5 IMPACTS OF WATER HARVESTING TECHNIQUES ON SOIL AND WATER CONSERVATION AT FIELD AND SUB-CATCHMENT SCALE IN THE OUED OUM ZESSAR WATERSHED

Schiettecatte W.¹, Ouessar M.², Gabriels D.¹* and Abdelli F.²

¹Department of Soil Management and Soil Care, Gent University, Coupure Links 653, B-9000 Ghent, Belgium.
²Institut des Régions Arides, Route de Djorf km 22.5, Médenine 4119, Tunisia.
*Corresponding author (email: donald.gabriels@rug.ac.be; fax +32 9 264 62 47)

Abstract
As part of the WAHIA-project (impact assessment of water harvesting techniques) infiltration and runoff measurements were carried out at the impluvium of the Amrich jessr, situated in the Zeuss Koutine watershed (Tunisia). The results of these experiments were used as input data for the Sediment Transport Model (STM) in order to estimate the effect of water harvesting techniques (WHT) like the jessr on soil and water conservation.

Infiltration and runoff were measured by means of a small Kamphorst infiltrometer and a large field rainfall simulator. The results showed that the infiltration rate measured by the infiltrometer was about 3 times higher than with the field rainfall simulator. Probably the breaking of the surface seal during installation had a much larger impact on the infiltrometer measurements. The field rainfall simulator provided a better approximation of natural rainfall and prevents breaking of the scaled soil surface. Therefore the results of the field rainfall simulations were used to estimate infiltration and runoff. In order to assess the transport of sediment with runoff, a sediment transport equation was developed on the basis of the field rainfall simulation results, using the stream power concept.

The infiltration characteristic and the sediment transport function enabled to estimate runoff and erosion on an event basis. Several simulations were done for different rainfall events that occurred since April 1998. The simulation results indicated that during intense rainfall a lot of sediment and water are retained by the terrace of the jessr, preventing it from being transported downslope. Therefore, WHT like the jessr are important for soil and water conservation. Over a period of 3 years, rainfall and infiltration data were used to assess the water balance on the terrace of the jessr. The results showed that especially during dry years the impluvium of the jessr provides an important supplementary amount of water for the cultivation of olive trees. Furthermore it was estimated that the ratio ‘area impluvium/area terrace’ should be larger than 7.4 in order to provide, on average, sufficient water for olive cultivation, taking into account an average annual precipitation of 235 mm. If the ratio ‘area impluvium/area terrace’ is larger than 29, enough water is provided by the impluvium in 97% of the years.

Keywords: Infiltration, erosion, water harvesting, water balance, evapotranspiration, jessr

5.1 Introduction

Arid zones are characterised by small, average annual rainfall amounts. However, very high rainfall intensities can occur, causing runoff and erosion on the hill slopes. In order to increase the amount of water available for crop production and cattle breeding, several types of water harvesting techniques (WHT) have been developed. In Tunisia, common WHT are jessour
(singular: jessr), terraces, tabias, cisterns, gabions, recharge wells and mescats. A more detailed description of these WHT is given by Ouessar et al. in Chapter 2.

The use of WHT is not only restricted to collecting water for agriculture. Runoff causes erosion of the fertile topsoil, resulting in soil degradation on site. Moreover, the eroded soil is transported towards the oueds, where it increases the risk of flooding in adjacent areas. WHT jessrs decrease the amount and velocity of the runoff water, and consequently reduce soil erosion. Moreover, part of the eroded soil is deposited on the terrace of the jessr, ameliorating the soil water storage capacity and resulting in higher soil fertility. The on site and off site benefits of WHT emphasise the need of restoring and maintaining these systems.

In order to be efficient, WHT should be constructed in proportion to the amount of water that can be expected during a rainfall event. Therefore, data are needed on rainfall, topography and soil characteristics like infiltration rate and water retention. However, in desert and arid areas the availability of these data is limited. The purpose of this study was to examine the impact of WHT like the jessrs on erosion and water availability for crop production. Therefore, existing rainfall data were analysed and additional field measurements were done in a small sub-watershed in southern Tunisia.

