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Full Length Research Paper

The effect of terracing on rainwater harvesting, regeneration and growth of *Juniperusus procera* Hochst. ex Endlicher on the Sarawat mountains in south western Saudi Arabia

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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) with the objective of investigation of the effect of terraces on rainwater harvesting and growth of *Juniperusus procera* Hochst. ex Endlicher. Study plots were established in four forests, two of which contained maintained terraces and the other two have 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. DBH, 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. In conclusion, maintained terraces improved rainwater harvesting and growth performance of *J. procera,* whereas abandoning and damage of terraces produced more soil loss, increased surface runoff and bulk density, reduced infiltration and less growth of *Juniperus* which was characterized by extremely poor regeneration.

Key words*:* *Juniperusus procera*, terracing, rainwater harvesting, soil erosion, surface runoff.

INTRODUCTION

Juniperus procera Hochst. ex Endlicher 1847 is a tree, max. height 30 - 40 m, dbh 1.5 m, usually monopodial, exposed trees sometimes multistemmed or branching very low; branches of first order thick and long, ascending and crooked in old trees; branches of higher orders assurgent in young trees, but spreading and finally pendulous in old trees; crown pyramidal in young trees, mature trees soon broad, irregular and open, domed or flat-topped in savannahs and on windswept sites; bark at first smooth, very soon with papery flakes, purplish, on older trees fibrous, deeply longitudinally furrowed, peeling in long, narrow strips, pale brown or grey-brown. The species is distributed in East Africa: North East Sudan near the Red Sea, the Ethiopian Highlands, in Djibouti, Somalia, Kenya, Uganda, Tanzania, in extreme eastern Congo Republic (Haut Katanga), Malawi, northeastern Zimbabwe; also in the mountains adjoining the Red Sea in Saudi Arabia and Yemen (Farjon, 1992). Forests in the Kingdom of Saudi Arabia are concentrated on the Sarawat Mountains (2.7 million hectares 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 *Juniperus* 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 *Juniperus* grow in varying mixtures with other trees. Below 1700 meters the dominant species are generally broad leaved trees dominated by wild

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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. *Juniperus* forests in Asir region, occupy the mountainous wetter and cooler zones. They provide several benefits as increased precipitation through the well-known water harvesting from the clouds/fog, rain-water regulation, improved infiltration, reduction of water runoff in the mountainous areas of the southwest which helps protect watersheds and reduce soil erosion especially on steep slopes and reduce silting and damage to dams at the foothills (Gorashi, 2005). In the past, the *Juniperus* woodlands were much more dense and widespread. Local communities have lived within the *Juniperus* 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 *Juniperus* wood and were thought to last for at least fifty years. The community have deep ties with *Juniperus* and farm lands were established within the ecosystem though at the expense of *Juniperus*-forest land. The terraces fields are well known in Asir mountains (Plate 1) and in the neighbouring Yemen: in the latter country the *Juniperus* forests have totally disappeared because of their destruction through human activity as is a common knowledge. However, due to drastic changes in the economy of the Kingdom only few maintained terraces existed and the majority were abandoned and got destroyed through neglect.

For more than three decades, it has been reported that *Juniperus* forests are suffering from serious decline and deterioration in the form of die-back. This issue has been addressed by various studies (Fisher, 1997, 2000; Barth and Strunk, 2000; El Atta, 2003; El Juhany et al., 2008). It is apparent that *J. procera* is under severe stress resulting from severe soil erosion, surface runoff and inefficient rainwater harvesting that predisposes trees to infestations by insect pests and pathogens. The phenomenon of *Juniperus* spp. deterioration is not unique to KSA. Case histories from *Juniperus* forests in Kenya, Kyrgyzstan, Morocco, Pakistan and the USA illustrate problems facing the world's *Juniperus* forests. Most *Juniperusus* 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 the National Parks there is severe soil compaction that hinders rainwater infiltration into the soil. This compaction was caused by heavy human and vehicle traffic especially during summer vacation. During this period the National Parks receive 2 - 3 million campers during June - September. Soil depth decreases dramatically with increasing distance from *Juniperus* trees (Barth and Strunk, 2000). El Atta (2006) reported that abandoning and destruction of the old terraces in the study area 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 *Juniperus*. In conclusion, 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). *Juniperus* ecosystem on the Sarawat Mountains is characterized by a severe runoff and erosion, low stocking density, sparse or no regeneration in many areas and a wide spread phenomenon of dieback (El Atta, 2006). Thousands of square kilometres of *Juniperus* forests have died off. This situation if continues for long without intervention, may lead to extinction of these important forests with all the adverse environmental consequences that follows. Saudi Arabia, a country of 25 million people, is as water poor as it is oil-rich. Relying heavily on subsidies, it developed an extensive irrigated agriculture based largely on its deep fossil aquifer. After several years of using oil money to support wheat prices at five times the world market level, the government was forced to face fiscal reality and cut the subsidies. Its wheat harvest dropped from a high of 4.1 million tons in 1992 to 1.2 million tons in 2005, a drop of 71 percent. Thus, water shortage is the most critical problem in Saudi Arabia (Brown, 2006).

