Agricultural Water Management 165 (2016) 190–197

Contents lists available at ScienceDirect

Agricultural Water Management

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

Water-harvesting designs for fruit tree production in dry environments

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ARTICLE INFO

Article history:
Received 21 January 2015
Received in revised form 5 November 2015
Accepted 7 November 2015
Available online 24 November 2015

Keywords:
Water management
Dry areas
Fruit trees
Hillslopes
Olive trees
Soil moisture content

ABSTRACT

Water scarcity and increasing demand coupled with climate change require maximizing the use of available resources. Water harvesting (WH) systems are currently being used in many areas to sustain crops and increase water productivity. This study investigated the effect of three treatments (S15: 50-m^2 catchment area with 15% slope, S8: 50-m^2 catchment area with 8% slope, and L8: 70-m^2 catchment area with 8% slope) on the amount of water harvested in tree basin for young olive (*Olea europaea* L.) trees from November 2002 to July 2003. Soil moisture was monitored weekly during the rainy season and bi-weekly afterwards. To determine moisture changes in the catchment and target areas and amount of water harvested (in liters) for each tree, volumetric soil moisture content was measured at three or four points along the slope using a neutron probe down to a maximum depth of 120 cm, as soil depth allowed.

WH structures increased soil moisture content in the rootzone compared to the catchment area. The rainfall threshold for runoff generation was less than 15 mm. Land slope was more important than micro-catchment size for increasing the amount of water harvested. Compared to the 8% slope, the 15% slope resulted in larger harvested amounts for small storms, but the two were comparable when storms were large. The large micro-catchment size resulted in higher amounts of harvested water only in the presence of storms greater than 26 mm. After adding the amounts lost by evapotranspiration, the net amount of water harvested in the tree basin of each tree for the 2002–2003 rainy season reached 722 and 688 l (or 361 and 344 mm) for treatments S15 and S8, respectively. Deeper soil profiles (i.e., >90 cm) were important to ensure longer storage periods. By early July, soil moisture content in the tree basin for treatments S15, L8 and S8 was still higher by 38, 13, and 5% respectively, than the levels recorded at the onset of the experiment. WH increased soil moisture content during the spring and early summer, a critical period for olive production.

1. Introduction

In recent years, fruit tree production in the Mediterranean basin and areas of similar climate (e.g., California) has been expanding to drier inland areas where annual rainfall might not be enough for successful production and irrigation is limited or not available. Rainfed olive trees are most successfully grown in areas receiving more than 350 mm of annual rainfall, with some particular exceptions along the southern coast of the Mediterranean (Tubeileh et al., 2004). However, the low and erratic amount of rainfall in drier inland areas is not enough to support olives, especially during the hot dry season that lasts from May through October, which also coincides with the most active olive vegetative and reproductive growth stages (Tubeileh et al., 2004). Moreover, recent climate change forecasts are suggesting that olive evapotranspiration will increase by 8% and irrigation requirements will jump by 18.5% (Tanasijevic et al., 2014). A traditional method of increasing available water for the trees in dry environments consists of using water-harvesting (WH) techniques. WH implies the collection of water from one area (catchment or contributing area) in order to supply water to crops in another (target) area (Bruggeman et al., 2008; Oweis et al., 2012). These techniques have been known in the Middle East for several thousands of years (Reij et al., 1988), and are currently being used in many drought-suffering countries in the

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http://dx.doi.org/10.1016/j.agwat.2015.11.006
0378-3774/

dry strip from North and sub-Saharan Africa across the Middle East stretching to India, Afghanistan, and China.

WH is of particular interest in hilly areas due to the high runoff potential and the difficult accessibility for irrigation equipment. Optimum WH design depends on the site conditions, climate, purpose, and crops to be grown (Reij et al., 1988; Oweis et al., 1999). Other authors such as Bulcock and Jewitt (2013), concluded that soil characteristics and minimum slope were the most important factors for system efficiency. Slope angle and slope length of the micro-catchment are of primary importance for runoff generation (Oweis et al., 2012). Although there is a general agreement that increasing slope increases runoff coefficient, some authors argue that there is a maximum slope after which there is no increase in the amount of water harvested (Nassif and Wilson, 1975). In the same vein, under monsoon climate in India, Sharma et al. (1986) have shown that slopes of 5 and 10% did not have a significant difference in the amount of water harvested. Under a similar monsoon climate in Pakistan, Suleman et al. (1995) arrived at the same conclusion for 7, 10, and 15% slopes.

However, as the efficiency of WH systems is highly dependent on rainfall characteristics and the properties of the runoff area, the above results might not be valid for WH systems on stony hillslopes in Mediterranean climate areas. Achieving functional WH designs might minimize the need to buy and convey irrigation water from distant sources and therefore ensure the sustainability of fruit trees in drier environments.

