Inside rocky slope (I.RS) between 2012 and 2017

O.RS: Outside rocky slope, I.RS: Inside rocky slope, I.En: Inside abandoned enclosure

A- Herbaceous biomass weight (HBW); B- Soil moisture content (SMC); C- Soil organic matter of the summer sets (SOM\text{\textsubscript{summer}}); D- Soil organic matter of the winter sets (SOM\text{\textsubscript{winter}})

As for the I.LD the herbaceous biomass has the fastest increase rate among the soil fertility properties reaching to 48% per year of the initial value (in 2012 = 100%), which was lower than the I.LD recovery rate of 97% per year. The SMC showed also a steady increase rate of 5.5% per year, as opposed to the I.LD which increased by 25% per year and reached the maximal level after 2 years (Fig. 4.19B). The SOM change of the summer sets showed a yearly significant increase rate of 6.6%. The AAC increase was ~10%, which is less compared to the value of the I.LD.

The estimated time durations for full rehabilitation, reaching the soil properties values of the abandoned ruminant enclosure (O.Ab), for the inside rocky slope treatment are given in Table 4.17
Table 4.1 The inside rocky slope normalization data (correlations, significances and time durations until rehabilitation)

<table>
<thead>
<tr>
<th></th>
<th>change [%]</th>
<th>R²</th>
<th>Duration estimation [years]</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBW</td>
<td>47.</td>
<td>0.5</td>
<td>35-36</td>
</tr>
<tr>
<td>SMC</td>
<td>5.5</td>
<td>0.7</td>
<td>13-14</td>
</tr>
<tr>
<td>SOM(summer)</td>
<td>6.</td>
<td>0.7</td>
<td>21-22</td>
</tr>
<tr>
<td>AAC</td>
<td>48.</td>
<td>0.1</td>
<td>27-28</td>
</tr>
</tbody>
</table>

HBW- Herbaceous biomass weight, SMC- Soil moisture content (SMC), SOM- Soil organic matter of the summer sets (SOMsummer), AAC- External ants' activity coverage (AAC)

In general, the time durations until rehabilitation, reaching the values of the ruminant enclosure’s values for the inside rocky slopes are longer than those of the loess deposit (I.LD), indicating that the fertility recovery processes in rocky slope are differ from the ones in loess deposits.

4.2.3 Tilled treatments

The soil quality properties normalized to determine the RhS in the tilled treatments (I.Tl, O.Tl and O.Ab) were: Herbaceous biomass weighs (HBW), based on the data in Fig. 4.12A, Soil moisture content (SMC) based on the data in Fig. 4.10, soil organic matter of the summer and winter sets (SOMsummer and SOMwinter) based on the data in Fig. 4.11 and the External ants activity coverage (AAC) based on the data in Fig. 4.12B. The soil quality properties were normalized by the outside loess deposits (O.LD) soil quality property’ values. The findings are presented in Fig. 4.22.
Figure 4.22 The normalized soil quality properties of the tilled treatments (I.Tl, O.Tl, O. Ab) between 2012 and 2017

(O.LD: Outside loess deposit, I.LD: Inside loess deposit, I.En: Inside abandoned enclosure)

A- Herbaceous biomass weigh (HBW); B- Soil moisture content (SMC); C- Soil organic matter of the summer sets (SOM\text{summer}); D- Soil organic matter of the winter sets (SOM\text{winter}); E- External ants activity coverage (AAC), all relative to the value of 2012 =100%.

The yearly herbaceous biomass increase of the inside tilled (I.Tl) was 97% of the initial value, similar to the inside loess deposit landform (I.LD). The abandoned (O.Ab) biomass increased by 30% and the outside tilled (O.Tl) by only 9% per year. The SMC annual increase in the I.Tl was 11%, twice higher than in the I.LD, which was 5.5%. In the O.Ab the yearly increase was 7% and in the O.Tl a decrease of 1.5% per year was calculated. The yearly SOM change of the summer sets was 2% for the I.Tl and O.Ab cultivations, while 0.6% change for the O.Tl was calculated. For the summer sets, the
O.Ab SOM increased annually by 1.5%. The I.Tl and O.Tl had less than 0.6% increase with high variability.

The AAC of the O.Ab was lower compared to the outside loess deposit (O.LD) taken as reference until the 3-4 years from study start. The AAC of the O.Tl and I.Tl were observed from 2015 and increased in 2016 and 2017 by 82 and 50% of the initial value per year, respectively, therefore it was not analyzed.

The time durations for rehabilitation, reaching the soil properties values of the abandoned ruminant enclosure (O.Ab), for the tilled treatments are given in Table 4.18.

**Table 4.18 The tilled treatments normalization data (correlations, significances and rehabilitation time durations until rehabilitation).**

<table>
<thead>
<tr>
<th></th>
<th>Change [%]</th>
<th>$R^2$</th>
<th>Duration estimation [years]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inside Tilled (I.Tl):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HBW</td>
<td>97.4</td>
<td>0.85</td>
<td>6-7</td>
</tr>
<tr>
<td>SMC</td>
<td>11.1</td>
<td>0.3</td>
<td>4-5</td>
</tr>
<tr>
<td>SOM (summer)</td>
<td>2.8</td>
<td>0.4</td>
<td>89-90</td>
</tr>
<tr>
<td>SOM (winter)</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>No rehabilitation</td>
</tr>
<tr>
<td>AAC</td>
<td>y = 50.8x - 100</td>
<td>$R^2$=0.72</td>
<td>*</td>
</tr>
<tr>
<td>* From last tillage, 2- years until O.LD state, than 20-21 years until I.En state</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Outside Tilled (O.Tl):</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HBW</td>
<td>9.2</td>
<td>&lt;0.1</td>
<td>67-68</td>
</tr>
<tr>
<td>SMC</td>
<td>-1.4</td>
<td>&lt;0.1</td>
<td>Degradation</td>
</tr>
<tr>
<td>SOM (summer)</td>
<td>0.6</td>
<td>&lt;0.1</td>
<td>No rehabilitation</td>
</tr>
<tr>
<td>SOM (winter)</td>
<td>0.6</td>
<td>&lt;0.1</td>
<td>No rehabilitation</td>
</tr>
<tr>
<td>* From last tillage, 2- years until O.LD state, than 11-12 years until I.En state</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Outside Abandoned (O.Ab)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HBW</td>
<td>29.9</td>
<td>0.65</td>
<td>21-22</td>
</tr>
<tr>
<td>SMC</td>
<td>7.0</td>
<td>&lt;0.1</td>
<td>10-11</td>
</tr>
<tr>
<td>SOM (summer)</td>
<td>2.2</td>
<td>0.3</td>
<td>83-84</td>
</tr>
<tr>
<td>SOM (winter)</td>
<td>1.5</td>
<td>&lt;0.1</td>
<td>*</td>
</tr>
<tr>
<td>AAC</td>
<td>26.2</td>
<td>0.5</td>
<td>**</td>
</tr>
<tr>
<td>* From last tillage, 2- years until O.LD state, then 100&gt; years until I.En state</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>** From last tillage, 4- years until O.LD state, than 41-42 years until I.En state</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(O.LD: Outside loess deposit, I.LD: Inside loess deposit, I.En: Inside abandoned enclosure)

*Rehabilitation lower than 1% was defined as 'No rehabilitation' and negative one as 'Degradation'
(HBW- Herbaceous biomass weigh; SMC- Soil moisture content (SMC); SOM- Soil organic matter of the summer sets (SOMsummer) or winter sets (SOMwinter); AAC- External ants activity coverage (AAC)).

The herbaceous biomass demonstrates a relatively short duration to rehabilitation to the abandoned ruminant enclosure- I.En state, in the inside tilled plots. In addition, the time duration to rehabilitation regarding the SMC is also short. Nevertheless, the SOM had a very long expected rehabilitation time, or no rehabilitation at all, primarily caused by rapid SOM oxidation during winter - back to the basal state (Table 4.18). The comparison of the related RhS values of the outside tilled plot (O.Tl) may deduced by influence of the conservation on RS, which is less correlated to the SOM, on the area productivity. The area demonstrated rehabilitated longer with respect to SMC and HBW factors, compared to the I.LD. Nevertheless, their duration was faster compared to the O.Tl (Table 4.18).

4.2.4 Dammed limans

The soil quality properties that normalized in order to determine the RS in the dammed limans (Limans 2-3, 4-5, 14-15) were as follows: herbaceous biomass weighs- HBW (based on the data in Fig. 4.18A), soil moisture content- SMC (based on the data in Fig. 4.16), soil organic matter of the summer and winter sets- SOMsummer and SOMwinter (based on the data in Fig. 4.17) and the External ants activity coverage- AAC (based on the data in Fig. 4.18B). The soil quality properties were normalized by the O.LD soil quality properties' values. The following dammed limans were analyzed, Limans 2:3- Inside, planted and embedded in un-cultivated area, Limans 4:5- Outside, bare and embedded in un-cultivated area, Limans 14-15: Inside, planted and embedded in tilled area. The findings are presented in Fig. 4.23.
Figure 4.23 The normalized soil quality properties of the dammed limans (Limans 1-2, Limans 3-4 and limans 14-15) between 2012 and 2017

O.LD: Outside loess deposit, I.LD: Inside loess deposit, I.En: Inside abandoned ruminant enclosure

A- Herbaceous biomass weigh (HBW); B- Soil moisture content (SMC); C- Soil organic matter of the summer sets (SOM\textsubscript{summer}); D- Soil organic matter of the winter sets (SOM\textsubscript{winter}).

The highest herbaceous biomass yearly increase (H.BW) was observed in limans 14-15 then in limans 2-3 and was the lowest in limans 4-5 (114, 71 and 7% annual increase, respectively, Fig. 4.21A). Similar trends were calculated for the winter Soil Moisture Content- SMC showing 27, 21 and 13% yearly increase respectively, Fig. 21B, and for the summer SOM (8, 6 and 3%, respectively). The changes of the winter SOM sets were similar among the limans groups and equal to 1% per year. The increase in Limans 4-5 was 2%, but was inconsistent in the course of the study.

The number of years needed for the soil fertility properties to increase from the O.LD values (start point) to the I.En calculated from the rehabilitation intensity of the limans groups is presented in Table 4.19.

As the liman plots are designed to harvest both water as well as running of resources, we expect and notice that several properties will likely exceed the values observed in the I.En plot thanks to higher water availability, an effect that will be further enhanced by contributions of trees.
Table 4.19 The dammed limans normalization data (correlations, significances and time durations until rehabilitation).

<table>
<thead>
<tr>
<th>Change [%]</th>
<th>R²</th>
<th>Rehabilitation duration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Limans 2:3</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HBW</td>
<td>y = 70.6</td>
<td>0.65</td>
</tr>
<tr>
<td>SMC</td>
<td>y = 20.7</td>
<td>0.95</td>
</tr>
<tr>
<td>SOM (summer)</td>
<td>6.0</td>
<td>0.8</td>
</tr>
<tr>
<td>SOM (winter)</td>
<td>1.2</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Limans 4:5</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HBW</td>
<td>6.6</td>
<td>R²&lt;0.1</td>
</tr>
<tr>
<td>SMC</td>
<td>y = 12.5</td>
<td>R²=0.55</td>
</tr>
<tr>
<td>SOM (summer)</td>
<td>y = 3.0</td>
<td>R²=0.4</td>
</tr>
<tr>
<td>SOM (winter)</td>
<td>y = 2.0</td>
<td>R²=-0.1</td>
</tr>
</tbody>
</table>

*inconstant increase of 2% per year

| **Limans 14:15** |       |                         |
| HBW        | 114.7  | R²=0.85 | 6-7 years |
| SMC        | 26.6   | R²=0.9  | 3-4 years |
| SOM (summer) | 8.2    | R²=0.15 | 31-32 years |
| SOM (winter) | 1.0    | R²<0.1  | No rehabilitation |

*Rehabilitation duration lower than 1% was defined as 'No rehabilitation'

(HBW- Herbaceous biomass weigh; SMC- Soil moisture content; SOM- Soil organic matter of the summer sets (SOMsummer) or winter sets (SOMwinter); AAC- External ants activity coverage (AAC)).

The rehabilitation durations of Limans 14-15 to the I. En plot were the shortest ones observed in the analyzed dammed limans groups. The longest rehabilitation period was expected for heavily grazed and un-planted limans 4-5. The rehabilitation duration to full achievable productivity of herbaceous biomass in limans 14-15 was not predictable. Though apparently similar to that of the the inside loess deposit, it was characterized by a drastic increase in rehabilitation rate from the fourth year of the study after irrigation of the planted trees was stopped, and surpassed the high productivity of I.En after 5 years.
4.3 The effects of harvester ants on rehabilitation of cultivated areas

Three complementary analyses were performed to determine the influence of harvester ant activity on soil and fertility rehabilitation: analysis of nest impact on nutrients pools, analysis of soil changes in nested areas to determine the rehabilitation rate, and an analysis to determine the influence of harvester ant activity on the soil fertility of their surrounding areas.

