Original Research

Agriculture Water Use Efficiency in Wadi Shu'eib Area, Jordan

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Abstract

Water percolation in upper soil at Wadi Shueib in Jordan was investigated using different irrigational methods and amounts of irrigation water. Four investigative periods were designed: two during the summer and two during the winter. The percentage of recharge from irrigated plots ranged from 42% to 78%, depending on the amount of irrigation water and the climatic conditions that prevailed in the investigated area. The main factor that controlled the amount of percolation was soil water content. Different methods of irrigation showed apparent variations in the amount of water losses. The covered fields (mulched and subsurface methods) had the lowest water consumption as compared to the uncovered plots (bare and meandering irrigational methods). This is mainly due to the reduction in surface evaporation from the topsoils. Accordingly, any improvement in water use efficiency should take this factor into consideration.

Keywords: water use efficiency, Jordan, groundwater recharge, percolation, irrigation

Introduction

The Middle East is inhibited by approximately 5% of the world's population. However, it has only 1% of the world's freshwater resources. Jordan is one of the countries suffering from immediate water deficit where demand exceeds natural supply by about 140%, and the renewable water supply by about 175%, thus making the country one of the top-ten water-deficient countries in the world. In Jordan, irrigation water consumes a large share of its water budget. It was estimated that more than 69% of Jordan's water resources were used for agriculture [1].

Jordanian farmers are keen to grow crops with the highest commercial value without paying attention to the possible impact on water resources and soil. Several irrigation methods are being used in Jordan, where surface irrigation is the oldest. Furrow and basin irrigation were the most common methods in the region, but due to water scarcity these have been replaced with drip irrigation to reduce water losses. Basin irrigation is used mostly for irrigating trees, mainly citrus. Many farmers are used to covering their fields with mulch to reduce evaporation under hot and dry climatic conditions. Facing severe agricultural and municipal water shortages, especially after the probable decrease in precipitation and an increase in options to meet its growing demand, efficiency can be achieved through saving the unproductive water used for irrigation. Marginal water (treated wastewater, grey water, and brackish water) has been recently considered as an important water resource in order to alleviate the aggravated dilemma of water shortage and precipitation decrease affected by climate change.

Many studies have been carried out to evaluate moisture fluxes in the unsaturated zone [2, 3], but they were concerned mainly with the amount of recharge paying great impact on meteorological conditions. Weiguang et al. [4]

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found that the macro pore flow could be an important factor influencing the soil water content during high precipitation events. Jiries et al. [5] evaluated water movement in typical soils in the Jordan Valley and found that water movement depends mainly on water content and soil type.

The hydrology of the Wadi Shu'eib area was investigated by Becker et al. [6] who reported three hydrogeological units: the lower cretaceous aquifer complex, upper Cretaceous aquifer complex, and upper Tertiary/Quaternary Jordan Valley alluvium aquifer complex. The current work examined water use efficiency under different irrigation methods and varying amount of irrigation water to estimate the amount of unused water. The impact of possible variation of the available water resources on agriculture within the study area of Wadi Shu'eib in the Jordan valley was investigated.

Methodology

Study Area

The experiment was carried out along the upper Wadi Shu'eib area, which is one of the main agricultural areas in the Jordan valley. The study area is located on sand deposit in the eastern flank of the Jordan valley along the Shu'eib Valley near the city of Salt, (31º 59` N – 35º 43 E) at an altitude of 586 meters above sea level (Fig. 1). The soil is sandy quartz in composition (> 70% sand and < 27% silt and clay) with very low organic content. Thin soils exist on the shoulders of the valley. The Wadi Shu'eib catchment is typically steep in hill slopes and along the Wadi course. Geologically, it is built up of fissured lime-, marl- and sandstones and is covered by a weathering zone called epi-zone, which favors the infiltration of precipitation. Marland sandstones form extended morphologic erosion shoulders that often occur on tectonic dislocations in connection with rock avalanches. On these shoulders, rain-fed and irrigation agriculture exist abundantly. On the contrary, limestone is exposed in steep hill slopes and are mostly bare of vegetation.