The main objective of the present study is to assess the impact of abandoning terraces in the *Juniperus* 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).

MATERIALS AND METHODS

Site selection

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). Figure 1 summarises the average rainfall distribution in the study area. Dominant climate in the area is the semi-arid with a temperate and warm tendency in Al Namas and Abha, respectively. Rainfall in the *Juniperus* forest area is characterized by short and

Plate 1. Terraces in Asir Mountains.

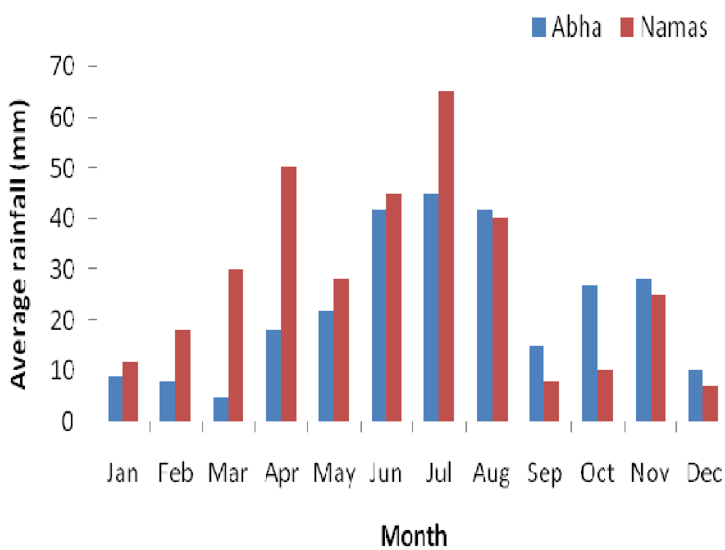

Figure 1. Monthly rainfall distribution.

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 *Juniperus* forests in the area in regulating water flow, reducing runoff and erosion (Abou-Alabbas, 2006).

In each location (Al Namas and Abha), a forest with abandoned and damaged terraces and a forest with maintained terraces were cho-sen provided that they are fairly close to each other. As such, Al Khashrum and Shaaf Al Khraim forests represented those with abandoned and maintained terraces in Al Namas, respectively (Map 1), whereas Al Jurrah and Ain Al Ghalab forests represent

Map 1. The study area.

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°, hence slope was not a major factor influencing water runoff and soil erosion.

Terrace widths were 2 - 12 m and riser heights 1 - 2 m. Three test plots measuring 2 m² (2 x 1 m) were chosen randomly in each terrace (Leonard et al. 2006; Thomaz, 2009). The test plots were close enough to avoid large 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

Soil loss and runoff studies at plot scales have been confirmed to be of crucial importance (Licznar and Nearing, 2003). Several rain gauges, from 5 - 70 l volume, were randomly placed throughout the test area, in order to record more reliable data. Each 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°C to constant weights (Thomaz, 2009). Measurements of runoff and soil loss were taken during every rain event for one year (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 FAO guidelines (Walker, 1989). Three infiltration measurements were done in each plot (nine per terrace).

Measurement 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 were laid out. Inside each sample plot, tree diameter (cm) at

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	Run off ratio %	Total Soil Loss kg/ha	t value	Bulk density g/cm³ ±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/hr ± 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)

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 *Juniperus* was determined by counting the number of seedlings per sample plot. All the above mentioned parameters were calculated as per hectare.

Correlation and regression analysis and t-tests were done using SAS statistical package.

RESULTS

Runoff

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 times higher 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.

