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Effects of Stonewalled Terracing Techniques on Soil-Water Conservation and Wheat Production Under Mediterranean Conditions

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ABSTRACT / A field plot experiment was conducted in the Palestinian Autonomous Areas to study the effect of stonewalled terracing on soil and water conservation as compared to the nonterraced areas. Effects of the wheat canopy were considered as a second treatment. The experiment was undertaken over a period of two seasons (2000 and 2001). The results of the experiment found that the mean soil erosion was significantly lower ($P < 0.05$) in the terraced plots than in those that were nonterraced (182 kg/ha and 3525 kg/ha during the first season, 1769 kg/ha and 5057 kg/ha during the second season for terraced and nonterraced plots, respectively). A similar trend was observed with respect to runoff in areas under the same treatments. The wheat canopy showed lower, but not significant runoff and erosion in most of the cases for both seasons. Due to better soil and water conservation, the terraced plots obtained significantly higher total plant dry matter than nonterraced plots (1570 and 630 kg/ha in 2000, 2545 and 889 kg/ha in 2001 for terraced and nonterraced treatment, respectively). The runoff coefficient was 20% and 4% for the nonterraced and terraced plots, respectively. Rainstorms with intensity ≥4 mm/hand rainfall ≥10 mm are more likely to cause runoff and erosion.

Most of the newly formed Palestinian Autonomous Areas are mainly mountainous with a limited amount of rainfall and other water resources. Agriculture in the area is subjected to high threats of soil-water erosion. The numerous stonewalled terraces that line the mountains' steep sides are currently used for soil and water conservation and comprises about 57% of the total mountainous area. Many of these terraces were initially built thousands of years ago and as many as 60% of them are currently cultivated in the same way as they were in ancient times (Ron 1966; Edelstein and Gat 1981).

From a geomorphologic perspective, terraces contribute to the reduction of the slope and its natural function as a transporting surface for eroded material. Terraces also cause an increase in the infiltration rate, a reduction in the overland flow (quantity) and velocity (energy), which leads to a reduction in soil erosion (Gachene and others 1997; Wakindiki and Ben-Hur 2002).

The central and eastern mountainous areas are, like other mountainous areas of the Mediterranean region, subject to sudden and drastic environmental as well as socio-economic changes. These changes lead to the partial and/or complete abandonment of large terraced areas in the region. The abandonment of terraces causes an increase in soil erosion, terrace deterioration, and land degradation. These areas are characterized by semiarid conditions with severe runoff and soil erosion. This is due to the erratic rainfall events and the long drought periods. These periods work in conjunction with the poor vegetative cover and expose the soil surface to overland flow and erosion (Soil and Water Conservation Society 1994).

Previous studies emphasized the benefits of applying various soil and water conservation techniques, such as stone lines, pits, protection ditches, and earth bunds under the semiarid conditions (Gritchley and others 1994). However, few of these studies have attempted to undertake quantitative investigations of these techniques (Richards 1985; Willcocks and Twomlow 1993). These studies show that the land treated by these conservation techniques had higher crop yields than the untreated lands (Gichangi and others 1992; Wedum and others 1996). Stonewalled terraces are one of the conservation techniques that are common in the Mediterranean regions in general,

KEY WORDS: Mediterranean; Terraces; Runoff; Soil erosion; Rainfall intensity; Wheat canopy

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*Author to whom correspondence should be addressed; *email:* ahmed.abu.hammad@ipm.nlh.no and specifically in the central and eastern heights of the Palestinian Autonomous Areas. Land reclamation by terrace construction proved to result in high economic returns. Well-maintained terraces increased the area's average annual productivity by 200% for olives and 83% for cereals (IFAD 1998). This is equivalent to an increase in annual profits by 1100 and 380 $US/ha for olives and cereals, respectively (IFAD 1998). The cost of constructing new terraces is estimated at 1000 $US/ha, which is recoverable within 1–3 years of production for olives and cereals. After that period, a net profit range of 300–1000 $US/ha would be achieved on an annual basis.

There are two types of terracing technique: angular terraces and curved terraces (Ron 1966). For curved terraces, a horizontal distance usually exists between two successive terraces, whereas in angular terraces, no gap exists between successive terraces. Few studies on the use of terraces in the study area are available. Those that are available are mostly qualitative (terrace classification and distribution) and do not investigate the quantitative aspect of terrace use (i.e., the amount of runoff and erosion, as well as crop characteristics) (Ron 1984; Ward and others 2001).

The effects of stonewalled terraces will be presented quantitatively in this article and will be compared to nonterraced land as a control. This article will focus on runoff, soil erosion, and plant characteristics as a result of moisture conservation under the said terraces. The relationship among erosion, runoff, and the prevailing climatic factors (i.e., rainfall amount, duration, and intensity) will also be studied.

