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Does Plastic Mulch Improve Crop Yield in Semiarid Farmland at High Altitude?

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ABSTRACT

Crop yields have increased greatly due to the use of plastic-film mulching in dryland areas of China at low to mid-altitudes. However, its effect at high altitude remains unknown. We studied the effect of ridge–furrow with plastic-mulching practices on crop yields in semiarid farmland at high altitude (2400 m) from 2010 to 2011. The three treatments were as follows: (i) flat plot with no mulching (CK); (ii) alternating ridges (60-cm wide, 15-cm high) and furrows (60-cm wide) without plastic film (RF); and (iii) alternating ridges (60-cm wide, 15-cm high) and furrows (60-cm wide), with the ridges mulched with plastic film (RFM). Potato (*Solanum tuberosum* L.) and maize (*Zea mays* L.) crops were planted in 2010 and 2011, respectively. The RFM treatment did not increase potato yields, but significantly increased the ratio of large tuber to total tuber yields (RBT). The RBTs for CK, RF, and RFM were 44.0, 46.8, and 66.7%, respectively. In 2011, the RFM treatment had significantly higher maize yield than the CK and RF treatments, and maize yield was mainly affected by temperature in May. In conclusion, ridge–furrowing with plastic film did not increase the total yield of potato crops compared with non-mulching treatments, but did increase large tuber yield. The increase in soil temperature in May caused by mulching was important for improving maize yield in semiarid farmland at high altitude.

Arid regions (or drylands) cover approximately 45% of the Earth's land surface (Schimel, 2010), drought has long been the primary factor which limits crop yields due to the shortage and uneven distribution of water resources in these regions (Ierna and Mauromicale, 2012; Liu et al., 2013; Valipour, 2014a, 2014b, 2015a; Valipour et al., 2015; Zhang et al., 2009). The predicted decline in precipitation will lead to yield reductions in many important crops, which will threaten the food supply in semiarid regions (Lobell et al., 2008). The development of rainfed dryland agriculture with optimized water use is a priority to ensure food security for the increasing population and the worsening environment.

Rainfed dryland agriculture depends on precipitation. Limited precipitation, with uneven distribution, often results in low crop yields. Increasing the efficiency of precipitation use for crops is important for farmers in these regions. Ridge and furrow micro-water harvesting (RFMH) in terraces, which collects runoff from slopes of ridges, is particularly useful in arid and semiarid regions, where irrigation water is expensive or not available (Boers et al., 1986; Hu et al., 2014; Valipour, 2012, 2015b). Mulching with plastic film was introduced to China in 1978, and is now widely used for crop production in dryland areas (Bu et al., 2013; Liu et al., 2009; Tian et al., 2003; Wang et al., 2005; Zhou et al., 2009). In these areas, this plastic-covered ridge and furrow rainfall harvesting system can reduce soil evaporation, and enhance infiltration of rainwater into the soil, which in turn increases soil water content (Jia et al., 2006; Zhou et al., 2009). In recent years, crop yields in these dryland areas have increased due to this rainwater harvesting system (Li et al., 2013; Qin et al., 2014; Zhang et al., 2011; Zhao et al., 2012; Zhou et al., 2009). At high altitude, mulching ridges and furrows increased growth of individual alfalfa plants, and the uptake of water from deep soil (Jia et al., 2006). Liu et al. (2009) reported that mulching applied 30 d before sowing at high altitude increased soil water content and temperature more than plastic-film mulching applied at sowing.

Potato and maize are two important crops (Fabeiro et al., 2001), being the main economic and staple food crops in semiarid and arid areas. In dryland areas, potato and maize yields have increased under ridge–furrow and plastic-mulching tillage systems, but this has only been observed at low to mid-altitudes (Bu et al., 2013; Huang et al., 2010; Ierna and Mauromicale, 2012; Li et al., 2013; Wang et al., 2005).

To determine if these effects occur in potato and maize crops at high altitude in arid regions, we designed an experiment to determine the following: (i) the effects of ridge–furrow and plastic-mulching practices on soil water content in various soil layers, soil temperature, crop yield, and water use efficiency

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Abbreviations: ET, evapotranspiration, sum of soil water change and rainfall during the growing season; RBT, ratio of big tuber yield to total tuber yield; SWC, soil water change, reduction in soil water content from planting to harvest at 0- to 200-cm soil depth; WUE, ratio of tuber yield per unit to evapotranspiration at 0- to 200-cm soil depth.

(WUE); and (ii) the principal factors affecting crop yield in the dryland areas at high altitude. This study will increase our knowledge of the effects of ridge–furrow and plastic-mulching practices on crop yield in potato and maize and WUE in high altitude arid regions in China.

MATERIALS AND METHODS

Description of Study Site

The field experiment was conducted from April 2010 to October 2011 at the Semiarid Ecosystem Research Station of the Loess Plateau (36°02′ N, 104°25′ E, 2400 m above sea level), Lanzhou University. The study area was located at Zhonglianchuan, in the northern mountainous region of Yuzhong County, Gansu Province, China. The area has a medium temperate, semiarid climate with an annual mean air temperature of 6.5°C (maximum of 19.0°C (July) and minimum of −8.0°C (January)). Mean annual precipitation is 320 mm, of which approximately 60% is from July to September, and average annual free water evaporation is approximately 1300 mm. Rainfall during the experimental period was measured by using an automatic weather station (WS-STD1, Delta-T Devices Company, Cambridge, England). The water table was very deep; therefore, ground water was unavailable for plant growth. The soil is Heiman soil (Calcic Kastanozem, FAO Taxonomy) (Shi et al., 2003) with 22.9% water content at field capacity (gravimetric), and 6.2% permanent wilting point.

