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Rainfall harvesting using sand ditches in Jordan

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Abstract

Rainfall harvesting in rain-fed agricultural areas increases water availability for plants during the growing season, thus increasing crop production. Rainfall can be stored directly in the soil for crop production using terraces, rippers, contour ridges, and other types of water collection methods. However, the efficiency of these methods is limited by the infiltration characteristics of soil and climatic conditions. In the rain-fed agricultural areas of Northern Jordan soils are predominantly clay having very low infiltration rates. In such cases the depth of water infiltration is very small and water may remain in the upper layer of the soil profile. With high evaporation rates, collected water is lost to the atmosphere very rapidly and is therefore, unavailable for plants.

Field experiments were initiated in Northern Jordan in 1996 to harvest rainfall and store it deeper in the soil profile thereby reducing the effect of evaporation. The experiment consisted of digging experimental trenches 80 cm deep, 5 m long and 1 m wide across the land slope between two rows of olive trees. The trenches were filled up to the original soil level using local deposits of fractured rock and river sand with large infiltration rate. These filled trenches, called sand ditches, were expected to collect rainfall, intercept runoff, and store water in the surrounding soil at greater depths to be used by plants for longer periods of time. It can be a very efficient method since it increases water infiltration and prevents evaporation during the growing season. The efficiency of sand ditches in storing water was assessed by monitoring soil moisture conditions and depth of infiltration in the sand ditch area, a 35 m² area located between four olive trees, and at a control area without a sand ditch, using an auger hole. The amount of water stored in the soil was calculated at each time interval and compared with total rainfall. Experimental results indicated that sand ditches increased both the percentage of rainfall stored in the soil matrix and the infiltration depth of water during the two winter seasons from 1996 to 1998. At one of the experimental areas on April 19,

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1998 the infiltration depth and water content in the sand ditch area were 100 cm and 28%, respectively compared to only 68 m and 19% in the control area. During the same period, the calculated ratio of depth of water stored in the sand ditch area to rainfall was 73% compared to only 45% in the control area. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

Water scarcity demands the maximum use of every drop of rainfall. The annual rainfall in Jordan is about 8500 million cubic meters. However, only 5% of this amount is being beneficially used and the rest is lost due to evaporation (85%) and floods (10%) (Salameh, 1992). Therefore, water management projects to collect and use the maximum amount of water is of national interest to the Government of Jordan.

Water harvesting to increase water supply has been practiced in many parts of the world, especially in arid and semi-arid countries like Jordan. The Jordanian Ministry of Water and Irrigation initiated a study for water harvesting that includes building earth dams and water ponds (Haffir) in about 80 locations all over the country (Abu-Zreig, 1997a). These projects are expected to increase annual water supply to about 30 million cubic meters. This type of water harvesting is called floodwater harvesting (Pacey and Cullis, 1986).

Water harvesting can also be achieved using pre-treated catchment and micro-catchment areas to increase the efficiency of runoff and maximize the amount of collected rainfall (Frasier and Myers, 1983). Rainfall is collected from areas specifically treated to increase precipitation runoff and stored in tanks for human and animal consumption and for supplemental irrigation. A report by the United Nations Environmental Program, 1983, classified various means of increasing the runoff from an area: (i) cleaning sloping surface, (ii) mechanical treatment including compacting the surface, contour terracing and smoothing, (iii) application of chemicals to reduce infiltration and surface-binding materials to seal the surface, and (iv) covering the catchment area with a rigid or a flexible surface.

Collecting rainfall in storage tanks can be very expensive and may result in wastage of large volumes due to evaporation. This is particularly important in arid and semi-arid regions where the amount of evaporation greatly exceeds the amount of rainfall. One solution to the evaporation problem is to use closed storage tanks. Covered tanks can practically eliminate water evaporation but the cost is extremely high. The other solution is to store collected rainfall directly in the soil for crop production (Crofts et al., 1961). The use of terraces, rippers, contour ridges, and micro-catchments is widely recognized to increase soil water storage and agricultural production. These methods use the soil profile as a storage media eliminating the need for storage tanks and reducing water evaporation at minimal cost. Some of these methods, however, obstruct agricultural activities and agricultural machinery, require continuous maintenance over the years, and are not suitable for agricultural lands with mild slopes. The benefits of these methods are also very limited in clay-type soils having low infiltration rates similar to the soil in the north

of Jordan. Thus, collected soil-water is subjected to high losses due to evaporation before it can be used by plants.