4.3.1 Harvester ant nest functioning as nutrients pools

We analyzed the interrelations between harvester ant activity and the soil fertility in different landforms (rocky slope and loess deposits) and cultivations (grazing intensities, tillage) in PWA. For this propose, two analyses were implemented: one aimed to determine the nest functioning on nutrients content and the second aimed to determine the effect of nests on land rehabilitation state (RS).

The first analysis is based on detailed nutrient content analysis from nests located in the inside and outside rocky slopes (I.RS and O.RS) compared to bare soil areas (matrix) and Anabasis sp. patches. Four nests each were randomly selected from the I.RS and O.RS. From each nest, a mix of soil was taken from the central unit, which is the area surrounding the main nest hole, and one sample, from the nests edges. In addition, four replicates were taken from the matrix and shrub patches. The sampling was carried out at in 7/2016. An Illustration for the rocky slope sampling scheme is presented in Fig. 4.22. Several soil fertility parameters were analyzed, including Nitrate (N-NO$_3$), Ammonium (N-NH$_4$), Phosphate (P-PO$_3$) and Potassium (K) based on the procedures described in section 3.3. The SOM content was analyzed by burning at 500°C for 5 hours.

In order to determine the influence of harvester ants' nests on the pH and EC an additional analysis was implemented in 7/2016 on loess area outside PWA in eight soil samples from nested and bare areas. The analysis was carried out on a mix of soil taken from surface until 15cm depth.
The soil samples were taken to the Lab and analyzed based on Sparks (1996) protocols.

**Nitrate**

The nitrate contents of the inside and outside rocky slope units together with statistical significance are presented in Fig. 4.25. The letters represent significant differences between sub-parts of the analyzed rocky slope and the asterisk represents significant difference between the rocky slopes for the analyzed unit.

Generally the nest units had higher nitrate content compared to the matrix for both rocky slopes. Nevertheless only the nests central part in both rocky slopes was significantly higher when compared to the other part. In addition, the nitrate content of the nest central unit in the I.RS was significantly higher compared to the O.RS. The Nitrate values found in the *Anabasis sp.* patches were lower than the ones in the nests central units and were similar to the nest edges.
Figure 4.2 Mean nitrate (N-NO$_3$) content of the rocky slope units, 7/2016 [mg Kg$^{-1}$]

Rocky slopes: O.RS- Outside rocky slope, I.RS- Inside rocky slope, 4 replicates per each measurement

Units: Mat- matrix, Nst.Cen- Nest center, Nst.Edg-Nest edges, *Anabasis sp.*- Anabasis sp. patches

Error bars± SE. Significance ($\alpha=0.1$), Letters above columns represent significance grade a- high grade, b-low grade (un labeled columns- not significant).

Significance data for the O.RS units- $F=3.1$, Prob>F=0.9, I.RS units- $F=2.8$, Prob>F=0.09, significance data the differences between the nests central units of the rocky slope $F=6.6$, Prob>F=0.06

**Ammonia**

The ammonia content of the inside and outside rocky slopes units is presented in Fig. 4.26.
Figure 4.26 The mean ammonia (N-NH$_4$) content of the rocky slope units, 7/2016 [mg Kg$^{-1}$]

Rocky slopes: O.RS- Outside rocky slope, I.RS- Inside rocky slope
units: Mat- matrix, Nst.Cen- Nest center, Nst.Edg-Nests edges, *Anabasis sp.*- *Anabasis* *sp.* patches, 4 replicates per each measurement

Lines on columns $\pm$ SE. Differences were not significant

In both rocky slope units (I.RS and O.RS) the lowest ammonia contents were found in the matrixes and the highest ones in the nest centers. In both rocky slopes, the ammonia content of the nests central units were higher compared to the edges values. The ammonia content in the central nest unit of the I.RS was higher when compared to the O.RS. However, only in the I.RS central area the ammonia content is significantly higher than in all other areas sampled.

**Phosphate**

The Phosphate contents of the inside and outside rocky slopes units are presented, together with their significance analysis in Fig. 4.27.
Figure 4.27 The mean phosphate (P-PO₃) content of the rocky slopes units 7/2016 [mg Kg⁻¹]

Rocky slopes: O.RS- Outside rocky slope, I.RS- Inside rocky slope

Units: Mat- matrix, Nst.Cen- Nest center, NstEdg- Nests edges, Anabasis sp. - Anabasis sp. patches, 4 replicates per each measurement

Error bars- ±SE. Significance for I.RS (α=0.1), a- high grade, b-low grade, F=5.95, Prob>F=0.01 (un labeled columns- not significant).

In both rocky slope units (I.RS and O.RS) the lowest phosphate contents were found in the matrixes and the highest ones in the nests. The Phosphate content of the central nests were significantly higher compared to the edge values in the I.RS. the phosphate concentration at the nests edges of I.RS were significantly higher than the matrix. Both nests parts (center and edges) had much higher Phosphate content in the I.RS compared to the O.RS. The phosphate content of the ORS nest plots was not significantly higher than that of the matrix. However, phosphate concentrations in patches were significantly higher both in I.RS and in O.RS, indicating the importance of perennial plant patches on the phosphorous cycle.

Potassium

The Potassium content of the inside and outside rocky slopes parts is presented in Fig. 4.28.
The lowest potassium contents were found in the matrices, while the highest in the nests. In addition, similar Potassium content was found in nests units, nevertheless the differences in all comparisons were not judged as significant. The Potassium content in the nests central unit of the I.RS was higher compared to the O.RS.

Figure 4.28 The mean potassium (K) content of the rocky slopes units 7/2016 [mg Kg\(^{-1}\)]


Rocky slopes: O.RS- Outside rocky slope, I.RS- Inside rocky slope, 4 replicates per each measurement

Error bars- ±SE. Differences were not significant

SOM

The Soil Organic Matter (SOM) of the inside and outside rocky slopes units and the significance analysis of the differences between rock grounds units are presented in Fig. 4.29.
Figure 4.29 The mean content of soil organic matter in the rocky slopes units 7/2016 [mg Kg⁻¹]

Rocky slopes: O.RS- Outside rocky slope, I.RS- Inside rocky slope

Units: Mat- matrix, Nst.Cen- Nest center, Nst.Edg- Nest edge, Anabsis sp.- Anabasis sp. patches, 4 replicates per each measurement

Error bars- ±SE. Significant analysis data (α=0.1), a- first significance grade, b- second significance grade, c- third significant grade, F=13.7, Prob>F=0.0004. (unlabeled columns- no significant).

The biogenic patches (nests and shrubs) of the outside rocky slope (O.RS) have similar SOM content, which was high compared to the matrix. The I.RS nests units had higher SOM values compared to the O.RS. In the I.RS the nests units had significantly higher SOM values compared to the matrix. The SOM content of the central unit was significantly higher compared to the ‘edges’ units. In addition, similar fertility contents were found in abandoned nests and those re-settled by termites in other locations in PWA. This confirms the long-term influence of the harvester ants nesting activity on soil nutrient cycling and mobilization (Jouquet et al., 2011) contributing to rapid restoration of degraded arid dryland areas (Mor-Mussery et al 2014a)

pH and EC

In addition to the nutrients content, the pH and EC inside nests compared to adjacent bare loess area were measured. The findings presented in Table 4.20.
Table 4.2 The mean salinity and acidity of nests and bare area in PWA, 12/2017

<table>
<thead>
<tr>
<th></th>
<th>Nests</th>
<th>Un nested</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.9(0.04)*</td>
<td>6.29(0.03)</td>
</tr>
<tr>
<td>EC (mv)</td>
<td>97.5(4.2)*</td>
<td>120.9(3.6)</td>
</tr>
</tbody>
</table>

*Significant difference (Alpha=0.1): EC- F=16.4, Prob>F= 0.002; pH- F=51.25, Prob>F= <0.0001

6 replicates per each measurement

From Table 4.20 it easily observed that the ant nests reduce the soil salinity and create more acid soil environment, which is essential for mobilizing essential nutrients into biomass, e.g. iron (Baligar et al. 2001).

**Nest influence on nutrient pools of PWA**

The nutrients content in the different nests units were higher compared to their matrix unit. The differences were mostly judged as significant in spite of small sampling numbers. The nutrient contents in the outside rocky slope (O.RS) were mostly lower compared to the I.RS. The overall nutrient contents of the soil samples taken from the nest units and the ones from *Anabesis sp.* patches were similar.

In order to determine the nest influence on the nutrient pools of PWA area, the nutrients values of the nests central and edges units were averaged and this value was normalized by the un-nested area, the matrix in the case of the rocky slope and the adjacent bare area in the case of the pH and EC analyses, Fig. 4.30.

The nutrients that were mostly influenced from the ants' activity are the Phosphate and Nitrogen compounds (Nitrate and Ammonia). The change for these nutrients was much higher in the inside rocky slope (I.RS) compared to the outside one, a 15 fold change in the I.RS compared to 5 in the O.RS). The SOM and Potassium demonstrate similar fertility changes in the nests for both rocky slope plots.
4.3.2 Changes in nested area as tool to determine rehabilitation

This analysis is based on the micro-topographical changes of the nested area coverage between 2012 and 2017 in PWA treatments. The external ants activity coverage (AAC) values were normalized by the values of the outside loess deposit (O.LD) for the inside loess deposit and the tilled treatments, while the values of the Inside rocky slope (I.RS) were normalized by the rocky slope (O.RS). Nevertheless, as opposed to the analyses demonstrated in section 4.2 the normalization calculation here is based on reducing the values of the reference plots.

In the inside and outside tilled plots between 2012 and 2014 no nesting activity was observed so the analysis was implemented using the data from 2015-2017. In order to correlate the harvester ants nesting activity changes with the overall soil property evolution, the values of the herbaceous biomass weight (HBW) were added. The findings are demonstrated in Fig. 4.31
Both factors, the herbaceous biomass weigh (HBW) and External ants' activity (AAC) demonstrates in general similar changes trends for all treatments. Nevertheless, two exceptions can be observed in the inside tilled plots (I.Tl) and the inside loess deposit plots (I.LD). In the I.Tl the yearly change of the AAC is as third from the HBW. This change can be explained by the damage to the nests due to tillage. In the I.LD plots as 25% higher yearly change was calculated for the AAC. Altogether, the nested area grows steadily and relatively high in all studied treatments, except the tilled one, even when compared to the HBW.

4.3.3 The influence of harvester ants on the soil fertility of their surrounding

Several methodologies were used to determine the influence of harvester ants activity on treatment fertility. Four loess deposit plots were chosen (Table 2.2). The External Ants Activity Coverage (AAC) of a given year for each plot was intersected with the soil fertility property of the next year. Two separate sets were defined; the AAC measured for all loess deposit plots in 2014 vs. the soil fertility properties of 2015 and the AAC of 2015 vs. the soil fertility of 2016.
The correlation between the AAC values of the rocky slopes and the soil quality properties were analyzed differentially from the one of the inside loess deposit plots, as only two plots represent the rocky slope- the outside rocky slope (O.RS) and inside rocky slope (I.RS). The AAC of these plots was intersected with their relevant soil fertility properties between 2015 and 2017 as one set.

Loess deposits
The intersection of the AAC of the loess deposits plots with their fertility properties of the next year (Soil moisture content, Infiltrability, Soil organic matter and Herbaceous biomass weight) is presented in Fig. 4.32.

Figure 4.32 The interactions between the External ants activity coverage (AAC) in 2015 and the soil fertility properties in 2016 of the loess deposits treatments
AAC- External ants’ activity coverage, SOM- Soil organic matter, SMC- Soil moisture content, HBW- Herbaceous biomass weight
A- The correlation to the SMC; B- The correlation to the infiltrability; C- The correlation of the AAC to the SOM; D- The correlation to the HBW
In the loess deposit treatments group, the tightest correlations were found between AAC and their landform water holding capacity properties (SMC and Infilterability) and SOM (all $r^2 = 0.85-0.99$). Although the correlation between the AAC and the herbaceous biomass were loser, a positive correlation can be observed.

The correlation between the AAC and the loess deposits nutrients is presented in Fig. 4.33.

![Figure 4.33](image)

**Figure 4.33 The interactions between the External Ants Activity Coverage in 2015 and the soil nutrient contents in 2016 of the loess deposits treatments**

A- The correlation with Nitrate; B- The correlation with Ammonia; C- The correlation with Phosphate; D- The correlation with Potassium

In the loess deposit landform, all the nutrients have positive and tight correlations between them and the AAC of the previous year. Nevertheless the tightest correlations were found between the phosphorus and ammonia ($r^2 = -0.95$). Similar correlations were found between the AAC of 2014 and the soil properties of 2015.