Materials and Methods

Experimental Site

Two sites were selected as locations in which to conduct the experiment. The two sites were 50 m apart. Both sites have similar characteristics (soil type, slope steepness, land-use history, etc.). The slope steepness for both sites was 2–3%, and the only difference between the sites was the presence or absence of terraces. The experiment was conducted during the winter seasons of 2000 and 2001 on a curved terrace area that was constructed at least 100 years ago, as confirmed by local inhabitants. Terraces in the study area had a height range of 1–1.2 m, with spacing between the successive terraces of 15–18 m. Similar experimental procedures on the nonterraced site were applied as a control. The study area is at 900 m above sea level located in the Ramallah District (Figure 1). Two well-marked summer and winter seasons prevail in the area, with a mean annual rainfall of 580 mm. More than 90% of all rainfall occurs within the months of October and April (Ministry of Transport 1998). The remaining rainfall usually occurs during the short spring and autumn periods. Summer time is completely dry with no rainfall. The mean monthly temperature is 17.1°C (for the period 1975–1997), with the hottest months being July, August, and September (Ministry of Transport 1998). The climate is semiarid, with a mean annual potential evapotranspiration of 861 mm, which causes a large summer soil moisture deficiency (Land Research Center 1999). According to the US Department of Agriculture (USDA) classification, the soil temperature and moisture regimes are Thermic and Xeric, respectively (Dan and others 1976; Soil Survey Staff 1998). The geological formation that prevails in the area can mostly be dated to the Turonian age and consists of limestone, marl, and dolomite (Abed 1999). The surface soil (0–15 cm) is a silty loam and the subsoil is silty clay loam (below 15 cm depth). The organic matter content of the soil surface ranges from 2% to 3%. The soil is classified according to USDA as Lithic Xerorthent loamy, mixed, thermic (Land Research Center 1999). In the sloped and hilly areas, the soil is shallow, with depths not exceeding 40 cm, whereas in the lower inclinations and into the terraced areas, the soil depth is moderate, with a maximum depth of 120 cm.

Experimental Design, Annual Crops, and Management

The experiment consisted of two sites 50 m apart. The two sites were a curved stonewalled terraced area and a nonterraced area of known history (i.e., used for the cultivation of wheat and barley) as the control. Soil depth was 100 cm and 40 cm for the terraced and nonterraced plots, respectively. For each site, six plots of 2 × 15 m were chosen. At each site, three plots were randomly assigned to winter wheat cultivation with tillage operation and manure addition, and the other three plots were kept fallow, but with tillage and manure addition (Figure 2).

The applied agronomic aspects (e.g., planting date, sowing rate, seed varieties, manure addition, etc.) were in accordance with the prevailing local practices. Wheat was planted immediately at the beginning of the winter season, either before the first rainfall or immediately after it. The sowing rate was 100 kg/ha. At the beginning of the season, animal plowing and the addition of farmyard manure of 3 t/ha occurred at both sites and for the cultivated and fallow plots. The spacing between wheat planted in rows was about 17

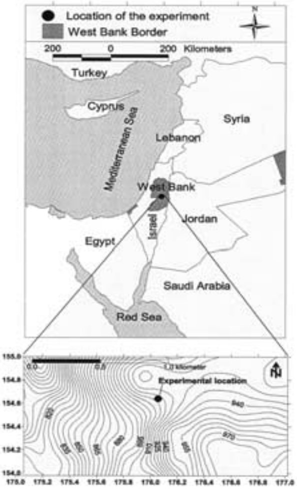

Figure 1. Location map of the experimental area and 5-m contour map showing the experimental location.

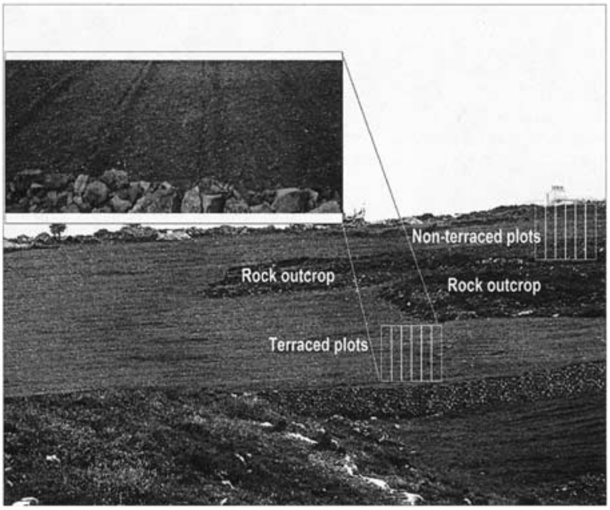

Figure 2. Landscape characteristic of the two experimental sites with schematic illustration of the runoff–erosion plots.

cm. All plots were kept free of weeds by hand hoeing during the season. At the end of the season, three samples of 1 m^2 (beginning, middle, and end of each plot) were taken from each cultivated plot. This method of sampling represented a systematic sampling procedure, which can provide an even distribution and an efficient way to deal with the periodical changes in each plot (Webster 1977). These samples were used to determine the 1000-grain weight, plant height, and number of plants per square meter, number of spikes per square meter, and number of grains per square meter. The rest of the plot area was harvested by hand and the total plant dry weight, grains, and straw from each cultivated plot were determined.