In this study a new rainfall harvesting method for Jordanian farmers that allows rainfall to rapidly enter the soil profile has been tested under field conditions. The method consists of constructing a ditch across the slope of the land and filling it with local sand and fragments of sedimentary rock that has high permeability. Due to its high infiltration rate, sand ditches permit large amount of water to enter the soil profile directly from rainfall and by blocking runoff from up-slope. The infiltrated water then slowly seeps to the adjacent clay soil through the side of the sand ditch due the high matric potential of clay soil compared to sandy soil. Sand ditches can prevent surface soil crusting due to rainfall and the high ESP which is responsible for the low infiltration characteristics of the clay-type soils of northern Jordan (Abu-Zreig, 1997b). They also reduce the amount of evaporation from the soil since infiltrated water is stored deeper in the soil profile.

2. Materials and methods

Two fields planted with olive trees were chosen for the experiments. The two sites (Location 1 and 2) have similar soil characteristics but different slopes ranging between 5 and 8%. Soil textures were analyzed using the hydrometer method and characterized as silt clay. Soil characteristics and site conditions are shown in Table 1. Olive trees were planted in parallel rows at a distance of 5 m across the slope and 7 m in the direction of slope (Fig. 1). An experimental ditch was dug at each site 5 m long, 1 m wide and 80 cm deep. The ditch was located in the middle between two rows of olive trees across the slope as shown in Fig. 1. Fractured sedimentary rock and river sand was collected from local sites and used to fill the ditches up to 70 cm height. The upper 10 cm of the ditch were filled with uniformly graded coarse sand and leveled with the original soil surface to prevent any disturbances during agricultural operations.

The efficiency of sand ditches to increase storage of soil water was assessed by monitoring changes in soil water content and infiltration depth in the sand ditch area in comparison to a control area located about 17 m up-slope from the sand ditch. The sand ditch area located between four olive trees was divided into seven strips of 5 m² each.

Table 1
Soil and site characteristics of experimental locations

	Location 1	Location 2
Sand (%)	14	16
Silt (%)	43	37
Clay (%)	43	47
Classification	Silt clay	Silt clay
Saturated hydraulic conductivity of original soil (m/s)	3.2×10^{-6}	3.0×10^{-6}
Saturated hydraulic conductivity of filling soil (m/s)	1.0×10^{-4}	1.0×10^{-4}
Bulk density (kg/m ³)	1330	1340
Bulk density of filling soil (kg/m ³)	1490	1490
Land slope (%)	8	5

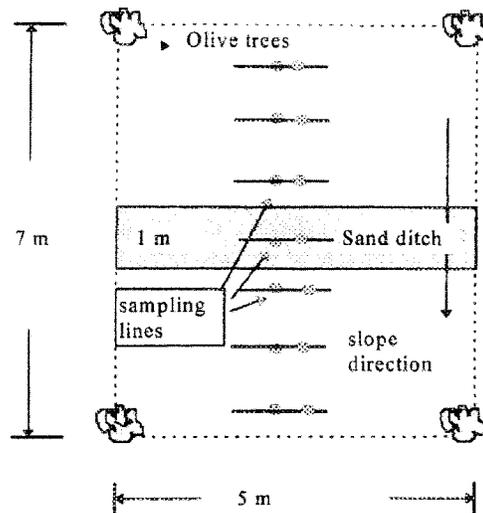


Fig. 1. Schematic diagram showing the location of a sand ditch in the field.

Two to three days following a rainstorm, eight auger holes, two in the middle of the sand ditch and six along the sampling lines were dug and the wetting depth for each strip measured. The average water content was calculated for each auger hole at the center and at distances 1, 2 and 3 m away from the center of the ditch for both locations (Fig. 1). Water content and wetting depth were also measured in duplicates for the control sites. Old auger holes were immediately covered with their original soil and new locations along sampling lines were used for new auger holes in the next sampling time.

The depth of water infiltration in the sand ditch area and in the control area was calculated from the average water content and depth of wetting in each location. This procedure was repeated at specific dates during the two winter seasons of 1996/1997 to 1997/1998. Data comparison between treatment and control was achieved using Tukey HSD multiple range test at 95% probability level.

To measure soil water content at a specific date and location, soil samples were obtained following the digging of an auger hole along each of the sampling lines, as shown in Fig. 1, until the appearance of dry soil indicated the depth of the wetting front. Wet soils were then mixed and homogenized and three random samples were taken to measure the average water content of the wetting zone using gravimetric methods (Bowles, 1986). Soil cores, 5 cm in diameter and 10 cm long, were taken from the surface and at 30 cm below soil surface to determine soil bulk densities. Volumetric water contents were obtained by multiplying the gravimetric water content by the dry density of soil.