5.2 Materials and methods

5.2.1. Study area

This study was carried out in the Oued Oum Zessar watershed, situated between Kébili, Gabès and Médenine in the southern part of Tunisia and having a surface area of 367 km². Within the watershed an ancient jessr at Amrich, located upstream of Oued Nagab, was chosen as an experimental site to assess runoff, erosion and the impact of the jessr on the water balance. A jessr is a WHT by which water coming from an impluvium is collected on a terrace surrounded by a dike (Figure 5.4). The terrace is used for crop cultivation; in the Amrich jessr 5 olive trees are grown on the terrace. The area of the terrace and impluvium are respectively 0.275 ha and 8 ha.

5.2.2. Field measurements

At Amrich the soil profile of the terrace was sampled at different depths (until 1.4 m) in order to determine the soil texture and the water retention curves. Soil texture data of the terrace are given in Table 5.1. Since April 1998 a tipping bucket raingauge (precision: 0.1 mm) was installed at El Beyara and Chouamek to record rainfall intensities continuously. The weather station nearest to the Amrich site is Chouamek at 2 km distance. Daily rainfall data of the weather station at Béni Khedache were available over the period 1969 – 2000 (data of the years 1971 and 1991 were missing). Table 5.2 shows that during the period 1969 – 2000 the average monthly rainfall varies between 0 and 40 mm, with the driest period from June till August. The potential evapotranspiration (PET) was calculated by means of the Penman-Monteith method (Smith, 1991), using data of the meteorological station at Médenine. Over the period 1985-1995 average PET values were calculated per decade of days, setting the number of days per month equal to 30. The maximum crop evapotranspiration (ETc) was calculated based on the PET values and the crop coefficient kc. Values of kc are based on data for olive trees given by Leleuvel (2001). In case the soil moisture content is insufficient to reach ETc, the actual evapotranspiration (ETa) will be lower than ETc. To calculate the ETa the equation of Rijtema and Aboukhaled (1975) was used, taking into account the fraction (p) of
the total soil water content that is easily available for the olive trees. The rooting depth of the olive trees was assumed to be 1.4 m (Doorenbos and Kassam, 1979). Values of PET, ETc, kc and p are given in Table 5.2.

Table 5.1 Soil characteristics at different depths in the soil profile of the terrace at the Amrich jessr (OM = organic matter; ϑfc = moisture content at field capacity (9.8 kPa), ϑwp = moisture content at wilting point (1554 kPa))

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>0-2 μm (g g⁻¹)</th>
<th>2-50 μm (g g⁻¹)</th>
<th>50-2000 μm (g g⁻¹)</th>
<th>OM (g kg⁻¹)</th>
<th>CaCO₃ (g kg⁻¹)</th>
<th>ϑfc (m³ m⁻³)</th>
<th>ϑwp (m³ m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.075</td>
<td>0.152</td>
<td>0.206</td>
<td>0.643</td>
<td>17.6</td>
<td>9.4</td>
<td>0.362</td>
<td>0.099</td>
</tr>
<tr>
<td>0.075-0.225</td>
<td>0.179</td>
<td>0.189</td>
<td>0.632</td>
<td>9.7</td>
<td>12.8</td>
<td>0.308</td>
<td>0.109</td>
</tr>
<tr>
<td>0.225-0.375</td>
<td>0.171</td>
<td>0.187</td>
<td>0.642</td>
<td>8.5</td>
<td>27.0</td>
<td>0.324</td>
<td>0.104</td>
</tr>
<tr>
<td>0.375-0.525</td>
<td>0.160</td>
<td>0.196</td>
<td>0.644</td>
<td>8.0</td>
<td>22.2</td>
<td>0.251</td>
<td>0.096</td>
</tr>
<tr>
<td>0.525-0.675</td>
<td>0.083</td>
<td>0.034</td>
<td>0.883</td>
<td>1.7</td>
<td>32.8</td>
<td>0.283</td>
<td>0.037</td>
</tr>
<tr>
<td>0.675-0.825</td>
<td>0.135</td>
<td>0.120</td>
<td>0.745</td>
<td>7.4</td>
<td>31.6</td>
<td>0.307</td>
<td>0.086</td>
</tr>
<tr>
<td>0.825-0.975</td>
<td>0.119</td>
<td>0.147</td>
<td>0.734</td>
<td>5.1</td>
<td>9.4</td>
<td>0.294</td>
<td>0.104</td>
</tr>
<tr>
<td>0.975-1.125</td>
<td>0.178</td>
<td>0.132</td>
<td>0.691</td>
<td>4.5</td>
<td>26.0</td>
<td>0.289</td>
<td>0.097</td>
</tr>
<tr>
<td>1.125-1.4</td>
<td>0.130</td>
<td>0.151</td>
<td>0.719</td>
<td>2.3</td>
<td>36.6</td>
<td>0.299</td>
<td>0.084</td>
</tr>
</tbody>
</table>