Rainfall, Runoff, and Erosion Measurements

The rainfall amount was measured at 30-min intervals using a tipping-bucket pluviometer with 0.2 mm per tip. The measurements were recorded in a data logger for each rainstorm. To facilitate the discussion of rainfall episodes, the term ''rainstorm'' will be used. It will be defined arbitrarily as one rain event separated from another rain event by more than 6 h (Soil and Water Conservation Society 1994). Erosion and runoff plots were setup at both sites, for wheat cultivated as well as fallow plots, with three replications. Each plot, for erosion and runoff monitoring, was 2 × 15 m with a main slope of 2–3% along the length of the plot. Each plot was bound on all sides (except terrace end) by earth levees 30 cm high and 15 cm wide. A cutoff drain was dug above each experimental location to prevent runoff from the upper areas outside of the experimental sites. For runoff and sediment measurements, a plate was installed at the end of each plot to block the runoff and direct it to a covered trough. The trough delivered the runoff and the eroded material into a 0.2-m^3 tank through a conveyor pipe. The tanks with their loads were emptied after each rain event. The amount of runoff was measured after allowing the sediments to settle. The runoff in each tank was then mixed thoroughly and four subsamples were taken to determine the weight of soil loss after oven-drying at 105°C. The average of the four subsamples was used to conduct statistical analysis.

Aggregate Stability, Infiltration Rate, and Organic Carbon Measurements

In each plot, two soil samples, at the beginning and the center of each plot, were collected from the upper 0–10 cm of topsoil to determine the water-stable aggregates (WSA). The samples were air-dried. The soil samples were then sieved automatically to separate the different ranges of aggregate (2–6 mm, 0.6–2 mm and <0.6 mm). The WSA was determined for both macroaggregates (2–6 mm in diameter) and microaggregates (0.6–2 mm in diameter). This method of WSA is basically dependent on the procedures described by Young (Amezketa 1999). It depends on subjecting 20 g of the air-dried soil aggregates placed into a 0.5-mm sieve to a certain rainfall intensity. The WSA percentage is then calculated by applying the following formula (Amezketa 1999):

$$\%\ \text{WSA} = [(\text{SA} - \text{SM})/(\text{Soil original mass} - \text{SM})] \times 100$$

where SA is the mass of the stable aggregate and SM is the mass of the sand.

Soil organic carbon was analyzed using the Walkley–Black method (Nelson and Sommers 1982). The infiltration rate was measured using the single-ring infiltrometer method (Bouwer 1986) with two measurements for each plot.

Statistical Analysis

Within each site, statistical analysis of runoff and erosion was undertaken using the paired *t*-test (MINITAB Statistical Software release 13.0). Between the two sites, the statistical analysis of runoff, erosion, WSAs, and the different wheat parameters was carried out using the one-way analysis of variance (ANOVA) of the MINITAB procedures (MINITAB Statistical Software release 13.0).

Results and Discussion

Soil Aggregate Stability

The resistance of the soil surface to disintegration and slacking by rainfall impact is a function of its aggregate stability (Le Bissonnais and Arrouays 1997). The results of the aggregate stability showed significantly higher ($P < 0.05$) WSAs for the terraced plots than for the nonterraced plots (Figure 3). A similar trend was observed in both the macroaggregates (2–6 mm) and microaggregates (0.6–2 mm). The water-stable macroaggregate in the terraced plots was 2–2.5 times that of the nonterraced plots. This ratio was 2.7 times that of the nonterraced plots for the water-stable microaggregates. The differences in WSA might be an important factor in controlling the surface runoff and soil erosion, as stated by previous researchers (Barthes and others 2000).

The relatively higher and significant organic matter content (detailed data are not shown) in the terraced plots (3.1%) contributed to more stable soil aggregates in the terraced plots, as compared to the nonterraced plots, which had lower organic matter (2.2%). Hence, the differences in soil aggregate stability between the two main treatments might be attributed to the differences in soil organic matter. These effects of soil organic matter, on aggregate stability, are in line with previous studies. These studies emphasize the importance of the soil organic matter in the formation, as well as the enhancement, of the soil aggregate stability through its cementing action between primary soil particles (Idowu 2003).

Precipitation: Amount and Intensities

The total rainfall was 488 and 683 mm for the 2000 and 2001 winter seasons, respectively. In 2000, the total was 16% lower and in 2001 18% higher than the mean annual precipitation. During the 2000 season, a snowfall event, the equivalent of 60 mm rainfall, occurred. This was on 27 January and the snow cover lasted for 48 h. Figure 4 shows the amount of rainfall for each rainstorm chronologically, starting on 1 October for both seasons. The maximum 30-min intensity and the frequency of distribution for the measured intensity (at the 30-min intervals) are also shown. The peak rainstorm amount for the 2000 season was 42 mm. The peak rainstorm amount for the 2001 season was 61 mm. The maximum 30-min intensity was 10.5 mm/h and 29.4 mm/h for the winter seasons of 2000 and 2001, respectively. For both winter seasons, 15% of the measured 30-min intensity was above 5 mm/h. In this semiarid region of the Mediterranean, low-intensity rainstorms, with the prevalence of occasional erratic rainfall events of a limited duration, are typical. In the winter season of 2001, about 3% of the measured intensities was higher than 10 mm/h with a maximum of 29.4 mm/h. In 2000, only 0.3% of the measured intensities was more than 10 mm/h, and these accounted for only one occasion.