Experimental Design and Field Management

As part of the field micro-catchment technique, alternate ridges and furrows were created on the flat land. The three treatments for this experiment were: (i) CK, (ii) RF, and (iii) RFM (Fig. 1). Each treatment was replicated three times in 5.4-m long by 5-m wide plots in a randomized block arrangement. Bare ridges between each adjacent plot prevented runoff. In accordance with local practices, fertilizers, at rates of 70 kg N ha^{-1} and 15.7 kg P ha^{-1} for potato crops, and 167 kg N ha^{-1} and 51 kg P ha^{-1} for maize crops, were incorporated into the soil using spades (across the entire plot for CK treatments, and in the furrows for the RF and RFM treatments) when the ridge and furrow systems were built in late April 2010 and 2011. The potato crop was planted with a row spacing of 60 cm in the CK treatment, and two rows in each furrow in the RF and RFM treatments, as illustrated in Fig. 1. The potato cultivar Xindaping was sown at a density of 33,225 plants ha^{-1} in all treatments on 28 Apr. 2010 and harvested on 3 Oct. 2010. Following the potato harvest, the configuration of double ridges and furrows, and the plastic film in the RF and RFM treatments, remained in the field until rebuilding the following year. The maize crop was planted with a 60-cm row space in CK, and two rows of maize were planted on the ridge, with a 40-cm space between the rows in the RF and RFM treatments as shown in Fig. 1. The maize cultivar Jiudan 3 was sown at a density of 54,000 plants ha^{-1} using a hole-sowing tool in all treatments on 29 Apr. 2011, and harvested on 5 Oct. 2011.

Sampling and Measurements

Soil moisture was gravimetrically determined to a depth of 200 cm in 20-cm increments, at the beginning and end of each growing season, using a soil auger (8-cm diam. × 20-cm high). Soil water content was measured in the furrows of the RF and RFM treatments. Before sowing in 2010, the soil bulk density was determined according to Robertson et al. (1999). Average

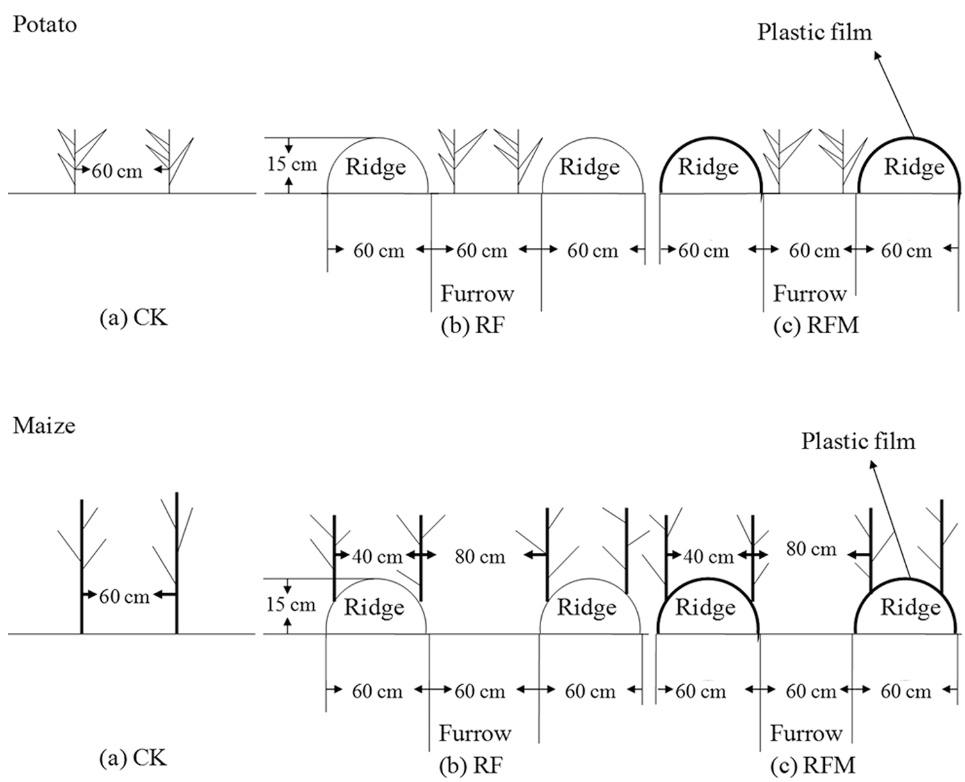

Fig. 1. Planting methods for potato and maize in different treatments: (a) flat plot with no mulching (CK); (b) alternating ridges and furrows with no mulching (RF); and (c) alternating ridges and furrows with only the ridges mulched with plastic film (RFM).

bulk density was 1.15 g cm^{-3} in the soil up to 20-cm depth, and 1.25 g cm^{-3} in the 20- to 200-cm layer.