3. Results and discussion

Six rain storms occurred from December, 1996 to April, 1997 with a cumulative rainfall of 250 mm. The cumulative rainfall depth in the winter season of 1997/1998 was

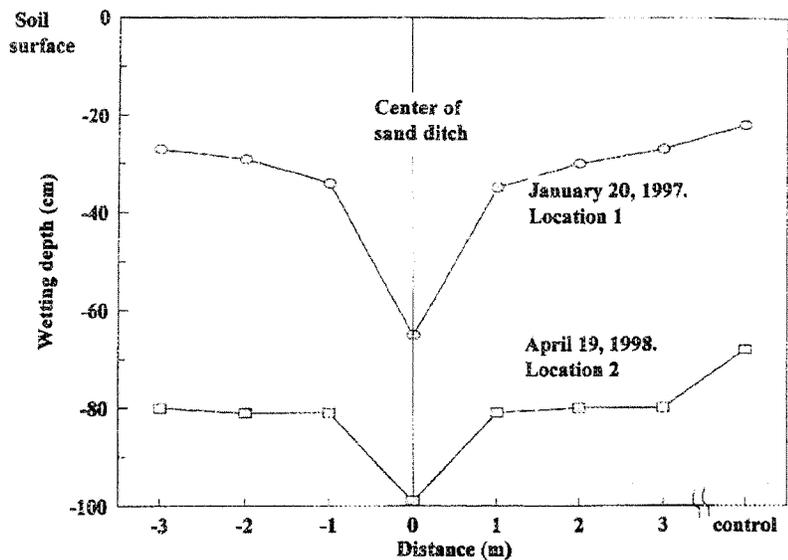


Fig. 2. Variation of wetting depth around sand ditch and control area.

283 mm. After each storm a set of data for water content and wetting depth was obtained for each strip in the sand ditch and control areas. Figs. 2 and 3 show the average water content and infiltration depth in each strip for only two dates, January, 1997 and April, 1998. Cumulative rainfall and water depth in the sand ditch and control areas for Location

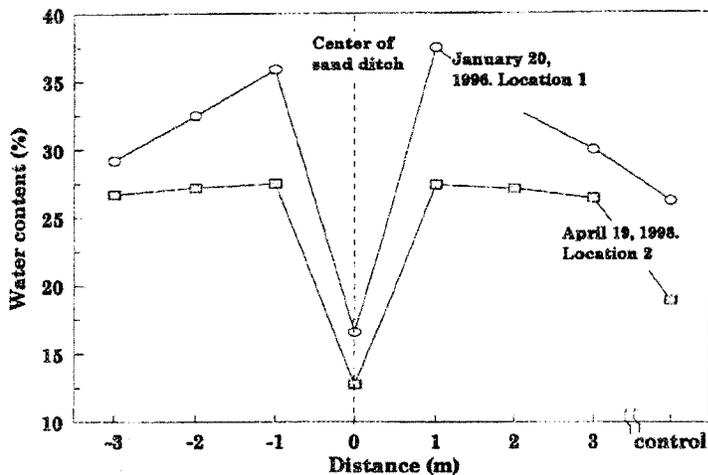


Fig. 3. Variation of water content around sand ditch and control area.

Table 2
Variation of cumulative water depth in the sand ditch and control areas during the 1996/1997 winter season^a

Date	Cumulative rainfall (mm)	Location 1		Location 2	
		Cumulative depth in the sand ditch area (mm)	Cumulative depth in the control area (mm)	Cumulative depth in the sand ditch area (mm)	Cumulative depth in the control area (mm)
December 7	50.9	35.7a	19.0b	37.3a	29.8b
January 20	115.2	101.5a	59.0b	82.8c	49.6d
February 23	196.1	194.2a	150.2b	156.1b	114.4c
March 9	221.9	158.2a	106.0b	132.7c	93.8d
April 1	244.7	148.5a	122.6b	101.4c	77.2d
April 15	251.7	75.5a	59.8b	66.1c	49.8d

^a Values with different letter in a row means they are significantly different at 95% probability level.

1 and 2 are summarized in Tables 2 and 3 for the two winter seasons 1996/1997 and 1997/1998, respectively.

