Agricultural Water Management 97 (2010) 449–456

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Evaluation of soil water storage efficiency for rainfall harvesting on hillslope micro-basins built using time domain reflectometry measurements

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ARTICLE INFO

Article history:
Received 2 July 2009
Accepted 8 November 2009

Keywords:
Water harvesting
Water conservation
TDR
Semi-arid areas
Micro-basins

ABSTRACT

Micro-basins are slope management structures built out of earth and stones on hillslopes around cultivated trees (e.g., olive trees) for the harvesting of rainfall and runoff water, and for the rehabilitation of land degraded by water erosion.

In this study, the results of an experimental survey for the comparison of soil water content for both inside and outside the micro-basins are analyzed. Measurements are taken after some rainfall events from January to December 2003 in a hilly region of Central Tunisia. The time domain reflectometry technique is used to measure soil moisture in 15 sets of soil profiles (inside and outside) at three different depths. Four different soils are evaluated, i.e., *Cambisols*, *Kastanozems*, *Arenosols*, and *Calcisols*.

The data analysis shows a significant improvement on the water stock obtained by this type of management. The differences in water storage with respect to soil type, depths, and tillage are evident, but strongly connected to farm management. For optimal management conditions an important increase of average water stock is observed; however, for bad or no farm management the amelioration is zero or is even deteriorating the state of vegetation.

1. Introduction

The hydrological cycle in soil begins with the entry of water by infiltration, then continues with a temporary storage of water in the soil, and ends with its removal from the soil by drainage, evaporation, and plant uptake. Infiltration determines how much water enters the root zone and how much will runoff. Runoff is considered as the portion of water that exceeds the infiltration capacity. Hence, the rate of infiltration affects not only the water economy of vegetation, but also the potential amount of surface runoff and the risk of soil erosion in semi-arid zone cultivated hillslopes (Senay and Verdin, 2004; Schiettecatte et al., 2005; Oweis and Hachum, 2006).

Water harvesting systems for runoff water collection and storage represent an attractive solution for resolving water scarcity in various parts of the world (e.g., Tabor, 1995; Van Wesemael et al., 1998; Oweis and Hachum, 2006; Schiettecatte et al., 2005; Frot et al., 2008). According to the Food and Agriculture Organisation (FAO) of the United Nations (2004), these methodologies can be useful in arid and semi-arid areas (such as the southern Mediterranean regions), which are often characterized by irregular distribution over space and time of the water resources.

Historically speaking, agriculture using surface runoff and rain harvesting techniques was extensively practiced as early as thousands of years ago. As recently reviewed by Vohland and Barry (2009), in these arid and semi-arid zones, a huge variety of traditional as well as innovative *in situ* rainwater harvesting practices exist. Typical *in situ* structures used on slope management are linear structures (e.g., embankment of stone and/or earth, or grass strips) which can be sophisticated, such as the *teras* system in Sudan (van Dijk, 1997) and terracing as practiced in East Africa. Semi-circular bunds are common in the arid and semi-arid zones of Northern Africa and Sahel (e.g., *micro-basins* or *half moons* or *demi lunes* (Barry and Sonou, 2003)). Pitting cultivation is practiced in different forms which are known as *Zai* in Burkina Faso (Kabore, 1995; Kassogue et al., 1996; Ouedraogo and Kaboré, 1996; Fatondji et al., 2001; Kabore and Reij, 2004), *Tassa* in Niger (Hassan, 1996), or the *Chololo pits* and *Ngoro pits* for the Matengo people in East Africa (Critchley and Mutunga, 2003; Kato, 2001; Mati and Lange, 2003; Malley et al., 2004). These various systems differ mainly in the size of the pits. In general, biomass production is improved by applying a layer of mulch in the pit before planting. Other approaches, such as conservation tillage, improve infiltration ability on the field scale (Stroosnijder, 2003).

Micro-basin watershed management is realized by little walls with semi-circular forms made out of soil and/or stones found

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doi:10.1016/j.agwat.2009.11.004

Fig. 1. Micro-basins built of earth and stone walls around olive trees.

within and on the hillside, around every cultivated tree. These micro-basins are comparable to little barriers built on the slope with the aim to retain water *in situ* (and eroded soil) or to slow down the runoff water velocity (Fig. 1). In the area considered for this study, the farmers are aware of the economical gain generated by this kind of management (Mancuso and Castellani, 2005). However, so far little hydrological evaluations of this type of applications exist in the literature (Boers and Ben-Asher, 1982; Sanchez-Cohen et al., 1997; Sepaskhah and Fooladmand, 2004; Schiettecatte et al., 2005).