In May 2010 and 2011, the soil temperature at 10-cm depth, central between two plants in the ridges of the RF and RFM treatments, and the flat plot in the CK treatment, was recorded at 0800, 1400, and 2000 h each day, for three consecutive days, in the middle of each month. The mean daily soil temperature was calculated as the average of the three daily readings.

The amount of rainfall stored in the soil profile during the non-growing season was calculated as the difference in soil water content within the 200-cm profile from the beginning to the end of the non-growing season. Due to the rainfall being too low to cause drainage below 2 m, and the lack of irrigation, evapotranspiration (ET) was calculated using the formula:

$$\mathrm{ET} = P + \mathrm{SWC} \quad [1]$$

where P is total seasonal precipitation (mm); and SWC is soil water content at sowing minus soil water content at harvest in the 0- to 200-cm profile. The experimental field was a terrace, and a bare ridge (80-cm wide by 20-cm high) was raised between plots to prevent runoff. Therefore, no runoff occurred at the site during the study. The WUE was calculated as potato or maize crop yield (kg ha^{-1}) divided by growing season evapotranspiration (mm).

The potato crop yield was calculated from the plot yield, with 10 plants randomly taken at the center of each plot at harvest to assess tuber size and class (Qin et al., 2014). There were two classes: large ≥ 100 g, and small < 100 g. The total number of tubers per plant was also counted (Qin et al., 2013). The growth stages of the maize crop were recorded, and spikes per plant, grain number per spike, and 100-kernel weight were measured at maturity. Ten representative maize plants per plot were used for each measurement at harvest; yield estimation was based on the combined area of land used in ridges and furrows. The harvested grain was oven dried at 105°C for 30 min and then at 75°C to a constant weight before calculating the yield (Bu et al., 2014).

Statistical Analysis

One-way ANOVA procedure in SAS software (SAS Institute,1990) was used to conduct analysis of variance. Mean values of the treatments were compared using least significant difference (LSD) at $P \leq 0.05$. Mean values are reported in the tables and figures. Stepwise regressions were performed to evaluate the relationship between soil water content before sowing in the 0- to 200-cm soil layer (SW) and soil temperatures at 10-cm depth in May (T_{May}), June (T_{Jun}), and July (T_{Jul}) as well as maize crop yields.

RESULTS

Precipitation and Growth Periods of Crops

Most of the precipitation occurred from July to September each year. The year 2010 was an average year, with 308.7 mm rainfall. However, 2011 was relatively dry with only 277.8 mm rainfall (Fig. 2). The growth periods for the potato and maize crops were 159 and 160 d, respectively. Precipitation during the potato and maize growth periods accounted for approximately 80% of total annual precipitation.

Dynamics of Soil Moisture and Soil Temperature

Mulching and the configuration of ridges and furrows regulated soil water conditions, which varied between soil layers. The soil water content in the 0- to 100-cm soil layer was always higher in the RFM treatment than in the CK and RF treatments, from October 2010 to October 2011, and significant differences were observed in October 2010 and April 2011 (Fig. 3a). Patterns of soil moisture in the 100- to 200-cm and 0- to 200-cm soil layers were similar in the two growing seasons, and soil water content was significantly higher in the

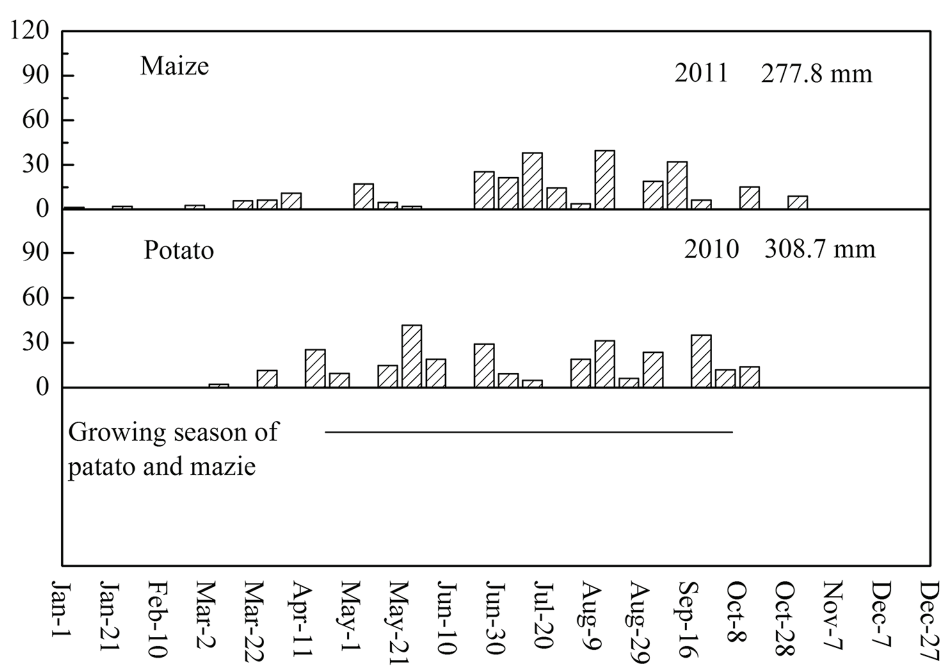

Fig. 2. The distribution of precipitation at the study site calculated every 10 d during the 2-yr experiment (2010–2011), with the growing seasons of potato and maize crops identified.