Table 5.2 Average monthly rainfall (P), rainfall days (N), potential evapotranspiration (PET), maximum crop evapotranspiration (ETc), crop coefficient (kc) of olive trees and fraction (p) of the total water content that is easily available for olive trees

<table>
<thead>
<tr>
<th>Month</th>
<th>P (mm)</th>
<th>N</th>
<th>PET (mm)</th>
<th>ETc (mm)</th>
<th>kc</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>37.5</td>
<td>3.4</td>
<td>69.6</td>
<td>27.8</td>
<td>0.40</td>
<td>0.88</td>
</tr>
<tr>
<td>Feb</td>
<td>30.6</td>
<td>2.8</td>
<td>88.6</td>
<td>35.4</td>
<td>0.40</td>
<td>0.88</td>
</tr>
<tr>
<td>Mar</td>
<td>40.0</td>
<td>3.0</td>
<td>121.2</td>
<td>66.7</td>
<td>0.55</td>
<td>0.86</td>
</tr>
<tr>
<td>Apr</td>
<td>16.3</td>
<td>1.8</td>
<td>159.3</td>
<td>79.6</td>
<td>0.50</td>
<td>0.83</td>
</tr>
<tr>
<td>May</td>
<td>11.2</td>
<td>1.2</td>
<td>198.4</td>
<td>89.3</td>
<td>0.45</td>
<td>0.80</td>
</tr>
<tr>
<td>Jun</td>
<td>1.0</td>
<td>0.3</td>
<td>213.5</td>
<td>85.4</td>
<td>0.40</td>
<td>0.81</td>
</tr>
<tr>
<td>Jul</td>
<td>0.0</td>
<td>0.0</td>
<td>234.8</td>
<td>82.2</td>
<td>0.35</td>
<td>0.82</td>
</tr>
<tr>
<td>Aug</td>
<td>2.0</td>
<td>0.3</td>
<td>220.9</td>
<td>77.3</td>
<td>0.35</td>
<td>0.83</td>
</tr>
<tr>
<td>Sep</td>
<td>17.1</td>
<td>2.0</td>
<td>166.6</td>
<td>75.0</td>
<td>0.45</td>
<td>0.84</td>
</tr>
<tr>
<td>Oct</td>
<td>23.0</td>
<td>2.4</td>
<td>126.8</td>
<td>63.4</td>
<td>0.50</td>
<td>0.86</td>
</tr>
<tr>
<td>Nov</td>
<td>19.9</td>
<td>2.3</td>
<td>91.1</td>
<td>41.0</td>
<td>0.45</td>
<td>0.88</td>
</tr>
<tr>
<td>Dec</td>
<td>36.7</td>
<td>3.3</td>
<td>67.4</td>
<td>26.9</td>
<td>0.40</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Because the number of rainfall events in arid environments is limited and shows a lot of variability, it was decided to determine runoff on an event basis, using the Time Compression Approximation (Ibrahim and Brutsaert, 1968). In order to apply this concept, infiltration data are needed. The soil infiltration characteristic was determined by means of two types of infiltration measurements carried out in the impiluvium of the Amrich jessr: a small rainfall simulator (Kamphorst infiltration meter (Kamphorst, 1987)) and a large, mobile field rainfall simulator (sprinkler) (Figure 5.1). At the impiluvium of Amrich three experiments have been carried out with the Kamphorst infiltration meter:
a) low initial soil moisture content (0.010 g g⁻¹), 10% stone cover, 16% slope.
b) high initial soil moisture content (0.104 g g⁻¹), 10% stone cover, 16% slope
c) high initial soil moisture content (0.121 g g⁻¹), 20% stone cover, 28% slope