The objective of this study is to quantify the soil water storage efficiency of micro-basins in relation to soil type, farm management and soil depth. To do so, water content measurements carried out by time domain reflectometry (TDR) method are taken inside and outside the micro-basins. The results obtained with and without soil water harvesting are compared.

Qualitative assessment of infiltration capacity will also be performed.

Suggestions for enhancing good management practices of micro-basins performances are presented.

2. Materials and methods

2.1. Experimental site

The highlands of Central Tunisia are known as "Tell"; they are an extension of Algerian "Tell". The climate can be considered as semi-arid to arid. For this study, 15 farms with micro-basins are selected, all located in the Kairouan district. This area is characterized by an average annual rainfall of 300 mm, which gradually decreases from north to south down to 240 mm (when averaged over the last 35 years).

The selected farm population consists of 9 farms with one-year-old micro-basins and 6 farms with five-year-old micro-basins. The walls of all micro-basins are built from soil and stones and the vegetation concerns olive trees.

The one-year-old micro-basins are located on *Cambisol*, *Kastanozem*, and *Arenosol* soils; the profiles are characterized as follows: (i) the *Cambisols* with a very fine textured *cambic* horizon; (ii) the *Kastanozems* with a *mollic* horizon with a moist chroma value of more than 2 to a depth of at least 20 cm (FAO, 1998); and (iii) the *Arenosols* composed of a sandy texture to a depth of at least 100 cm from the soil surface.

The five-year-old micro-basins are located in the *Hajeb el Ayoun* area on *Calcisol* soils (FAO, 1998), characterized by a *calcic* or *petrocalcic* horizon within 100 cm of the surface.

For each micro-basin and its associated micro-watershed, measurements are carried out to evaluate vegetation, soil tillage and slope, and surface characteristics (Table 1).

The geographical position of the study area is given in Fig. 2; the UTM coordinates of each farm are located between 55,2825–57,7001 latitude and 3,908,596–3,953,207 longitude (Table 1) with an altitude range between 130 and 350 m a.s.l.

2.2. Measurements

This paper contains a preliminary assessment of the value of soil hydraulic data for the management of olive trees in a hilly semi-arid area.

All collected measurements are presented, but the discussion mainly regards the water content values, therefore the infiltration data has only been analyzed in a qualitative way in this paper. However, information about texture and structure collected by evaluating the soil hydrological behaviour through falling head tests, can lead, by knowing the initial water content measurements conditions, to estimate the full set of retention and hydraulic conductivity curves of the considered soils and use physically based simulation models (e.g., Lassabatère et al., 2006).

2.2.1. Soil parameters

Two pits of 1 m depth (one inside and one outside the soil and stone wall) are dug for every micro-basin to examine the pedological profiles. Soil texture, soil structure, skeleton, colour, and organic matter are analyzed at three different depths. The results are shown in Table 2.

2.2.2. Soil water content

Measurements are carried out by an ensemble of a three-wire probe connected to a Tektronix 1502C TDR cable tester using a 50 Ω coaxial cable and a BNC connection. The Roth et al. (1990)

Table 1
Micro-basin locations and relative morphologic data.

Farm no.	Soil type	Latitude	Longitude	Slope (%)	Vegetation cover (%)	Tillage	Catchment area (m^2)	Micro-basin area (m^2)
1	Cambisols	568,055	3,949,631	33	20	No	70	18.4
2	Cambisols	571,371	3,953,207	27	15	Outside (old)	36	12.5
3	Kastanozems	577,001	3,948,214	14	5	No	51	29.3
4	Arenosols	568,342	3,942,826	21	2	No	33	29.0
5	Calcisols	55,2852	3,911,191	16	5	Inside (superficial)	63	32.3
6	Calcisols	568,622	3,951,355	26	10	Inside and outside	76	28.1
7	Cambisols	568,567	3,942,923	9	2	No	346	27.3
8	Kastanozems	576,781	3,947,481	19	20	No	51	10.8
9	Calcisols	553,004	3,911,052	21	10	Inside	35	22.8
11	Arenosols	567,537	3,941,074	17	1	No	79	29.0
12	Calcisols	555,357	3908596	18	5	Outside (recent)	35	13.8
13	Kastanozems	576,715	3,947,598	10	20	Inside	48	18.5
14	Calcisols	555,831	3,914,163	12	10	Inside	350	7.0
15	Calcisols	555,561	391,4424	5	10	No	40	7.3
16	Calcisols	552,825	3,911,421	15	10	No	410	28.5