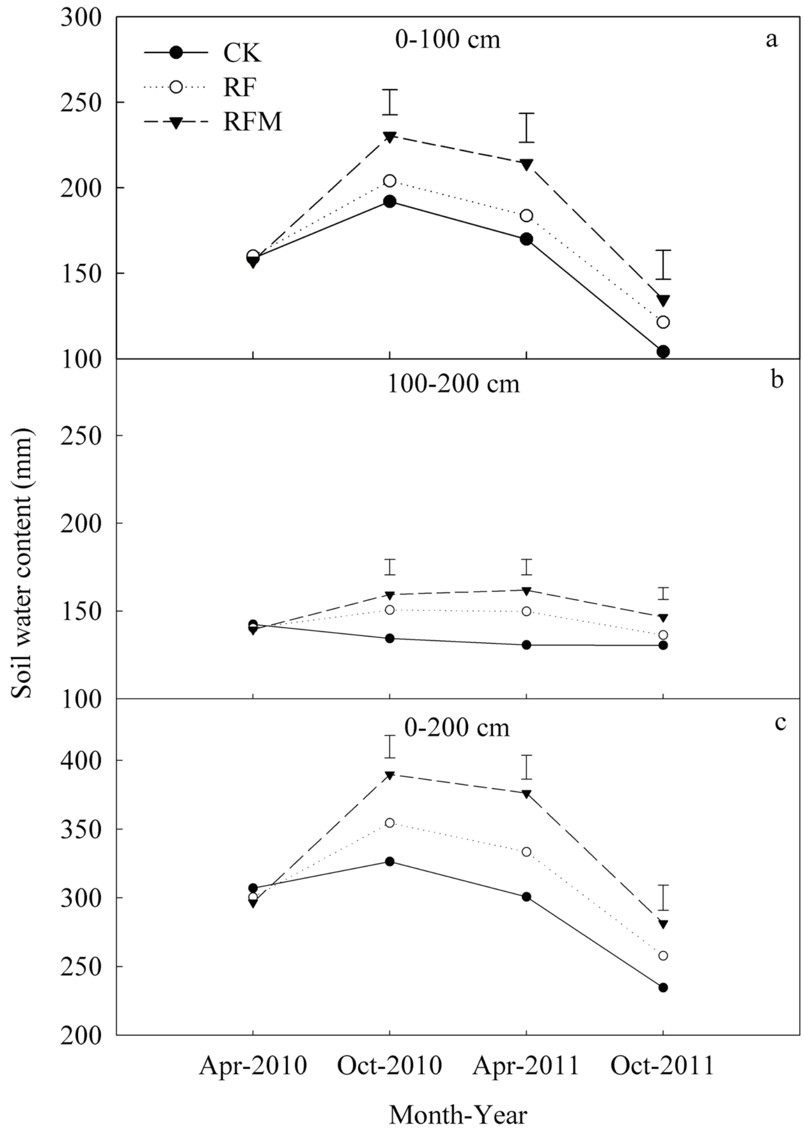

Fig. 3. Profile of soil water content from 0 to 100, 100 to 200 and 0 to 200 cm in the various treatments from April 2010 to October 2011. CK, flat plot with no mulching; RF, alternating ridges and furrows with no mulching; RFM, alternating ridges and furrows with only the ridges mulched with plastic film. Error bars are the LSD at $P \leq 0.05$.

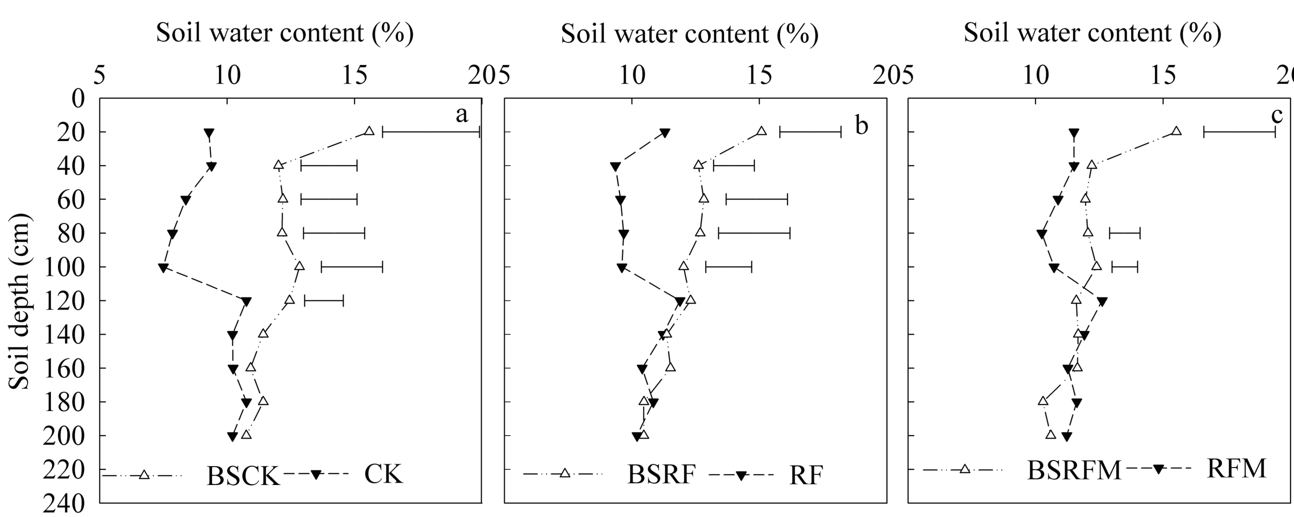

Fig. 4. Soil moisture profile in the upper 200-cm layer in 20-cm increments for each treatment in April 2010 and October 2011. BSCK, BSRF, and BSRFM are the soil moisture contents in April 2010 for the CK, RF, and RFM groups, respectively. CK, flat plot with no mulching; RF, alternating ridges and furrows with no mulching; RFM, alternating ridges and furrows with only the ridges mulched with plastic film. Bars are the LSD at $P \leq 0.05$