Minimum thickness of the epi-zones of sand- and marlstones are several decimeters, where maximum thickness of one meter with porosities exceeding 30% can be observed. This increases infiltration capacities in the semi-arid Shueib catchment significantly. The area hydrology is characterized by successive dry (May to October) and wet seasons (November to April) over the entire region. Annual long-term average precipitation in the area is about 500 mm, where snow precipitation is generally rare.

Experiment Design

Four plots with an area of 25 m^2 each were leveled and confined by a 20-cm-deep soil panel. The first plot (bare) was kept without vegetation, representing unvegetated land of the Shu'eib Valley. The second plot (meandering) was planted and irrigated using meandering method. The third plot (subsurface) was planted and irrigated using subsurface method by installing perforated pipes distributed evenly at 10 cm depth. A fourth plot (mulched) was planted and covered with mulch. The plants used in this investigation were pepper plants during summer and cornflower during winter.

Suction cups were installed in each plot to collect water samples from soil pores at 30, 50, and 70 cm depths (in triplicate for each depth) as the bed rocks exist at 70 cm depth. A vacuum pump (UMS, Germany) was used to establish a 0.5 atmospheric pressure in the suction cups for collection of pore water samples.

Each of the experimental plots was decorticated and irrigated with 300 L of water (corresponding to around 40% of top soil humidity) before the tracer application, to reduce the presence of clay crack in topsoil.

Over the entire experiment phases, a nonreactive chemical tracer (ammonium bromide) was applied to each plot at a concentration of 250 mg/L. The tracer solution (50 L) was applied to each plot using an irrigation basket to assure a uniform distribution of bromide over the plot area. One hour after the tracer application, each plot was irrigated with another 50 L of tracer-free water to allow penetration of the tracer into subsurface soil.

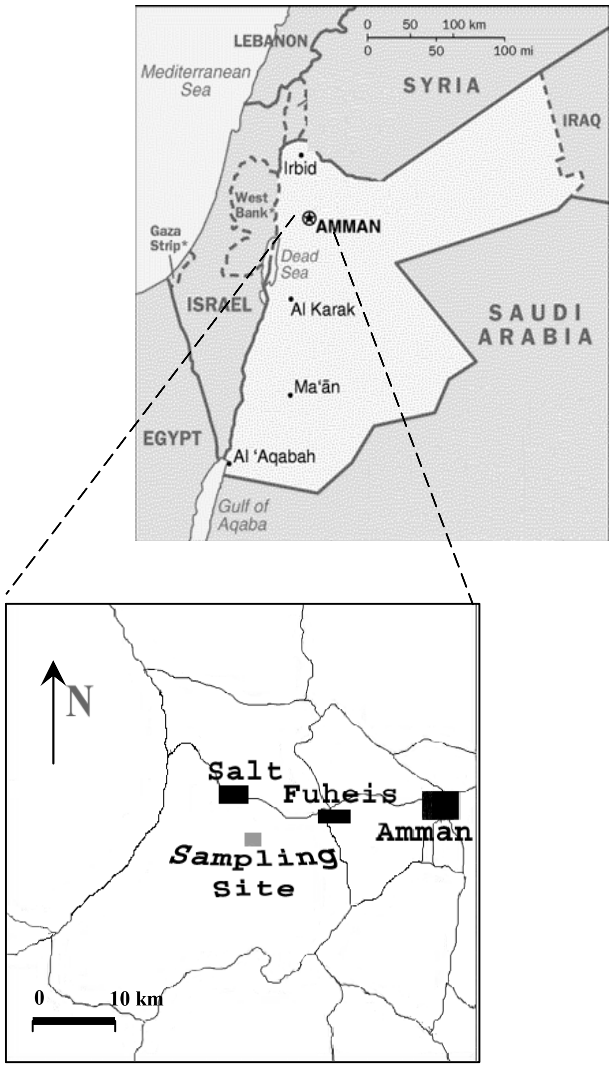

Fig. 1. Experimental site at Wadi Shu'eib area, Jordan.