**Rocky slope**

The intersection results between the AAC of the rocky slope plots and their fertility properties in the same year (Soil moisture content, Infilterability, Soil organic matter and Herbaceous biomass weight) are presented in Fig. 4.34
The interactions between the External ants activity coverage in 2015 and the soil fertility properties in 2016 of the rocky slopes

AAC- External ants activity coverage, SOM- Soil organic matter, SMC- Soil moisture content, HBW- Herbaceous biomass weigh

A- The correlation of the AAC to the SMC; B- The correlation of the AAC to the infiltrability; C- The correlation of the AAC to the SOM; D- The correlation of the AAC to the HBW

Although the different methodologies used for the loess deposits analyses, similar correlations were found between the AAC and the rocky slopes fertility properties (SMC, Infiltrability, and HBW). Among all the soil fertility properties, those of the water balance have the tightest correlation with the AAC.

Tilled plots

Between 2012 and 2014 no nest activity was observed in the tilled plots (except for the abandoned one). In order to study potential effects of other ants' activities, we analyzed together with the AAC the ants foraging effects, which has not been studied well hitherto (Wagner et al., 2004). Four tilled plots located inside the farms were defined in 7/2017: North-West (I.T.L.NW), North-East (I.T.L.NE), South-East (I.T.L.SE) and South-West (I.T.L.SW), Table 2.2. These plots were similarly managed PWA establishment. The plots were separated by 6-8 m unpaved ways to prevent foraging between studied plots.
Fig. 4.35 The correlations between SOM and the External ants activity Coverage and the active nests density of the inside tilled plots (7/2017)

SOM- Soil organic matter

Fig. 4.35A demonstrates negative relation between SOM and the External ants' activity coverage (AAC). Admittedly, the AAC values and the differences among the plots were small. Additionally, wide part from the AAC in these plots was calculated based on highly distributed holes. Therefore the AAC here in the tilled plots may not be correlated with an influence on fertility. However, SOM is related to the number of nested holes (Fig. 4.35B), better representing the influence of harvester ants foraging on soil fertility.
5. Discussion

The study is novel in both the width, depth and detail of analysis undertaken in a well-defined study site in the Negev. The novelty uniqueness is summarized as follows:

(i) Determining several mechanisms or “ecosystem engineers” participating in rapid rehabilitation of degraded drylands, and how those mechanisms may be inhibited by the current state of art management methods;

(ii) Providing a clear order of events leading to soil rehabilitation, starting with enhanced water infiltration and soil moisture, to rapid increase in annual herbaceous plant productivity, leading to slowly increasing SOM and soil nutrient pools, supported by rapidly expanding biodiversity;

(iii) Describing in detail the profound impact of harvester ant nests on soil recovery correlated with increased annual biomass production, and demonstrating that this mechanism seems far superior to the often claimed shrub patch mechanism;

(iv) Providing detailed, double-controlled normalization of achievable rainfed annual herbaceous above ground productivity and its increase with ongoing rehabilitation;

(v) Describing in detail the transition from a patchy degraded shrubland into a closed homogenous, species-rich grassland as a consequence of conservation at the border between an arid and a semi-arid climate zone, accompanied by massive gains in soil carbon sequestration and biological productivity to rates hitherto not reported in the Negev.

(vi) The underlying mechanisms dealing with the temporal change in soil moisture content;

(vii) The speed and rate of soil carbon sequestration into recovering dryland soils as an important tool towards fighting global warming and the interdisciplinary data assessments performed in the large scale, long-term controlled conditions proving that adequate dryland restoration approaches will successfully address all three UN conventions and most sustainable development goals. These aspects are hereafter reviewed.
5.1 General findings and rehabilitation mechanisms of arid cultivated areas

Three mechanisms of possible RhS changes for degraded arid lands have been suggested: unchanged, further degraded or rehabilitated (Mor-Mussery et al., 2014b). These mechanisms are built on previous empirical studies that analyzed the soil quality changes and productivity of long-term cultivated arid lands in the northern Negev (Leu et al., 2014) or correlated with NDVI (Hellman et al. 2014). These studies indicate that where 3 – 10 fold productivity increases, and 50 – 100% increases in SOM were observed after 18 – 20 years of regime change, including grazing control, manure application, or afforestation by A. victoriae (Mor Mussery et al 2013), in China (Zha and Gao, 1997) and in Africa (Stringer et al., 2009). As opposed to these studies, here we aimed to study the dynamics and mechanisms of soil quality changes in the initial stage and during the first five years from implementation and their influences on the rehabilitation state.

5.1.1 Core rehabilitation mechanisms of arid areas in PWA study

The mechanisms of RhS changes in rangelands and tillage cultivations in different landforms are presented in Fig. 5.1.

In general, the values of all the soil quality and biological activity properties increased or did not change in all PWA treatments during the study period (section 4.1). Within this general trend, two specific groups of treatments can be defined: those with minimal or insignificant RhS, those resembling the gradually rehabilitation mechanism and those resembling a further degradation mechanism.

Treatments with minimal or insignificant RS

All treatments outside the farm fences were exposed to overgrazing and intense tillage, as expressed by the vegetation state during the study period and were characterized by maximal 10% of gross change of their soil quality properties (soil moisture content, soil organic matter and nutrients content) and net changes of less than 5%. The herbaceous biomass weight changes for these treatments varied as much as 30% per year (section 4.2). Similar trends were also described in continuous rain fed cereal-cultivated fields in the northern Negev (Stavi et al., 2015) as well as in the semiarid rangelands of Colorado (Burke et al., 1995).
Figure 5.1 A schematic representation of the major degradation and rehabilitation mechanisms in arid lands

This scheme represents the three mechanisms of rehabilitation in arid cultivated lands. The common state is continuation of the used practices, which leads to un-changed state. The gradually rehabilitated mechanism is caused by implementation of conservation practices and the further degradation mechanism is caused by implementation of massive soil disturbance practices that increase the degradation state. The arrow on the right represents factors that may enhance the rehabilitation process. Mechanisms written in black have been previously described by Mor-Mussery et al. (2014a); the ones in red were identified in this study (will be further described)

Treatments that resemble the gradual rehabilitation mechanism

As opposed to the outside treatments, for inside the SOM and nutrients treatments increased consistently and continuously by 10% per year; the herbaceous biomass increased by 50 - 100% of the initial annual value (section 4.2.1 and 4.2.3). In the inside
treatments, the maximal soil moisture content reached 15% after 3-5 years from initiation, equal to the field capacity values of loess soils in the Negev. These findings are strengthened by Bonet and Pausas (2004) a gradual rehabilitation mechanism in abandoned and rainfed grain fields in Spain by the term "secondary succession", based on a 60-yr Chrono sequence (Ward et al., 2001). These data are in good agreement with the estimated rehabilitation rates observed by in this study and colleagues in the empirical studies listed above and may therefore, be considered as benchmarks for ecosystem responses to certain regime changes as confirmed by an experimental large-scale and detailed assessment. The properties of biological activity of inside treatments demonstrate a similar trend as those of soil quality properties (section 4.3) as described on isopod hole density in an ecological transect between conserved and degraded plots (Mor-Mussery et al., 2014). The ongoing increase of soil fertility and biological activity of these plots represents the continuation of the rehabilitation mechanism.

**Further degraded mechanism**

Several heavily grazed limans located outside the PWA constructed by massive landform design (re-modelling); they demonstrated negative RS of their soil quality properties compared to the reference plot. For example, a 10% reduced herbaceous biomass weight was observed in these plots. These findings indicate the "further degradation" mechanism especially associated with massive soil movement or deep tilling, thereby destroying the essential soil structure integrity by mixing of the O,A,B,C,D horizons (PMamo, 2013). This further degradation mechanism was also found to occur in the Chiran contour trenching area (Mor-Mussery et al., 2013; Helman et al., 2015) and was expressed by a decrease of 15% of the herbaceous biomass and SOM by 20-30% compared to the heavily grazed degraded rangeland (Leu et al., 2014). This degradation mechanism has been demonstrated on a massive land interruption, such as intense tillage or soil re-modelled landforms in the Chinese loess plateau (Zhang et al., 2001).

**Treatments that resemble the restored/ sustainable state**

Lal (2006) defines restored land as land with "enhanced soil quality and agronomic productivity per unit area". Here the term: "agronomic productivity" collectively relates
to herbaceous biomass production without separation between the optional grains breeding or pasture utilization. Li et al. (2009) claim that the potential utilization of the different rainfed cultivations has high influence on the land conservation state.

Between 2012 and 2018, the abandoned small ruminants enclosure (I.En) displayed several fold higher herbaceous biomass production (Fig. 4.3), soil fertility (e.g. SMC, SOM, nutrients, infilterability) and biological activity in comparison to the other treatments (section 4.1.1). In addition, analysis of the herbaceous biomass values of the I.En demonstrates relatively low differences and correlation with rainfall patterns (Table 5.2), characteristics that were previously described in abandoned enclosures located in Amboseli ecosystem (southern Kenya) and carried out on soil quality parameters such as nutrients and species richness (Muchiru et al., 2008).

In conclusion, the relatively constant soil quality values of the abandoned enclosure and the high difference when compared to the ones in the other treatments, although the different ratios, justify its definition as restored treatment with maximal achievement values. Its soil fertility values can be used as the target for the rehabilitation processes.

There are additional productive cultivation practices, additional to the abandoned small ruminant enclosure. As example, the effect of ”conservation” state in the Chiran A. victoriae woodland rangelands on soil fertility parameters (herbaceous biomass and SOM) were seemingly higher compared to the influence of the A. victoriae litter on the common cultivation, degraded rangeland (Helman et al., (2014; Mor-Mussery et al., 2014a).

In summary, three basic RhS mechanisms resembling the conserved state have been observed also in PWA treatments. In order to define the specific rehabilitation mechanisms of PWA, we identified the interrelations between soil quality properties and the rehabilitation mechanisms.

5.1.2 Interrelations between the soil quality properties and the rehabilitation of the area

Different soil quality parameters relationships are being affected by each other until reaching a threshold. This state has been described by Karlen et al. (1997) as follows: "The soil resource must be recognized as a dynamic living system that emerges through
a unique balance and interaction of its biological, chemical, and physical components”. An area with continuously increasing threshold of soil quality properties represents a system in rehabilitation mode, while one, with a decreasing threshold during a period of years is being degraded (Fig. 5.1). In order to determine the most influential soil quality property affects the RhS in PWA and similar areas, their changes during the study were compared.

**Vegetation cover**

The soil quality property, which demonstrated the highest and fastest change along the years was the herbaceous biomass - HBW (e.g. 97% normalized change of productivity per year for the inside loess deposits (I.LD) and inside tilled cultivation (I.Tl), 47% for the inside rocky slope (I.RS) and 29.9% for the abandoned area outside of the fence (O.Ab), section 4.2). Similar recovery rates were found, also in previous studies. Helman et al., (2014) found HBW changes by 50%-150%, in a 20 years partly conserved area compared to an excessively overgrazed control plot (Helman et al. (2014); Leu et al. (2014); Mor Mussery et al. (2014)). The SOM increased by around 25% from 3.5 – 4.5%. Tessema et al., (2011) found a change of 7 fold of the HBW vs. only 2% of SOM after 10 years of grazing intensity' reduction in the Ethiopian rangelands. The high change of the vegetal cover relative to the other soil quality properties can be explained by multi sub-mechanism changes caused by interaction and synergism between the other soil quality properties as described by Carter (2002). The increased vegetal cover alone changes the soil quality properties by supplying shading (Givnish, 1998), soil loosening expressed by higher infiltrability as described by Angers and Caron (1998): "By penetrating the soil, the roots form macro-pores which favor fluid transport"); SOM and nutrients supply by plant root decompensation (Wardle et al., 2004); litter and plant roots supply nutrients and can rehabilitate soil and the biogenic crust (Kinast et al., 2016). Austin et al. (2004) claim that in arid areas the influence of the vegetation spatial patterns became more crucial for the soil biogenic system functioning due to its relative high stability to the episodic rainfall patterns, compared to the SOM and nutrients.

**SMC (Soil Moisture Content)**

The soil moisture content – SMC in the winter sets of most of the treatments demonstrated linear increase from the cultivations implementation until a constant
value, which was achieved in the third to fifth year, remaining constant after that (e.g. inside loess deposit- I.LD and abandoned enclosure-I.En, Fig. 4.18; Inside tilled- I.Tl, Fig. 4.20; limans, Fig. 4.21). This type of change based on in-field data strengthen the theoretical mechanism suggested by Jensen and Allen (2016), as follows. Until the minimal thresholds in soil nutrient contents, infiltration, seed availability etc. are achieved, much of the soil moisture evaporated through direct solar radiation exposure on bare soil patches, while after exceeding the required thresholds any of the excess moisture will be used for increasing vegetation growth and evapotranspiration from the plants thanks to saturating penetration of the topsoil by plant roots (Jensen and Allen, 2016).