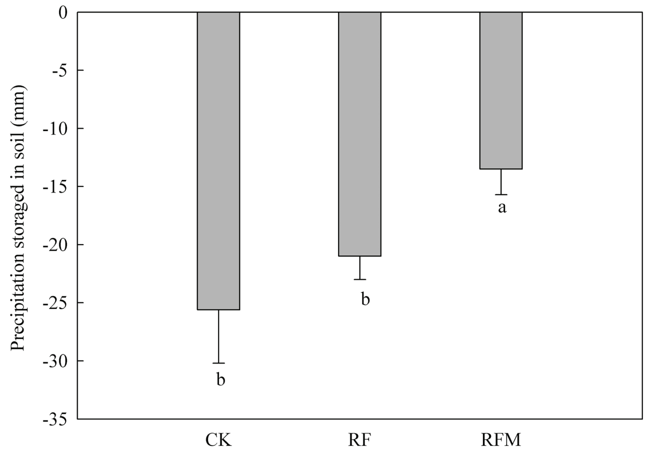

Fig. 5. The effect of various treatments on the storage of precipitation in the 0- to 200-cm soil layer during the non-growing season. CK, flat plot with no mulching; RF, alternating ridges and furrows with no mulching; RFM, alternating ridges and furrows with only the ridges mulched with plastic film. Different letters indicate significant differences at $P \leq 0.05$. Error bars are the standard deviation of means (n = 3).

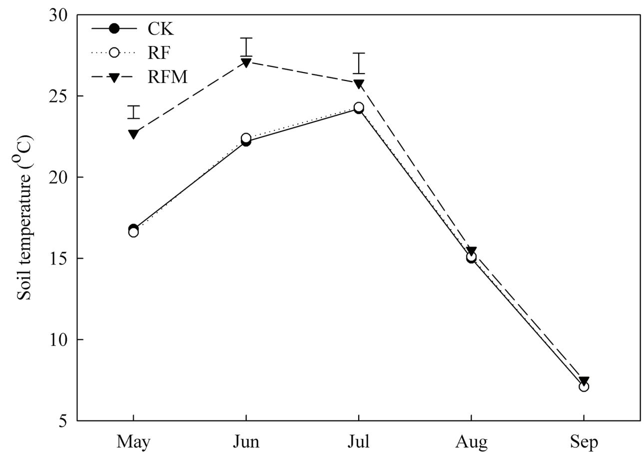

Fig. 6. Mean daily soil temperature at 10-cm soil depth in the middle of the planting zone in 2011. CK, flat plot with no mulching; RF, alternating ridges and furrows with no mulching; RFM, alternating ridges and furrows with only the ridges mulched with plastic film. Bars are the LSD at $P \leq 0.05$

RFM than in the CK and RF from October 2010 to October 2011 (Fig. 3b, 3c).

At the end of the two growing seasons, the soil water content significantly decreased in the 0- to 100-cm soil layer in the CK and RF treatments, when compared to their initial values at sowing in April 2010 (Fig. 4). However, in the RFM treatment, soil water content only decreased significantly in the 0- to 20-cm and 80- to 100-cm soil layers, when compared to the initial values at sowing in April 2010.

The ridge–furrow and plastic-mulching practices affected the amount of soil water stored during the non-growing season (Fig. 5). The amount of water stored in the soil profile (0–200 cm) between harvesting the potato crop and sowing the maize decreased by 26, 21, and 14 mm in the CK, RF, and RFM treatments, respectively.

In 2011, soil temperature was significantly higher in the RFM treatment than the CK and RF treatments from April to June, with no significant differences observed in all treatments during the late growing period (Fig. 6).

Grain Yield, Yield Components, and Water Use Efficiency

In 2010, potato yield did not significantly differ between treatments (Table 1). However, big tuber yield and the ratio of big tuber yield to total tuber yield (RBT) were significantly higher in the RFM treatment compared with the CK and RF treatments; RBT increased by 51.6% and 48.9%, respectively. Mulching and the configuration of ridges and furrows reduced ET to 142.8, 181.8 and 216.7 mm for the RFM, RF, and CK treatments, respectively. The WUE of the potato crop was significantly higher in the RFM treatment compared with the CK and RF treatments (60.5, 73.1, and 94.0 kg ha^{-1} mm^{-1}, respectively). Mulching reduced the average number of tuber per plant to 4.8, 4.0 and 2.5 per plant for the CK, RF and RFM treatments, respectively (Fig. 7).

In 2011, seedlings emerged in the RFM treatment 21 to 26 d earlier and reached the heading stage and maturation earlier than the CK and RF treatments (Table 2). In the CK and RF treatments, the ears did not develop.