The depth of water infiltration in the middle of the sand ditch was significantly higher than that in the adjacent soil profile, as shown in Fig. 2 ($p < 0.05$). Water depth decreased with distance from the center of the ditch to reach a minimum value at the control area. In January, 1997, the wetting depth at the center of the sand ditch was about 60 cm and decreased steadily to 35, 30, 27 and 22 at distances of 1, 2, 3 and 20 m away from the center of the ditch (Fig. 2). The difference in wetting depth between sand ditch area and control area was significant ($p < 0.05$). Similar results were found for the next winter season in April, 1998 where the infiltration depth at the center of the sand ditch was 100 cm compared to 80 cm at 3 m away from the sand ditch and only 68 cm in the control area (Fig. 2). The wetting depths were much higher in April, 1998 compared to January, 1997 since the cumulative rainfall in April was much higher than that in January. The results shown in Fig. 2 are expected since the infiltration rate of sandy soil is much higher than clay soils. It is believed that sand ditches became quickly saturated, then infiltrated

Table 3
Variation of cumulative water depth in the sand ditch and control areas during the 1997/1998 winter season^a

Date	Cumulative rainfall (mm)	Location 1		Location 2	
		Cumulative depth in the sand ditch area (mm)	Cumulative depth in the control area (mm)	Cumulative depth in the sand ditch area (mm)	Cumulative depth in the control area (mm)
November 14	50.6	44.1a	32.1b	42.3a	29.8b
December 20	111.2	106.7a	80.2b	98.0c	73.8d
February 17	208.9	193.7a	141.7b	175.7c	127.8d
March 3	215.7	178.4a	128.9b	167.3c	110.4d
April 19	283.6	225.0a	151.0b	204.8c	128.6d
April 28	283.6	150.1a	118.2b	139.1c	108.2d

^a Values with different letter in a row means they are significantly different at 95% probability level.

water started seeping into adjacent clay soil due to its higher matric potential (Hillel, 1980). Water seepage from the sand ditch to the adjacent clay layer will continue until the matrix potential of the two soils is equal (Foth, 1990). This phenomenon will also increase the water content of clay soil adjacent to the sand ditch. Fig. 3 supports this argument since water content at 1 m from sand ditch was 37% and steadily decreased to 33, 30 and 26% at distances of 2, 3 and 20 m away from the center of sand ditch. The average water content in the sand ditch was 16.6% due to its low porosity whereby the depth of water stored in the sand ditch is less than that in the original soil. This may raise the question of the efficiency of replacing the original soil with sand. However, sand ditches facilitate rapid water collection and subsequent infiltration to the adjacent clay soil through the sides of the ditch. Rainfall infiltration through clay soils, predominant in northern Jordan, decreases rapidly due to soil dispersion and surface crusting. The use of sand ditches decrease the significance of this mechanism by increasing water infiltration through the ditch sides which are not affected by rainfall impact and crusting. The overall effect of the sand ditch is to increase water storage in the immediate area of the four olive trees.

The cumulative rainfall and water depths stored in the sand ditch and control areas for 1996/1997 winter season are summarized in Table 2. Results indicated that the construction of sand ditches significantly increased the depth of water storage in the soil profile compared to control during the whole measurement period ($p < 0.05$). A graphical representation of the data for Location 1 and 2 is shown in Figs. 4 and 5, respectively. These figures allow direct comparison between water storage in the sand ditch and control areas with respect to cumulative rainfall.

Figs. 4 and 5 show that the depth of water stored around the sand ditch or in the control area increased with time from December 7, 1996 to February 23, 1997. After that, the

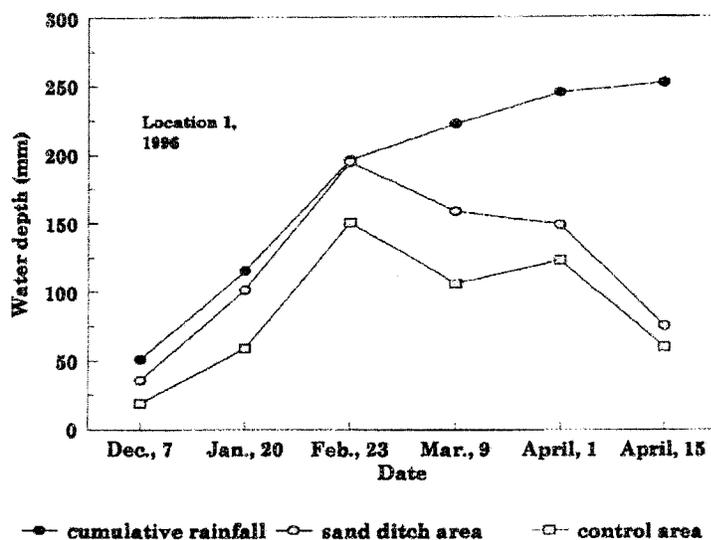


Fig. 4. Variation of water depth around sand ditch and control area (Location 1).

