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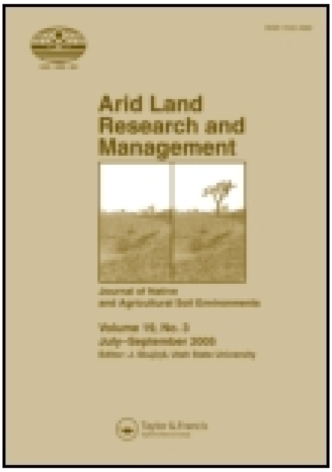

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The Effect of Planting Techniques on Arid Ecosystems in the Northern Negev

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The Effect of Planting Techniques on Arid Ecosystems in the Northern Negev

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Forestation is a widely accepted way to combat desertification. This approach can have tremendous beneficial effects on soil and environment. The United Nations Food and Agriculture Organization recommended Acacia victoriae *for rehabilitation of degraded arid environments. For that purpose areas in the Northern Negev were planted with* Acacia victoriae *in the period of 1990–1993. The planting techniques were: sparse plantings (Contour trenching and Savanna), and dense planting of woodland. We divided each of those treatments into planted and control plots. In the plots planted by contour trenching the values of annual biomass per area, nutrient and Soil Organic Carbon (SOC) contents underneath the tree's canopies were the lowest, while those values in the planted savanna and woodland plots were significantly higher. Contour trenching also harmed the soil by causing erosion, and decreasing the soils water holding capacity. Therefore, Woodland and Savanna plantings should be preferred over contour trenching in arid areas.*

Keywords *Acacia victoriae*, contour trenching, planting techniques, woodland

Land degradation in drylands (often termed desertification) affects about two-thirds of global dryland areas in 54 countries (Malagnoux, 2007). In 1997 the United Nations Environment Program (UNEP) estimated that one quarter of the earth's land is threatened by desertification (UNEP, 1997). Forestation is one of the most common ways to fight these environmental threats (Malagnoux et al., 2007), for example, by reducing soil erosion (Reubens et al., 2007). The efficiency of forestation depends on the survival and growth of the planted trees and the choice of species

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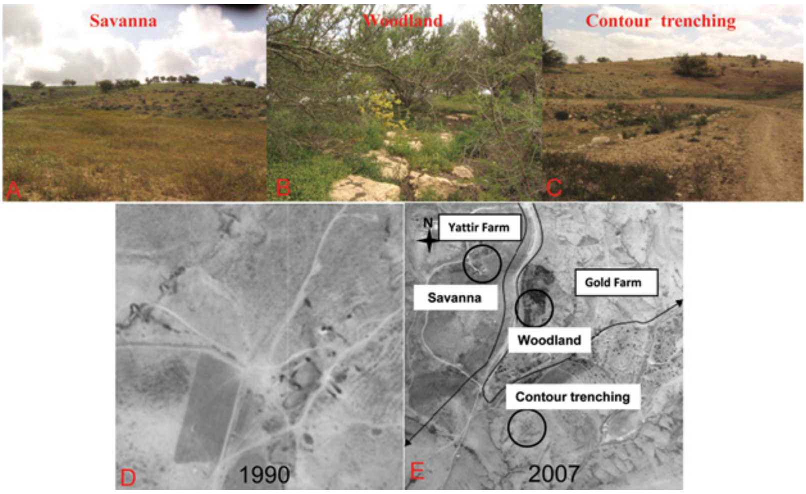

Figure 1. Visual views of the different planting plots: Above - close view of the different planting plots, A – Savanna, B – Woodland, C – Contour trenching (* Photos by A. Mor-Mussery, July 2010.) Below aerial photographs of the research area in 1990 (left, D, planting time) and in 2007 (right, E). (The Israeli National Agency for Geodesy, Cadastre, Mapping and Geographic Information®.) (Figure available in color online.)

(Chazdon, 2008). The planting technique (Cao, Tian, et al., 2010), planting density (Lengkeek et al., 2005), and soil preparation before planting (Cao, Wang, et al., 2010) are important as well. Yet, so far only few studies, explored the effects of different planting techniques and planting density on arid ecosystems (Cao, Tian, et al., 2010). Most of those studies were hampered, among other reasons by the fact that it was hard to find different planting types at the same site (same soil properties and climate), and by the low growth rate of desert trees. In order to overcome these obstacles, we located an area featuring three different planting techniques (sparsely planted contour trenching or savanna and woodland areas) within an area of five square kilometers (Figure 1) characterized by essentially identical topography and soil. Of note, these planting techniques were applied in the same time period (1990–1993).