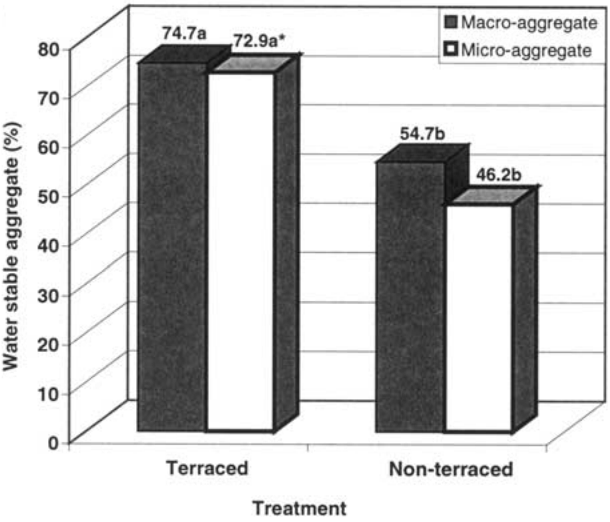

Figure 3. Aggregate stability for the stonewalled terraced and nonterraced systems. The asterisk indicates that values are the mean of 12 replicates. Along each category (macro or micro), values followed by the same letters are not significantly different at $P = 0.05$.

Seasonal Wheat Yield

Different yield components during both seasons are shown in Table 1. All of the yield components show significant differences ($P < 0.05$) between terraced and nonterraced plots, with the exception of the number of spikes and plants per square meter. The nonsignificant differences for the spike and the plant number can be

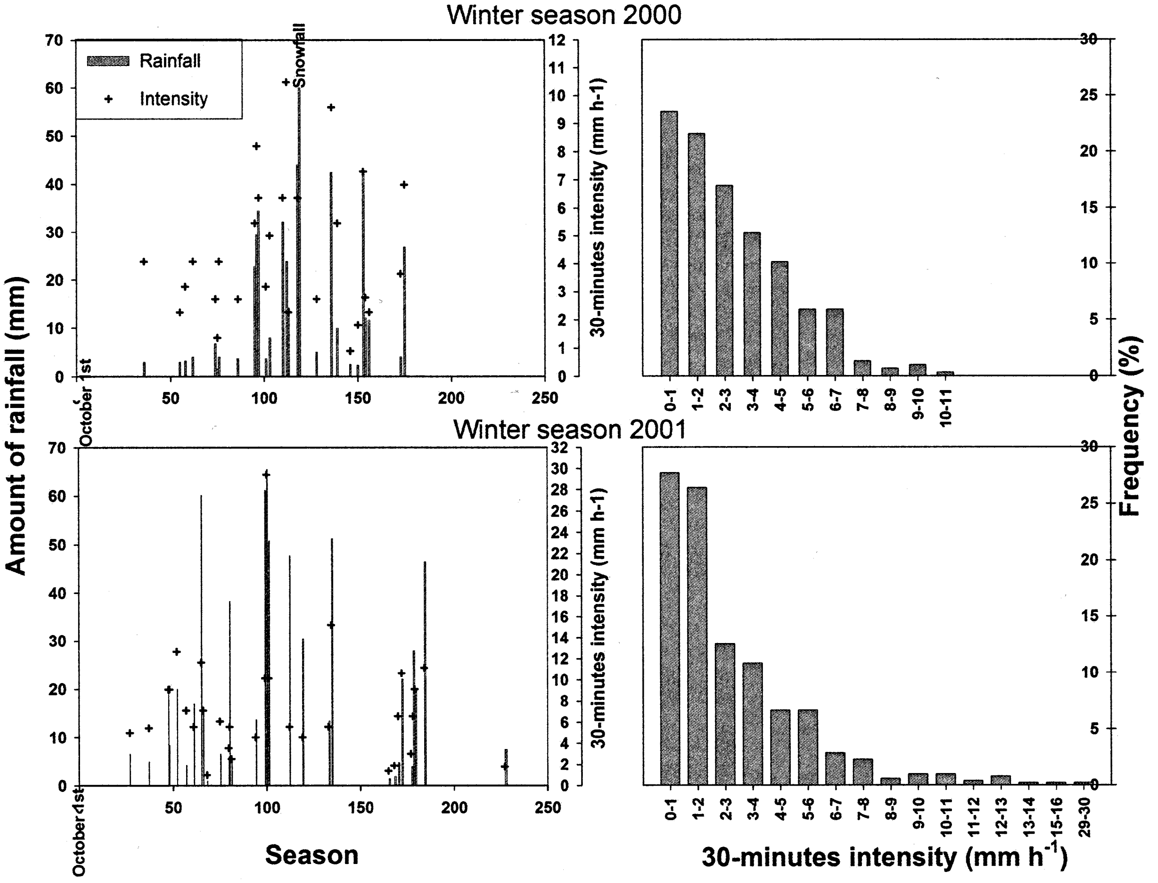

Figure 4. Amount of rainfall, 30-min intensity, and frequency–intensity relationship for different rainstorms during the two seasons.

attributed to the following: (1) the higher erosion early in the season in the nonterraced plots, which caused a loss of the seeds in some plots, and (2) the drier condition of the surface layer in the nonterraced plots, which resulted in an increased failure of the seed to germinate. The overall effect of the previous attributes was a high variation within the plots. Nevertheless, the terraced plots had a 2.3 times higher grain yield and a 3.3 times higher dry matter of straw than the nonterraced plots. In general, the yield of the terraced plots was about two times higher than the average of the area.