Spikes per plant did not significantly differ between treatments (Table 3). The RFM treatment had significantly more grains per spike than the CK and RF treatments. The 100-kernel weights were 2.8, 2.9, and 18.1 g for CK, RF and RFM, respectively. Maize yield in the RFM treatment significantly increased by 885.7% and 800.0% of the CK and RF treatments, respectively. The WUE was significantly higher in the RFM treatment (11.7 kg ha^{-1} mm^{-1}) than in the CK (1.3) and RF (1.4) treatments.

Stepwise regressions were used to evaluate the relationships between soil water content before sowing in the 0- to 200-cm soil layer (SW, mm) and temperatures (°C) at 10-cm soil depth in May (T_{May}), June (T_{Jun}), and July (T_{Jul}) with maize yield. The relationship of maize yield (Ym) to the parameters was:

Table 1. Mean (± SD, n = 3) yield, soil water change, evapotranspiration and water use efficiency of the potato crop in various treatments.

Treatment	Big tubers	Small tubers	Total yield	RBT†	SWC	ET	WUE
	kg ha^{-1}			%	mm		kg ha^{-1} mm
CK	5773 ± 610b‡	7343 ± 487a	13,116 ± 1064a	44.0 ± 1.3b	−19.2 ± 14.5a	216.7 ± 14.5a	60.5 ± 2.9c
RF	6222 ± 715b	7065 ± 673a	13,287 ± 1377a	46.8 ± 0.9b	−54.1 ± 0.2b	181.8 ± 0.2b	73.1 ± 7.6b
RFM	8940 ± 847a	4462 ± 520b	13,402 ± 681a	66.7 ± 4.2a	−93.1 ± 3.6c	142.8 ± 3.6c	94.0 ± 3.1a

† Abbreviations: RBT, ratio of big tuber yield to total tuber yield; SWC, soil water change, reduction in soil water content from planting to harvest at 0- to 200-cm soil depth; ET, evapotranspiration, the sum of soil water change and rainfall during the growing season; WUE, ratio of tuber yield per unit to evapotranspiration at 0- to 200-cm soil depth. CK, flat plot with no mulching; RF, alternating ridges and furrows with no mulching; RFM, alternating ridges and furrows with only the ridges mulched with plastic film.

‡ Values within a column followed by the same letters do not differ at $P \leq 0.05$.

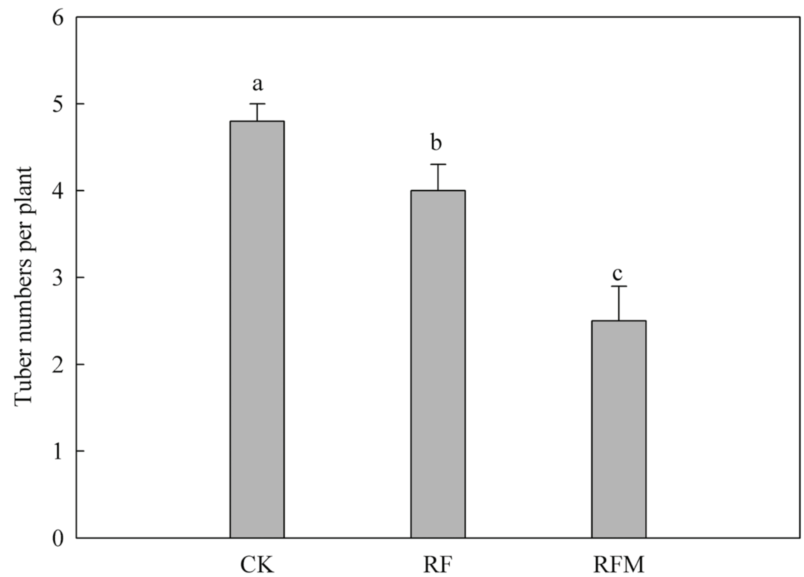

Fig. 7. Average tuber numbers per plant in the various treatments in 2010. CK, flat plot with no mulching; RF, alternating ridges and furrows with no mulching; RFM, alternating ridges and furrows with only the ridges mulched with plastic film. Different letters indicate significant differences at $P \leq 0.05$. Error bars are the standard deviation of means (n = 3).

$$Ym = 1.03T_{\mathrm{May}} + 0.04\mathrm{SW}\ (R^2 = 0.99, P \leq 0.01)$$

The yield for maize crops in dryland areas at high altitude was mainly affected by temperatures in May and not by soil water content.

DISCUSSION

In this study, the RFM treatment significantly increased soil moisture in dryland crop fields when compared to RF and CK treatments during the two growing seasons. Tian et al. (2003) reported that average runoff efficiencies (expressed as a ratio of runoff to rainfall) for three mulched ridge treatments (mulched ridge with widths of 0.3, 0.45 and 0.6 m) were 53.1, 63.3, and 69.7%, while those for three bare-ridge treatments were 5.9, 6.8, and 9.9%, respectively, when average precipitation was 223 mm. Zhao et al. (2012) also reported that rain harvesting efficiencies using mulched ridges was more than 85% when average precipitation was 382 mm. Therefore, mulching ridges can efficiently use light rain in dryland areas, thereby increasing the availability of water to plants, when compared with not mulching (Gan et al., 2013; Gao et al., 2014; Wang et al., 2011a; Zhou et al., 2009). There are reports where ridges and furrows covered with plastic film during the non-growing season aids rainfall harvesting, and prevents soil water evaporation. Plastic mulching significantly increased the amount of water stored at 0- to 200-cm soil depth compared to plots without plastic mulch during the non-growing season (Liu et al., 2009). In this study, the configuration of ridges and furrows and the plastic film used in the RFM treatment were left in place during the non-growing season. This led to the retention of significantly more stored water than the RF and CK treatments. The improvement in WUE for grain yield is the focus of research studies and crop producers in arid and semiarid areas. Increases in WUE have been achieved by increasing crop yields and decreasing ET (Han et al., 2013; Mahajan et al., 2012; Wang et al., 2005, 2011b; Zhou et al., 2011). The dynamics of soil water content in the soil profiles of different treatments—measured on 28 April (before sowing) and 3 October (after harvesting)

