Soil & Tillage Research 150 (2015) 21–29

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Improved yield by harvesting water with ridges and subgrooves using buried and surface plastic mulchs in a semiarid area of China

Li-Min Zhou [a,1], Feng Zhang [b,1], Chang-An Liu [c,*]

[a] Jiangsu Key Laboratory of Agricultural Meteorology, School of Applied Meteorology, Nanjing University of Information Science & Technology, Nanjing 21044, China
[b] State Key Laboratory of Grassland Agro-Ecosystem, Institute of Arid Agroecology, School of Life Sciences, Lanzhou University, 730000 China
[c] Key Laboratory of Tropical Plant Resources and Sustainable Use, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Menglun town, Mengla county, Yunnan Province 666303, China

ARTICLE INFO

Article history:
Received 24 June 2014
Received in revised form 1 January 2015
Accepted 17 January 2015

Keywords:
Ridge-furrow
Plastic film mulch
Subgroove
Semiarid area
Loess Plateau

ABSTRACT

This paper determines the responses of soil temperature, water status and crop yields to a new planting pattern involving ridges and subgrooves with plastic film mulching in a millet-field pea-spring wheat-potato cropping system. The study was conducted in a typical semiarid area, during the four annual growing seasons of 2005–2008 and five treatments were designed: (1) a flat plot with no mulching, which is the conventional tillage practice (CK); (2) alternating ridges and furrows with no mulching (M0C0); (3) alternating ridges and furrows with no mulching, and subgrooves mulched with plastic film (M0C); (4) alternating ridges and furrows, with only the ridges mulched with plastic film on the surface (MC0); and (5) alternating ridges and furrows, as well as subgrooves, with the ridges and subgrooves mulched with plastic film (MC). The subgrooves with plastic film mulching increased topsoil temperature, the average daily soil temperature of the 4-growing seasons was 16.7, 16.8, 16.9, 17.4 and 17.2 °C for the CK, M0C0, MC0, M0C and MC, respectively. The soil temperature was significantly higher in the M0C and MC than in the CK, M0C0 and MC0 in May 2006, September in 2007 and May 2008. In average and wet years, the soil water content in the 20–40 cm soil layer was 6.2–37.7% higher in the MC than in the CK. The ridges and subgrooves with plastic film mulching improved crop yields, and the average yield over the four years was higher in the MC than in the CK, M0C0, M0C and MC0 by 163%, 98%, 62% and 21%, respectively. Potato is a staple and economic crop in this region, and the ratio of large and moderate-sized potato tuber yield to total tuber yield was 21.7% higher in the treatments with subgrooves than in the treatments without subgrooves. In conclusion, the technique of ridges and subgrooves with plastic film mulching is an effective practice for improving crop yields in semiarid agroecosystems.

1. Introduction

Precipitation is the main water resource affecting crop production in semiarid areas (Gan et al., 2013; Xiao et al., 2013; Nyakudya et al., 2014). In these regions, low intensity and unpredictable precipitation, and high evaporation always severely limit crop yields (Turner, 2004; Zhou et al., 2009; Liu et al., 2013a). Agricultural production in these regions depends on precipitation, and farmers are concerned about the optimized water use. The highly effective use of precipitation is a key priority in guaranteeing food security and sustainability. The Loess Plateau of northwestern China is characterized by a semiarid monsoon climate, where no water resources are available for agriculture irrigation. From the 1960s–1990s, in order to reduce runoff and soil erosion and increase the rainfall use efficiency in this region, a large number of terraced fields and silt-retention dams were built (Zheng, 2003; Lu et al., 2006; Yang, 2006; Chen et al., 2007). Although terraced fields and silt-retention dams increase the crops water use efficiency, they need significant inputs of much money and labor. Since the 1990s many more cheaper and effective technologies, including plastic film mulching and rainwater harvesting, have been widely applied in semiarid agroecosystems (Wang et al., 2005; Jia et al., 2006; Zhou et al., 2009; Liu et al., 2009, 2014; Zhao et al., 2014). In particular, ridge-furrow rainwater harvesting with plastic film has proven to be one of the most

* Corresponding author. Tel.: +86 691 8713369; fax: +86 691 8713369.
E-mail address: changan78@163.com (C.-A. Liu).
[1] Both authors contributed equally to this work.

http://dx.doi.org/10.1016/j.still.2015.01.006

effective methods to increase crop yields and water use efficiency (WUE), which it does by means of collecting water from light rain, retaining the surface runoff from heavy rain, and reducing evaporation, and compared to the conventional tillage practice, the maize and potato yields in the ridge-furrow with plastic film mulching increased by 28–90% and 57–78%, respectively, and the corresponding WUE increased by 26–88% and 62–70%, respectively (Bu et al., 2013; Gao et al., 2014; Zhao et al., 2014).

In the semiarid regions of China, the major shallow-root crops including Millet (*Setaria italica* L.), field pea (*Pisum sativum* L.), spring wheat (T*riticum aestivum* L.) and potato (*Solanum tuberosum* L.) (Xiao et al., 2007; Wang et al., 2008; Duan et al., 2013). The soil water and nutrient contents in the top soil layers are crucial for the growth of shallow-root crops (Ju et al., 2006; Liu et al., 2013a). Existing studies have mainly been aimed at the effects of ridge-furrow rainwater harvesting with plastic film on these crop yields and WUE. The new tillage practice of harvesting water with ridges and subgrooves which are plastic films that are buried 40 cm below the soil surface has been recently introduced into rainfed farming systems on the Loess Plateau of China, which significantly increased spring wheat yield by improving the soil water content and temperature in the topsoil of the subgrooves (Lin et al., 2006).