**SOM and nutrients**

Most of the nutrients molecules chemically interact with the SOM (Olk, 2006), therefore here they will be referred to together. In the wet seasons the values were low, while increasing in the dry seasons. The changes were noticeable mainly in the first 3-4 years after cultivations implementation. A possible explanation for these changes was proposed by Austin et al. (2004), which claim that these differences are caused by changes in soil microbial activity, that correlate to the water availability in soil. In the later years (4-6), the difference between the summer and winter sets were reduced, compared to the first 3 years. This change is explained by accumulation of stabilized SOM as described previously by Six et al. (2002) on grasslands. Still, the accurate differences are nevertheless correlated to the climate patterns of the year and their extremes, as the values seen in the 2016 winter-spring seasons (Fig. 4.2, 4.6, 4.11, 4.17).

In summary, the threshold changes between the vegetal cover and the soil moisture is the basis for the different rehabilitation schemes in PWA. Findings that are strengthened by Verdoott et al. (2010) claimed that: "The rehabilitation generally starts from relict vegetation". Therefore, the vegetation productivity and the water holding capacity can be considered as "enhancers for restoring degraded lands" (Fig. 5.1).
5.2 Main mechanisms of ecosystem rehabilitation in PWA

5.2.1 Rehabilitation mechanism of conservation

The changes of the soil quality properties along the study in PWA treatments reflect a combination of specific rehabilitation mechanisms. These mechanisms can be divided into the following groups: management methods, e.g. conservation from grazing and tillage, patchy mechanisms caused by ecosystem engineers, and landform mechanisms caused by sloped areas and limans.

Conservation from grazing can prevent repressive factors on vegetation growth. The highest influence occurs due to the prevention of excessive flora removal and increasing the seedbank. This enriches the soil with litter, and thickens the O layer, as described in the Chiran rangelands by Leu et al. (2014). The lack of trampling by animals reduces the soil compaction and enhances the infiltration into the plants roots zone, enhancing germination (Descroix et al., 2001). The lack of flora harvesting and trampling also enhanced infiltrability (Table 4.2, 4.7, 4.11) and water holding capacities as expressed in the conserved treatments (Fig. 4.1, 4.5, 4.10) and encourages the bio-genic crust development, a phenomenon described by Eldridge et al. (2000) in its experimental study in the Negev. These influences, as Belnap et al. (2001) describe, enhance mutually positive, “Win-Win” interactions between different factors to increase vegetation growth.

In summary, the conservation interventions at PWA continuously increased the herbaceous biomass and as a result, the other soil fertility parameters, and its concluding expression is land rehabilitation.

5.2.3 Rehabilitation mechanism in PWA' tilled treatments

Most of the previous studies claimed that tillage reduces the soil fertility. As example Guo and Gifford (2002) found after using meta-analysis of 97 observations from different studies that cultivation changes from rangeland into crop field (using tillage) reduced the C$_{\text{Organic}}$ by 60%. The negative influences of tillage are correlated to SOM and nutrients oxidation, as modelled by Peigné et al. (2007). The influence on soil compaction in the traction path and underneath the tilled layer was reviewed by Mor-Mussery et al., (2016) and the soil abrasion was studied by Swanson (1993) using...
different tillers. Here, in contrast to former studies we observed increased fertility values in the tilled treatments inside the farm, although temporal decreases of the soil quality properties were measured after each tillage event (see section 1.3), with the most noticeable change observed in the HBW with net increase of 97% per year see Fig. 4.12. In order to determine the rehabilitation mechanism involved in the tilled treatments inside the PWA farm, their patterns have to be studied compared to the classical tillage scheme, which were characterized by Guo and Gifford (2002), Peigné et al. (2007), Lal (2004a) and many other studies. In parts of the tillage patterns of PWA the tilled plots were similar to the classical scheme as the tillers patterns and tillage depth. However, they differ from the other tilled fields in the surrounded areas exposed to grazing due to the conservation from grazing, reduced tillage events intensity and fallow handling.

a. The conservation influence on the rehabilitation mechanism of the tilled plots
In spite the tillage, the conservation from grazing contributed to partial rehabilitation, as expressed by increased soil quality properties of the inside plots (I.Tl) compared to the outside ones (O.Tl), assuming that the tillage intensities of both groups were similar (section 4.1.3). The rehabilitation mechanisms are possibly the same that affect the loess deposit and the rocky slope landforms that were described previously.

b. The tillage intensity influence on the rehabilitation mechanism of the tilled plots
Three tillage sets were implemented during the study (between 2012 and 2017). Between subsequent tillage sets the soil was not cultivated for one or two years. Halvorson et al. (2002) found in their study in Ohio that reduced tillage intensity decreased the bulk density, which resulted in increased water holding capacities and increasing SOM. Tebrügge and Düring (1999) describe the positive influence of reduced tillage on soil stability and reduced erodibility. Castellanos-Navarrete (2012) claim that reduction in tillage intensity, also contributed to enhanced biogenic crust formation.

c. The influence of fallow handling on the rehabilitation mechanism of the tilled plots
The common ways to deal with the left straw are its removal from the field by mechanic collecting or using it as pasture for animals that are moved to the field in the fallow season, a practice described by Rudnitzky and Ras (2012) as the common use in the
traditional farming of Mediterranean area farmers. In PWA, the dry biomass and crop residues were left in the area, as suggested by Leu (1995). Wander (2004) claim that this type of handling increases litter accumulation in the O soil horizon, which resulted in increased SOM amounts in the A soil horizon. This practice, in addition, enhances the biogenic crust formation (Castellanos-Navarrete, 2012), increases the infiltrability and decreases the evapotranspiration (Gholami et al., 2014). These factors contribute to increased yield as found by Nyborg et al. (1995) on rain-fed barley fields.

Collectively these unique patterns of tillage scheme in PWA are possibly the bases of the rehabilitation mechanism found in PWA tilled treatments. However, further study is needed in order to translate it to practical guidelines for the farmers.

5.2.3.1 Rehabilitation mechanism of field abandonment

In the abandoned treatment, outside the farm, additional influences reduced the rehabilitation efficiency compared to the other outside plots (section 4.2.3). PWA findings are similar to the ones of the Chiran area (Helman et al., 2014a). Both present a decrease in the fertility levels similar to degraded areas even five years after tillage. Differences that can be possibly explained by the over grazing in the Chiran area, which was much more intensive compared to the PWA outside area. Besides the reduced fertility, both areas (Chiran and in PWA) suffered from intense incision and enhanced overland erosion even few years after being abandoned. The PWA abandoned area was lastly tilled in 2011 (Fig. 5.2). Similar geomorphological and soil fertility influences have been described previously in Spain by Garcia-Ruiz et al. (2010), China (Lin et al. 2012), and Troiani et al., (2016).
5.2.3 Patchy rehabilitation mechanism of the ecosystem engineers

This rehabilitation mechanism is found in all landform treatments (loess deposits, rocky slopes and limans) inside and outside the farm, initiated by ecosystem engineers, such as shrubs, harvester ant nests and planted savanna trees. In the initial state the rehabilitation mechanism develops concentrically, similar to the one described by Helman et al., (2017) on *Acacia victoriae* trees in the Chiran savanna. In the course of this study, differences were created between the influences of different ecosystem engineers. While in the outside treatment their patchy appearance remained, inside the farm the patches developed into fully recovered grassland areas, Fig. 5.3
Fig. 5.3 The influence of conservation on the patchy rehabilitation mechanism

A- Shrubs outside the farm (O.LD plot) where their patchy shape stayed locally; B-Harvester ants nests that changed their patchy rehabilitation manner into areal recovery during the study

Similar influence patterns of locally vs. fully recovered area, were found over transect between the conserved and degraded plots in the Chiran area (Mor-Mussery et al., 2014a).

In summary, the conservation enhances the patchy rehabilitation mechanism of the ecosystem engineers until full area recovery even in semi-arid to arid climate zones.

5.2.3.1 Rehabilitation mechanism of harvester ants

The influences of harvester ants activity on the soil quality properties of PWA treatments

Previous studies claim that the harvester ants can serve as a reliable indicator for the rehabilitation state of arid areas, all over the globe as studied on mines restoration in Australia (Cristescu et al., 2012), on rangelands, as studied by Mor-Mussery and Budovsky (2017) in the northern Negev and on field crops, as reviewed by Ribas et al., (2012) in Brazil. None of these publications describes the active influence of harvester ants on the rehabilitation state of a given area. Here we demonstrate six ways in which the harvester ants influence the rehabilitation state of the areas. Some of them combined within the patchy rehabilitation scheme according to their nests influence were
described previously. Others are related to the additional biological activities of the harvester ants (Table 5.1).

Table 5.1 Summary of the influences of harvester ants on the area rehabilitation state

<table>
<thead>
<tr>
<th>Observed</th>
<th>Possible causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enriched SOM (low amounts)</td>
<td>The ants foraging enriched the SOM by importing biomass, Fig. 4.33.</td>
</tr>
<tr>
<td>Enriched SOM and nutrients pools</td>
<td>The constructed nest is a sink for organic matter from the surrounding. The organic matter composted rapidly into soluble nutrients due to the nest microclimate and enriched micro-fauna, Fig. 4.23-4.27 that spread to the surrounded underground area, Fig. 4.32-4.34 (Cammeraat et al., 2002)</td>
</tr>
<tr>
<td>Increased infiltrability and SMC</td>
<td>Soil loosening due to ants tunnels diggings, Fig. 4.32, Lei, 2002</td>
</tr>
<tr>
<td>Reduced pH (more acidity)</td>
<td>The high amounts of SOM, the nest microclimate and enriched micro-fauna encourage the reduced pH (Table 4.22).</td>
</tr>
<tr>
<td>Enhanced vegetal cover</td>
<td>The nest soil loosening enables salt infiltration. The previous ants activities enhance the vegetal cover, Fig. 4.32-4.34 and parallel RS changes of the HBW and AAC</td>
</tr>
</tbody>
</table>

The rehabilitation efficiency of the harvester ants vs. shrubs effects

In the PWA area two natural ecosystem engineers were abundant, harvester ants and shrubs. Therefore our second question related to the comparison of their rehabilitation efficiency. The study demonstrated two categories where the harvester ant' nests have higher rehabilitation influence compared to the shrubs: a- the nutrients content in the nests, which is mostly higher compared to the shrub patches in areas inside and outside the farm, Fig. 4.23-4.27, and, b- the expansion of the nested area during the study was noticeable, while almost no change was observed in the shrub patches total size (Fig. 4.8 and Table 4.5). Mor-Mussery et al., (2014a) found opposite results in Chiran rangeland where shrubs coverage was 50% higher compared to the nests coverage in the conserved area. This difference can be explained by different shrubs species diversity. In PWA almost all the shrubs in the rocky slopes were *Anabasis articulata* while in Chiran area several species were found such as *Thymelaea hirsute*, *Anchusa strigose* and *Plantago albicans*. A complementary analysis carried out in July 2018
aimed to analyze the spatial distribution of SOM in the nests and in *A. articulate* patches as additional indicator for their influence on the ecosystem. Soil mixes from surface until 15cm depth were taken adjacent to the shrubs stem, in the middle and the end of the canopy and at the patch end. From the nest the samples were taken from the area adjacent to the main entrance hole and from the nest edge, Fig. 5.4

![Diagram showing SOM distribution](image)

**Figure 5.4** The relative SOM contents in *Anabasis sp.* patches and harvester ants' nests.

Inside rocky slope (I.RS), 7/2018, un dimensional distance units

Error bars±SE.

Fig. 5.8 demonstrates the high amounts and homogenous distribution of the SOM content in the nests area, when compared to the SOM' content in the units of the *A. articulate* patches. Comparison among the *Anabasis sp.* patches, reveals high SOM' content only underneath the middle of the canopy.

In conclusion, the harvester ants group has high influence on the rehabilitation state of the common arid cultivations. This influence is remarkable mainly in areas void of other natural ecosystem engineers. Therefore, rehabilitation of degraded arid areas may be enhanced initially by the harvester ant activity. These findings are important for fertility management as both tilling and application of pesticides reduce the harvester ants' influence.
5.2.4 Sloped expansion mechanism of rehabilitation

The patterns of this mechanism were defined as expansion of fertility uphill onto the slope, Fig.5.5. The slope mechanisms patterns were observed in slope with rocky cover inside the farm (I.RS and A6(East part), starting in 2015 three years after conservation initiation. Until then only patchy forms of shrubs and nests were identified in the area. The most noticeable pattern of this mechanism is formation of fertile areas in the lower hill slope, which expands into the upper part of the slope in the course of the years (Fig. 5.5).