We focused on *Acacia victoriae* (Family *Mimosaceae*[1]). This ever-green tree, acclimatized from Australian savannas (Ladigesa et al., 2006), is recommended for rangeland improvement and rehabilitation of degraded arid areas by the Food and Agriculture Organization of the United Nations (Rouchiche & Mirsadeghi, 2003), and is known for its rapid growth rate under arid conditions. The closeness of plots with *A. victoriae* Benth. trees planted at the same time, but by different techniques, motivated us to explore their impact on the ecosystem.

We based our methodology upon defining control areas for each of the planted plots allowing comparing between them. Here we describe detailed analysis of the applied planting techniques at the chosen research site. In the future such an analysis will allow selecting the most efficient planting strategies for combating

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[1] Ben Gurion University scientists and the JNF planting team have identified these species.

desertification. Such an approach could be also relevant for examining the introduction of other tree species into arid environments.

Materials and Methods

Research Area

The study area is located in the Chiran Forest, 2.5 km south of Yattir Forest, 4 km North-East of Hura and 3.5 km east of Meitar in the Northern Negev, Israel (34°59′04″E, 31°19′34″N; Figure 1). It is a hilly, generally south facing slope with an average altitude of 450–500 m. The soil is sandy loam/sandy clay loam (USDA, 1999). The entire area was heavily grazed until 1990. Subsequently, the Jewish National Fund (JNF) planted various native species) such as *Acacia raddiana* Savi, *Tamarix aphylla* (L.) H.Karst., *Ceratonia siliqua* L. and *Pistacia atlantica* Desf., and exotic species such as *Eucalyptus camaldulensis* Dehnh., *Prosopis alba* Grisebach., *Acacia salicina* Lindl. and *Acacia victoriae*[2] (http://www.kkl.org.il/kkl/kklmain_eng.aspx). The major reason of those plantings was watershed protection and combating desertification (http://www.kkl.org.il/eng/forestry-and-ecology/combating-desertification), though *A. victoriae* was also planted on private farmland to improve range conditions. In most of the area, the trees were planted inside 10 m wide contours separated by 1 m high, 2 m wide mounds (or berms, http://www.indiawaterportal.org/book/export/html/6961) at about 80–100 trees per hectare. The contours were designed to have moderate slopes enabling water drainage from rains into their lowest parts which actually contained the planted trees (Critchley & Siegert, 1991). The JNF also planted trees in small ditches without contour trenching inside the farms in Savanna form (sparse planted trees inside shrubland) and in woodlands planting 250–400 trees per hectare with little soil movement. In contrast to the other techniques the design of the contours requires use of heavy mechanical equipment and is controversial.

Classifications of Plots

In the *Contour trenching* area three plots were defined.

- "Mound" (or berm), the soil dams raised at the lower end of each contour;
- "Source," the sloped part draining into the lowest part or sink of the contour;
- "Sink," the lowest part or contour trench where the runoff water is accumulating, unplanted area;
- "Planted," the sink area which is canopied by *A. victoriae* trees.

In the *Woodland area* (located at Yattir farm, Figure 1), the following plots were defined:

- "Planted," representative area of 225 m^2 inside the woodland (underneath and between the trees' canopies).

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[2] Lately JNF stopped planting of this species in the northern Negev due to the invasiveness concerns (Wilkie, 2010). Of note, our observations do not confirm this claim (unpublished data).

- "Patch," two sub-areas in the woodland, adjacent to the "Planted" plot (~25 m) without canopy cover, surrounded by *A. victoriae* trees. Surface of ~40 m^2 each (similar to the definition of Honnay et al., 1999).
- "Shrubland," shrubland area 10–30 m west of the woodland.

In the *Savanna* (~8 hectare sparsely planted with *A. victoriae*, located at Yattir Farm, Figure 1)

- "Planted," the area underneath the *Acacia victoriae* canopies;
- "Shrubland," the unplanted shrubland surrounding the trees.