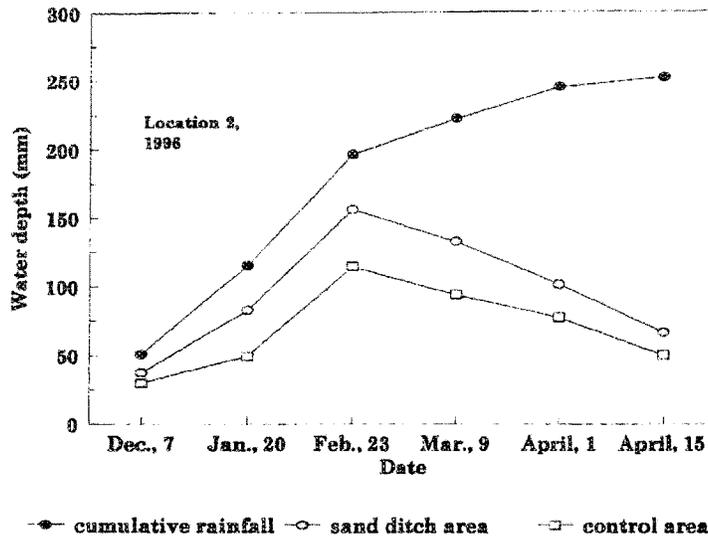


Fig. 5. Variation of water depth around sand ditch and control area (Location 2).

amount of water steadily decreased with time in both locations and control areas. In Location 1, the depth of water stored in the ditch area was 194 mm (99% of cumulative rainfall) compared to only 150 mm in control area. For Location 2, 156 and 114 mm were stored in the sand ditch and control area, respectively. At the end of the winter season the average depth of water stored in sand ditch and control areas had decreased to 70 and 55 mm, respectively. Note that evapotranspiration at the end of February, 1997 began to exceed the amount of rainfall due to high temperatures, plant uptake, and light rain storms, thus increasing the rate of soil moisture depletion. Nevertheless, the sand ditch had a significant effect on the amount of stored water compared to control.

At the end February, 1997 in Location 1, shown in Fig. 4, the percentage of water stored around the sand ditch was 99% of the cumulative rainfall. This high percentage is possible because sand ditches intercept water runoff, since they are constructed across the slope, thus increasing the amount of water stored to a value that may reach or even exceed cumulative rainfall. This behavior has been noticed in Location 1. The field in Location 1 has a greater slope (8%) and faces west, apposite to the direction of precipitation, thus receiving more rainfall and runoff which is intercepted and collected by the sand ditch. Visual observations after a heavy storm in late February 1997 support this argument.

Water storage data for the winter season of 1998 are summarized in Table 3. Similar to the previous season, the depth of rainfall stored in the sand ditch area was significantly higher than that in the control area during the whole 1998 season ($p < 0.05$). For example, water storage in the sand ditch area of Location 1 at the end of December was about 107 mm (96% of the cumulative rainfall) compared to only 80 mm in control area (Table 3). Similar results were found for Location 2. However, as mentioned before, the

efficiency of the sand ditch for water storage was significantly higher in Location 1 than in Location 2 for the two seasons: (a) land slope in Location 1 was higher (8 versus 5%), and (b) the site was facing the direction of rainfall thus increasing the chance of runoff and possibly interception by the sand ditch.

Table 3 shows that the depth of water storage in the sand ditch area steadily increasing until February, 1998 then started to decrease slowly to a value of 150 and 139 mm in April 28, 1998 in Locations 1 and 2, respectively. However, during the 1996/1997 winter season, water storage steadily decreased after February, 1997 to only 75 and 66 mm for Locations 1 and 2, respectively (Table 2). This is because rainfall during the winter of 1998 was higher and more uniformly distributed than that in 1997. Therefore, the amount of water storage at the end of the 1997/1998 winter season was higher than that for the 1996/1997 winter season.

4. Conclusions

1. The construction of sand ditches in the north of Jordan increased the depth of rainfall infiltration and soil moisture content, thus increasing the percentage of rainfall stored inside the soil matrix.
2. Sand ditches also intercepted runoff thus, maximizing water collection and preventing soil erosion.
3. Sand ditches are simple and easy to construct and do not interfere with agricultural operations.

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