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Effect of terracing on rainwater harvesting and growth of *Juniperus procera* Hochst. ex Endlicher

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ABSTRACT: The present study was conducted in two forests in Abha (Capital of Asir Region) and two forests in Al Namas (130 km north of Abha), south western Saudi Arabia (Asir region) to investigate the effect of terraces on rainwater harvesting and growth of *Juniperus procera* Hochst. ex Endlicher. Farmers grow their crops within Juniper forests and woodlots by constructing terraces from soil and stones to harvest rainwater. Juniper forests and woodlots present important watersheds and sources for water. Study plots were established in four forests, two of which contained maintained terraces and the other two have been covered by abandoned and damaged terraces. The results showed that maintained terraces served as important means for rainwater harvesting, whereas abandoning of terraces resulted in increased soil loss, surface runoff, bulk density and reduced infiltration rates. Significant correlations and regression between soil loss, total runoff, soil bulk density and infiltration rate were provided. Diameter at breast height, total height, basal area, volume, number of trees, crown coverage and regeneration/ha of *J. procera* were significantly ($P < 0.0001$) higher in forests with maintained terraces compared with abandoned terraces. Finally, maintained terraces improved rainwater harvesting and growth performance of *J. procera*.

Keywords: *Bulk density; Infiltration; Rainwater management; Soil erosion; Surface runoff*

INTRODUCTION

Forests in the Kingdom of Saudi Arabia (KSA) are concentrated on the Sarawat Mountains (2.7 million ha equivalent to 1.35 % of the area of the Kingdom) in the south western part extending from Hejaz Mountains in the north to Asir Mountains to the south in addition to scattered tree formations along the water catchments, valleys and meadows in the interior of the Kingdom. The main forest cover is composed of juniper forests and woodlands which are coniferous evergreen forests that grow in pure stands at elevations 2000-3000 m above sea level. At lower altitudes, the junipers grow in varying mixtures with other trees. Below 1700 m, the dominant species are generally broad leaved trees dominated by wild olives. At the foothills the plant cover consists of mixtures of deciduous trees mainly of *Acacia* – *Commiphora* scrub formations before they merge into the dry scattered acacia country which virtually disappears into the barren interior plateaus. Juniper forests in Asir region, occupy the mountainous wetter and cooler zones. They provide several benefits, including reduction of water runoff in the mountainous areas of the southwest which helps to protect watersheds and reduce soil erosion especially on steep slopes, as well as reduce silting and damage to dams at the foothills (Gorashi, 2005). In the past, the juniper woodlands were much more dense and widespread. Local communities have lived within the juniper wood lands and took part of the benefits derived from the wood lands. The wood provided construction material and firewood. Main pillars were used to be made from juniper wood and were thought to last for at least fifty years. The community have deep ties with juniper and farm lands were established within the ecosystem because juniper make excellent resource of water and has superior water retaining capabilities. The terraces fields are well known in Asir mountains. In addition to rainwater regulation, juniper has the capability of trapping the mist, which is very common in Asir Mountains, which then flows down into the soil (Anonymous, 2006). However, due to drastic changes in the economy of the Kingdom only few maintained terraces still existed and the majority were abandoned and destroyed. For more than three decades, it has been reported that juniper forests are suffering from serious

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decline and deterioration in the form of die-back. This issue has been addressed by various studies (Fisher, 1997; Barth and Strunk, 2000 ; Fisher, 2000; El Atta, 2003; El Juhany *et al.*, 2008). It is apparent that juniper is under severe stress resulting from severe soil erosion, surface runoff and inefficient rainwater harvesting that predisposed trees to infestations by insect pests and pathogens. The phenomenon of juniper deterioration is not unique to KSA. Case histories from juniper forests in Kenya, Kyrgyzstan, Morocco, Pakistan and the USA illustrate problems facing the world's juniper forests. Most juniper forests are fragile ecosystems, open grown, trees often have poor form, natural regeneration is sparse and they are affected by damaging agents which are often not well understood (Ciesla 2002).

