Agricultural Water Management 131 (2014) 87–94

Contents lists available at ScienceDirect

Agricultural Water Management

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

Effect of ridge–furrow and plastic-mulching planting patterns on yield formation and water movement of potato in a semi-arid area

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ARTICLE INFO

Article history:
Received 30 April 2013
Accepted 19 September 2013
Available online 13 October 2013

Keywords:
Rainfed potato
Ridge–furrow and film cropping patterns
Yield
Tuber quality
Evapotranspiration
Water use efficiency

ABSTRACT

Field experiments were conducted to study the effects of different ridge–furrow plastic-mulching planting patterns (RFM) on potato (*Solanum tuberosum* L.) growth, tuber yield and quality, and water use efficiency (WUE) in an arid area of Northwestern China in 2010 and 2011.

Six treatments were used: (1) a flat plot without mulch (CK); (2) alternating mulched with plastic film and bare plots with no ridges (MNR); (3) completely mulched alternating wide and narrow ridges with furrow planting (CF); (4) completely mulched alternating wide and narrow ridges with ridge planting (CR); (5) alternating mulched ridges and bare plots with no ridges and with furrow planting (HF); (6) alternating mulched ridges and bare plots with no ridges and with ridge planting (HR).

RFM systems greatly improved tuber yield and WUE of potato in comparsion to CK. Compared to CK, the magnitude of yield in RFM increase were 50.1–86.8% in 2010 and 36.3–60.5% in 2011, respectively. Two completely mulched treatments (CF, CR) produced the highest tuber yield. Compared to CK, the highest increase in WUE was 83.9% (CR) and 65.8% (CF) in 2010 and 2011, respectively. Evapotranspiration in RFM was significantly decreased compared to CK during the early and end growing stages. But ET in CF, CR, HF and HR became higher at vigorous growth stages (from 6 July to 27 August) due to higher transpiration, which may imply a higher ratio of transpiration/evaporation. CF and CR treatments resulted in higher dry matter and relative growth rate than other treatments, and had higher output efficiency of dry matter from aboveground to tuber. Potato in CR showed the highest tuber yield, output value, net revenue and WUE, produced tubers with good size, low percentages of green and blemished tubers, and high protein content. In conclusion, CR is the best planting pattern for rain-fed potato.

1. Introduction

Water scarcity limits the sustainable development of rain-fed agriculture in semi-arid areas. Agricultural production on rainfed farms is dependent on rainfall, and farmers are generally more concerned about the availability of water. Hence, the key to increasing agricultural productivity lies in the maximal utilization of precipitation, which requires harvesting light rainfall (Li, 1997; Qin and Li, 2005; Qin et al., 2013). Therefore, water management practice must be aimed at fully enhancing the efficiency of the limited water being used (Shan and Xu, 1991). In recent years, some new technologies have been developed and adopted to improve the crop productivity, including rainwater harvesting, timely fertilization, manure application, and the use of terraces in the agroecosystem (Li et al., 1999; Qin et al., 2013; Wang et al., 2008).

Ridge and furrow micro-water harvesting (RFMH), which collects runoff from ridges, is especially useful in arid and semi-arid regions, where irrigation water is not available or is costly (Boers et al., 1986; Wang et al., 2008). The RFMH system can improve soil moisture storage, prolong the period of crop water availability, and enhance crop growth (Boers et al., 1986; Carter and Miller, 1991). Plastic film mulch has been used for conserving and channeling rainwater (Gan et al., 2013), and it is now becoming a well-evolved technique for agriculture in arid, semiarid and sub-humid areas, especially where irrigation is not available and spring temperatures are low (Hou et al., 2010; Zhang et al., 2011). This technology has proven to be highly effective in improving soil moisture and increasing topsoil temperature (Li et al., 2007; Song et al., 2002; Wang et al., 2003).

Recently, a new mulching pattern, where narrow ridges are alternated with wide ridges, completed mulched with plastic films, with ridge or furrow planting, has been widely adopted and

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http://dx.doi.org/10.1016/j.agwat.2013.09.015

achieved a significant improvement in grain yield and WUE of maize per unit area (Zhao et al., 2012). This pattern has been shown to improve topsoil temperature, especially at the seedling stage, decrease soil evaporation (Ye et al., 2012), increase topsoil moisture (Zhou et al., 2012), and enhance plant maturity and grain yield in maize (Li et al., 2012; Zhang et al., 2006; Zhou et al., 2012).

The yield of potato (*Solanum tuberosum* L.), one of the dominant crops in the semi-arid areas on the Western Loess Plateau of China, is typically low, and its profitability and WUE are also low (Hou et al., 2010; Qin et al., 2013). Some research reported that potato tuber yield might be reduced by light plastic mulch because soil temperature could raise to a level beyond the optimum during part of the potato growing period (Baghour et al., 2002; Liang et al., 1998), but there were also examples of increased tuber yield with the use of plastic mulches (Sun and Li, 2004). These differences in yield response might be attributable to differences in climatic conditions (Döring et al., 2005).

