Agricultural Water Management 98 (2011) 1641–1648

Contents lists available at ScienceDirect

Agricultural Water Management

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

Yield and seasonal water productivity of sunflower as affected by tillage and cropping systems under dryland conditions in the Limpopo Province of South Africa

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ARTICLE INFO

Article history:
Received 3 January 2011
Accepted 6 June 2011
Available online 30 June 2011

Keywords:
Cowpea
Dryland
Precipitation use
Sunflower
Tillage
Water harvesting

ABSTRACT

Sustainable food production in semi-arid tropical countries can be achieved through efficient utilization of rainwater. A field experiment to assess the grain yield, seasonal water use (WU), water use efficiency (WUE) and precipitation use efficiency (PUE) of sunflower (*Helianthus annuus* L.) intercropped with cowpea (*Vigna unguiculata* L.) on two tillage systems was conducted during the 2007/2008 and 2008/2009 cropping seasons at the University of Venda (22°58′ S, 30°26′ E at 596 m above sea level). The experiment was configured as a 2 × 2 × 2 factorial design with three replications. The tillage treatments were conventional tillage (CT) (control) and in-field rainwater harvesting (IRWH) system. The IRWH is a special crop production technique that promotes runoff on 2.0-m wide no-till strip between crop rows and collects the runoff water in basins where it infiltrates into the soil profile. The treatments in the cropping system (CS) consisted of a sole crop (sunflower or cowpea) and an intercrop (sunflower × cowpea). Results of the experiment revealed that IRWH led to a significant ($P < 0.05$) increase in sunflower grain yield in the second season but cowpea grain yield was not influenced by tillage systems. IRWH resulted in significantly higher WU, WUE and PUE of both crops compared to CT system in the second season. The CS had significant effects on sunflower grain yield in both seasons but none on the cowpea grain yield. WU was significantly higher in intercrops than in sole cowpea and sole sunflower in the first and second season, respectively. WUE and PUE were significantly greater in sole sunflower than in the intercrops but less in the sole cowpea than in the intercrops.

1. Introduction

Constraints to food production in semi-arid tropical countries often result from water loss by runoff and evaporation (Mando, 1997). Maximizing precipitation use efficiency (PUE) is therefore important in the semi-arid regions to stabilize or improve food production. Two primary sources of water loss are runoff and soil evaporation (Botha, 2006). Es is more important than runoff in contributing to inefficient precipitation use in dryland crop production (Beukes et al., 1999). Bennie and Hensley (2001) reported that in arid and semi-arid areas between 60 and 85% of the rainfall evaporates from the soil surface before making any contribution to crop production. Runoff losses range from 6 to 30% of annual rainfall on various soil types under conventional tillage (CT) (Botha, 2006). The in-field rain water harvesting (IRWH) technique, developed by Hensley et al. (2000), can stabilize yields.

The IRWH system promotes rainfall runoff on a 2.0 m wide no-till strip between crop rows and collects the runoff water in basins where it infiltrates into the soil profile (Fig. 1). Two distinct areas namely a 2.0 m catchment area or runoff strip and a 1.0 m collection basin are created. In order for the runoff strip to direct surface water into the collection basins, a slope towards the basins is created. The runoff created in this way is called in-field, which differs substantially from ex-field runoff that occurs in the CT system. In-field runoff can be captured and used to enhance water use (WU) and PUE, stabilizing or increasing crop yields. Rain drop impact on the runoff strip causes surface compaction and therefore contributes to the formation of soil crusts, which stimulate in-field runoff. No-till is practiced on the runoff strip so that a smooth surface can be maintained (Hensley et al., 2000). The IRWH system is synonymous with the mini-catchment runoff farming and is a special form of no-till system. IRWH has been proven to contain runoff from the soil surface, increasing plant available water and crop yields on small-

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doi:10.1016/j.agwat.2011.06.003

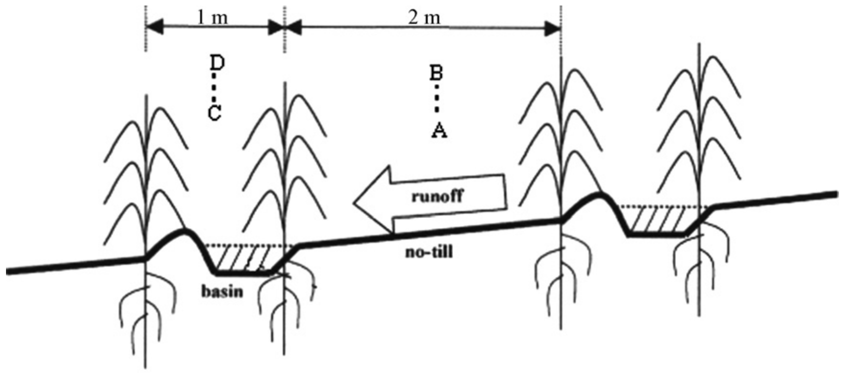

Fig. 1. Diagrammatic representation of IRWH technique, showing distribution of access tubes (A, B, C, D). Row spacing and access tubes distribution was similar in CT treatments (after Hensley et al., 2000).