In national parks there is severe soil compaction that hinders rainwater infiltration into the soil. Soil depth decreases dramatically with increasing distance from juniper trees (Barth and Strunk, 2000). El Atta (2006), reported that abandoning and destruction of the old terraces, which are very common in the Juniper ecosystem, might have played an important role in increasing water surface runoff and soil erosion which led to various adverse results among which is the decline and deterioration of juniper. Consequently, severe soil erosion had occurred uphill and sedimentation downhill. The clearing of natural vegetation on hillsides and any kind of agricultural field surface or slope management modifies the movement of water and sediment down the slope (Wilken, 1987). Agricultural land abandonment is currently widely spread in Mediterranean countries and a further increase is expected. Previous research has shown that abandoned fields in semi-arid areas are more vulnerable to gully erosion. The absence of ploughing and slow vegetation recovery cause the formation of soil crusts with low infiltration rates, resulting in increased runoff and gully erosion risk (Lesschen *et al.*, 2008). Potential soil and water conservation practices to mitigate soil erosion after abandonment are: 1) maintenance of terrace walls, as a result more water is retained, which increases vegetation cover and consequently decreases erosion; 2) Re-vegetation with indigenous grass species on spots with concentrated flow, especially near terrace walls (Lesschen *et al.*, 2008). If this situation continues for long without intervention, may lead to extinction of these important forests with all the adverse environmental consequences that follow.

The main objective of the present study is to assess the impact of abandoning terraces in the juniper ecosystem on water harvesting and the consequent runoff, soil erosion and the overall growth of *J. procera* on the Sarawat Mountains (south-western Saudi Arabia). The study was carried out in forests with abandoned and damaged terraces and forests where terraces are well or fairly maintained in Abha (Capital of Asir Region) and Al Namas (130 km north of Abha) during 2006-2007.

MATERIALS AND METHODS

Site selection

Fig. 1 summarises the average rainfall distribution in the study area. The dominant climate in the area is the semi-arid with a temperate variance in Al Namas and a worm variance in Abha. Rainfall in the Juniper forest area is characterized by short and intense rains. This aspect, combined with the steep topography, reduced vegetation cover and the soil profile, explains the violent and short duration floods that characterized most of the valleys in the area. This signifies the vital importance of the juniper forests in the area in regulating water flow, reducing runoff and erosion (Aboulabbas, 2006). In each location (Al Namas and Abha), a forest with abandoned and damaged terraces and a forest with maintained terraces were chosen fairly close to each other to avoid considerable differences in climatic conditions especially rainfall. As such, Al Khashrum and Shaaf Al Khraim forests represented those with abandoned and maintained terraces in Al Namas, respectively, whereas Al Jurrah and Ain Al Ghalab forests represent forests with abandoned and maintained terraces in Abha, respectively. In each forest three terraces were selected randomly. More than 80 % of the selected terraces had slope angles less than 10 º, hence slope of the terraces was not a major factor influencing water runoff and soil erosion (Gardner and Gerrard, 2003). Terrace widths were 2-12 m and riser heights 1-2 m. Three test plots measuring 2 m² (2m × 1m) were chosen randomly in each terrace (Leonard *et al*. 2006; Thomaz, 2009). The test plots were close enough to avoid big variations. The catchments were relatively similar in terms of area, topography, geology and vegetation; and the distance between the catchments was small enough to avoid dissimilarity in weather conditions. Consequently, the catchments were expected to respond identically to any form of manipulation (Cosby *et al.*, 1996).

Measurement of runoff, soil loss and bulk density

All the following measurements were done for one year (2006-2007) after each rain event. Soil loss and runoff

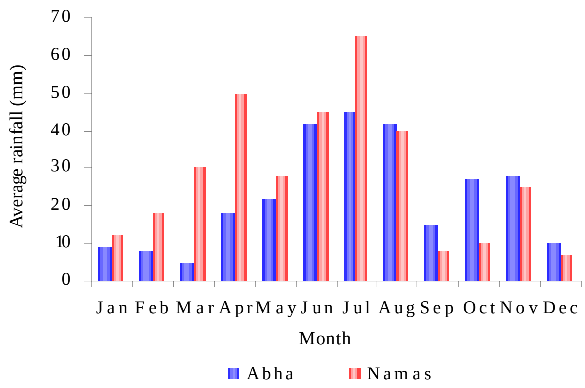

Fig. 1: Monthly rainfall distribution

studies at plot scales have been confirmed to be of crucial importance (Licznar and Nearing, 2003). To avoid variability in the study area and its surroundings, several rain gauges, from 5 to 70 l volume, were randomly placed throughout the test area, in order to record more reliable data. Every plot was coupled to a sediment Gerlach trough which was connected to a 100-l drum. This procedure permitted all runoff and soil loss to be collected. The collected wet soil was oven dried at 105 ºC to constant weights (Thomaz, 2009). In this way runoff and soil loss were measured in each plot. Measurements of runoff and soil loss were taken during every rain event in the period 2006-2007. Bulk density was determined for each test plot in three randomly selected replicates (5-30 cm) using a soil sampler (Li and Shao, 2006).