Soil loss

Total soil loss was significantly ($p = <0.0001$) higher in abandoned terraces compared to maintained terraces (Table 1). In Al Namas, total soil loss was considerably higher in abandoned than in maintained terraces (20.2 kg/ha, and 1.6 kg/ha, respectively), whereas it was more than thirty times higher in abandoned (29.7 kg/ha) than in maintained terraces (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 forests studied. 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 than in abandoned terraces in all forests studied (Table 2). Infiltration rates recorded were 8.0 and 20.0 mm/h in abandoned and maintained terraces, respectively in Abha forests, whereas in Al Namas forests they were 12.4 and 34.2 mm/h in abandoned and maintained terraces, respectively. Soil loss increases with increasing total runoff. Total runoff explains 68% of the difference in soil loss (Figure 2) in Abha, and 81% in Al Namas (Figure 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 respectively (Figure 4 and 5). Soil loss was significantly ($R^2 = 0.647$) negatively correlated with soil bulk density in Al Khashrum and Shaaf Al Khraim forests (Figure 6). This was also the case for Ain Al Ghalab and Al Jurrah forests in Abha ($R^2 = 0.759$) (Figure 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 (Figure 8) that is, the more the infiltration rate, the less the total runoff. Similarly, total runoff was also significantly negatively ($R^2 = 0.906$) correlated with the infiltration rate in Abha forests

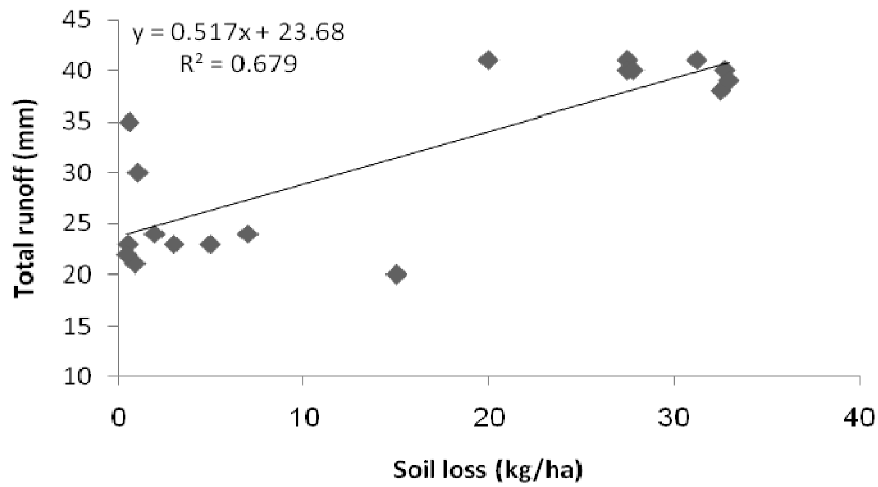

Figure 2. Soil loss estimation (Abha Forests).

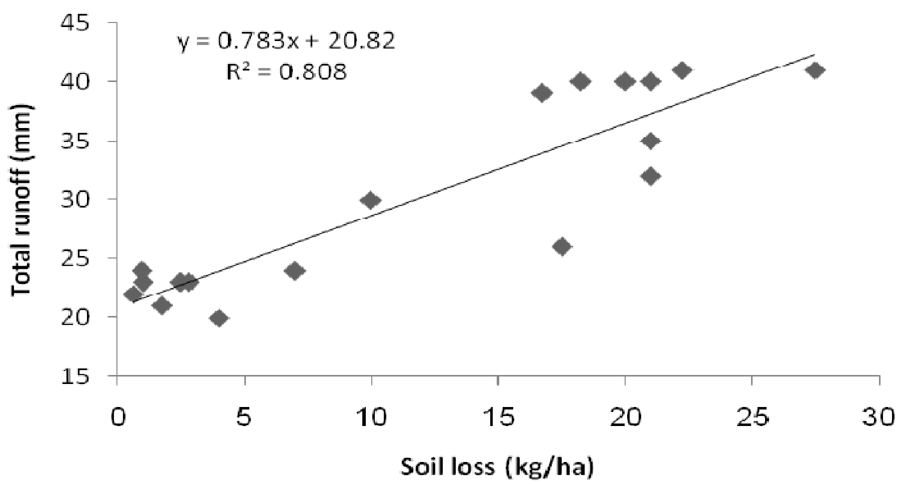

Figure 3. Soil loss estimation (Al Namas Forests).