Potato is a shallow-rooted and cool-season crop, and its yield is highest when average daytime temperatures are about 21 °C. Cool night temperatures are critical for the accumulation of carbohydrates and dry matter in the tubers (Bélanger et al., 2000). Lower night temperatures decrease plant respiration, and enhance the storage of starch in the tubers. Some studies have shown that black plastic mulch controls water evaporation from the surface soil, improves soil water retention, controls weeds and reduces heat stress under high temperature conditions (Abu-Awwad, 1998; Grose, 2012). However, little is known about the effect of different black plastic film patterns on the growth, yield, quality and WUE of rain-fed potato, especially in Northwest China. Therefore, the objectives of this experiment were to (i) examine the effects of different ridge–furrow and black plastic mulching cropping patterns on yield formation and soil water movement in potato grown in a semi-arid agroecosystem, and (ii) elucidate the appropriate patterns of film mulching for maximum WUE, tuber yield and net revenue of potato.

2. Materials and methods

2.1. Description of the experimental site

The field experiment was conducted in 2010 and 2011 at the Experimental Station (35°33′ N, 104°35′ E, elevation 1874 m a.s.l.) of Rain-fed Agricultural Research Institute of Gansu Agricultural University, at Dingxi, Northwest China. The experimental site had a Huangmian soil in the Chinese soil taxonomy (Chinese Soil Taxonomy Cooperative Research Group, 1995) and Calcaric Cambisols in the FAO soil map of the world (FAO, 1990), which is typical on the Loess Plateau. It is a sandy-loam with low fertility (Table 1), representing the major cropping soil in the area (Zhu et al., 1983). The average long-term (1970–2011) annual precipitation at Dingxi is 391 mm (from the weather bureau of Dingxi city, China). The monthly rainfall in 2009–2011 compared with long-term average is shown in Table 2. On average, about 54% of the annual rainfall occurs between July and September. Daily maximum temperatures can reach 38 °C in July, while minimum temperatures can drop to −22 °C in January. Hence, summers are warm and moist, whereas springs and winters are cold and dry. The annual average accumulation of physiological days (P-days) for potato was 719.3. The term P-days is a parameter similar to growing-degree-days, and yet, it incorporates the minimum, optimum, and maximum temperatures into a single index for the assessment of heat units available for the growth and development of potato (Yuan and Bland, 2005). The annual average radiation is 5929 MJ/m^2, and sunshine 2477 hours per year.

2.2. Experimental design and treatment description

The following six treatments were arranged in a randomized, complete block design with three replicates in each year: (1) flat-plot planting without mulching. The row distances were 70 and 40 cm with wide and narrow rows, respectively, and the narrow rows were ridged for potato at the flowering stage (CK) (Fig. 1a); (2) alternating the strip mulched with black plastic film (70 cm wide) with the strip of bare land (40 cm wide) with no ridges (designated as MNR). Two rows of potato were planted in the mulched strips and spaced at 40 cm (Fig. 1b); (3) completely mulched wide ridges (70 cm) were alternated with narrow ridges (40 cm) and with furrow planting (designated as CF). The height of wide ridges was 15 cm and of the narrow ridge 10 cm. All of these ridges and furrows were mulched with black plastic film. The plastic film was joined at the top of narrow ridges and sealed with soil. Two rows of potato were planted in the furrows with dibblers, spaced at 70 and 40 cm with wide and narrow rows, respectively (Fig. 1c); (4) completely mulched wide ridges (70 cm) were alternated with narrow ridges (40 cm) and with ridge planting (designated as CR). The same as treatment 3 (CF) with the exception of planting at the top of wide ridges (two rows) with dibblers and small holes were made (spaced at 30 cm) on the plastic film in the furrows with a sharp object for rainfall infiltration (Fig. 1d); (5) ridges mulched with black plastic film (70 cm) were alternated with bare land (40 cm) that had no ridges and no mulches. Two rows of potato were planted in the non-mulched strips and spaced at 40 cm (designated as HF) (Fig. 1e); (6) ridges mulched with black plastic film (70 cm) were alternated with bare land (40 cm) that had no ridges and no mulches. Two rows of potato were planted in the mulched ridges and spaced at 40 cm (designated as HR) (Fig. 1f).

The plastic film used in the study was polyethylene, black in color, and 0.01 mm thick. The ridges were formed and plastic film was placed with a ridging-film machine on 12 April 2010 and 15 April 2011. Soil was heaped on the film in bands every 3 m to prevent wind from shifting the plastic film. Small holes were made in the film of furrow every 30 cm to permit rainfall infiltration. The potato cultivar “Xindaping” was sown at the density of 45,460 plants per hectare on 23 April 2010 and 24 April 2011. Plots were 16 m × 11 m in size. There was a buffering area between plots (1.0 m) and between blocks (1.2 m). All plants were harvested on 24 September 2010 and 26 September 2011. In each plot, there were twenty rows of potato plants for all treatments. In all treatments, the intra-plant distance within a row was 40 cm.

Potato specific fertilizer was applied with broadcast application at a rate of 96 kg N ha^{-1}, 84 kg P_2O_5 ha^{-1}, and 120 kg K_2O ha^{-1}. The plot area also received 30 m^3 ha^{-1} of the compost of cattle and sheep manure which contained 1.34% of N, 0.293% of P, and 0.698% of K, applied before mulching.

2.3. Measurements and methods

2.3.1. Soil moisture

Gravimetric water content (using the oven method at 105 °C) was determined at each potato morphological stage from soil samples taken at the depths of 0–10, 10–20, 20–30, 30–50, 50–70, 70–90, 90–110, 110–130 and 130–150 cm. At sowing, the experimental area was uniform, and thus, 12 randomized samples were taken to measure moisture for the whole experimental area. Bulk densities were measured at the very beginning of the experiment and used for soil moisture calculations (Table 1).