Measurement of infiltration

Infiltration capacity was measured using a single ring infiltrometer following the Food and Agriculture Organization (FAO) guidelines (Walker, 1989). Three infiltration measurements were done in each plot (nine per terrace).

Measurements of the forest stand

In each forest, sampling was carried out using stratified random sampling on the basis of stand density and altitude. Circular sample plots 17.8 m radius (approximately 1000 m² (0.1 ha)) were laid out and demarcated in each forest. A total of 16 sample plots measuring 16000 m² (1.6 ha) were laid out. Inside each sample plot, tree diameter (cm) at breast height (DBH), total height (m), crown diameter (m) of the three tallest, medium and shortest trees was measured and averaged. Crown diameter (m) was measured by making two measurements at right angles and averaged for the three trees. The latter was averaged for the whole sample plot and calculated as a percentage of the sample plot area in an attempt to define the stand as a forest (10 % of the land area) or woodland (< 10 %). Regeneration intensity of Juniper was determined by counting the number of seedlings per sample plot. All the above mentioned parameters were calculated as per hectare. The effect of water harvesting in terms of maintained or abandoned terraces, on the Juniper ecosystem was assessed.

RESULTS AND DISCUSSION

Runoff

Fig. 1. summarizes the average monthly rainfall distribution in the study area. Total runoff was significantly higher ($P < 0.0001$) in abandoned terraces (40.1 mm = 11.9 %) as compared to maintained terraces (13.8 mm = 4.1 %) in Al Namas (Table 1). Total runoff was about three folds more in abandoned terraces. Similarly, a significantly higher ($P = < 0.0001$) runoff occurred in abandoned terraces (40.7 mm = 15 %) as compared with maintained terraces (23.5 mm = 8.7 %) in Abha (Table 1). A total of 23.7 % runoff ratio was recorded in Abha, whereas 16 % was the runoff ratio in Al Namas regardless of the terrace condition. Runoff from a watershed plays a decisive role on soil erosion (Sui *et al.*, 2008).

Soil loss

Total soil loss was significantly ($P = < 0.0001$) more in abandoned terraces compared to maintained terraces (Table 1). In Al Namas, total soil loss was more tha ten folds higher in abandoned terraces than in maintained ones (20.2 kg/ha and 1.6 kg/ha, respectively), whereas it was more than thirty folds in abandoned terraces (29.7 kg/ha) than in maintained ones (0.8 kg/ha) in Abha.

Soil bulk density

Soil bulk density was significantly ($P < 0.001$) higher in abandoned than in maintained terraces (Table 1) in all studied forests. It was 1.89 and 1.24 g/cm³ in abandoned and maintained terraces in Al Namas forests and 1.44 and 1.17 g/cm³ in Abha forests, respectively.