A rainfall intensity of 200 mm h⁻¹ was applied on a surface area of 0.25 × 0.25 m during a period of 800 to 900 s. Runoff was collected every minute.

The large field rainfall simulator was used for 6 runs on 3 different places at the impluvium of Amrich:
- plot 1: 50% stone coverage and 18% slope; one run at low (0.012 g g⁻¹) and one at high (0.067 g g⁻¹) initial soil moisture content
- plot 2: 80% stone coverage and 28% slope; one run at low (0.039 g g⁻¹) and one at high (0.178 g g⁻¹) initial soil moisture content
- plot 3: gully with 90% stone coverage and a 23% slope; one run at low (0.019 g g⁻¹) and one at high (0.16 g g⁻¹) initial soil moisture content

Plots 1 and 2 were situated near the spots where the infiltrometer experiments a, b and c were done. A rainfall intensity of 50 mm h⁻¹ was applied on a surface area of 3x1 m. Runoff and sediment discharge were measured every minute. The rainfall simulation runs lasted for 360 to 900 minutes.

![Image](image.png)

**Figure 5.1 Mobile rainfall simulator (left) and Kamphorst infiltrometer (right) used in the Amrich jessr**

### 5.3 Results and discussion

#### 5.3.1 Infiltration and runoff

The average cumulative infiltration values of the rainfall experiments carried out on plots 1 and 2 are presented in Figure 5.2. Although plots 1 and 2 were situated near the spots where the Kamphorst infiltrometer was used, comparison of the results obtained with the infiltrometer and the field rainfall simulator shows a higher infiltration rate when the infiltrometer was used (Figure 5.2). Because only a small surface area is used in the infiltrometer experiments, disturbing the sealed surface during installation of the infiltrometer device has a large impact on the infiltration rate. In case of the field rainfall simulations only the borders of the delineated experimental area are disturbed during the experimental set-up. Therefore, infiltration characteristics determined by the field rainfall simulations will correspond better to reality and are used in calculating the water harvested on the impluvium.
Figure 5.2 Comparison of infiltration characteristics based on measurements with the Kamphorst infiltrometer (i) and field rainfall simulator (r) on initially dry and wet soil

5.3.2 Sediment transport

In Figure 5.3 the unit sediment load is plotted as a function of the stream power of runoff water. The following sediment transport equation was fitted to all the measurements of the field rainfall simulations:

\[ q_s = 0.00001 \omega^{1.231} \]  \hspace{1cm} (R^2 = 0.846) \hspace{1cm} (equation 1)

where:

- \( q_s \) = unit sediment load (g cm\(^{-1}\) s\(^{-1}\))
- \( \omega \) = stream power of runoff (g s\(^{-1}\))

\[ \omega = \rho g s q \]

where:

- \( \rho \) = density of water (g cm\(^{-3}\))
- \( g \) = gravitational constant (cm s\(^{-2}\))
- \( s \) = slope gradient (m m\(^{-1}\))
- \( q \) = unit discharge of runoff (cm\(^3\) cm\(^{-1}\) s\(^{-1}\))