Vegetative and Soil Tests

The litter (ecological impact reviewed by Berg & McClaugherty, 2008) and the annuals' biomass were measured by manually collecting the vegetative material from the soil surface using an iron frame (20 × 30 cm). The samples were randomly collected in five locations per each plot at the *Contour trenching, Woodland* and *Savanna* areas in 2009 and 2010 in March or April, at the end of the rainy season, when the herbaceous species reach maximal weight. The collected samples were dried for 48 hours at 60°C and separated into herbaceous biomass and litter. Weight values were calculated per 1 m^2 as described by Fan et al. (2008).

The root biomass in the top 20 cm of soil was measured by sampling 500–1000 g of soil from each plot. The dry soil was weighed, and then mixed with water, the floated material was gathered, washed, dried for 48 hours at 65°C, and weighed. The root biomass is presented as grams of organic matter per kg of dry soil, according to Sava (1994).

The most crucial factor in arid areas (highly affected by floods and irregular rains) is the moisture content (function of the water holding capacity) (Eldridge et al., 2000; Zaady, 2005). With this in mind, the moisture content was compared one week after the last massive rain event in the contour trenching plots, and in all plots described in May 2010. Soil moisture (weight) was determined by calculating the weight differences of the soil samples before and after drying at 105°C over night (Sava, 1994). For additional measurements the samples were taken to Gilat Field Service Labs. The following examinations were performed: SOC (Soil organic carbon), ammonium, nitrate, phosphorus, field capacity (maximal optional water content), and clay content.

Statistical Analysis

Analysis was performed using JMP ver. 5.0 SAS Institutes Co. software.

ANOVA analysis was performed with 90% confidence ($\alpha = 0.1$); differences were considered significant between the values marked as "a" (lowest), "b" (intermediate), and "c" (highest). Mixed letters (a/b or b/c) reflect differences between values with less than 90% confidence (Sall and Lehman, 1996).

Results

Plant Growth in the Research Area

As can be seen from the air photos of the study area [taken at planting time in 1990 (D) and 17 years after the initial planting in 2007 (E)] vegetation development in the three tree planting approaches was significantly different. Highest vegetation density is observed in the *Woodland* [black in the aerial photograph of 2007 (E) and the photograph (B)], and the lowest in the *Contour trenching* [almost white reflection in E with little vegetation (C)] with intermediate values in the *Savanna* (E, A), inside Yattir Farm (Figure 1). The poor soil quality at the *Contour trenching* area is reflected by the presence of soil cracks and erosion gullies which appeared after floods.

Annuals and Perennials Biomass Tests

In all the examined treatments (*Savanna, Woodland*, and *Contour trenching*), the highest annuals' biomass and litter per area unit was observed in the "Planted" plots underneath the *A. victoriae* canopies (Figure 2). The lowest values were found in the control plots in *Woodland* and *Savanna*, the "Shrubland" plot, and in *Contour trenching* the "Source" plot. The planted plots (underneath *A. victoriae* canopies) and the control plots belonging to the *Contour trenching* areas had lower herbaceous species biomass per area unit than the respective *Savanna* and *Woodland* plots. The *Woodland* and *Savanna* did not differ in the amount of herbaceous biomass in separate comparison of the Shrubland and the Planted plots. The litter amount was significantly higher in the Planted plot of the *Woodland* (due to the high amount of tree leaf and seed pod litter), as compared to the Planted plot from the *Savanna* (more wind dispersal than the *Woodland*). The "Patch" plot of the *Woodland* was unique due to the impact of the surrounding trees. It had high biomass per area unit (litter and herbaceous species) compared to the plots from other treatments (also observed by Greene & Johnson, 1996).

In order to obtain more accurate representative values of the biological activity in the plots, we measured the below ground biomass (roots) in the top 20 cm of soil