Flow velocity from each plot was determined by monitoring the percolated water at three depths (30, 50, and 70 cm). The water samples were collected on a weekly basis and analyzed for bromide concentration according to the Standard Method for Examination of Water and Wastewater [7].

The experiment was performed during two dry summer seasons (summers of 2004 and 2005) and two pluvial winter seasons (winters of 2003-04 and 2004-05). The amount of irrigation water applied to each plot during the summer seasons was close to what has been actually used in the area, so that during the dry summer of 2004 (started on 16 June 2004), the average weekly water input was 33 L/m^2. In the summer of 2005 (starting in June 2005), the average weekly water input was 21 L/m^2.

During the winter seasons, rainfall was the only source of water input, which was monitored by using a rain gauge installed at the experimental sites. This has contributed in a variation of the amount of irrigation water to each plot over the different seasons of the test, so that possible differences in climatic conditions among successive seasons might be quasi simulated. At the subsurface irrigation plot and during the wet seasons, subsurface irrigation plot was covered with mulch 30 cm above the soil surface. However, the plot was irrigated with the same amount of rainfall in the area to obtain similar input conditions.

Frequent soil and water sampling was conducted to estimate fluxes of bromide tracer into groundwater. Time domain reflectometry (TDR) techniques have been proven to be well-suited to this purpose because of their potential for automation and limited calibration work required [8]. Soil water content at three depths was checked on a daily basis with the use of TDR, which was installed at 30, 50, and 70 cm depths.

The investigation period for each plot was controlled by the time required for the tracer to pass the lower sampling suction cup at 70 cm depth. Therefore, test duration was variable at different plots and different seasons. All plots were irrigated with fresh water between successive runs to wash out any residual traces of bromide before commencing the next run with new tracer dose.

Results and Discussion

As previously mentioned, the investigated area is primarily sandy soil without any agricultural activities. Therefore, the boundary conditions represent a large portion of the area in the upper reach of Shu'eib valley. The results obtained from the investigation at the experimental site during different seasons by applying different irrigational methods at different climatic conditions are discussed below.

Precipitation

The amounts of precipitation at the two winter seasons of the experimental time have been monitored. The results are shown in Figs. 2 and 3. The distribution, duration, and intensity of rain are expected to have a great impact on soil water content and recharge rate as they were not uniform during both seasons. During the winter season 2003-04, the 180.4 mm of rainfall during 51 days of experiment gave a weekly average water input of 25 L/m^2. The amount of rain was distributed on 16 rainy days ranging from drizzle rainfall to 23 mm/day. However, the site has received precipitation in one event of about 39 mm/day.

During winter 2004-05, the amount of rain was higher than the previous winter season. It mounted up to 346 mm of rainfall over 77 days, giving an average weekly input of 31.5 L/m^2. The intensity of rain was variable, ranging from 1.6 mm/day to 70 mm/day distributed over 10 rainy days. Around 64% of the rainfall was experienced in three successive days, where most of the water from these rain events left the site as surface runoff as it was above the soil infiltration capacity.