Infiltration

The infiltration rate was significantly ($P < 0.001$) higher in maintained terraces rather than in abandoned ones in all forests studied. Table 2 summarizes the results of infiltration measurements. Infiltration rates recorded were 8.0 and 20.0 Mm/h in abandoned and maintained terraces in Abha forests, respectively, whereas in Al Namas forests they were 12.4 and 34.2 mm/h in abandoned and maintained terraces, respectively. Soil loss was runoff dependent i.e. soil loss increases with increasing total runoff. In Abha the total runoff explains 68 % of the difference in soil loss (Fig. 2), whereas in Al Namas total runoff explains 81 % of the variation in the soil loss (Fig. 3). Total runoff was significantly correlated with soil bulk density since 68 % and 63 % of the variations in total runoff were explained by differences in bulk density in Al Namas and Abha forests, respectively (Fig. 4 and 5). Soil loss was significantly (R^2= 0.647) negatively correlated with soil bulk density when data from Al Khashrum and Shaaf Al Khraim forests was analyzed (Fig. 6). This was also the case for Ain Al Ghalab and Al Jurrah forests in Abha (R^2= 0.759) (Fig. 7). In general, soil loss decreased with increasing bulk density. A significant (R^2= 0.890) negative correlation was recorded between total runoff and infiltration rate in Al Namas forests (Fig. 8) i.e. the more was the infiltration rate, the less was the total runoff. Similarly, total runoff was also significantly negatively (R^2= 0.906) correlated with the infiltration rate in Abha forests (Fig. 9). Thus, it is possible to estimate the total soil loss with the knowledge of the total runoff, soil bulk density and the infiltration rate in all forests investigated. Regression analysis was highly significant (R^2= 0.906 and 0.890) between soil loss (dependent variable) and total runoff, soil bulk density and infiltration rate (independent variables) in Abha and Al Namas forests, respectively (Tables 3 and 4).

Measurements of the forest stand

Growth parameters of *J. procera* were compared between forests to assess the impact of the terracing on the various growth parameters. Generally, the number of trees/ha, mean DBH/ha, total height, basal area/ha, volume/ha, the number of seedlings/ha and canopy coverage percent were significantly higher in forests with maintained terraces than in those with abandoned and damaged terraces (Tables 5 and 6). The most warning result is the extremely smaller number of seedlings/ha in forests with abandoned terraces (45.5 and 87.4 seedlings/ha in Al Jurrah and Al Khashrum forests, respectively) as compared to forests with maintained terraces (3892.3 and 453.8 seedlings/ha in Ain Al Ghalab and Shaaf Al Khraim forests, respectively). Vegetative cover prevents the build-up of the aggregates, which could lead to the formation of surface crusts that reduce water infiltration. The vegetative cover reduces runoff as well as the concentration and the size of the transported sediment particles and thus, the rates of loss of both soil and moisture. It also influences the soil moisture and temperature dynamics (Sultani, *et al.*, 2007). Tree transpiration and tree canopies affect air temperature, radiation absorption and heat storage, wind speed, relative humidity, turbulence, surface albedo, surface roughness and consequently the evolution of the mixing-layer height. These changes in local meteorology can alter pollution concentrations in urban areas (Anyanwu and Kanu 2006).

The results clearly indicated that terracing is an effective technique for water harvesting in the study plots especially if terraces are maintained periodically. They reduced significantly rainwater runoff and soil bulk density, and increased significantly the infiltration rate. On the other hand, abandoning and damage of

Table 1: Rainfall, runoff, bulk density and soil loss in the experimental plots

Location	Forest	Terrace condition	Total rainfall (mm)	Total runoff (mm) ± "SD"	T value	Runoff ratio (%)	Total soil loss (kg/ha)	T value	Bulk density (g/cm^3) ±SD	T value
Al Namas	Al khashrum	Abandoned	338	40.1 ±1.1	38.1	11.9	20.2	15.34	1.49 ± 0.04	7.11*
	Shaaf Al Khraim	Maintained	336	13.8 ± 0.94		4.1	1.6		1.24 ± 0.06	
Abha	Al Jurrah	Abandoned	271	40.7 ± 1.1	30.79	15.0	29.7	19.0	1.97 ± 0.07	9.24*
	Ain Al Ghalab	Maintained	270	23.5 ± 1.3		8.7	0.8		1.38 ± 0.12	

*Significant at P<0.0001

Table 2: Infiltration rate in the study plots (Mm/h ± SD)

Location	Forest	Terrace condition	Infiltration rate (Mm/h)	T value
Abha	Al Jurrah	Abandoned	8.0±1.58	11.34*
	Ain Al Ghalab	Maintained	20±1.85	
Al Namas	Al Khashrum	Abandoned	12.4±2.7	7.43**
	Shaaf Al Khraim	Maintained	34.2±7.5	

* Significant (P < 0.0001), **Significant (P < 0.001)