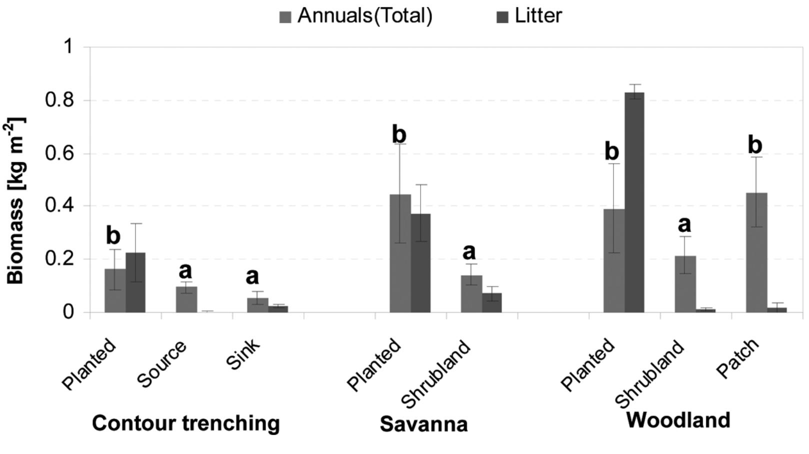

Figure 2. Annual herbaceous and litter biomass in the different plots, March, 2010: Error bars on columns represent the Standard Error; Letters above columns represent significant differences between plots averages ($\alpha < 0.1$ see tools and methods, statistical analysis). Of note, the annuals biomass differences between the planting plots were as follow: Contour trenching-a, Savanna-b, Woodland-b. The litter biomass differences between the planting plots were as follow: Contour trenching-a, Savanna-a, Woodland-b.

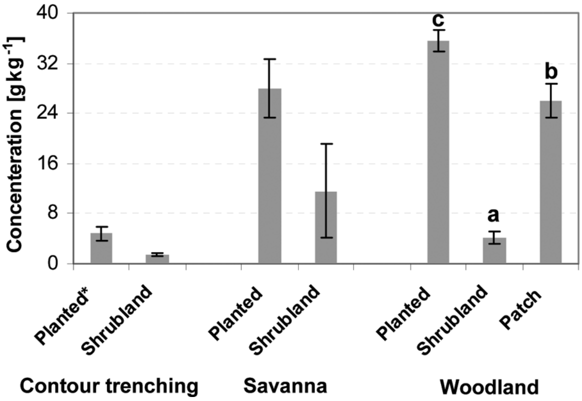

Figure 3. Near surface soil biomass (roots) in the different treatments, measured in February, 2009. Error bars on columns represent ± SE (Standard Error); Letters above columns represent significant differences between plots averages ($\alpha < 0.1$ see tools and methods, statistical analysis). Of note, the near surface soil biomass differences between the planting plots were as follow: Contour trenching-a, Savanna-a/b, Woodland-b.

in each plot. As demonstrated in Figure 3. The Planted plots have the highest values in all the treatments and between the treatments the highest values were found in the *Woodland* plots Planted plots (underneath *A. victoriae* canopy).

Soil Tests

Soil moisture was measured at the beginning of the summer (Figure 4A) and in the *Contour trenching* plots (Figure 4B), also in the middle of winter. The measurements showed that the tree canopies helped conserving the moisture content in the planted plots as compared to those found in the open control plots (Figure 4).

This was also true in case of the patch plot of the *Woodland* (plausible explanation is the wind break effect provided by the woodland trees; as described by

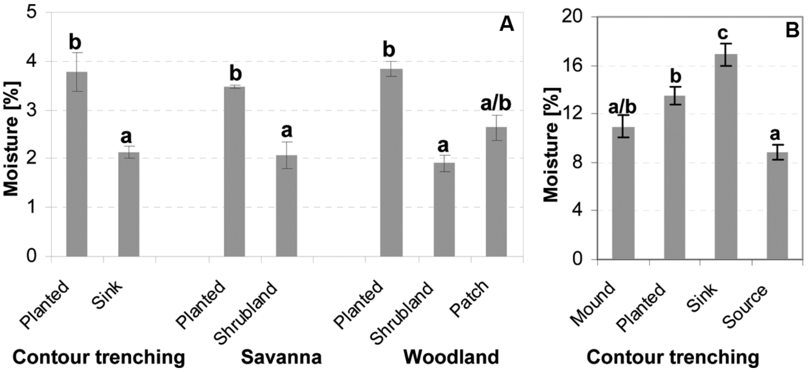

Figure 4. Soil moisture in the different plots. A- May 2010 and B- January 2011 in *Contour trenching* plots only. Error bars above columns represent ± SE (Standard Error). Letters above columns represent significant differences between plots averages ($\alpha < 0.1$ see tools and methods, statistical analysis).