Table 1. Seasonal wheat yields for the stonewalled terrace (Tr) and nonterraced (NTr) plots for 2000 and 2001winter seasons

	2000 season			2001 season		
Crop parameter	Tr	NTr		Tr	NTr	
Total plant dry weight (kg/ha)	1570.3	630.0	S[a]	2545.0	889.7	S
Straw yield (kg/ha)	797.5	297.4	S	1667.0	511.6	S
No of plants/m^2	83	67	NS	98	58	NS
No of spikes/m^2	76	50	NS	82	54	NS
Plant height (cm)	53.0	41.7	S	59.6	46.3	S
Grain yield (kg/ha)	772.4	332.3	S	877.8	378.0	S
Number of grains/m^2	1221	556	S	1388	631	S
1000-grain weight (g)	57.5	50.2	S	65.3	57.0	S

[a] Along rows, S means significant difference and NS not significant at $P = 0.05$.

Measurements of the plant height for both winter seasons are shown in Figure 5. Figure 5 shows a gradual increase in the plant height differences between those in terraced and nonterraced plots throughout the winter season. In general, the canopy development and the yield were better for the 2001 season than for the 2000 season. The reasons for such differences between the years can be attributed to (1) the delay of the rainfall onset during the 2000 season by about 40 days compared to the 2001 season, which delayed plant emergence (Figures 4 and 5), (2) better rainfall distribution in the 2001 season than in the 2000 season,

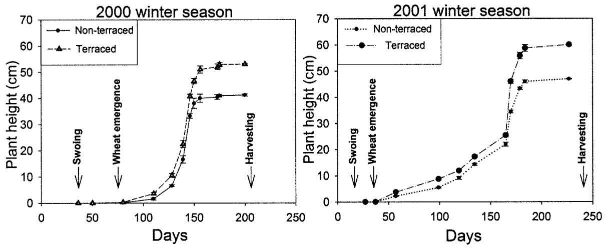

Figure 5. Wheat canopy height during both winter seasons under the terraced and nonterraced plots from the beginning of October. Bars represent the standard deviation.

especially during critical periods of the plant growth (Figures 4 and 5), and (3) the differences in the rainfall amount between both seasons (almost a 195-mm difference).

The higher wheat yield components for the terraced plots rather than nonterraced plots can be attributed to many factors, including the following: (1) The soil depth had a direct effect on plant productivity; the deeper the soil depth, the higher the soil moisture storage, availability, and productivity and vice versa; (2) the fertility status of the soil could be another possible factor, with more organic matter found in terraced plots than nonterraced plots; (3) soil erosion caused the depletion of soil plant nutrients and other organic constituents that affect wheat growth and its yield. Higher erosion resulted in a low fertility status and lower plant growth and production. This nutrient depletion/crop production relationship is in line with previous studies (Pimentel 2000; Ward and others 2001).

Surface Runoff

Table 2 presents the cumulative surface runoff during both winter seasons. During both seasons, there was a significant reduction in the surface runoff from the terraced plots. The results show an increase in surface runoff from the noncultivated plots and a decrease from cultivated ones, although this increase was not significant. The main reasons for such differences between the cultivated and noncultivated plots can be attributed to the following: (1) plant coverage and protection against the direct impact of rain drops, which decreased aggregate slacking and surface sealing, and (2) the lower water content of the cultivated plots, mainly due to more water uptake by the plant; this led to dry soil with a high infiltration capacity and low runoff.

Runoff coefficient, defined as a percentage of the precipitation measured as surface runoff, for the winter 2000 season, was 4% and 18%, for terraced and nonterraced plots, respectively. For the winter 2001 season, the runoff coefficient was 12% and 20%, respectively, for the correspondent treatments. A similar trend for the cultivated and noncultivated plots is be shown (Table 2). In some rainstorms, the runoff coefficient reached 56%.

Table 2. Surface runoff under terraced and nonterraced conservation practice, and with or without wheat canopy cover during the 2000 and 2001 winter seasons

	Terraced[a] (mm)	Nonterraced[a] (mm)		Mean (mm)	Rainfall (mm)
2000					488
Cultivated	15.4	68.5	a[b]	42.0	
Noncultivated	23.6	104.1	a	63.9	
	—[c]	—			
Mean (mm)	19.5	86.3			
2001					683
Cultivated	69.4	116.8	a	93.1	
Noncultivated	93.3	157.7	a	125.5	
	—	—			
Mean (mm)	81.4	137.3			

[a] Values are the mean of three replicates.

[b] a means significant difference between terraced and nonterraced plots at $P = 0.05$.

[c] No significant differences.

Rainfall, runoff, and total dry matter of wheat are shown in Tables 1 and 2 for both terraced and nonterraced treatments. The two tables reveal lower runoff in the terraced plots as compared to the nonterraced plots, with a higher total dry matter in the terraced plot. Limited soil depth, in addition to a low water storage capacity, of the nonterraced plots led to more runoff, whereas the terraced plots had greater soil depth with a higher soil moisture storage capacity, leading to a lower amount of runoff and more moisture availability contributing to a higher yield.