Fig. 5.5 The sloped expansion' mechanism of rehabilitation in the inside slope with rocky cover (I.RS), June 2016

From 2016 the differences between the soil quality properties of the lower and upper parts became significant, as exemplified by differences in the herbaceous biomass and SOM. These differences were observed only in the inside rocky slope (I.RS), while the outside area values remained homogenous along the slope units and similar to the I.RS upper part, Fig. 5.6.
The sloped expansion rehabilitation can be explained by several mechanisms which were previously discussed, e.g. conservation from grazing and patch widening downhill. Additional mechanisms can be correlated to the accumulation of fertile sediments from the upper part downhill due to the hilly topography. Schlesinger et al., (1990) claim that degradation, and the transfer from grasslands into shrub lands, may result from a combination of opposite phenomena, so these findings are among the first documentation for this rehabilitation mechanism. This mechanism is based on transformation of patchy shrubland into a closed grassland state, due to progressive rehabilitation. In addition, it may indicate on the initial state of most of the shrublands that were originally grasslands, in contrast to common approaches (Lavee et al., 1998).

5.2.5 Dammed limans mechanism of rehabilitation

This study describes comparisons between two Dammed liman groups, one conserved and planted, which includes limans 2-3, 14-15 and the other bare and grazed, limans 4-5. Nevertheless, complementary studies were implemented on other limans and of their findings will be used here to clarify issues regarding the unprocessed limans mechanism of rehabilitation.

The differences between the net change of the herbaceous biomass in the inside unprocessed limans (No. 2,3, 12 and 13) reached 7 fold by comparison to the reference plot, the outside loess deposit O.LD (Fig. 4.20). Conservation from grazing alone, contributed to a fivefold difference from the reference plot, deduced by comparison.
between the inside loess deposit- I.LD and the outside O.LD (Fig. 4.17). Therefore, beside the conservation, additional mechanisms must be involved in the limans rehabilitation, whereby irrigation for tree planting may be contributed.

**Trees plantation mechanism**

The second noticeable difference between the outside and inside unprocessed limans is the trees plantation. Analysis of PWA limans in February 2018 indicates on a 500 Kg ha\(^{-1}\) difference of the annuals biomass cover between two adjacent limans inside the farm (conserved from grazing), with similar sizes and similar basin, located adjacent to each other on the same contour lines, one planted with savanna trees and one not (Fig. 5.7).

![Fig. 5.7 The influence of savanna trees on the vegetation coverage in limans](image)

**Fig. 5.7 The influence of savanna trees on the vegetation coverage in limans**

Limans 25 (A) and 26 (B) inside PWA farm, 4/2018

The figure demonstrates the influence of planted savanna trees, in this figure- the *Prosophis sp.* On enhanced herbaceous growth compared to unplanted area with similar landform patter

Similar influence of savanna trees plantations was found in Chiran *A.victoriae* woodland, as expressed by vegetal cover difference of 4-5 fold found by Mor-Mussery et al., 2013 underneath trees of *Acacia victoriae* compared to bare area, data assessed also by NDVI data from MODIS satellite (Helman et al., 2014). Leu (1995) correlates the influence of trees plantation to an enhanced patchy rehabilitation mechanism, as described previously with harvester ants' nests and shrubs. In the study duration, we
noticed that the influence of this mechanism expanded to areas outside the limans, similar to the influence of unirrigated \emph{A. victoriae} woodland in Chiran (Fig. 5.8).

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure5.8}
\caption{The influence of planted trees on the surrounding}
\end{figure}

A- The influence of dense \emph{A. victoriae} planted woodland on increased vegetation coverage adjacent the planted area in Chiran. March, 2016; B- The influence of planted limans on increased vegetation coverage in their surrounded areas, Limans 13-15, March 2016

\section*{The influence of limans modeling on mechanisms of rehabilitation}

The limans of PWA were constructed using different landform designing techniques: simple soil dams preventing runoff, gully channel filling and landform re-modelling by filling and massive soil movements (section 3.2). Due to the fact that both groups have similar shape, which is based on soil terraces in the upper- west and lower- east parts, the area streambed direction to the wadi, and sloped banks in the north and south, the rehabilitation mechanism caused by their landform patterns is similar. Still, due to the use of massive landform design in the re-modelled limans, their influences on the total rehabilitation state are more noticeable, so their influences will be discussed.

The limans were constructed by heavy machinery, which leads to soil compaction (Hillel, 2003). The compacted soil, in turn, together with the slopy pattern of the banks enhances the runoff and fine particles accumulation in the limans lower parts, leads to conservation of high moisture amounts in the soil, which is noticeable in the summer (Fig. 4.14). On the other side, it resulted in a drastic decrease of the seeds germination and emergence that can be explained by the high frequency of flooding and drought events characteristic to arid areas, which harm the seeds viability (Porcello et al., 2000).
The poor soil quality due to the massive soil disturbance, reduced seedbank and compaction initially reduced the annuals cover and soil fertility (Fig. 4.15, 4.16) in the 3-4 years after the limans construction, even when compared to the degraded state of most of the northern Negev lands, as expressed in the outside loess deposit- O.LD (section 5.1). In the following 4-5 years the wind dispersible seeds accumulation in the limans, together with the high SMC content and recovering soil quality resulted in massive growth of annuals (Fig. 5.9).

The figure demonstrates the low vegetal cover until 2015, even when compared to the reference plot (Outside loess deposit- O.LD). From 2016, enhanced growth is observed.

The interrelations among limans in a chain and the influence on total RhS

The limans in PWA farm were constructed on gullies' channels in chain' mode. In order to study possible interrelations between chained limans, an analysis was implemented on limans 19, located uphill until 26, located adjacent the wadi, in 2/2016. These limans were straightly constructed, one after the other by soil' filling and damming of former gullies, all with similar sizes, donate basins and similar distance between them (data not shown), limans 19 until 24 were planted by savanna trees and limans 25 and 26 are bare. In each liman 8 herbaceous biomass samples were harvested randomly as described in 'Tools and Methods' (Fig. 5.10).
Figure 5.10 The herbaceous biomass (HBW) of limans 19:26 in 2/2018

L. Liman, Error bars represent SE. L19, uphill and L.26, downhill
(Differences were not significant)

In general, the herbaceous biomass decreases along the slope from uphill to the lower part. Nevertheless, exceptions can be observed.

The general trend resemble decrease of the HBW along the slope, trend, which can be explained by the relative location on the hill, and as result the soil water holding capacity of the limans soil, as discussed by Lu et al. (2009) on other agriculture terraces in the Chinese loess plateau. Neverthelessm, many noticeable differences from the general trend can be observed. Possibly these differences can be explained by different water inflows, sediments and fertilizers' runoffs etc. among the limans. Therefore in order to maximize the limans' RS, one has to take into account, not only the properties of specific liman, but the locations and patterns of the other limans in a 'chain', which requires further integrated geomorphological, soil and fertilization study.

Summary

In summary, three factors influence the limans rehabilitation state, land modeling technique, the liman cultivations regime, such as conservation from grazing, tree plantations, the correlations and the distribution of limans inside their chain and the patterns of surrounded areas. Koulouri and Giourga (2007) define these factors as the most influential ones on agriculture terraces productivity based on an empirical study on other terraces type in Spain. Koulouri and Giourga (2007) add also the ratio between the donated basin area and the terrace size as influential factor. Only adequate implementation of all the sub-mechanisms will lead to effective holistic rehabilitation.
Fig. 5.11 demonstrates the herbaceous biomass RS values of different limans groups (Limans 2-3: unprocessed, conserved, planted; Limans 4-5: unprocessed-heavily grazed, bare; Limans 14-15: unprocessed, conserved, planted (embedded in tilled field); Limans 9-10: re-modelled-conserved-planted; Limans 6-7: re-modelled, heavily grazed, bare).

**Figure 5.11** The yearly rehabilitation state change (RS) of the different limans groups during the study deducted from herbaceous biomass values

Limans 2-3: unprocessed, conserved, planted; Limans 4-5: unprocessed-heavily grazed, bare; Limans 14-15: unprocessed, conserved, planted (embedded in tilled field); Limans 9-10: re-modelled/filled-conserved-planted; Limans 6-7: re-modelled, heavily grazed, bare).

Fig. 5.10 demonstrates the resulting rehabilitation rates in different combinations of the reviewed factors. Adequate implementation of such practices leads to rehabilitation values of 120% in the sixth year compared to the reference plot, while un-suitable implementation will lead to further degradation, as demonstrated on limans 6-7, due to the combination of massive landform remodeling with grazing.

In summary, the highest potential of limans to rehabilitate surrounding lands, together with the high increase of their soil fertility, justify the addition of these carefully planted and constructed limans as rehabilitation enhancers (Fig. 5.1) an issue, which is worth of further study.
5.3 Normalizing the soil quality data by rainfall parameters vs. reference plots.

Although, the trends of the soil quality properties can be detected from the core data, it is necessary to determine the net change excluding influences of climate heterogeneities. This process is crucial in order to detect the rehabilitation trend and achieve sustainable utilization, as previously described by Geerken and Ilaiwi, (2004) on rangelands and by Ayoub (1998) on croplands. Mathematically, this process is defined: "data normalization".

Data normalization using climatic parameters

The annual aboveground net primary production (ANPP), which resembles the biomass amounts, of an arid terrestrial ecosystems (or agro-ecosystems) is correlated positively to the efficient rain units, due to the existence of maximal Rain Use Efficiency (RUEmax) value (Veron et al., 2006). This value can characterize even extremes (drought years or rainy ones), as described by Huxman et al., (2004) on different cultivations representing arid areas all over the globe. The herbaceous biomass amount is used, mostly to determine the ANPP. This value is determined in field or by using satellite imaging as reviewed by Sala and Austin (2000). However, the definition of the ‘efficient rain’ property is under disagreement among the scientists. One theory claims that the total rainfall per year has the tightest correlation to the ANPP, an assumption proven empirically in the northern Negev by Helman et al., 2014a and 2014b and on other studies all over the globe (Huxman et al., 2004; Hiernaux et al., 2016 etc.). Others claim that rainfall heterogeneity has the highest influence on the ANPP (Esler et al., 1999; Huxman et al., 2004 etc.). This theory is strengthened by the increasing rainfall spatial and temporal heterogeneity during the last century in arid and in desertified lands as determined by Dai (2004) and others. Also the definition of rainfall heterogeneity is under disagreement among scientists. Nevertheless, the most common factors for defining the rainfall heterogeneity are as follows:

- The rainfall coefficient of variation (CV) value, which is calculated by dividing the standard deviation and average and was experimentally verified by Huxman et al., (2004) on north America semi-arid areas.
The number of rainfall days, which represents the number of days with rainfall higher than 1mm, a value suggested by Huxman et al. (2004) in addition to the CV, and was experimentally verified in North America’s semi-arid lands.

The number of rainfall events, which represents the number of rainfall events with accumulated rainfall higher than 5mm, a value determined by Esler and Rundel (1999) as the most influential factor on ANPP based his studies in Mojave desert ecosystems.

We performed a partial analysis correlating the total seasonal rainfall, number of daily rainfall pulses, and rainfall events with the herbaceous biomass weighs (HBW) of the different PWA treatments during the study. Collectively, the correlations of all rainfall patterns and the HBW were not significant, but the highest correlations were found to the number of rainfall pulses, which was used as a visual comparison for the different soil quality properties and biological activity changes during the study (see Table 5.2). Two exceptions were found regarding the correlations of the number of rain pulses and the HBW, in the outside land deposit (O.LD) and the inside abandoned enclosure (I.En).

Table 5.2 The correlations of different rainfall parameters and the herbaceous biomass weights of the outside loess deposit and the inside abandoned enclosure

<table>
<thead>
<tr>
<th>Rainfall parameter</th>
<th>O.LD</th>
<th>I.En</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total seasonal rainfall- x</strong></td>
<td>HBW=0.0007x - 0.03 (r²=0.6)</td>
<td>HBW = 0.0033x - 0.115 (r²=0.2)</td>
</tr>
<tr>
<td><strong>No. rainfall pulses (days with total rainfall &gt;1mm)-x</strong></td>
<td>HBW=0.0075x - 0.06 (r²=0.7)</td>
<td>HBW=0.0436x - 0.4</td>
</tr>
<tr>
<td><strong>Rainfall CV (Stdv/Average)- x</strong></td>
<td>HBW = 0.1495x - 0.2037 (r²=0.04)</td>
<td>HBW=0.3456x +</td>
</tr>
<tr>
<td><strong>No. rainfall events (events with total rainfall&gt; 5mm- x</strong></td>
<td>HBW= 0.0185x - 0.101x - 0.7544 (r²=0.5)</td>
<td>y = 0.101x - 0.7544</td>
</tr>
</tbody>
</table>

HBW- herbaceous biomass weight, O.LD- outside loess deposit (O.LD), I.En- inside abandoned enclosure.
In conclusion, a far more integrated model assessment will be required to achieve a satisfactory normalization of herbaceous biomass and other soil fertility properties based on climatic data.