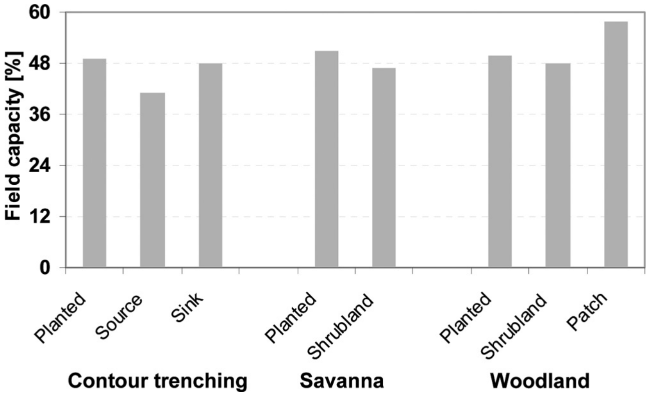

Figure 5. Soil field capacity in the different plots, March 2010. Five soil samples from each plot were mixed and analyzed at the Gilat field service laboratory.

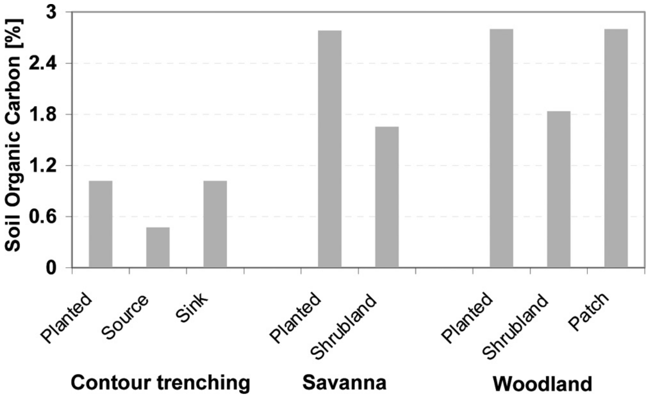

Figure 6. SOC (Soil Organic Carbon) content in the different plots, March 2010 Five soil samples from each plot were mixed and analyzed at the Gilat field service laboratory.

Greene & Johnson, 1996). In case of the *Contour trenching* the moisture was the highest in the 'Sink' plot, where runoff water is accumulating, one week after the rain event, but the sink lost its moisture rapidly afterwards. The lowest moisture values were found in the Source plot.[3] These results are further strengthened by the Field capacity measurements (Figure 5). In the sparse planting treatments the highest field capacity values were found in the Planted plots. In the *Woodland* the Patch has the highest value. Among the Planted plots the *Contour trenching* plot has the lowest field capacity, while the *Savanna* and the *Woodland* show almost the same field capacity.

An important element for soil health and plant development is the Soil Organic Carbon content (SOC). The results of the SOC measurements in the different plots appear in Figure 6. In similarity to the vegetative biomass (Figure 3) and the soil root

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[3] Of note, In other Contour trenching areas near the study site, we found (winters of 2010 and 2012) big puddles (all over the tunnels) that remained till May.

biomass content (Figure 4), the Planted plots (underneath the *A. victoriae* canopies) had the highest SOC values. Among the planted plots, the *Savanna* and the *Woodland* plots had similar SOC values, while the lowest were found at the *Contour trenching* plots. Paradoxically, the soil of the Sink plot of the *Contour trenching* had high values of field capacity, though low SOM content. This could be explained by high level of clay (31% as compared to 18–21% in other plots; Gong et al., 2003). The same trend in plot measurements was also observed in case of nitrate, phosphorus, and potassium contents (data not shown).

Discussion

Afforestation has become the primary tool for ecological restoration of degraded arid and semi- arid areas in Israel. The Jewish National Fund (JNF) has planted various native and exotic species (http://www.kkl.org.il/kkl/kklmain_eng.aspx) at the arid-semi arid interface for watershed protection, combating desertification, and control of soil erosion (http://www.kkl.org.il/eng/forestry-and-ecology/combating-desertification), with *A. victoriae* being planted also to improve range conditions. Little attention so far has been rendered to carefully monitoring the environmental impacts of widely varying planting approaches and species. Especially the so called contour trenching approach is highly controversial among environmentalists.

Understanding the interactions of the planted trees with the surrounding environment is a precondition to enable establishing prosperous woodlands in arid areas. This, in turn, will contribute to the best choice of the suitable species for rehabilitation of the local ecosystem and supply valuable economical asset for nutrition and grazing.