Table 2. Growth stages of maize sown in a flat plot with no mulching (CK); alternating ridges and furrows with no mulching (RF); and alternating ridges and furrows with only the ridges mulched with plastic film (RFM) in 2011.

	Days after sowing		
Growth stage	CK	RF	RFM
Seedling emergence	38	33	12
Jointing	70	67	54
Silking	134	132	107
Maturity	–	–	160

Table 3. Mean (± SD, n = 3) yield components, yield, soil water change, evapotranspiration and water use efficiency of maize in various treatments.

Items	CK†	RF	RFM
Spike, plant^{-1}	1.0 ± 0.0a‡	1.0 ± 0.0a	1.0 ± 0.0a
Grain number, spike^{-1}	250 ± 27b	264 ± 32b	381 ± 62a
100-kernel weight, g	2.8 ± 0.1b	2.9 ± 0.2b	18.1 ± 0.4a
Yield, kg ha^{-1}	378 ± 54b	414 ± 31b	3726 ± 677a
SWC, mm	66.1 ± 9.7b	75.7 ± 2.1b	94.8 ± 6.2a
ET, mm	290.2 ± 9.7b	299.8 ± 2.1b	318.9 ± 6.2a
WUE, kg ha^{-1} mm	1.3 ± 0.2b	1.4 ± 0.1b	11.7 ± 1.9a

† Abbreviations: CK, flat plot with no mulching; RF, alternating ridges and furrows with no mulching; RFM, alternating ridges and furrows with only the ridges mulched with plastic film; SWC, soil water change, the reduction in soil water content from planting to harvest at 0- to 200-cm soil depth; ET, evapotranspiration, the sum of soil water change and rainfall during the growing season; WUE, ratio of grain yield per unit to ET at 0- to 200-cm soil depth.

‡ Values within a row followed by the same letters do not differ at $P \leq 0.05$.

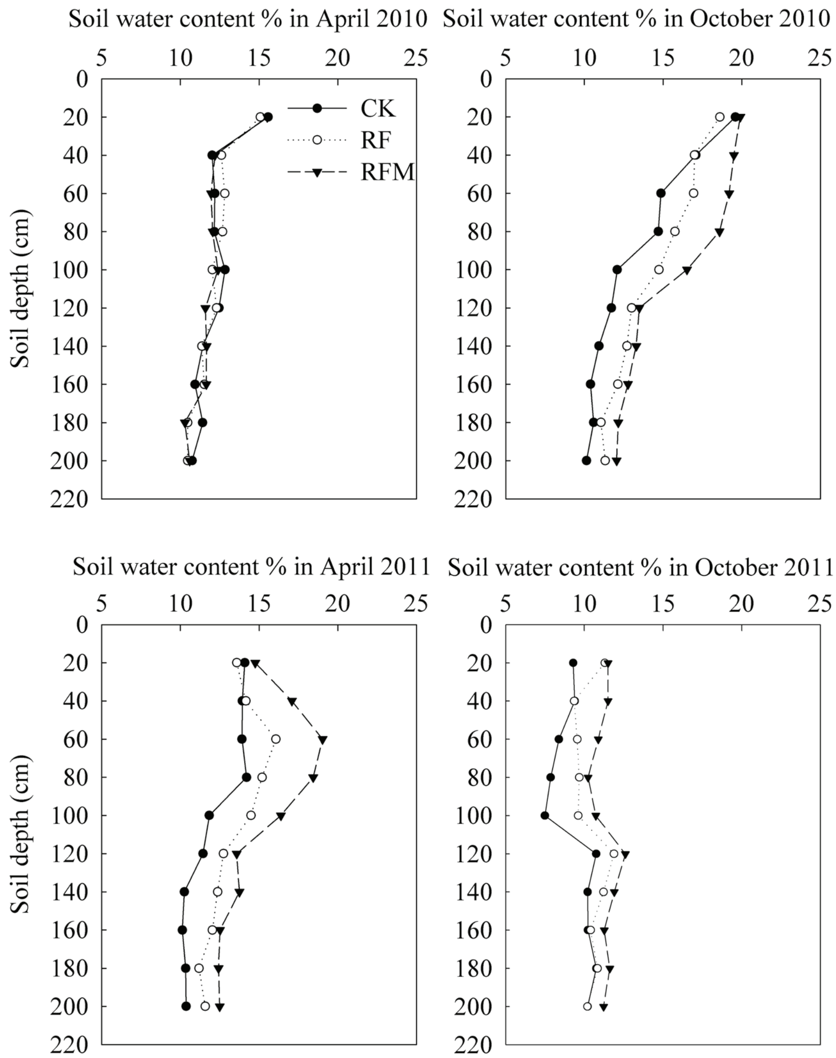

Fig. 8. Profile of the soil moisture in the upper 200-cm layer at 20-cm increments in the various treatments measured on 28 April (before sowing) and 3 October (after harvesting) in 2010, and on 29 April (before sowing) and 5 October (after harvesting) in 2011.