**Data normalization using reference plots**
The insignificant correlations of each different rainfall properties to the HBW possibly justify the use of multi rainfall factors equation to assess the ANPP, which must be further studied. Therefore we used an alternative approach of normalization based on reference plots. A reference plot is an area with similar patterns as the studied plots, remaining unchanged regarding its agriculture utilization, geomorphological state, etc. Comparison between such control areas and the studied ones enable to determine the geomorphological, fertility, etc. influences of the studied managements.

A few studies used this approach. For example, Bakker et al. (2005) determined the influence of different cultivations dozens of years ago in hilly landform formation in Spain. Landres et al. (1999) used this approach to define the natural variability influences due to anthropogenic interruption in 1960. This is one of the first times this approach was used to monitor consistently changes of RS for different cultivations in order to determine the most suitable management scheme for an area to achieve sustainable utilization.

**Reference plots for data normalization in PWA**
Two types of reference plots were defined, one to determine the rehabilitation rate and the second to determine the time duration required until rehabilitation. The term: "rehabilitation" is somewhat relative and does not represent the maximal rehabilitation state. This mismatch is exemplified by the higher herbaceous biomass values of the unprocessed limans in 2016 compared to the I.En (section 4.3 and 4.16). Therefore probably, in future, a new plot has to be determined to the RS changes of limans. The principles of using reference plots (combined with previous data from Bakker et al. (2005) and Landres et al. (1999) studies) are presented in Table 5.3.
Table 5.3 Principles for locating reference plots and calculations for determination of the yearly rehabilitation rate and the duration until restoration

<table>
<thead>
<tr>
<th>Reference plot type 'A'</th>
<th>Reference plot type 'B'</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Aimed to determine the rehabilitation rate)</td>
<td>(Aimed to determine the time duration until rehabilitation)</td>
</tr>
</tbody>
</table>

Plot locating principles

a. The reference plots must have similar soil and landform as the studied treatments.
b. The reference plots and studied areas must be located adjacent (due to the locally patterns of rainfall in arid areas).

a. The reference plots must have similar fertility as the studied areas, before the implementation of the tested cultivation regime.
b. The reference plots must be cultivated similar to the studied areas, until the implementation of the tested cultivation regime (in the studied areas).
c. The reference plot cultivation must continue in the common method.

Calculation principles

a. Calculating the net yearly difference of the soil quality properties of the studied treatments by comparison to the reference plot type A
b. Calculating the net yearly change by intersecting the net yearly differences with the passed durations from cultivation implementation in order to.
c. Calculating the time duration until rehabilitation based on the annual change of the analyzed soil quality parameter and its' final values, which presented in the reference plot, type B.

In summary, due to global processes such as global warming and desertification, new states of ecosystem and agroecosystem are being created, as Hobbs et al. (2009) describes: "Many ecosystems are rapidly being transformed into new, non-historical configurations owing to a variety of local and global changes". Therefore, only the use of reference plots in cultivated areas may maximize their yield and agriculture utilization.

5.4 Agriculture utilization efficiency of PWA cultivations

The common cultivations in arid (or semi-arid) areas are the rainfed ones, grazing and grain crops (Dregne, 1983), therefore the agricultural utilization of PWA area will refer to them.
Pasture for grazing

In all treatments, the five years of conservation increased the normalized vegetal productivity by 6 fold (section 4.2) compared to the state of the common cultivation from 0.5 Ton ha\(^{-1}\) year\(^{-1}\) to 3 Ton ha\(^{-1}\) year\(^{-1}\), which can feed 4 mature small ruminants ha\(^{-1}\) year\(^{-1}\) (Rashid, 2007). The herbaceous biomass weights are similar the ones of Mor-Mussery et al. (2013), which determined a fivefold increase compared to the degraded state in the Chiran area. The pasture utilization of the liman areas built on gullied landform in a highly incised area with no agriculture utilization, reached after limans construction up to 3.5 Ton ha\(^{-1}\) feeding 4.5 ruminants ha\(^{-1}\) year\(^{-1}\). Except for the enhanced herbaceous biomass in the limans, there is browsing potential of the savanna trees canopies, which was not measured here, but has been calculated, by Mor-Mussery et al., (2014). Importantly this potential expands the grazing duration and also is available during drought (Fig. 5.12).

![Fig. 5.12 Browsing utilization of savanna trees](image)

A- Browsed *A. victoriae* tree, Chiran area (3/2016); B- Factors that influence on savanna tree browsing utilization (accessible height of the animal, fresh biomass amount, canopy volume, etc.), Based on Mor-Mussery et al.(2014b).

Livestock-crop cultivation potential

The integrated crop–livestock system benefits from the nutrients cycling of the cultivated area. The animals eat the crop residues that are being returned back to the soil by their excrements. In addition, such rotational schemes have high ecological benefits, as Thornton and Herrero (2001) summarized: "Integrated crop–livestock
systems could provide opportunities to capture ecological interactions among different land use systems to make agricultural ecosystems more efficient at cycling nutrients. In this study I got a high values of HBW productivity with a normalized increase of \(~100\%\) per year (Fig. 4.20). The high and growing values of vegetation amounts indicate on optional utilization of the fields for grazing in years that the field is not used for crop breeding. Sainju et al., (2011) found that the yield of rainfed wheat fields in arid areas increased after controlled grazing in the fallow season. Both studies (of PWA and Sainju et al. (2011)) indicate on potential and sustainable use of rotational utilization of grazing and cereals breeding years in the northern Negev open lands. This crop-livestock scheme, except from increase in the soil fertility and productivity, will encourage the Bedouin farmers to cultivate the lands towards reaching a sustainable state. Similar rotation was suggested by Hilimire (2011) for wide parts of the American rangelands. Still wider studies have to be carried out taking into account ecological and economical aspects.

5.5 The influence of PWA cultivations on carbon sequestration and nutrient enrichment from natural substrates

Except for increasing agriculture utilization of arid loess areas, the study aimed to analyze the ecological influences of the studied treatments on the carbon and soluble nutrients enrichment. Nutrient enrichment by anthropogenic drivers is mostly resulted from constant addition of nutrients, defined as "chronic nutrient addition" (Isbell et al., 2013). In the short-term this nutrient addition leads to higher yield, but in the long-term it may cause unwanted effects on plant biodiversity (Isbell et al., 2013). However a strong and contrary effect was observed at PWA (http://www.sustainabilitylabs.org/ecosystem-restoration/biodiversity/), or in Chiran area (Leu et al., 2014) with massive gains in species richness and, so far, no loss of species observed in spite of strongly increasing SOM and nutrient pools. The PWA area is unique because no additive nutrients supply was given during the study, which allows us to analyze the impact of resource enrichment by natural resource cycles. Here I will use the term: "carbon sequestration" for C-Organic enrichment. Lal (2004a) defines this process as follows: "transferring atmospheric CO\textsubscript{2} into long-lived pools and storing it securely so it is not immediately reemitted". The common parameter describing carbon sequestration is the soil organic matter. For the other nutrients (Nitrogen, Phosphate
and Potassium) we will use the term "soluble nutrient enrichment from natural sources" (Read and Perez-Moreno, 2003), where the substrates are dust, atmospheric sources of nitrogen from pollution or lightning, or mobilization of nutrients from deep soil layers by plant roots, where trees and other perennials play a key role.

The study plots of PWA can be grouped statistically into the following categories. The reference plots representing the common cultivations are the outside loess deposit (O.LD) and the outside rocky slope (O.RS). Nutrient enrichment in the other treatments was normalized relative to the reference plot values. All calculations are calculated for the fifth year, per hectare in a 15 cm soil layer assuming a bulk soil density of 1.53 gr cm$^{-3}$ (Table 4.1). The SOM values used were taken from the summer data sets (see figures 4.2, 4.6, 4.11, 4.15).

The soluble nutrient contents of the common cultivation

In order to demonstrate the nutrient enrichment from natural substrates in test plots I used the absolute values of the reference plots O.LD (Table 4.3) and O.RS from 2016 as the reference. For calculating carbon sequestration, I used the absolute values of 2017 summer set (Fig. 4.2 and Fig.4.6, respectively). The results of this calculation are presented in Table 5.4

**Table 5.4 The soil organic matter and soluble nutrients content per hectare in the top 15 cm of soil of the common cultivations: outside loess deposit and the outside rocky slope of PWA in 2016 and 2017.**

<table>
<thead>
<tr>
<th>Nutrient [Kg ha$^{-1}$]</th>
<th>O.LD</th>
<th>O.RS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>33.3</td>
<td>40.1</td>
</tr>
<tr>
<td>Phosphate</td>
<td>16.5</td>
<td>18.8</td>
</tr>
<tr>
<td>Potassium</td>
<td>37.9</td>
<td>23.0</td>
</tr>
<tr>
<td>SOM</td>
<td>66,600</td>
<td>62,600</td>
</tr>
</tbody>
</table>

The SOM content is based on July 2017 data. The soluble nutrients were calculated based on the 2016 set.

O.LD- Outside loess deposit, O.RS- Outside rocky slope Table 5.4 demonstrates similar SOM and nutrient values of the common cultivation in the rocky slope and the loess deposit. The nutrients content for both plots are also very similar values along the study,
as expressed by low CV. As example, for the SOM values in the O.LD the CV is 0.23 and for the O.RS- 0.28.

The nutrients and SOM enrichment of the referenced cultivations

The nutrient enrichment values per studied treatment were calculated by subtracting the reference plot SOM content from the treatment value based on 7/2017 measurements, and for the nutrients we used the same methodology on the 2016 set data. The findings are demonstrated in Fig. 5.13.

a. The influence of conservation from grazing on the nutrients enrichment

The five years of conservation enriched PWA soil for both landforms (loess deposit and rocky slope) by about 17 Ton ha$^{-1}$ of SOM, indicating a yearly soil CO$_2$ sequestration rate of over 5 tons per hectare and year, higher than predicted by Lal (2004a) and others. The soil nutrients content was increased by 11 Kg ha$^{-1}$ for Nitrogen and by 16 Kg ha$^{-1}$ for Potassium. In the rocky slope, conservation did not contribute to Phosphate enrichment. However, in the loess deposit Phosphate enrichment of 12 Kg ha$^{-1}$ was observed. The reduced enrichment values of the rocky slopes is strengthening Li et al. (2009) and Quinton et al. (2010) findings on the influence of intensive overland erosion, causing the rocky slope formation originally from an initial state of loess deposit. Furthermore, phosphate is mostly lost from sloped land forms by surface runoff removing Phosphorus rich' dust and litter, indicative for the longer restoration period required compared to rather flat loess plateaus. Comparison of the tilled plots inside and outside the farm reveals decreases in comparison to the reference plots especially for phosphate and SOM. Nevertheless, the reduction of the SOM in I.TI was only 13 Ton ha$^{-1}$, compared to reduction of -32 Ton ha$^{-1}$ of the O.TI. In other words, the conservation moderates the reduction in the SOM due to grazing by 19 Ton ha$^{-1}$. Loss of SOM and N in tilled soils is expected, as organic matter is more easily oxidized in the loosened top soil. Furthermore, nitrate can be washed from the top-soil into deeper layers by rain, thanks to the higher water penetration in freshly tilled loess (Reicosky et al., 1995). Nevertheless, the comparison between the O.TI and I.TI reveals that the conservation of the tilled plots enriched the Phosphate content in the soil by 1.5 Kg ha$^{-1}$ and the Potassium content by 18 Kg ha$^{-1}$. These values are similar to the ones of Leu et al., (2014) and Helman et al., (2014) from adjacent area (Chiran area 7 Km north of PWA), which was only partly conserved. This leads to the conclusion, that reduced
grazing will lead to nutrients enrichment in rates similar to the ones achieved due to total conservation.

b. The influence of tillage on nutrient enrichment

Comparison between the net SOM values of the Inside loess deposit (I.LD) and the inside tilled (I.Tl) reveals lower Nitrogen content of 7 Kg ha\(^{-1}\) due to the tillage sets (I.LD - 20 Kg ha\(^{-1}\), I.Tl - 13Kg ha\(^{-1}\)), nevertheless the values in the I.Tl were higher compared to the control (O.LD). The Phosphate content enrichment of the I.Tl was by 9 Kg ha\(^{-1}\) lower than the I.LD, Nevertheless it was higher compared to the O.LD. Phosphate content enrichment of the I.Tl was by 9 Kg ha\(^{-1}\) lower than the I.LD, Nevertheless it was higher compared to the O.LD. Potassium was not enriched in the tilled treatments inside the farm. The SOM content of the tilled plots inside the farm was reduced by 13,000 Kg ha\(^{-1}\), as compared to the O.LD. Taking the absolute SOM contents of the O.LD and I.Tl, 53.7 and 66'500 Kg ha\(^{-1}\), respectively, reveals 20% reduction in the SOM content. This value is much lower compared to the one found by Guo and Gifford (2002) that describe an average change of 60%. The low decrease in PWA tilled plots indicates the high level of degradation of all of the Northern Negev’s open areas with soils holding minimal SOM reserves, as described by Helman et al. (2014). That further reductions in SOM remain small, while the potential to increase SOM pools gets higher and easier to realize, by simple conservation from grazing and tilling, as demonstrated here (section 5.4).
Figure 5.13 The net additive nutrient contents for the different cultivations in the fifth year of the PWA study deduced by the differences relative to the reference plot

A- The additive Nitrogen, B- The additive Phosphate, C- The additive Potassium, D- The additive Soil organic matter (SOM) as compared to common cultivations, the outside loess deposit (O.LD) or the outside rocky slope (O.RS) respectively. The soil fertility contents were calculated per hectare in a topsoil layer of 15cm.