In terms of water use efficiency (WUE), which can be defined as the ratio between the total plant dry weight and the total evapotranspiration (expressed as kilogram dry weight per millimeter evapotranspiration), where evapotranspiration of wheat is assumed to be equal to the difference between total precipitation and runoff, the WUE was 3.3 and 1.5 kg/mm for the terraced and nonterraced plots during the 2000 season, respectively, whereas the WUE was 4.2 and 1.6 kg/mm for the 2001 season. This suggests that the terraced plots are more efficient in the storage and usage of water than the nonterraced plots. This could be mainly due to the differences in soil depths between both treatments (100 and 40 cm for terraced and nonterraced plots, respectively). As a consequence, terraced plots had a higher yield with a higher WUE than the nonterraced plots. These results are consistent with other research findings (Pimentel and others 1995; Troeh and others 1991; Wakindiki and Ben-Hur 2002), which establish the usefulness of such conservation techniques for soil moisture storage and availability to plants.

Soil Erosion

During both seasons, terraced plots showed a significantly ($P < 0.05$) lower amount of eroded material than nonterraced plots (Table 3). This might be due to more stable aggregates and a denser canopy cover, with more surface protection against raindrop impact, in the terraced plots. The results also illustrate an increase in soil erosion from noncultivated plots.

The average surface runoff for both years was two times higher for the nonterraced plots than for the terraced plots (Table 2). At the same time, soil erosion was about 4.5 times higher comparing the same treatments and as an average for both years. This means that the sediment concentrations in the runoff water increased more for the nonterraced plots than for the terraced plots. The average sediment concentrations in runoff water for the whole period was 1.5 and 4.1 g/L for the terraced/cultivated and the nonterraced/noncultivated plots, respectively.

The cumulative surface runoff and soil erosion for each treatment is shown in Figure 6, including the cumulative rainfall for both winter seasons. Figure 6 showed higher runoff and erosion in the nonterraced plots than in the terraced plots. A similar trend was observed for the noncultivated and cultivated plots. However, terraced plots were more effective in reducing surface runoff and soil erosion than the wheat canopy cover.

Another important trend of the erosion process, which can be seen in Figure 6, is that most of the surface runoff and erosion occurred as the result of a few successive rainstorms, which occurred within a short period of time (i.e., days 100, 112, and 150 for the 2000 winter season and days 60 and 100 during the 2001 winter season). These sudden and intense rainstorms were responsible for at least 80% of the erosion that took place during the entire winter season. A common phenomenon of the erosion process is where the initial rainstorm produces disaggregation and surface slacking albeit with minimal erosion, whereas the subsequent rainstorms cause a considerable runoff and erosion of the already detached soil particles.

For example, a storm with 15 mm rainfall and 7-mm/h 30-min intensity (such as occurred in the 2001 winter season on day 66) produced two to six times more eroded material than a storm with 20 mm rainfall and 13-mm/h 30-min intensity (such as occurred in the 2001 winter season on day 52). In the first case, one or more rainstorms occurred within a short time, making the soil surface weak and easily erodible and producing an appreciable amount of eroded material during the successive rainstorms. In the second case, however, there were no preceding rainstorms, and as a result, the soil surface was kept intact and strong against rainfall impact.

Runoff water, caused by rainstorms at the beginning of the season, in general had two to three times the sediment concentration of runoff water caused by rainstorms, with similar characteristics, occurring at the middle or the end of the season (10–12 g/L at the beginning of the season, 2–4 g/L at the end of the season). This difference was mainly due to the availability of the fine soil particles that were easily detached and transported at the beginning of the season.

Generally, the effect of the wheat canopy on soil erosion and runoff was not well marked, although there was a general trend for the canopy cover to reduce the surface runoff and eroded material. However, this was not significant in many cases. The terrace system appeared to be more efficient in reducing both the amount of runoff and its associated energy, with a significant reduction in soil erosion. The effect of stonewalled terraces on soil and water conservation stands in agreement with many previous studies (Roose 1996; Wakindiki and Ben-Hur 2002; Gardner and

Table 3. Soil erosion under terraced and nonterraced conservation practice, and with or without wheat canopy cover during the 2000 and 2001 winter seasons

	Terraced[a] (kg/ha)	Nonterraced[a] (kg/ha)		Mean (kg/ha)
2000				
Cultivated	139	2742	a[b]	1441
Noncultivated	225	4308	a	2267
	—[c]	—		
Mean (kg ha^{-1})	182	3525		
2001				
Cultivated	1361	3616	a	2489
Noncultivated	2176	6497	a	4337
	—	b[d]		
Mean (kg ha^{-1})	1769	5057		

[a] Values are the mean of three replicates.

[b] a means significant difference between terraced and nonterraced plots at $P = 0.05$.

[c] Dash means no significant differences.

[d] b means significant difference between cultivated and noncultivated plots at $P = 0.05$.