Equation 1 can be used as a general equation to estimate sediment transport in the Amrich sub-catchment. Figure 5.3 shows that Equation 1 is different from the sediment transport equations developed by Nearing et al. (1997) and Biesemans (2000). The equation of Biesemans predicts higher sediment load values, because this equation was derived from rainfall simulations on loose soil aggregates without stone cover. On the other hand, the equation of Nearing underestimates the measurement results for low stream power values. Nearing et al. (1997) used flume experiments on loose soil aggregates without stone cover and rainfall impact. At low stream power values, rainfall impact seems to be important, while at higher values the increase in water level reduces the raindrop impact. The measurement results at high stream power values are overestimated by the equation of Nearing. These measurements were done on a gully causing more concentrated overland flow, and therefore having another sediment transport capacity than the rills that were investigated in the experiments of Nearing et al. (1997).
5.3.3 Application of the Sediment Transport Model (STM)

In order to estimate runoff and erosion on the impluvium of the Amrich jessr, the Sediment Transport Model (STM) was used. The original STM (2D-version) developed by Biesemans (2000) was modified to take better into account the characteristics of the study area. Infiltration was calculated on the basis of the Time Compression Approximation (Ibrahim and Brutsaert, 1988) using the infiltration characteristics measured during the field rainfall simulations (Figure 5.2). Overland flow was estimated by using a finite difference scheme of the kinematic wave approximation. The amount of sediment transported by runoff was assessed on the basis of Equation 1.

The modified STM (2D-version) was applied at the Amrich sub-catchment, using data of some rainfall events recorded at the gauging stations of Chouamek and El Bhayra. The area of the impluvium and terrace are 8 ha and 0.275 ha respectively. Following a detailed topographic survey of the study site, a digital elevation model (DEM) was built with a resolution of 5×5 m. Based on the DEM a slope map was calculated. The slope values were classified into 7 classes (hillslope segments). The total area of each segment and its distance from the watershed outlet were calculated. Based on these values the width of each segment was estimated (Figure 5.4) (Table 3.3).

Rainfall data of Chouamek and El Bhayra were used as input data for the modified STM. It was assumed that the soil was initially dry (soil moisture content = 0.09 g g\(^{-1}\)) before the rainfall events. The results of the simulations are given in Table 5.4. These results indicate that it is important to know the rainfall intensity during the event. High daily rainfall amounts might not cause large runoff amounts, if the rainfall intensities are low. Therefore, it is impossible to assess the probability of occurrence of a certain runoff amount on the basis of daily rainfall data.

The simulation results show that WHT like the jessr are important for erosion and flood control. Large amounts of sediment and water are collected on the terrace. The decrease in velocity of the runoff water causes deposition of sediment on the terrace. Because of the
stability of the dike, the height of the spillway is limited. Therefore, only a certain part of the sediment and water can be retained on the terrace. Increasing the height of the dike may result in instability problems, causing a breakdown of the dike during high rainfall intensities. This can result in destruction of dikes of jessr systems situated downslope. The optimal height of the dike should be related to the amount of water needed for crop growth. If possible, another terrace can be constructed downslope in order to collect the remaining part of the harvested water and sediment. In case of the Amrich jessr no other terrace is actually present downslope.

Figure 5.4 Schematic representation of the Amrich sub-catchment

<table>
<thead>
<tr>
<th>Segment</th>
<th>Cumulative distance to the outlet (m)</th>
<th>Altitude (m)</th>
<th>Segment width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 77</td>
<td>431 - 410</td>
<td>207</td>
</tr>
<tr>
<td>2</td>
<td>77 - 120</td>
<td>410 - 390</td>
<td>249</td>
</tr>
<tr>
<td>3</td>
<td>120 - 162</td>
<td>390 - 370</td>
<td>269</td>
</tr>
<tr>
<td>4</td>
<td>162 - 207</td>
<td>370 - 350</td>
<td>284</td>
</tr>
<tr>
<td>5</td>
<td>207 - 293</td>
<td>350 - 330</td>
<td>254</td>
</tr>
<tr>
<td>6</td>
<td>293 - 349</td>
<td>330 - 317</td>
<td>94</td>
</tr>
<tr>
<td>7</td>
<td>349 - 374</td>
<td>317 - 315</td>
<td>100</td>
</tr>
</tbody>
</table>
Table 5.4 Simulation results of the modified Sediment Transport Model (2D-version) at the Amrich sub-catchment assuming an initial dry soil (moisture content = 0.09 g g\(^{-1}\))