Comparison between the O.LD and O.Tl reveals reduction of the soil enrichments content of the Phosphate, Potassium and SOM. The Nitrogen content enrichment was relative high compared to the O.LD (11 Kg ha⁻¹), which justify additional study.

The abandoned field reveals a consistent trend as compared to the O.LD with reduced nutrient contents for the Phosphate and Potassium and minor increases for the SOM and the Nitrogen contents. These findings strengthen Lasanta et al. (2000) and Garcia-Ruiz, (2010) claiming that cultivation of abandoned fields requires nutrients addition due to long-term resource depletion and degradation.

In summary, tillage at PWA farm somewhat reduced soil quality as compared to the uncultivated treatments inside.

c. The influence of tree plantation on the nutrient enrichment of the limans
The un-planted limans demonstrated low nutrients contents when compared to the outside loess deposit (O.LD). The Nitrogen is exceptional, possibly due to sampling reasons. The planted limans however demonstrated higher values as compared to the un-planted ones, except for Nitrogen. Nevertheless, the nutrients contents were similar or only little higher as compared to the O.LD. The high biomass weight values but the relatively low nutrients content and sequestered Carbon, indicates that in order to maximize the vegetation efficiency to enrich the soil nutrients by the roots, litter etc. ecosystem engineers as harvester ants (Mor-Mussery et al., 2017) and micro fauna (Ponge, 2013) may be needed.

Summary

In 2012 (before site construction) a nutrients analysis was performed in 24 bore holes drilled from top soil to bed-rock within the PWA area. Jobbágy and Jackson (2001) claim that the nutrient content in the deep soil layers of common cultivated areas is minimally changed and in some cases: "even negative correlation between nutrient abundance and the ratios of their topsoil concentration"; therefore, the nutrient pools are been conserved there. This stored pool is available for agriculture utilization by practices as trees plantation, which mobilize them to the upper cultivated layer by their root system (Moreno and Obrador, 2007). The nutrient content of the 50 cm thick soil layers are as follows.

Table 5.5 Nutrients pools of PWA soil.

<table>
<thead>
<tr>
<th>Soil layer cm</th>
<th>Nitrogen</th>
<th>Phosphate</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>70.8</td>
<td>26.3</td>
<td>424.5</td>
</tr>
<tr>
<td>50-100</td>
<td>48.3</td>
<td>29.4</td>
<td>308.4</td>
</tr>
<tr>
<td>100-150</td>
<td>52.3</td>
<td>29.8</td>
<td>262.6</td>
</tr>
</tbody>
</table>

PWA site, as other loess areas (Catt, 2001) has therefore significant nutrients pools especially in depth inaccessible to annual vegetation roots in arid conditions. Therefore, combination of adequate cultivation practices such as conservation of perennial vegetation, plantation of adequate trees species and encouragement of natural agents such as harvester ant activity resulted in enhanced nutrients' mobilization into the
topsoil layer from the deep loess substrate together with carbon sequestration into the deep root zone not quantified here, which will benefit all agriculture utilizations in these areas and supports the high potential benefits of technologies such as agroforestry or permaculture (for example see 9http://www.sustainabilitylabs.org/ecosystem-restoration/permaculture/0 ) for reviving large tracts of degraded dryland areas.
6. Conclusions

This study dealt with several issues concerning rain-fed agriculture in arid areas including defining rehabilitation or degradation states of different cultivated arid lands based on normalized soil quality changes, determine the influences of harvester ants activities on the rehabilitation of these lands and defining the influences of these cultivations on the ecosystem. The main findings of PWA are as follows:

1. Five years of conservation from grazing increased the pasture amounts of PWA lands by 3-5 folds compared to the common cultivation, enriched dramatically the vegetal and faunal biodiversity*, enriched the nutrients content of the root zone layer and induced massive sequestration of the greenhouse gas CO₂ into SOM, at a rate of around 5 Ton per hectare, excluding growth of trees and other perennial vegetation.

2. The use of reference plots for monitoring rehabilitation changes is adequate for long time monitoring of cultivated arid areas.

3. The harvester ants' activity has a highly positive influence on cultivated areas rehabilitation state.

4. Adequate cultivated and planted limans strongly reduce erosion, increase the areas fertility fivefold (or ten-fold including planted trees) compared to the common use, and stabilize and rehabilitate topography, fertility and geomorphology.

* www.sustainabiltylabs.org/ecosystem-restoration/biodiversity/?lang=en

Collectively, this study demonstrates for the first time based on broad interdisciplinary data assessment that appropriate sustainable dryland exploitation may be far more profitable than predicted, while mitigating CO₂ emissions and enhancing biodiversity . The main factor for this success is a rapid transition from degraded patchy shrub lands to closed fertile savanna vegetation mediated by improvement of soil fertility (nutrients and SOM) and soil hydrology (infiltration), and high organic litter cover that massively improve biological productivity. This results also justify grazing control, as old paradigms on the impact of grazing (e.g. trampling) were disproven, while the single most major cause for degradation
shown here is excessive removal of biomass without adequate replenishment by manure.

Figure 6.1 Schematic representation of the combined influence of leftover biological patches and different agriculture practices in cultivated lands on their rehabilitation or degradation state.

Overall, the restoration methods shown here prove conclusively that a global dryland restoration program will successfully address: (i) the United Nations convention to combat desertification; (ii) the UN convention on biological diversity; (iii) the UN framework convention on climate change, (iv) as well as contribute to the Sustainable Development Goals, among others food and water security, economic and socioeconomic development.
7. References


Appendix 1. The limans in Project Wadi Attir

The current study deals with part of the 'unprocessed limans' group (limans 2-3, 4-5 and 14-15) in PWA. Nevertheless, complementary studies were implemented on other limans; their findings were used to clarify issues regarding the rehabilitation mechanism of the unprocessed limans. The description and locations of PWA limans is presented in Table 1 and Fig. Ap1.

Table Ap1. The limans' groups

<table>
<thead>
<tr>
<th>Category</th>
<th>Shape</th>
<th>location</th>
<th>Re-modulation and management</th>
<th>Surrounding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unprocessed-Inside-T.1</td>
<td>rectangle</td>
<td>Inside</td>
<td>Light, Planted</td>
<td>Un-cultivated</td>
</tr>
<tr>
<td>Unprocessed-Inside-T.2</td>
<td>rectangle</td>
<td>Inside</td>
<td>Light, Planted</td>
<td>Tilled</td>
</tr>
<tr>
<td>Unprocessed-Inside-T.3</td>
<td>rectangle</td>
<td>Inside</td>
<td>Light, Planted</td>
<td>Service area</td>
</tr>
<tr>
<td>Unprocessed-Inside-T.4</td>
<td>rectangle</td>
<td>Inside</td>
<td>Light, Bare</td>
<td>Tilled</td>
</tr>
<tr>
<td>Remodeled/filled-Inside</td>
<td>rectangle</td>
<td>Inside</td>
<td>Massive, Planted</td>
<td>Tilled</td>
</tr>
<tr>
<td>Wadi' limans-Inside*</td>
<td>rectangle</td>
<td>Inside</td>
<td>Moderate, Bare</td>
<td>Un-cultivated</td>
</tr>
<tr>
<td>Unprocessed-Outside</td>
<td>rectangle</td>
<td>Outside</td>
<td>Light, bare</td>
<td>Un-cultivated</td>
</tr>
<tr>
<td>Remodeled/filled-out</td>
<td>rectangle</td>
<td>Inside</td>
<td>Massive, Bare</td>
<td>Abandoned</td>
</tr>
</tbody>
</table>

*Aimed to decelerate the erosion to wadi and to prevents banks' crushes*
Figure Ap.1 The limans locations and groups in PWA

Figure Ap.2 The remodeled grazed limans

A, B- outside farm; C, D- Inside farm
Figure Ap.3 Ongoing soil protection work, limans' construction (2012)

Left figures- before limans construction, Right figures- in limans construction
Appendix 2. PWA initial rehabilitation state

Several analyses carried out to determine the rehabilitation state of the PWA site before treatment implementation on December 2012. The soil samples for the nutrient analyses were taken randomly all over PWA area, from the soil surface to bedrock, measured according to common procedures (Sparks, 1999) and documented with their location, using GPS. The nutrient content is presented in Table Ap.2