holder farms in Thaba Nchu, South Africa (Botha et al., 2003). The IRWH increased corn and sunflower yields by as much as 50% compared to conventional production systems on duplex soils (soils that have an abrupt textural change) in the Free State province of South Africa (Hensley et al., 2000). However, despite the increase in crop yields, the researchers recorded high evaporation losses of water from the fields. For example, 79% of annual rainfall was lost from IRWH corn plots treated with organic mulches (Botha et al., 2003). Experiments at Glen documented that improving PUE above 7.4 and 4.8 kg ha^{-1} mm^{-1} for maize (*Zea mays* L.) and sunflower respectively, Es must be reduced to improve yield stability. A continuing constraint for successful utilization of IRWH is excessive loss of soil water from the soil profile by evaporation (Hensley et al., 2000; Botha et al., 2003). In a study designed to examine the effect of a combination of ridge and furrow with gravel mulch, the bare furrow treatment resulted in less corn grain yield compared to the film-covered surface ridges and gravel-mulched furrows (Li et al., 2000). The yield advantage was attributed to suppression of evaporation losses. Previous research efforts in South Africa focused on suppressing evaporative soil water losses from IRWH plots with organic or stone mulches (Botha et al., 2003). Despite these efforts, results to date indicate that water loss by evaporation remains problematic. Living soil cover between crop plants (live or green mulches) has been proposed as an environmentally viable option to suppress water loss from the soil surface. This is a sound option if living mulches are integrated in an intercropping design in order to derive other benefits of intercropping such as increased yield under conditions of moisture stress, protection against risks of drought and pests as well as provision of more balanced human diet and weed suppression (Aladesanwa and Adigun, 2008).

The influence of cowpea (*Vigna unguiculata* (L.) Walp.) living mulch on soil evaporation has not been tested within IRWH systems. Information on the effects of tillage practices and intercropping on the performance of crops remains scanty and inconclusive. In particular, interaction between IRWH technique and sunflower × cowpea intercrops has not received attention in South Africa. Knowledge on how cowpea affects water utilization and yield of sunflower under IRWH would be important in forming a scientific basis for recommending this practice to smallholder farmers who produce this legume usually in intercrop systems. Therefore, this study was designed to assess the grain yield, water use, water use efficiency and precipitation use efficiency of sunflower intercropped with cowpea under IRWH and CT practices in Ferralsols that crust readily. The crusted no-till runoff strip can increase runoff into the basins resulting in rainfall storage (Fig. 1). It was hypothesized that (i) IRWH is a sustainable crop production technique that will increase crop yields in Ferralsols compared to the CT system, and (ii) cowpea can reduce unproductive soil evaporation losses under IRWH tillage practice resulting in improved sunflower yield and water productivity compared to the CT system in Limpopo (South Africa).

2. Materials and methods

2.1. Experimental site

A two-year field experiment was conducted during the 2007/2008 and 2008/2009 cropping seasons. The study was conducted at the University of Venda Experimental Farm at Thohoyandou (22°58′ S; 30°26′ E) in the Limpopo province in South Africa. The site is 596 m above sea level. The study area falls in the eastern part of the lowveld within the Limpopo River basin. The site is on undulating topography with average slopes of about 8% in the north–south direction.

The annual rainfall at the site is highly seasonal with 85% occurring in summer between October and March (Table 1). Mzezewa et al. (2010) reported a large variability (315%) in the rainfall pattern at the location over a 23-year period. The highest evaporative demand also occurs during the summer period when the mean maximum temperature (T_{max}) and the mean minimum temperature (T_{min}) is about 30 °C and 20 °C respectively. Based on the mean annual aridity index (0.52) and the UNESCO classification systems, the site can be classified between semi-arid and sub-humid zone.

Soil at the study site was classified as a Hutton form according to the South African System (Soil Classification Working Group, 1991), equivalent to a Rhodic Ferralsol (World Resource Base, 2006). The soil is deep (>1500 mm) with a high clay concentration (60%) dominated by kaolinite (99%), high silt concentration, and low bulk density (Table 2). The mean bulk density for 0–150 cm is 1.2 Mg m^{-3}. Water holding capacity is high due to the clay concentration.

Meteorological data were recorded in both seasons by an automatic weather station located within 100 m of the experimental blocks. Rainfall was measured within the experimental plot area using three rain gauges.

2.2. Agronomic details

Soil samples were taken for fertility tests prior to each cropping season. The soil samples were obtained from 0 to 20 cm depth. The fertilizer applications were based on potential yield of 2500 kg ha^{-1} and 1000 kg ha^{-1} for sunflower and cowpea, respectively. Planting material consisted of a short season hybrid of sunflower (cv.