We have therefore performed an analysis on the impact of planting *A. victoriae* in well defined, nearby, comparable plots using three different approaches: contour trenching for low density plantation, savannization, or dense woodland planting without soil disturbance. In all plots open shrublands areas served as controls for quantification of the impacts of the planted trees compared to unplanted areas.[4]

Soil quality such as nutrient content, soil organic carbon, and, as a consequence, productivity of annual vegetation were profoundly different among the three planting techniques, as well as below the trees canopies and in the shrubland parts. While the contour trenching plot revealed depleted soil organic carbon and nutrients, the savanna and woodland plots revealed higher soil organic matter, nutrient, and soil moisture contents. Interestingly, values under the tree's canopies were significantly higher than those in uncanopied control plots. Our observations indicate that annual herbaceous plants contribute the major part of SOC, based on the good agreement between SOC observed and the amount of top soil root biomass content observed. This is in excellent agreement with the claims of Cao and coworkers derived from large studies on China's afforestations (Cao, Tian, et al. 2010; Cao et al., 2011), that disturbance of local vegetation by planting should be avoided.

Our observations in the contour trenching plot are also in general agreement with observations in China where large areas of eroding semi-arid land has been subject to afforestations (Cao, 2008; Cao et al., 2009; Cao, Tian, et al., 2010; Cao et al., 2011). Massive soil disturbances such as those required for contour trenching,

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[4] Cao et al. (2007) suggests examining the natural processes occurring in the untreated or partially treated areas.

amplified by grazing and planting of unsuitable "thirsty" trees, have been detrimental to rehabilitation efforts. Unfortunately, the major planting method in the Northern Negev and in wider parts of the Negev desert remains *Contour trenching* (data from JNF; Critchley & Siegert, 1991). This method was developed in order to conserve the rain water in the pits, where the trees were planted (defined as the "Sink" plot in this paper). *Contour trenching* was mainly studied with regard to its physical and geographical aspects (Dalvi et al., 2009) without focusing on its effects on the ecosystem and trees' growth (Critchley & Siegert 1991). Our analysis demonstrates that this method performs clearly worse than the less invasive planting techniques, an observation supported by others (Chapin et al., 2002; Cao, 2008), causes oxidization of the soil components[5,6] (Reicosky et al., 1995), and demands structuring and re-design after floods along with constant maintenance (Data from JNF planting department; Critchley & Siegert, 1991).

Various tree species planted can deplete soil moisture and consequently reduced biodiversity and related ecosystem services in drylands (Cao, Tian, et al. 2010; Cao, Wang, et al., 2010; Malagnoux et al., 2007; Morris et al. 2004).

Our analyses in savannization and woodland *A. victoriae* plantations demonstrated significant improvements in biological productivity and soil quality, even though recorded in significantly drier conditions than those recorded in China (Cao et al. 2008). We attribute this to specific properties of *A. victoriae* making it specifically suitable for restoration of arid-semiarid rangelands. Evidently *A. victoriae* is not a "thirsty" tree, but rather conserves and enhances soil moisture and nutrient contents by providing ample litter from seeds pods and leaves, while lacking allelochemicals that might suppress growth of annual vegetation (Molina et al. 1991).

It has been suggested that tree planting can either accelerate the rehabilitation of arid areas, or cause soil degradation depending on their planting density requiring separate investigation for each tree species (Cao, Wang, et al., 2010). We have compared the denser *Woodland* with the *Savanna* plots whereby the denser woodland plot had significantly higher annual biomass cover together with much increased tree cover. This is again in contrast to other observations and linked to the fact that *A. victoriae*, in contrast to other species, does not excessively exploit soil resources, but rather contributes to their enrichment by providing shade, litter cover and nitrogen fixation thus creating a possibly ultimately productive and diverse ecosystem even under the extremely harsh conditions at the arid-semiarid interface in the Northern Negev.

The results of our study (biomass quantity, soil quality, and water retention) suggest that the best way to profit from the *A. victoriae* and other species in arid areas is by avoiding *Contour trenching. A. victoriae* plantations consistently revealed higher soil moisture content than unplanted control plots with resulting increase in annual vegetation, and this species thus seems to be especially suitable for land rehabilitation in semi-arid and even arid zones.

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[5] For example, in April 2010 (two months after the last massive rain event), we measured the SOC content value of 4.31% and Nitrate content of 3.9 mg Kg-1, while two months before the rains the values were much higher (6.31% and 28.5 mg Kg-1, respectively).

[6] Of note, Cao et al., 2008 demonstrated that by using biodegradable plastic cover the oxidizidation effects can be decreased. Still use of this method requires researching the effects on the ecosystem.

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