<table>
<thead>
<tr>
<th>Date</th>
<th>Total rainfall (mm)</th>
<th>Average rainfall intensity (mm h(^{-1}))</th>
<th>Harvested water (m(^3))</th>
<th>Harvested sediment (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21/10/1998</td>
<td>77.3</td>
<td>77</td>
<td>4315</td>
<td>50444</td>
</tr>
<tr>
<td>26/11/1999</td>
<td>40.0</td>
<td>1.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>27/04/1998</td>
<td>25.5</td>
<td>6.4</td>
<td>55</td>
<td>92</td>
</tr>
<tr>
<td>21/10/1998</td>
<td>24.9</td>
<td>60</td>
<td>1076</td>
<td>10216</td>
</tr>
<tr>
<td>25/05/2000</td>
<td>12.5</td>
<td>2.3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>24/09/1998</td>
<td>10.4</td>
<td>14.5</td>
<td>100</td>
<td>378</td>
</tr>
</tbody>
</table>

5.3.4 Water balance

The water balance is given by the following general equation:

\[
\Delta S = P + I - ET - D - R - S_o + S_i
\]

where:

- \(\Delta S\) = change of water storage in the soil (mm)
- \(P\) = rainfall (mm)
- \(I\) = irrigation (mm) (i.e. harvested water from the impluvium)
- \(ET\) = evapotranspiration (mm)
- \(D\) = deep drainage (mm)
- \(R\) = runoff (mm)
- \(S_o\) = water output by subsurface flow (mm)
- \(S_i\) = water input by subsurface flow (mm)

Based on the rainfall data of Chouamek (period September 1998- August 2001) (Figure 5.5) the water balance was calculated for the terrace at Amrich. Because of the shallow soil depth and the dry climatic conditions, subsurface flow was considered as being negligible. It was also assumed that runoff and deep drainage are equal to 0 and that the maximum amount of water on the terrace (by rainfall and by runoff from the impluvium) was 200 mm because of the height of the spillway. Three different scenarios were calculated:

- scenario 1: no runoff from the impluvium (i.e. irrigation \(I = 0\))
- scenario 2: calculation of runoff from the impluvium based on the infiltration characteristic measured by the field rainfall simulator on an initially dry soil (Figure 5.2)
- scenario 3: calculation of runoff from the impluvium based on the infiltration characteristic measured by the field rainfall simulator on an initially wet soil (Figure 5.2).

These scenarios were calculated for 3 consecutive hydrologic years:

- hydrologic year 1999 (September 1998 – August 1999): wet year (annual rainfall = 325.7 mm)
- hydrologic year 2000 (September 1999 – August 2000): dry year (annual rainfall = 146.5 mm)
- hydrologic year 2001 (September 2000 – August 2001): extremely dry year (annual rainfall = 11.5 mm)

The results show that during a wet year (September 1998 – August 1999) the effect of the jessr system (i.e. the impluvium) is small (Figure 5.6, 5.7 and 5.8). Without taking into account the harvested water, optimal growing conditions occur during half of the year. In case of a dry year (September 1999 – August 2000) the runoff from the impluvium provides
enough water for optimal growing conditions during at least half of the year, while without water harvesting, maximum evapotranspiration is almost never attained. During extreme dry years (September 2000 – August 2001), taking into account the amount of harvested water, maximum evapotranspiration is only attained during short time periods.

