Agricultural Water Management 166 (2016) 9–16

Contents lists available at ScienceDirect

Agricultural Water Management

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

Effects of intercropping of maize and potato on sloping land on the water balance and surface runoff

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ARTICLE INFO

Article history:
Received 3 May 2015
Received in revised form
30 November 2015
Accepted 4 December 2015

Keywords:
Biodiversity
Soil evaporation
Soil moisture content

ABSTRACT

It has been suggested that the increased yields of intercropping are strongly correlated to its effect on controlling water loss. However, studies of the effect of intercropping on controlling water loss on sloping land are few. In this study, with maize (*Zea mays* L.) and potato (*Solanum tuberosum* L.) as experimental crops, a comparison was made of surface runoff, soil evaporation, soil moisture content, crop transpiration and crop yield between the intercropping and the sole crop on sloping land during 2012–2013. Data showed that: (1) the accumulative runoff in maize and potato intercropping (IC) was not significantly different from that in sole potato (SP), but significantly decreased by 56.75–74.53% ($P < 0.05$) as compared with that in the sole maize (SM); (2) the daily mean soil evaporation in IC decreased by 20.83–28.44% ($P < 0.05$) as compared with that in SM, and decreased by 6.99–14.85% ($P = 0.034$ in 2012 and $P = 0.064$ in 2013) as compared with that in SP; (3) the soil moisture content in IC at each observation period was higher than that in SM and SP ($P = 0.101$ in late July and $P < 0.05$ in other periods); (4) the transpiration in IC was significantly higher than that in SM and SP ($P < 0.05$); and (5) the land equivalent ratio (LER) of IC was 1.19–1.34 ($P < 0.05$), indicating that the maize and potato intercropping induced a yield advantage. Overall, the results suggested that on sloping land, the maize and potato intercropping can reduce the water loss from the surface runoff and the soil evaporation, thus increasing the soil moisture content and contribute to the increase of the transpiration and crop yield. Data also indicated that the lower runoff in maize and potato intercropping compared with sole maize is associated not only with the higher leaf area index, but also with the potato tubers.

1. Introduction

Intercropping is the cropping pattern in which two or more crops are grown in the same field at the same time (Anil et al., 1998). The major advantage of such cropping pattern is to increase crop yield (Lithourgidis et al., 2011; Yang et al., 2014). Hence, intercropping has been widely practiced in China, India, South-East Asia, Latin America and Africa (Lithourgidis et al., 2011). The increased yields of intercropping have long been studied and have been found to correlate, not only with the efficient utilization of such resources as sunlight, moisture and nutrients (Launay et al., 2009; Mucheru-Muna et al., 2010), but also with the positive effect of reduced water loss (runoff and soil evaporation) in the field (Sharaiha and Ziadat, 2008; Ghanbari et al., 2010).

Until now, the effect of intercropping on controlling water loss on sloping land remains unclear. On sloping land, measurement of both runoff and soil evaporation are required to thoroughly justify the water loss. However, most studies on intercropping controlling water loss on sloping land, such as the studies on the barley and pea intercropping (Sharaiha and Ziadat, 2008) and the maize and soybean intercropping (Zöbisch et al., 1995), have only checked the effect of intercropping on runoff, without paying much attention to the soil evaporation. The studies on flat land have shown that the effect of intercropping on soil evaporation could be quite variable. For example, soil evaporation rates decreased in the maize and faba bean intercropping (Walker and Ogindo, 2003; Ghanbari et al., 2010), but increased in the maize and wheat intercropping (Chai et al., 2011). It is also notable that the influence of intercropping on soil evaporation on flat land could be quite different

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http://dx.doi.org/10.1016/j.agwat.2015.12.006
0378-3774/

from that on sloping land. On sloping land, the intercropping could decrease runoff, and thus increase the soil moisture content, which might further trigger higher soil evaporation (Kurc and Small, 2007; Koster et al., 2011).

The maize and potato intercropping, as an important intercropping of staple food crops, has been extensively applied in many regions of the world. While there are in-depth studies about the population micro-environment effect (Mushagalusa et al., 2008; Al-Dalain, 2009), pest management effect (He et al., 2010) and utilization efficiency of nutrients (Wu et al., 2012; Kour et al., 2014), only a few studies have been conducted on the effect of controlling water loss. It has been found that the potato and polythene film mulching maize intercropping decreased the runoff as compared with the sole polythene film mulching maize (An et al., 2007). However, the study only partly revealed the water loss control effect of this intercropping, because runoff rates and processes were influenced by the plastic film.

Therefore, the current study investigated the effect and mechanism of the maize and potato intercropping on controlling water loss by comparing leaf area index, surface runoff, soil evaporation, soil moisture content and crop yield between intercropping and the sole crops growing on sloping land in Yunnan, China.