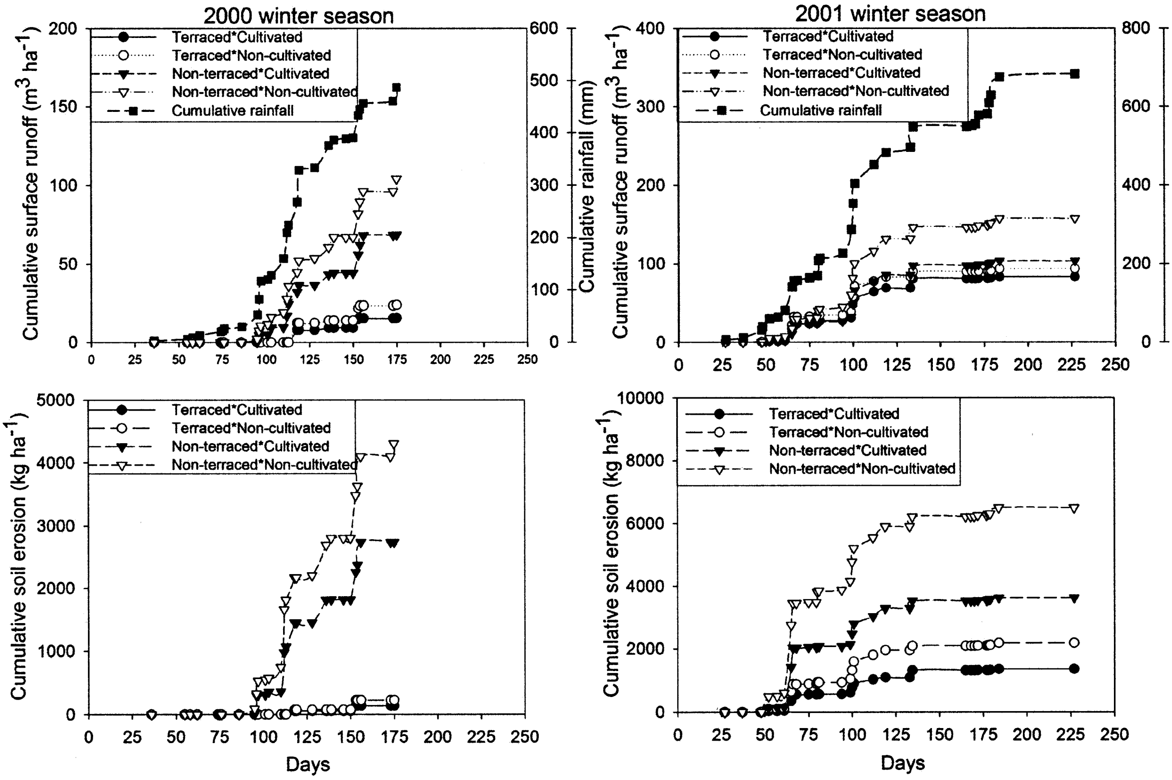

Figure 6. Cumulative seasonal rainfall, surface runoff, and soil erosion during the 2000 and 2001 winter seasons for different treatment combinations.

Gerrard 2002; Hartanto and others 2003) that illustrate the positive effects of terracing, along with the effects of canopy cover on the reduction of runoff, and the associated soil erosion with an increase in crop production.

The results indicated a positive and close relationship among aggregate stability, runoff, and soil erodibility. This is in accordance to other research findings (Reichert and Norton 1994; Le Bissonnais and Arrouays 1997; Barthes and others 2000). The study also emphasized the role of the differences in aggregate stability between terraced and nonterraced plots on soil erosion.

Snowmelt resulted in the production of runoff, especially in the nonterraced plots and in both the cultivated and noncultivated treatments. However, none of the treatments produced erosion. Comparatively, an equivalent amount of rainfall (60.2 mm) during the 2001 season resulted in four times the runoff produced from an equivalent amount of snowmelt (24.6% as compared to 6.2%).

Scatterplot relations, between the maximum 30-min intensity and the amount of storm rainfall and soil erosion (Figure 7), showed that soil erosion and surface runoff, for both years, was most likely to occur in intensities above 4 mm/h. Lower intensity levels had negligible amounts of surface runoff and no erosion was noticeable. This threshold level of intensity coincides with the steady-state infiltration of the soil at around 3.5 mm/h (Figure 8). The intensity–erosion interaction is also dependent on the amount of rainfall: the general trend was that rainstorms of less than 10 mm were not likely to cause erosion (Figure 7), especially when the intensity was lower than 4 mm/h. At the beginning of the season, when the soil was dry with a high infiltration rate and moisture storage capacity, no runoff and erosion was registered for rainstorms with intensity >4 mm/h and rainfall >10 mm. The intensity–erosion relationship had been, and continues to be, a controversial question among researchers. Some researchers have emphasized only the importance of extreme events with 25 mm/h intensity (Morgan 1974; Hudson 1981). Other research has found that a significant part of erosion occurred during moderate rain events of 30–60 mm and with intensities of ≤6 mm/h (Morgan 1977; Van Asch and Epema 1983). Nevertheless, the assumption that intensity-threshold values vary with the type of erosion process, soil surface conditions,