Soil Water Content

Water content of the field soils was monitored over the entire experimental runs at all plots. The average results are

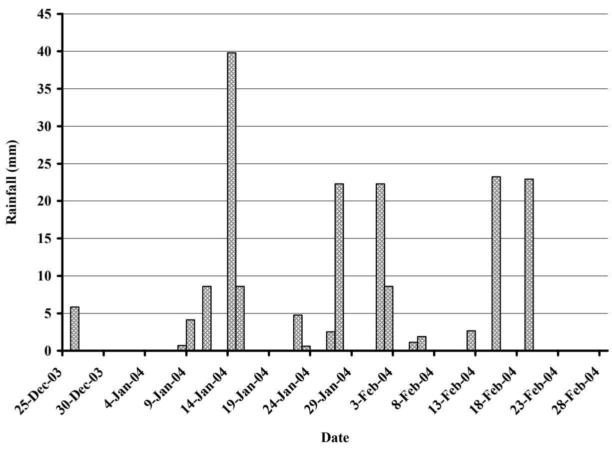

Fig. 2. Precipitation amount and distribution in the investigated area during winter 2003-04.

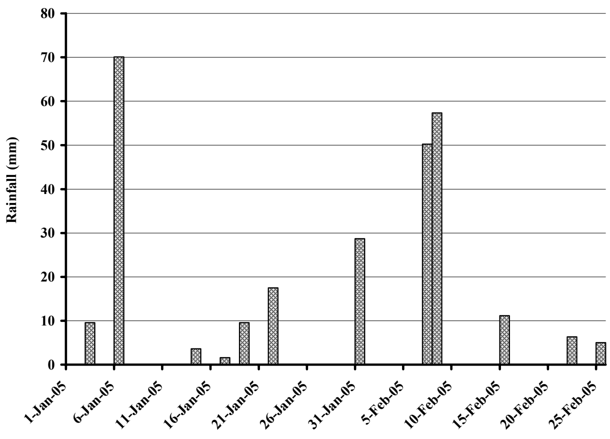

Fig. 3. Precipitation amount and distribution in the investigated area during winter 2004-05.

Table 1. Average soil water contents at the four irrigation plots during different seasons.

Method of Irrigation	Average soil water content%			
	Winter 2003-04	Summer 2004	Winter 2004-05	Summer 2005
Meandering	13.6	16.2	9.2	9.7
Mulched	14.9	15.7	10.7	9.6
Bare	14.9	18.4	11.1	11.9
Subsurface	15.7	18.5	11.0	10.9

Table 2. Summary of amount of recharge at the four irrigation plots during different seasons.

Method of Irrigation	Average amount of recharge (L/m²/day)			
	Winter 2003-04	Summer 2004	Winter 2004-05	Summer 2005
Meandering	8.4	5.2	5.6	5.2
Mulched	8.4	6.7	6.4	5.6
Bare	8.2	6.9	6.4	4.5
Subsurface	8.3	8.4	5.0	6.6

shown in Table 1. The results show that the soil water content was found to vary with the used method of irrigation. The highest water content was recorded in the mulched and subsurface plots as less evaporation occurred from these sites than the meandering and the bare plots, which were exposed to evaporation directly from the surface. The average water content before starting the experiment was measured to be as low as 8.1%. This is due to the fact that only a few rainfall events of low intensity occurred before starting the experiment. During the experimental period, the water content was increased due to rainfall percolation. The average soil water content in the four plots during winter 2003-04 were 13.6%, 14.9%, 14.9%, and 15.7% for plots bare, meandering, subsurface, and mulched, respectively. These values were higher than the average soil water content during the following winter (2004-05), which were found to be 9.2%, 10.7%, 11.1%, and 11.0% for the above-mentioned plots, respectively. The highest recorded soil water content was during winter 2003-04 in spite of the fact that during the following winter, the amount of rainfall observed was higher. The main reason for the variation in soil water content is attributed to the frequency and amount of rainfall in the area during the winter seasons (Fig. 2) and not due to evaporation that was characterized by low and similar rates at both seasons (6.5 to 7 mm/day).