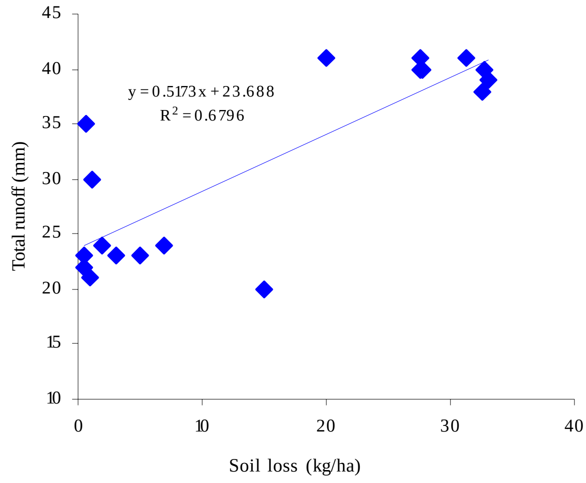

Fig. 2: Soil loss estimation (Abha forests)

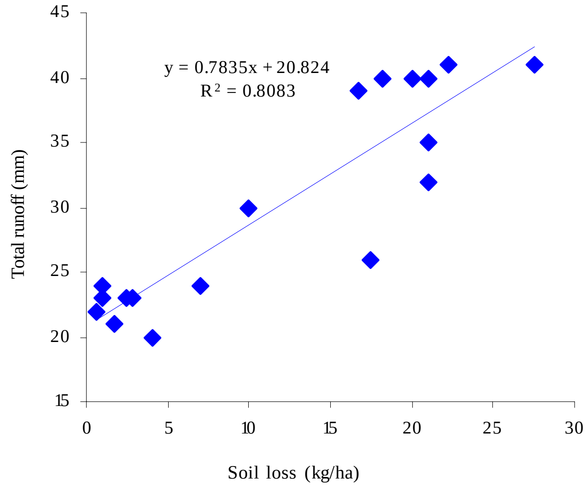

Fig. 3: Soil loss estimation (Al Namas forests)

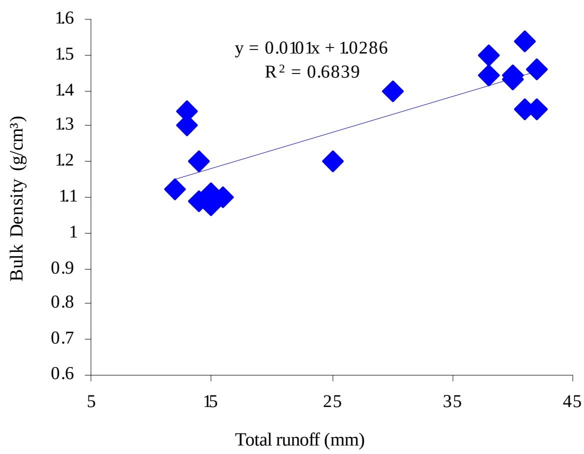

Fig. 4: Total runoff estimation (Al Namas forests)

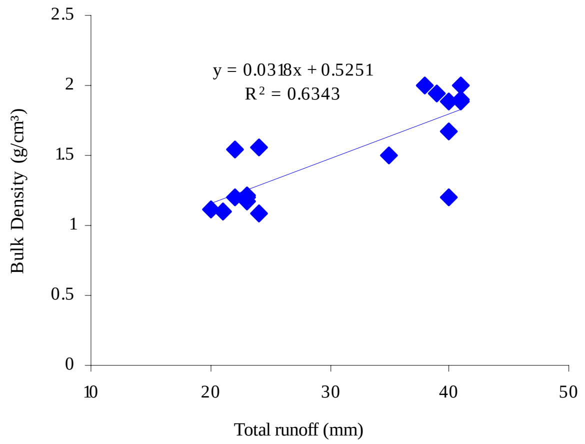

Fig. 5: Total runoff estimation (Abha forests)

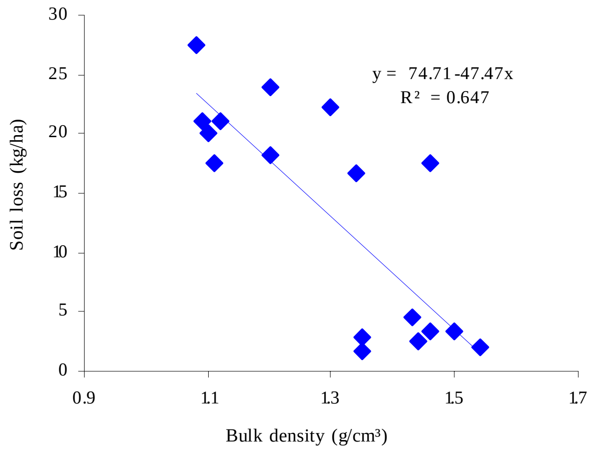

Fig. 6: Soil loss estimation (Al Namas forests)