2. Materials and methods

2.1. Experimental site

The field experiment was conducted during two growing seasons in 2012–2013 using runoff plots ($3 \times 10\,m^2$, slope angle 10°), which were located at the Agricultural Experimental Station, Faculty of Agronomy and Biotechnology, Yunnan Agricultural University (25°18′N, 102°45′E, 1930 m above sea level). The sunshine hour and frost-free period per year are around 2617 h and 240 days, respectively, with a mean annual temperature of 14.7 °C. The soil of the experimental site is “mountain red soil” with pH value of 5.7, and contained soil organic matter of 24.14 g kg^{-1}, total nitrogen 1.4 g kg^{-1}, total phosphorus 3.21 g kg^{-1}, total potassium 4.47 g kg^{-1}, ammonia nitrogen 4.34 mg kg^{-1} (measured by KCl extraction distillation method), nitric nitrogen 5.38 mg kg^{-1} (measured by phenol disulfonic acid spectrophotometric method), available phosphorus 17.0 mg kg^{-1} (measured by $NaHCO_3$ extraction molybdenum antimony anti-colorimetric method) and available potassium 113.6 mg kg^{-1} (measured by ammonium acetate extraction flame photometer); these methods in parentheses were from the book of “soil agrochemical analysis” (Bao, 2000).

2.2. Experimental design

The variety of maize and potato used for the experiment were Yunrui-88 and Hui-2, respectively, which are widely used in Yunnan Province. The field experiment was designed as the single factor randomized complete block with 3 replications for 3 treatments: sole maize (SM), sole potato (SP) and 4 rows maize intercropped with 4 rows potato (IC). The intercropping was adapted with the additive scheme which has been commonly used in the practice of maize and potato intercropping (Ebwongu et al., 2001; Mushagalusa et al., 2008). The maize density in IC was consistent with that in SM (53,333 plants ha^{-1}), and the potato density in IC was less than that in SP (51948 plants ha^{-1} in SP and 37037 plants ha^{-1} in IC). The plant and row spacing of the crops for each treatment were 0.25 m × 0.75 m for SM, 0.35 m × 0.55 m for SP, 0.20 m× 0.50 (2.20) m for maize in IC and 0.35 m × 0.40 (2.50) m for potato in IC (for the intercropped maize and potato, the number before brackets was narrow row spacing, and the number in brackets was wide row spacing, respectively).

2.3. Crop management

In 2012, the sowing and harvest date of potato were April 3rd and August 27th respectively, the transplanting and harvest date of maize were May 20th and October 12th respectively. In 2013, the sowing and harvest date of potato were April 2nd and August 27th respectively, and the transplanting and harvest date of maize were May 21th and October 9th respectively. When sowing potato, calcium superphosphate of 350 kg ha^{-1}, urea of 95 kg ha^{-1} and potassium sulfate of 65 kg ha^{-1} were applied as fertilizer. When sowing maize, calcium superphosphate of 560 kg ha^{-1}, urea of 150 kg ha^{-1} and potassium sulfate of 100 kg ha^{-1} were applied as base fertilizer and urea of 120 kg ha^{-1} and 240 kg ha^{-1} were applied as top dressing at the seedling and elongation stages, respectively. Weeds, pests and diseases were controlled accordingly with local practice.

2.4. Measurements

2.4.1. Rainfall

The daily rainfall and rainfall intensity were measured and recordedusing Vantage Pro 2 automatic weather station (Davis, USA) installed at the experimental site. The maximum 30-min rainfall intensity (I_{30}, mm/min) was used to reflect the rainfall intensity. $I_{30} < 0.25$ means low intensity rainfall, $0.5 > I_{30} > 0.25$ means moderate intensity rainfall and $I_{30} > 0.5$ means high intensity rainfall (Yair and Enzel, 1987). The mean long term rainfall was calculated from 2006 to 2011 data, and all of the rainfall data were collected from the weather station at the experimental site.

2.4.2. Leaf area index (LAI)

The SunScan Canopy analysis system (DELTA-T, UK) was used to measure LAI. The BF3 Sunshine Sensor was horizontally placed above the crop canopy on a tripod, avoiding shade in the area of influence. The 1 m long probe was handheld underneath the crop canopy at a diagonal to the crop rows (the two ends of the probe reached the two crop lines respectively) to measure LAI (Szumigalski and Van Acker, 2008). For sole crops, two inter-rows were selected in the central part of the plot for observation, and each inter-row was measured twice; all measured values were averaged as the LAI of the plot. For intercropping, two central inter-rows of maize and potato strips were selected in the middle part of the plot for observation, with each inter-row being measured twice; the measured values were averaged as the LAI of the maize and potato strip, and the LAI of the intercropping plot was calculated from weighted average of LAI measured in the maize and potato strips (the weight value of the maize and potato strip was set to the maize and potato growing area to the plot area, equal to 54% and 46% respectively). The LAI was periodically observed during the peak time of crop water utilization, i.e., the symbiotic period (Szumigalski and Van Acker, 2008), specifically speaking, the sunny days in mid-June, early July, late July and mid-August at an interval of 20 days after the sowing of maize.

2.4.3. Runoff

The runoff collecting tank in the bottom of the runoff plot and plastic buckets were used to collect and measure the runoff generated by each rainfall event from June to August. Fig. 1 shows the scale of this system.

2.4.4. Soil evaporation

A PVC tube-made micro-lysimeter was used to measure soil evaporation. The inside diameter of the inner tube and the outer