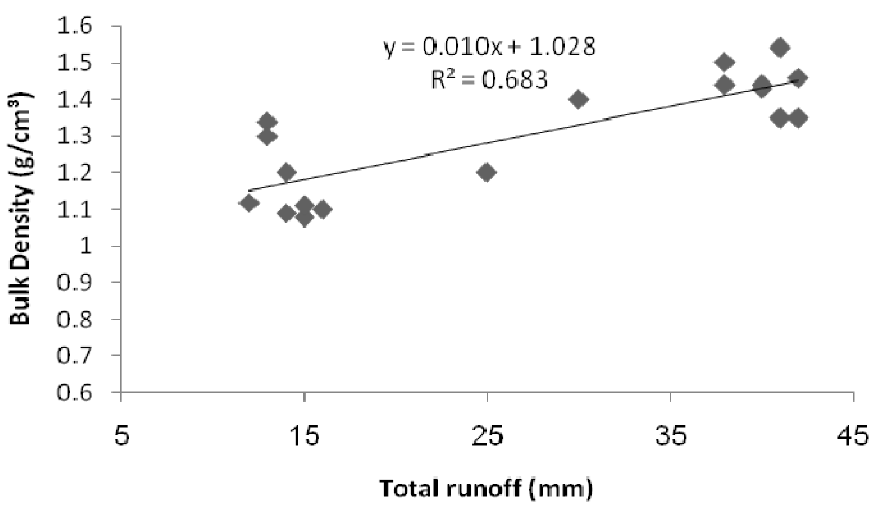

Figure 4. Total runoff estimation (Al Namas Forests).

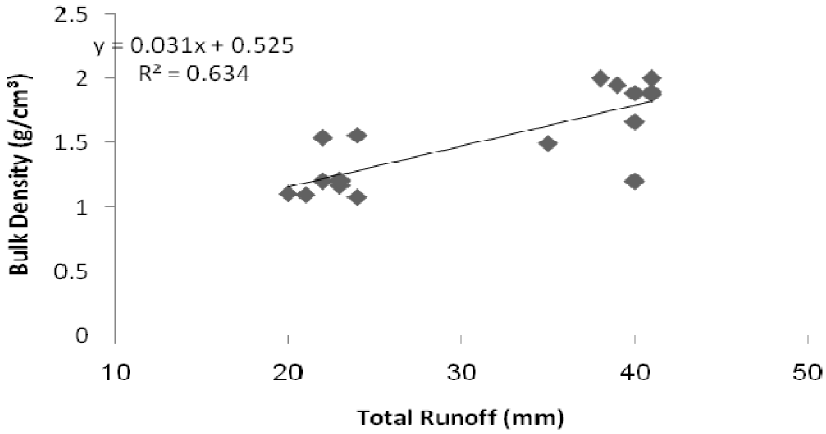

Figure 5. Total runoff estimation (Abha Forests).

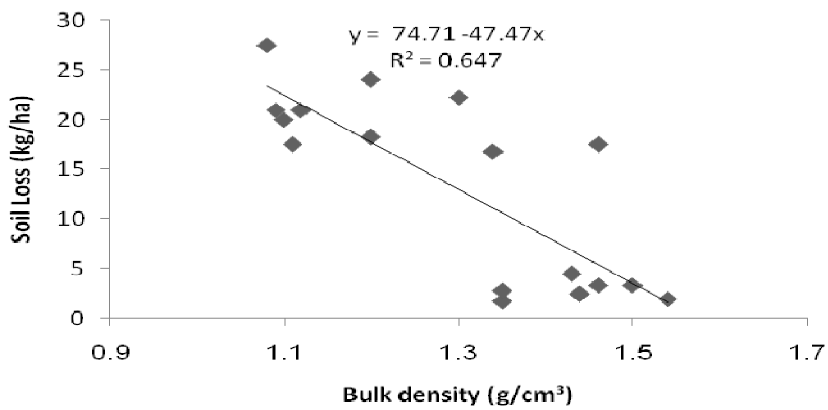

Figure 6. Soil loss estimation (Al Namas Forests).

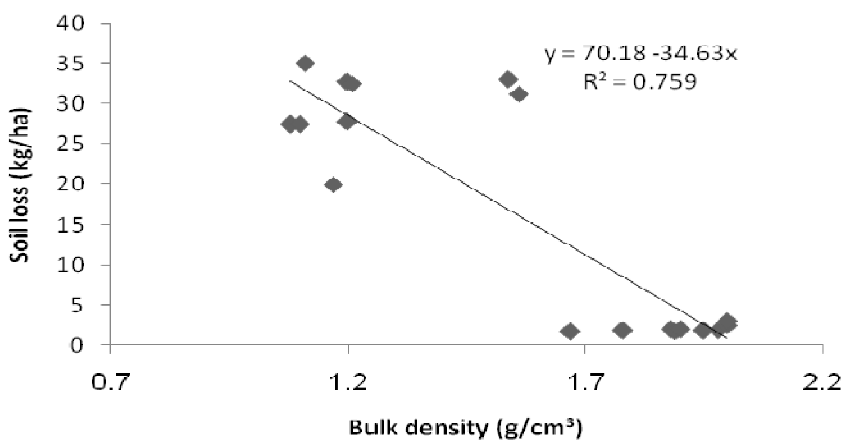

Figure 7. Soil loss estimation (Abha Forests).