However, currently the response of crop yields to ridges and subgrooves with plastic film mulching remains unknown. Much work in this area remains to be done, therefore the objectives of this study are to investigate the influence of the ridges and subgrooves with plastic film mulching on soil temperature, soil water retention and crop yields in a semiarid area.

2. Materials and methods

2.1. Description of study site

The field experiment was conducted from July 2005 to August 2008, at the Semiarid Ecosystem Research Station of the Loess Plateau (36°02′N, 104°25′E, 2400 m above sea level), Lanzhou University, Gansu Province, China. The study area is located at Zhong-Lian-Chuan in the northern mountainous region of Yuzhong County, Gansu Province. The area has a medium temperate semiarid climate, with an annual mean air temperature of 6.5 °C, a maximum of 19.0 °C (July), and minimum of −8.0 °C (January). The mean annual precipitation is 320 mm, about 60% of which falls in July–September, and the average annual free water evaporation is about 1300 mm. Rainfall during the experimental period was measured using an automatic weather station (WS-STD1, England). The water table is very deep, thus groundwater is unavailable for plant growth. The soil is Heima soil (Calcic Kastanozem, FAO Taxonomy), with the water content of 22.9% at field capacity (gravimetric) and a permanent wilting point of 6.2% (Shi et al., 2003). In the 0–20 cm soil layer, soil sand (>50 μm), silt (2–50 μm) and clay (<2 μm) is 17.7%, 82.1% and 0.2%, respectively, and water-stable aggregation size >2.0 mm, 2.0–1.0 mm, 1.0–0.25 mm and <0.25 mm is 3.0%, 3.5%, 21.4% and 72.1%, respectively. In this region, the major land use form was cropland, other land use systems, including pasture and plantations (Liu et al., 2010).

2.2. Experimental design and field management

In this experiment, we applied five treatments: (1) a flat plot with no mulching (CK); (2) alternating ridges and furrows with no mulching (M0C0); (3) alternating ridges and furrows with no mulching, with the subgrooves mulched with plastic film (M0C); (4) alternating ridges and furrows, with only the ridges mulched with plastic film (MC0); (5) alternating ridges, furrows and subgrooves, the ridges and subgrooves mulched with plastic film (MC). A sketch showing different treatments is presented in Fig. 1. The design of the soil subgrooves in M0C and MC treatments was as follows: the subgrooves were 2 m long, 0.5 m wide and 0.4 m high; the soil in the subgroove was removed; the walls and bottoms of the subgrooves were mulched with plastic film (0.03 mm); and the soil was back filled in the subgrooves. The white plastic film mulched on the ridges is 0.0075 mm thick. In the ridges and subgrooves system, crops were planted in the furrows between the two ridges, and the subgroove basically acted as a barrier for deep percolation that holds water in the root zone. Each treatment was replicated three times, and each plot was 3 m long and 2 m wide, placed in a randomized block arrangement. In this study, the big agriculture farming machine could be applied because of the relatively small fields, and the ridges and subgrooves were built with a spade. Bare ridges were made between every second plot to prevent runoff. According to local fertility practices, fertilizers at the rates of 105 kg N ha^{-1}, 12 kg P ha^{-1} and 25 kg K ha^{-1} for crops in each year were incorporated into the soil by spade (across the entire plot for CK treatments, and into the furrows for the M0C0, M0C, MC0 and MC treatments), when the ridge and furrow system built in July 2005 and in April 2006, 2007 and 2008. After harvest of every year, the configuration of double ridges and furrows, as well as the plastic film in the M0C0, M0C, MC0 and MC treatments were left in the field until the new system of ridge-furrow and plastic mulching was rebuilt the following year, and subgrooves with plastic film were used for four years. The crops were millet, field pea, spring wheat and potato, grown in this order from 2005 to 2008. The planting date, seeding rate, depth of seeding and harvesting date of each crop is presented in Table 1. Millet, field pea and spring wheat were planted with a special planting machine, and potato was planted with a spade.

2.3. Sampling and measurements

During the growing seasons, the soil temperature at the 5 cm depth between the plant rows was recorded at 08:00, 14:00 and 20:00 h with a geothermometer (Zhou et al., 2009; Wang et al., 2011; Li et al., 2013), every day for three consecutive days in the middle of every month. The mean daily soil temperature was calculated as the average of the three daily readings.

Soil moisture was measured gravimetrically (g g^{-1}) to a depth of 100 cm at 20 cm intervals (0–40 cm in M0C and MC) in the middle of every month of each growing season, using a soil auger (4 cm diameter, 20 cm height), and soil water content was measured in the furrows of the M0C0, M0C, MC0 and MC treatments. The soil samples were collected into self-sealing plastic bags in the field, and upon arrival at the laboratory each sample was immediately enclosed in an aluminum soil box. All soil samples were weighed within 1 h after collection to obtain the fresh weights, and oven-dried at 105 °C to a constant weight, then weighed again to determine the gravimetric water content. The soil bulk density at 0–100 cm depth was determined using the core method. The bulk of stainless ring was 100 cm^3. Nine core samples were collected randomly from the experiment field in July before the beginning of the experiment in 2005, the core samples were immediately weighed, then dried at 105 °C for 24 h to a constant weight and reweighed. The average bulk density was 1.15 g cm^{-3} in the soil to a depth of 20 cm, and 1.22 g cm^{-3} in the 20–100 cm layer. The moisture content volumetrically was calculated by soil gravimetrical moisture multiplied by soil bulk density.

Millet, field pea and spring wheat were harvested by hand, and potato was harvested by spade. The crop yields were estimated based on the total plot land area, including the ridges and furrows. In order to prevent the change and consumption of the chemical composition of the plants, all samples of herbage, grain and tubers