Under summer climatic conditions, the decrease in the amount of irrigation water from 33 L/m²/week to 21 L/m²/week was found to have a remarkable decrease in soil water contents in all plots. The water content in the four plots during summer 2004 were found to be 16.2%, 15.7%, 18.4%, and 18.5% for the plots bare, meandering, subsurface, and mulched, respectively. These values were found to be higher than those recorded during summer 2005, which were found to be 9.7%, 9.6%, 11.9%, and 10.9% for the above-mentioned plots, respectively. Soil water contents at the irrigation plots under all climatic conditions did not show any significant differences between planted and unplanted plots. This indicated that transpiration was low as plot vegetation was young. The average soil water content for the top 30 cm of the soil profile, where most of the roots exist, was slightly lower in meandering plots than bare plots. The average water content in summer 2004 was 21.1% and 17.8% for bare and meandering plots, respectively, and 12.2% and 9.9% for bare and meandering plots, respectively, in summer 2005. This slight difference can be attributed to the transpiration effect.

Depth Flow Velocity and Recharge

The water flow velocity in the irrigated plot under different irrigation methods was determined for the four above-mentioned seasons. The amounts of water recharge for all different amounts of irrigation water under different climatic conditions are summarized in Table 2. The results showed that there was a slight increase of recharge in both mulched and subsurface plots as compared to meandering and bare plots. This is due to higher soil water content brought about by reduced evaporation at both plots.

Table 3. Net input, recharge loss, and percent of recharged water at the four plots during different seasons.

Net week recharge at the investigated area (L/m²)													
Season	Weekly input L/m²	Meander			Mulched			Subsurface			Bare		
		R	L	% R	R	L	% R	R	L	% R	R	L	% R
Winter 2003-04	25	19.5	5.5	78.0	19.6	5.4	78.4	19.4	5.6	77.6	19.2	5.8	76.8
Winter 2004-05	31.5	13.4	18.1	42.5	15	16.5	47.6	15	16.5	47.6	13.1	18.4	41.6
Summer 2004	33	15.5	17.5	47.0	15.6	17.4	47.3	19.7	13.3	59.7	16	17	48.5
Summer 2005	21	11.9	9.1	56.7	12.8	8.2	61.0	15.2	5.8	72.4	10.5	10.5	50.0

R: Recharge, L: Lost water,%R: percentage of recharged water, ND: Not Determined

Summary of irrigation input, recharge, lost water through evaporation and surface runoff, and percentage of recharge with respect to input for the four plots during different seasons are shown in Table 3. The results showed that the amount of recharge from all plots were higher during summer 2004 than those during summer 2005. This was due to higher amounts of applied irrigation water during summer 2004 (33 L/m^2/week) as compared to those during summer 2005 (21 L/m^2/week). Table 3 shows that a reduction of 36% in irrigation quantity exhibited variable decrease in the percentage of recharged water, which were recorded to be 23.2%, 17.9%, 22.8%, and 34.4% for meandering, subsurface, bare and mulched plots, respectively.

The impact of transpiration on water recharge in all plots and at all seasons was not very clear. The slight difference in water recharge between bare and meandering plots during both seasons, summer 2004 and summer 2005, was about 3.6 L/m^2/week. However, the difference was always higher in the bare plot. This could be attributed to the transpiration process during the summer seasons of the young and small pepper plants in the meandering plot, as well as the high evapotranspiration from soil under higher water content [8].

Conclusions

The present situation of irrigation practice showed that an excess amount of irrigation is being used in Jordan, where a reduction in precipitation due to climate change will have no great impact on irrigation amount but will affect the amount of water being recharged. Reduction in the amount of irrigation water in both summer and winter seasons would not reduce recharge in the same portion because:

1. During the summer season, a reduction in irrigation water by 36.4% resulted in a change of recharge by 23.2%, 17.9%, 22.8%, and 34.4% for meandering, mulched, subsurface, and bare method of irrigation, respectively.
2. For the winter seasons, distribution and intensity of rain are the major components in the recharging process. Moderate precipitation intensity and frequent rain led to more water recharge than high precipitation intensity and less rain frequency. If a decrease in precipitation occurs due to possible climate change, the recharge as well as soil moisture will not be reduced by the same ratio.

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