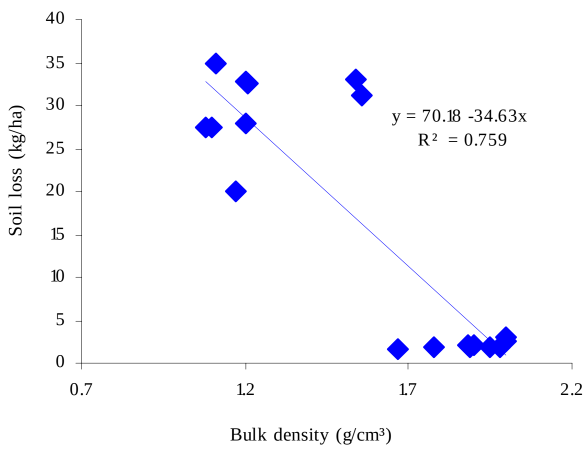

Fig. 7: Soil loss estimation (Abha forests)

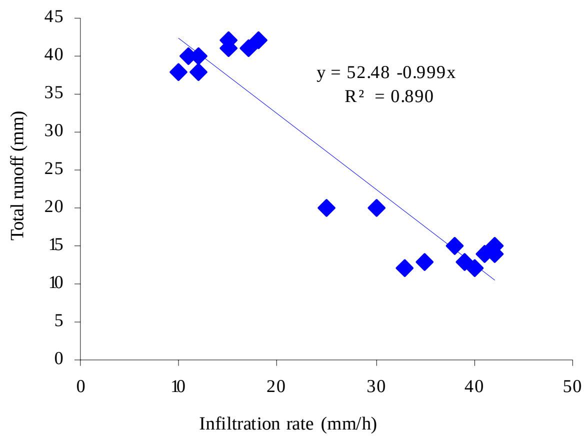

Fig. 8: Runoff estimation (Al Namas forests)

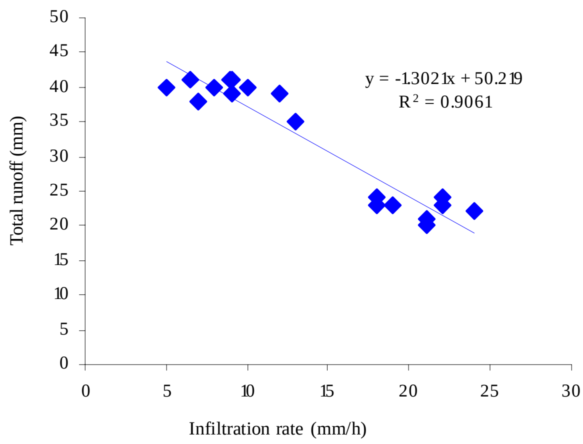

Fig. 9: Total runoff estimation (Abha forests)