(Figure 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 (indepen-

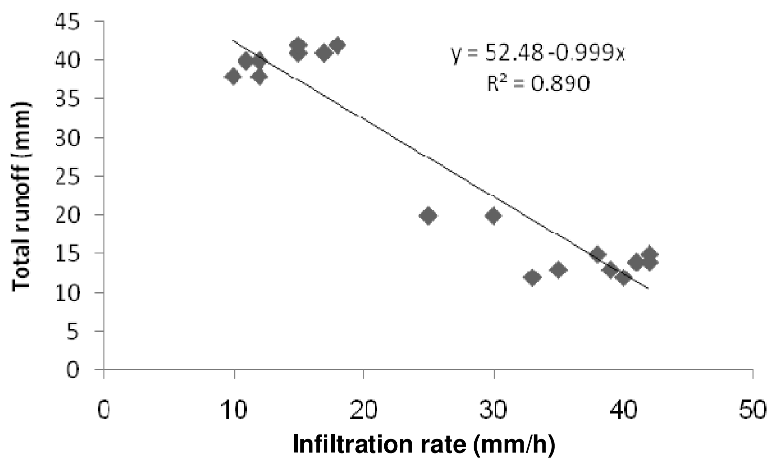

Figure 8. Total runoff estimation (Al Namas Forests).

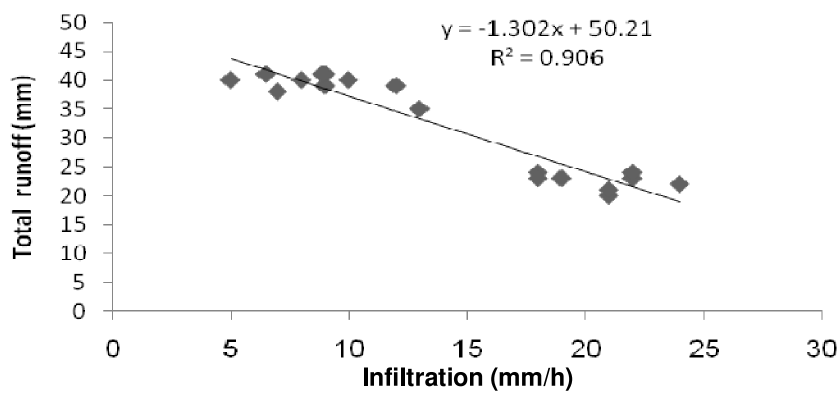

Figure 9. Total runoff estimation (Abha Forests).

Table 3. Regression analysis (Abha).

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

*Significant ($p < 0.0001$)
Y = 1.063 x1 - 8.79 x2 + 0.416 x3 +2.58
Y = Soil loss x 1= total runoff x 2= soil bulk density x 3= infiltration mm/h

Table 4. Regression Analysis (Al Namas).

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

Significant ($p < 0.0001$) *
Y = 0.345 x1 - 16.76 x2 + 0.022x3 – 24.68
Y = Soil loss x 1= total runoff x 2 = Soil bulk density x 3 = Infiltration rate

dent 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 alarming result is the considerably 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).

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

DISCUSSION

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 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 limit 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 (Adekalu and Osunbitan, 2001; Ohu et al. 1987; Ohu and Folorunso, 1989; 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 *Juniperus* trees (Barth and Strunk, 2000). 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 and 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. One of the alarming results in this study is the very low regeneration (expressed by the small number of seedlings/ha) of *Juniperus* 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. One of the major tools for conservation of *Juniperus* forests is improvement 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.

Conclusions

Terraces play an important role in rainwater harvesting in the *Juniperus* ecosystem on the Sarawat mountains in south western Saudi Arabia. If maintained, they reduced soil loss, surface runoff and bulk density and increased infiltration rate which resulted in much better growth and regeneration of *J. procera*. However, abandoning the terraces resulted in increased soil loss, surface runoff, bulk density and reduced infiltration and consequently less favourable growth environment for *Juniperus* especially very poor regeneration which threatens the existence of the species in these mountainous areas.

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