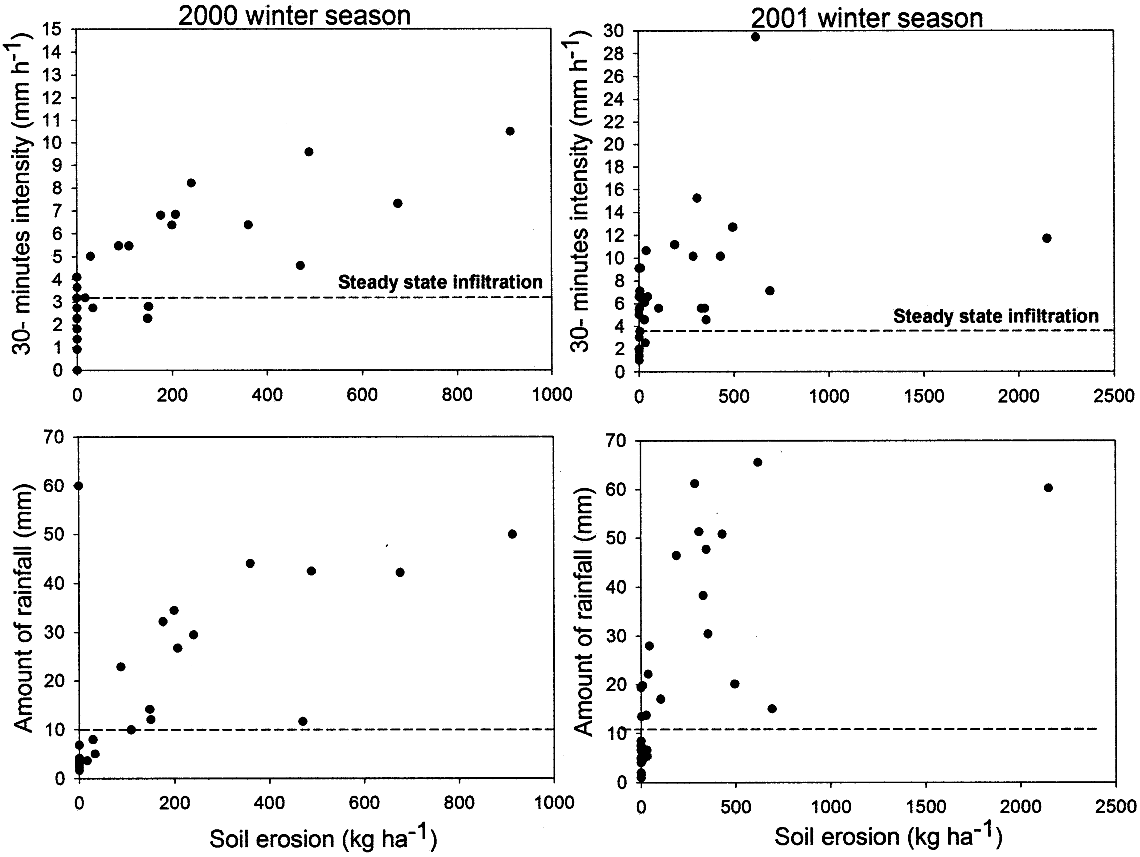

Figure 7. Scatterplots for the relation between soil erosion, amount of rainfall, and the 30-min intensity for different rainstorms, during both winter seasons in the nonterraced/noncultivated plots.

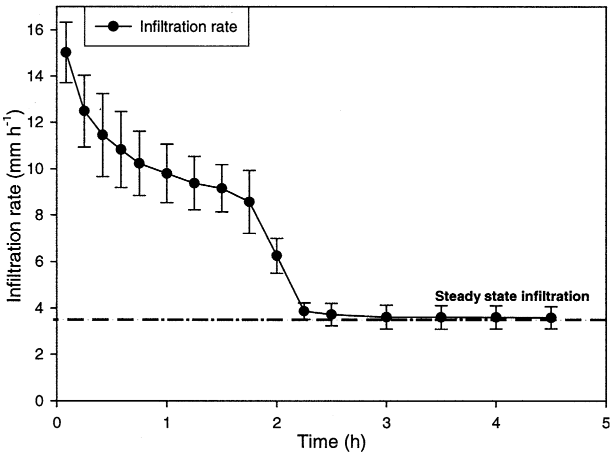

Figure 8. Infiltration rate with time for the nonterraced/noncultivated plots. Bar represents the standard deviation.

and rainfall characteristics is well established (Morgan 1986). The effects on surface runoff and erosion caused by these erratic rainstorms under semiarid conditions are illustrated in this study. They are an important contributor to runoff and soil erosion, under certain soil and climatic conditions, particularly when high intensity coincided with high soil moisture content and exceeded the steady-state infiltration, thus causing runoff and erosion to occur.

Conclusions

The results of the study showed a higher rate of runoff and erosion in the nonterraced areas as compared to the curved and well-maintained terraces. If erosion continues in the nonterraced and the poorly maintained terrace lands, it will lead to the environmental deterioration of the agricultural sector. In addition, higher-yield components for the stonewalled terraced areas, than for the nonterraced areas, were obtained. Rainstorms, with a threshold intensity of 4 mm/h and an amount of 10 mm, were found to be an important contributor to erosion under certain circumstances. The water use efficiency of the terraced plots was almost three times that of the nonterraced plots (3.3–4.2 for terraced plots and 1.5–1.6 kg/mm for nonterraced plots). In semiarid areas with limited land and water resources, water availability and its related use efficiency continue to be major challenges.

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