terraces had significantly resulted in increased runoff and soil bulk density and reduced the infiltration rate. As a result of increased runoff and bulk density and reduced infiltration rate, soil loss was significantly higher in abandoned terraces as compared to maintained terraces. These results are in line with Hammad *et al.* (2006) who reported that terrace conservation system reduced the negative effect of intense rainfall, resulting in a lower amount of runoff and erosion than in the non-terraced system under Mediterranean conditions. The increase in soil bulk density significantly increased runoff . This is because as the bulk density increases, the soil porosity decreases which limits the depth of water flowing through the soil and thereby increasing the depth of water flowing on the surface as runoff (Adekalu *et al.*, 2006). However, increased bulk density resulted in less soil loss. This may be attributed to the fact that compaction of soil results in high dry density (Ohu *et al*. 1987; Ohu and Folorunso, 1989; Adekalu and Osunbitan, 2001; Berli *et al.*, 2004) which definitely reduced the rate of detachability and transportability of the soil particles. Soil erosion was evident in the abandoned terraces where soil depth decreases dramatically with increasing distance from Juniper trees (Barth and Strunk, 2000). The present study has shown the possibility of estimating the soil loss with the knowledge of total runoff, bulk density and infiltration rate. In the present study, all growth parameters of *J. procera* were significantly higher in forests with maintained terraces as compared to those with abandoned and damaged terraces. This may be attributed to the greater soil losses resulting from increased total runoff and decreased infiltration rates in the latter as compared to the former. In addition, soil erosion causes a decrease in soil fertility and its ability to sustain plant growth (Truman and Bradford, 1990; Deuchras *et al.*, 1999). The reduction in soil fertility associated with soil erosion was attributed to the fact that total N and P are transported by surface runoff (Hansen *et al.*, 2000; Kwong *et al.*, 2002). Since total runoff and soil erosion were much higher in abandoned terraces, it is anticipated that more N and P were lost as compared with maintained terraces. Hence, it may be concluded that abandoning and damage to terraces resulted in poor growth of Juniper due to inefficient rainwater harvesting and soil erosion, and leaching of N and P which are very essential for plant growth. One of the warning results in this study is the very low regeneration (expressed by the small number of seedlings/ha) of Juniper in abandoned terraces. This may be attributed to unavailability of sufficient water and soil due to increased surface runoff, low infiltration, soil erosion and the more N and P transport by runoff. Juniper forests in the Sarawat Mountains are characterized by short and intense rainfall. This aspect, combined with the steep topography, reduced vegetation cover and the soil profile, explains the violent and short duration floods that characterize most of the wadis in the area. It also shows that juniper vegetal cover can play a very important role in the regulation of the rainfall intensity and consequently the violence of runoff (Aboualabbas, 2006). Hence, juniper forests and woodlands must be conserved. One of the major tools for conservation of these forests is improvement

Table 3: Regression analysis (Abha)

Model	SS	MS	F	R^2
Regression	3038.49	1012.83	61.93*	0.930
Residual	228.97	16.36		
Total	3267.46			

*Significant ($P < 0.0001$), Y= 1.063 x1 - 8.79 x2 + 0.416 x3 +2.58, Y= Soil loss x1=total runoff x2=soil bulk density x3=infiltration Mm/h

Table 4: Regression analysis (Al Namas)

Model	SS	MS	F	R^2
Regression	1440.39	480.13	29.28*	0.833
Residual	229.6	16.4		
Total	66799468			

Significant ($P < 0.0001$) *, Y= 0.345 x1 - 16.76 x2 + 0.022x3 – 24.68, Y= Soil loss x1= total runoff x2= Soil bulk density x3= Infiltration rate

Table 5: Comparison of *J. procera* growth parameters (Abha Forests)

Parameter	Forest		T-value	P <
	Ain Al Ghalab*	Al Jurrah**		
Tree number/ha	2059.8	874.3	56.3	0.0001
DBH (cm)	17.8	11.7	8.9	0.002
Total height (m)	8.8	5.0	10.36	0.0002
Basal area/ha (m^2)	56.0	31.7	16.9	0.0001
Volume/ ha (m^3)	157.5	129.2	21.15	0.0001
Crown diameter/ha (%)	65.4	54.0	12.41	0.0001
Seedlings/ha	3892.3	45.5	16.91	0.0005

*Maintained terraces, **Abandoned terraces

Table 6: Comparison of *J. procera* growth parameters (Al Namas Forests)

Parameter	Forest		T-value	P <
	Shaaf Al* Khraim	Al Khashrum**		
Tree number/ha	1981.5	1021.5	121.92	0.0001
DBH (cm)	11.8	7.3	8.22	0.001
Total height (m)	10.9	5.0	16.69	0.0002
Basal area/ha (m^2)	32.7	4.0	57.96	0.0001
Volume/"ha (m^3)	131.5	3.7	192.86	0.0001
Crown diameter/ha (%)	55.5	29.5	28.48	0.0001
Seedlings/ha	453.8	87.4	53.16	0.0001

*Maintained terraces, **Abandoned terraces

of water harvesting through maintenance of the abandoned and damaged terraces which were used in the past to grow food and other crops. It seems that agriculture is no longer rewarding after the economic prosperity following the oil exports era in the Kingdom.

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