The objective of this work was to study the effect of three different micro-catchment designs on the amount of water harvested under dry hillslope conditions in northern Syria in order to recommend the designs that are most capable of increasing soil moisture content in the rootzone of olive trees under semi-arid conditions.

2. Materials and methods

2.1. Site description

This experiment was carried out in a four-year-old olive grove (*Olea europaea* cv. 'Qaisi') in Habs village (35.49°N; 37.29°E), Khanasser Valley, 80 km to the southeast of Aleppo in northern Syria. This area is a typical example for arid inland areas on the eastern and southern parts of the Mediterranean basin. Upon establishment of the site, cultivar 'Qaisi', a dual-purpose variety (Tubeileh et al., 2008a), was chosen due to its high tolerance to drought and its popularity in the areas to the east of Aleppo (Tubeileh et al., 2004, 2008b). The valley is characterized by long dry and hot summers with maximum temperatures that can sometimes reach 50 °C in July and August. The monthly average maximum temperature in July (hottest month) is 37 °C, while the monthly average minimum temperature in December (coldest month) is 0.7 °C. Average annual rainfall recorded during the period 1957–2001 is 223 mm, received mainly from November through April. This small amount of rainfall is not homogenously distributed over the rainy season and is extremely variable from one year to another. High temperatures and low humidity lead to a high annual reference evapotranspiration that amounts to 1840 mm (2002–2004).

The soil of the experimental site is a Lithic Xerothent (U.S. Dept of Agriculture Soil Survey Staff, 1975) with 21% clay, 37% silt, and 42% sand in the top 15 cm. Table 1 shows the main physical properties of the soil. Overall, it can be classified as clay loam, with a top–down progressive increase in bulk density, field capacity, and permanent wilting point. The depth of this well-drained soil ranges between 60 and 90 cm for most of the trees and does not exceed 135 cm in best cases. The parent material is chalky limestone.

The land slope is east-facing and rather irregular, between 2 and 20% for most of the field. Before planting the trees, the site was a degraded, natural rangeland area. The trees were planted at an approximate spacing of 8 m × 10 m. When planted, each tree received 10 kg of unfermented sheep manure. In February 2003, each tree received 136 g nitrogen in the form of ammonium nitrate, which is consistent with the low-input systems in dry areas (Thomas et al., 2006). All the trees used in the experiment had a single trunk.

2.2. Procedure

Twelve trees were selected to study the effect of slope and micro-catchment size on the amount of runoff-water harvested. Two micro-catchment sizes (50 and 70 m^2) were selected according to topography, available space between the trees, and the direction of the slope. For the catchment slope, two predominant slopes were naturally present in the field; 8 and 15%, the treatments are described as follows:

- S15: catchment area of 50 m^2 with a slope of 15%.
- S8: catchment area of 50 m^2 with a slope of 8%.
- L8: catchment area of 70 m^2 with a slope of 8%.

The effect of the slope was investigated through the comparison of treatments S15 and S8, while the effect of catchment area was determined by comparing treatments S8 and L8. In addition to these three treatments, one 50 m^2 catchment with a slope of 5% was kept without a tree to serve as a control (C) for monitoring runoff water accumulation in the soil without tree transpiration. All treatments are described in Table 2.

2.3. Determination of soil moisture content

Soil moisture content was recorded from 17 November 2002 to 3 July 2003. Readings were taken every week during the rainy season and at two-week intervals thereafter (May–July). Soil moisture content of the upper layer (0–15 cm) was determined gravimetrically while an onsite-calibrated neutron probe (Type IH-II, Didcot Instruments Co. Ltd., Abington, UK) was used for the deeper layers. Aluminum access tubes were inserted at three locations around every tree; 0.5 m upslope from the trunk (inside the tree basin or target area), 1.2 m from the tree upslope, and 2 m from the tree downslope (outside the catchment area) to measure water infiltration in different locations of the micro-catchment (Fig. 1). For treatments S15 and S8, a fourth access tube was inserted at 4 m upslope for two trees each, to estimate soil moisture in the catchment area. These access-tube locations will be referred to as '0.5 m up', '1.2 m up', '2 m down', and '4 m up', respectively. These locations were selected based on previous research, and are supposed to represent soil moisture content in catchment area (4 m up), bottom-end of catchment area (1.2 m up), target area (0.5 m up) and lateral flow outside target area (2 m down).

Soil moisture content was measured in 15-cm soil increments to a maximum depth of 90 cm. This soil depth encompasses the olive root zone, as several studies have shown the vast majority of the olive root system to be in the top layers of the soil, especially for young trees (Fern&#x00E1ndez and Moreno, 1999). Rainfall was recorded using an automatic rain gauge installed in the middle of the grove.

2.4. Determination of the recharge area around the tree

The runoff target area was the tree basin, covering 2 m^2 (or 0.8 m radius around tree trunk) based on the different soil moisture contents measured at '0.5 m up' and '1.2 m up' from the trunk. With an