Table Ap.2 Nutrients content in different soil depth in PWA 12/2012

<table>
<thead>
<tr>
<th>North-South</th>
<th>East-West</th>
<th>Depth [cm]</th>
<th>N-NO₃</th>
<th>N-NH₄</th>
<th>P-PO₃</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>005-75-633N</td>
<td>001-93-705E</td>
<td>0-50</td>
<td>13.2</td>
<td>1.48</td>
<td>4.2</td>
<td>46.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50-100</td>
<td>8.5</td>
<td>1.25</td>
<td>4.9</td>
<td>37.9</td>
</tr>
<tr>
<td>005-75-310N</td>
<td>001-94-012E</td>
<td>0-40</td>
<td>15.3</td>
<td>1.88</td>
<td>3.5</td>
<td>135.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40-80</td>
<td>5.2</td>
<td>1.18</td>
<td>3.3</td>
<td>101.1</td>
</tr>
<tr>
<td>005-75-488N</td>
<td>001-93-643E</td>
<td>0-50</td>
<td>10.5</td>
<td>0.13</td>
<td>3.5</td>
<td>44.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50-100</td>
<td>4.2</td>
<td>0.77</td>
<td>5.1</td>
<td>37.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-140</td>
<td>2.8</td>
<td>0.91</td>
<td>4.3</td>
<td>40.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>140-180</td>
<td>2.9</td>
<td>1.21</td>
<td>6.8</td>
<td>53.2</td>
</tr>
<tr>
<td>005-75-339</td>
<td>001-94-025</td>
<td>0-70</td>
<td>8.4</td>
<td>1.14</td>
<td>4.2</td>
<td>37.9</td>
</tr>
<tr>
<td>005-75-311</td>
<td>001-94-025</td>
<td>0-70</td>
<td>6.8</td>
<td>1.56</td>
<td>3.5</td>
<td>37.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0-50</td>
<td>13.3</td>
<td>0.82</td>
<td>3</td>
<td>88.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50-100</td>
<td>11.2</td>
<td>0.11</td>
<td>3.5</td>
<td>48.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-140</td>
<td>14.5</td>
<td>0.28</td>
<td>3.8</td>
<td>31.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>140-180</td>
<td>15.2</td>
<td>0.81</td>
<td>3.7</td>
<td>37.9</td>
</tr>
<tr>
<td>005-75-405N</td>
<td>001-94-091E</td>
<td>0-50</td>
<td>12.9</td>
<td>2.12</td>
<td>3.1</td>
<td>53.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50-100</td>
<td>3.5</td>
<td>1.74</td>
<td>4.5</td>
<td>25.5</td>
</tr>
<tr>
<td>005-95-516</td>
<td>001-94-090E</td>
<td>0-45</td>
<td>10.8</td>
<td>3.95</td>
<td>3</td>
<td>73.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45-90</td>
<td>2.8</td>
<td>1.18</td>
<td>3.2</td>
<td>31.7</td>
</tr>
<tr>
<td>005-75-428</td>
<td>001-94-090E</td>
<td>0-50</td>
<td>3.1</td>
<td>1.88</td>
<td>3</td>
<td>53.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50-100</td>
<td>2.7</td>
<td>1.13</td>
<td>4.9</td>
<td>31.7</td>
</tr>
<tr>
<td>005-75-630N</td>
<td>001-93-718E</td>
<td>0-50</td>
<td>4</td>
<td>0.93</td>
<td>3.2</td>
<td>44.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50-100</td>
<td>2</td>
<td>1.14</td>
<td>5.1</td>
<td>29.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-140</td>
<td>2</td>
<td>1.39</td>
<td>4.6</td>
<td>44.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>140-180</td>
<td>2</td>
<td>1.09</td>
<td>5.2</td>
<td>37.9</td>
</tr>
<tr>
<td>005-75-460N</td>
<td>001-93-866E</td>
<td>0-45</td>
<td>7.7</td>
<td>1.92</td>
<td>3</td>
<td>53.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45-90</td>
<td>2</td>
<td>1.57</td>
<td>3</td>
<td>27.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90-160</td>
<td>10.3</td>
<td>1.08</td>
<td>3.5</td>
<td>62.2</td>
</tr>
<tr>
<td>005-75-139</td>
<td>001-93-787</td>
<td>0-50</td>
<td>8.9</td>
<td>1.45</td>
<td>3</td>
<td>46.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50-90</td>
<td>4.6</td>
<td>1.59</td>
<td>3.6</td>
<td>37.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90-130</td>
<td>2.3</td>
<td>1.04</td>
<td>3.8</td>
<td>21.5</td>
</tr>
<tr>
<td>North-South</td>
<td>East-West</td>
<td>Depth [cm]</td>
<td>N-NO₃</td>
<td>N-NH₄</td>
<td>P-PO₃</td>
<td>K</td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
<td>-----------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>---</td>
</tr>
<tr>
<td>005-75-189</td>
<td>001-93-888</td>
<td>0-45</td>
<td>4.9</td>
<td>1.43</td>
<td>3.1</td>
<td>48.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45-90</td>
<td>9.4</td>
<td>0.55</td>
<td>3.1</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90-130</td>
<td>13.5</td>
<td>0.62</td>
<td>3</td>
<td>29.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>130-170</td>
<td>27.4</td>
<td>0.54</td>
<td>3</td>
<td>29.6</td>
</tr>
<tr>
<td>005-45-045</td>
<td>001-93-749</td>
<td>0-50</td>
<td>6</td>
<td>1.73</td>
<td>3.1</td>
<td>40.1</td>
</tr>
<tr>
<td>005-75-209</td>
<td>001-93-764E</td>
<td>0-55</td>
<td>4.6</td>
<td>2.81</td>
<td>8.7</td>
<td>111.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>55-110</td>
<td>9.4</td>
<td>1.71</td>
<td>3.9</td>
<td>29.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>110-160</td>
<td>13.7</td>
<td>1.67</td>
<td>4.6</td>
<td>27.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>160-210</td>
<td>12.2</td>
<td>1.85</td>
<td>4.8</td>
<td>31.7</td>
</tr>
<tr>
<td>005-75-146</td>
<td>001-93-611</td>
<td>0-60</td>
<td>12.3</td>
<td>1.84</td>
<td>3.6</td>
<td>93.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60-120</td>
<td>4.9</td>
<td>1.57</td>
<td>4.1</td>
<td>46.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120-170</td>
<td>3</td>
<td>1.9</td>
<td>4</td>
<td>27.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>170-220</td>
<td>2.2</td>
<td>1.59</td>
<td>4</td>
<td>29.6</td>
</tr>
<tr>
<td>005-75-687</td>
<td>001-93-944</td>
<td>0-45</td>
<td>2.2</td>
<td>0.53</td>
<td>3</td>
<td>31.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45-90</td>
<td>10.4</td>
<td>0.71</td>
<td>3</td>
<td>53.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90-150</td>
<td>2</td>
<td>1.04</td>
<td>3.9</td>
<td>40.1</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>0-45</td>
<td>9.8</td>
<td>1.5</td>
<td>3</td>
<td>53.2</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>45-90</td>
<td>2</td>
<td>1.73</td>
<td>3</td>
<td>29.6</td>
</tr>
<tr>
<td>005-75-625</td>
<td>001-94-138</td>
<td>0-60</td>
<td>2.9</td>
<td>2</td>
<td>3</td>
<td>46.6</td>
</tr>
<tr>
<td>005-75-877</td>
<td>001-93-966</td>
<td>0-55</td>
<td>8</td>
<td>1.74</td>
<td>3.3</td>
<td>48.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>55-110</td>
<td>6.1</td>
<td>2.27</td>
<td>4.8</td>
<td>51</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>0-45</td>
<td>6.2</td>
<td>1.44</td>
<td>3</td>
<td>46.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45-90</td>
<td>2</td>
<td>1.19</td>
<td>3.1</td>
<td>29.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90-145</td>
<td>2</td>
<td>1.48</td>
<td>3</td>
<td>25.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>145-200</td>
<td>2</td>
<td>1.36</td>
<td>3</td>
<td>23.5</td>
</tr>
<tr>
<td>005-75-757</td>
<td>001-93-835</td>
<td>0-60</td>
<td>5.8</td>
<td>1.62</td>
<td>3</td>
<td>53.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60-120</td>
<td>2.2</td>
<td>1.36</td>
<td>3.9</td>
<td>33.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120-180</td>
<td>2</td>
<td>1.19</td>
<td>4.8</td>
<td>25.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>180-240</td>
<td>2</td>
<td>1.37</td>
<td>3.9</td>
<td>31.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>240-300</td>
<td>2</td>
<td>1.4</td>
<td>3.7</td>
<td>42.2</td>
</tr>
</tbody>
</table>
ילואי קודה

פריקות אור שונים, שמשךorld מברברים. מכניים של שיקום שטחי

א. המרחב העשורית באזורי תעירים עלו במרחק המשדר מינימום 50% בעשור לקואור לשנה לארבעת

ב. נצאי שטח צהריים יד-سورיה של מרחק מבקר חקדילום חקלאיים ו.scalarיהם יגוזים מ inversión יוחסין לחדור.

ג. תילוקו אורות מדיחיים.

ד. נצאי שטחי 5 שנות מחקר המחבר לשיא קיבוץ השחף שארים על ערך לעלות 35% מחוון שאפקב-15%, אשלגן בו-20% וה慬ר-30%. ה-

ס. נצאי שיתוספים שיקום של שיקום שלו להעלאה במשק המים.

עקרונות מחקר זה המבוססים על בחינת תפיסת קריפת שטחי שינוי בשיקום ולערבקל הקריפת שרידים בביה. הנחת מחקר זה מאשימים על מחקר לחיבור השיתוף של שיקום השחף שארים עם הנחת מחקר מרחב משיקום חידושי ושיקום חידושי, סיכום של מחקרים שונים מclide השיחים והを通して מицы השלבים.

ינטיפס התרחבי השיתוף בין מחקרים לעובד ו-19 ב-2012 שיפ══ג על בושם משיקום חידושי השיחים והを通して מицы השלבים.
היצורנת הצמחית, הגיעה ל-5% ולאו דווקאпочтיה על המחירים והגמים, ממראה של היבט ענין של ייצור הפקודות. הקצבה בשתי היבט הצמחי, ח勍 לה היבטים מליגזור אחד ויצירת הקוקב והגיים. בשתי היבטים של הניבים צמצומים מ稳ות花纹 של בוגר הקוקב ורדה.\\n\\nלימונים, בליגזור התוך בוגר ויצירת הקוקב, מאפיין עצמו במעברים של שיקום ענין של פיזור וتروוח. הקצבה בשתי היבטים מליגזור אחד ויצירת הקוקב של ייצור הפקודות,\\n\\nנמצאים אלה דומים לממצאים במחקרים אחרים בנגב ובכול העולם.\\n\\nמסקנותיהם מתאימים למנגנון השיקום של אזורי מדוררים (Degraded). קבוצת העיבודים הראשונה מאפיינה את אלו שהận העיבוד בימינו. קבוצת העיבודים השנייה מציגה את הנקודות בתוך החווה השמורות מרעייה.\\n\\nשקום של השדה עשה之美ון כללי של היבט הצמחי, ושקום ענין של פיזור וتروוח.\\n\\nהקבוצה השלישית מייצגת בעיקר את החלים праздник החולייתים (מצויים מחוץ לחווה) ושאינם עברו עיבוד חקלאי כלשהם. כדוגמה, בליגוזס של ייצור הפקודות עד פי-15% ומדדי פוריות נוספים בהשוואה לנקודה הייחוס בנוסף.\\n\\nמאפיינים אלה מתאימים גם למגנון השיקום של שלב מבחנה של עיבוד חקלאי (דרדרי שיקום של השלב)._lettered א.zag מתאימים\\n\\nמנגנוני השיקום התחרותיים בשתי ההעדים. מאפיין השיקום התחרותי פעיל ב-15%.\\n\\nשימור הקרקע מרעייה העלה, כנראה את הביומסה העשבונית בהשוואה לשנה הקודמת ב-100%. הסיבה לכך היא שיקום הקרום הביולוגי, עלייה בכמות הזפרה, החומר האורגני וחומרי החזקה ויסודות של תצורת הקרקע.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. שימור הקרקע מרעייה העלה, כנראה את הביומסה העשבונית בהשוואה לשנה הקודמת ב-100%.\\n\\nמשימה זו מתאימה לכל סדרות השיטה של השיטה השחקונית.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם. ב_reverse מנגנון השיקום והחריש המשקם.\\n\\nב_reverse מ再说 של שיטה של השיטה השחקונית.\\n\\nכל זה מתאימה\\n
המצב הנוכחי של חלק ניכר מהשטחים המעובדים באזורים המדבריים (והחצי מדבריים) ביבשת ובעולם מוגדר כ"מדורדר" דבר הנובע מרעיית יתר וחריש שאינו מתאים. במצב זה המשך העיבוד החקלאי המקובל יוביל לירידה מתונה בפוריות הקרקע וכתוצאה מכך ירידת "מצב שיקומו", ערך המבטא את יכולת שימושה החקלאי העתידי (Rehabilitation state).

עיבודי קרקע משמרים (רעיית בעוצמות נמוכות, חריש מופחת ומשמר וכו') יגרמו לתהליך שיקום קבוע אך איטי, שתבטא בשלב ראשוני בростה בכמות הצמחייה ופוריות קרקע גבוהה. בשלב השני הצמחייה מייצרת שלף, חומר אורגני, ופעילות מואצות של ניסוחי הסביבה, דבר התורם לייצוב השטח (קטנת סחף הקרקע) עד מצב של עיבוד חקלאי ב-קיימא. 가능ות שלישית לניהול קרקע זאת היא שילוב עיידות קריטיות הפקודות וה FHA בטיפולי עיבודים אלה יגרמו לกระเปורים חמישים שצמודים בכניסה, דבר הפוגע רבות ב��ונם ויישומם בשטח. בהתאם לכך מטרות המחקר נקבעו כדלהלן.

א. ניתוח השינויים לרפואה שיקום בכמות הצמחייה והפוריות של קרקעים של תזוזה בעיבודים החקלאים המובילים בשטחים המדבריים

ב. השוואת ערכים פוריות הקרקע וא.Sequentialiros של מוחה של המוחה של החדר העליון (שודר), על תזוזות בשתי deltaXים, לעיכובים בינוניים של קצבור של השיקום ב-סיבוב ב-טבע.

ג. הגדרת השפעת תצורות נוף שונות על פוריות הקרקע ותרומתם למנגנונים השיקומיים

לשם כך, בוצע מחקר ארוך-טווח בין 2011 ל-2018 בשטחים מדבריים בלוחות אורי עופי, שבא ל-60% ממימדים במיתו של מים." (Project Wadi Attir).

הנולタイプ המים נפגעים בשם השיקום של המים, והם מוגנים ב-70% מ GLES ב-70% מ GLES." (Project Wadi Attir).

הנולתקופת המים נפגעים בשם השיקום של המים, והם מוגנים ב-70% מ GLES ב-70% מ GLES." (Project Wadi Attir).
אבולוציה של מערכות חקלאיות – אколоוגיות תחת מקרי ניירות שונים בשטח לס ביצים ಶְׁנֵים

מחקך למש מandering חלק של הדירישות לקבלת תואר דוקטור לפילוסופיה

מאת

עמיר
מור-מוסרי

הוגש לשוחט אוניברסיטת בן גוריון בנגב

תאריך ערבי  י"ח בטבת ה'תשע"ט

תאריך לועזי 26/12/2018

תאריך העברי "י"ח בטבת ה'תשע"ט"ש

בואר שביעי
אבולוציה של מערכות חקלאיות- אקולוגיות تحت משטרים שונים
בשעיה של בצפון הנגב

מחקlando بلد מיולי חלקי של הדורוות לקבבל תואר "דוקטור לפילוסופיה"

מאת

עמי מור-מוסרי

הועש לסינייטאט אוניברסיטת בנגוריון בנגב

תאריך עדיני "ה בחודש ה'תשע"ט

תאריך לועזי 26/12/2018

baar שביעי