**Figure 5.5** Maximum crop evapotranspiration (ETc) (based on climatic data of Médenine (1985-1995)) and total rainfall (P) (recorded at Chouamek (September 1998 – August 2001)) per decade of days

**Figure 5.6** Maximum crop evapotranspiration (ETc) and actual evapotranspiration (ETa) per decade over the period September 1998 – August 2001 (scenario 1: no irrigation)
Figure 5.7 Maximum crop evapotranspiration (ETc) and actual evapotranspiration (ETA) per decade over the period September 1998 – August 2001 (scenario 2: amount of irrigation water calculated on the basis of an initially dry soil)

Figure 5.8 Maximum crop evapotranspiration (ETc) and actual evapotranspiration (ETA) per decade over the period September 1998 – August 2001 (scenario 3: amount of irrigation water calculated on the basis of an initially wet soil)

5.3.5 Catchment to cropping ratio

In the long term, a jessr can only be effective for crop cultivation if the area of the catchment (impluvium) is large enough to provide sufficient water to the crops. On the other hand, the cropping area (terrace) should be as large as possible. According to Meinzinger (2001) the minimum ratio 'impluvium/terrace' can be calculated using the equation:

58
CCR = (WR-P)/(C*P)

where:
- **CCR** = catchment to cropping ratio
- **WR** = area impluvium/area terrace (-)
- **P** = average annual precipitation (mm)
- **C** = average annual runoff coefficient (-)
- **WR** = annual amount of water needed by the crop (mm)

Meinzinger (2001) estimated that for olive trees the required amount of water is 500 mm y^{-1}. The average annual rainfall amount (at Béni Khedache) is 235 mm. For the period April 1998 to August 2001 the rainfall data of the weather station at Chouamek were analysed according to the Time Compression Approximation (Ibrahim and Brutsaert, 1968), using the infiltration characteristics measured during the field rainfall simulations at the site of Amrich (Figure 5.2). The runoff amounts calculated for these rainfall events gave average runoff coefficients of 0.153 and 0.217 when the infiltration characteristic of an initially dry, respectively initially wet soil was used. The median runoff coefficients were 0.064, respectively 0.147.

Using an average runoff coefficient of 0.153 and 0.217, the CCR value is 7.4, respectively 5.2. The actual CCR at Amrich is 29 (impluvium = 8 ha; terrace = 0.275 ha). Based on the CCR value of 29 and the runoff coefficient of 0.153, the minimum amount of annual rain should be 92 mm. Analysis of the rainfall data of Béni Khedache showed that, during the period 1969 – 2000, the annual rainfall amount of 92 mm is exceeded in 97% of the years.

Additionally to the CCR value also other factors have to be taken into account to obtain sufficient water supply for crop production, e.g. the number of olive trees should be not too large, otherwise competition for water will decrease the yield. Also the spillway should be high enough in order to retain enough water on the terrace to increase the soil water content to field capacity till the rooting depth of the crop.

### 5.4 Conclusions

In this study the effect of a jessr in the Oued Oum Zessar watershed was examined on soil and water conservation. Rainfall simulations provided input data about infiltration and sediment transport, which were used to simulate runoff and erosion during rainfall events. These simulation results indicated that large amounts of runoff and sediment are collected on the terrace. Therefore, the jessr plays an important role in reducing transport of water and sediment downslope. Over a period of 3 consecutive years the water balance of the terrace was assessed. This showed that especially during dry years the impluvium provides an important additional amount of water needed for the cultivation of olive trees on the terrace. Furthermore, it was found that the ‘catchment to cropping ratio’ (CCR) should be larger than 7.4 in order to provide, on average, a sufficient amount of water for the cultivation of olive trees. However, other factors like the number of olive trees and the height of the spillway also have to be taken into account.

### Acknowledgements

The assistance of S. Heirman and S. Tanghe (M.Sc. students at Ghent University) and the collaborators of the ‘Institut des Régions Arides’ in Tunisia are highly appreciated.
References