in 2010, and on 29 April (before sowing) and 5 October (after harvesting) in 2011—indicated almost no deep drainage below 200 cm (Fig. 8). When compared with the CK treatment, a lower seasonal ET in the ridge–furrow and mulching treatments was observed throughout the growth period in 2010. The lower ET in the RF and RFM treatments may have been due to the higher rainwater harvesting efficiency of the ridge–furrow configuration during the low rainfall period, and reduced evaporation losses which were attributed to the use of plastic film. However, seasonal ET was higher in the RFM treatment than in the CK and RF treatments in 2011; maize in these treatments failed to reach maturity thereby reducing the need for soil water during the growing season, hence the lower seasonal ET.

Many research studies have reported that ridge–furrow and plastic-mulching practices significantly increased potato crop yields when compared with flat-farming practices in dryland areas where the altitude is not greater than 2000 m (Qin et al., 2011, 2014; Wang et al., 2005; Zhao et al., 2012). In this study, ridge–furrow and plastic-mulching practices did not increase the potato crop yield when compared with flat-farming practices. However, the practice of mulching ridges with plastic film significantly increased the ratio of big tuber yield to total tuber yield. Potato is considered a cool-season crop, with cool night temperatures critical for the accumulation of carbohydrates and dry matter in tubers (Bélanger et al., 2000). Lower night temperatures decrease the plants' respiration, and enhance starch storage in tubers. In high altitude (2400 m) areas, large diurnal air temperature fluctuations, along with abundant sunlight, make these regions suitable for growing potato crops (Liu et al., 2013; Wang et al., 2008; Zhou et al., 2009). Potato crops also grow rapidly during the flowering season (July and August), and require large amounts of water, which is plentiful at this time in high altitude regions. In this study, these factors led to no obvious differences in potato crop yields in the various treatments. However, limited water resources and low temperatures in spring have often resulted in poor establishment of crops in this region (Liu et al., 2009). Jia et al. (2006) reported that the soil temperature at 5-cm soil depth with mulched treatments was 2.2°C higher than with conventional cultivation in a flat plot without mulch. In this study, we found that the soil temperature at 10-cm soil depth in May in the RFM treatment was 1.4 to 1.5°C higher than in the CK and RF treatments (Fig. 9). High moisture and temperature in the topsoil advanced the emergence of plants,

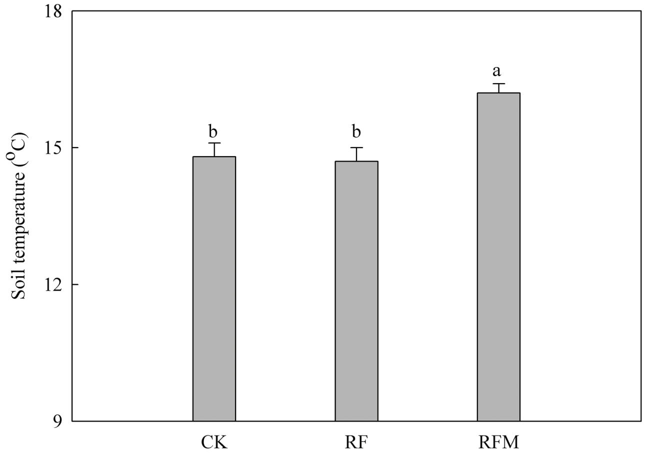

Fig. 9. Mean daily soil temperature at 10-cm soil depth in the middle of the planting zone in May 2010. CK, flat plot with no mulching; RF, alternating ridges and furrows with no mulching; RFM, alternating ridges and furrows with only the ridges mulched with plastic film. Different letters indicate significant differences at $P \leq 0.05$. Error bars are the standard deviation of means (n = 3).

when compared to non-mulched controls (Zhao et al., 2012). Seed germination and seedling establishment are key processes in plant development and yield formation in later stages of crop growth (Liu et al., 2009). In this study, the emergence of potato seedlings in RFM treatments was 5 to 7 d earlier than in the other treatments. Seedlings which establish early can use soil nutrients effectively, which promotes tuber growth, and increases the ratio of big tuber yield to total tuber yield (Qin et al., 2014; Zhao et al., 2012).

In this study, the growth period from seedling emergence to silking was 132 to 134 d for the CK and RF treatments, and only 107 d for the RFM treatment. The longer growth for the CK and RF treatments led to maize failing to reach maturity due to lower soil temperatures in the late growth period, and grain yields of only 378 and 414 kg ha^{-1}, respectively. This study showed that temperature in May was important for improving maize yield and not soil water content before sowing. Higher temperatures in May promoted maize emergence in the RFM treatment, which was 21 to 26 d earlier than in the other treatments. Maize also grew better during the early growth period due to the higher topsoil temperature, and absorbed more water during the later growth period. Grain yield in the RFM treatment was almost 6 to 10 times more than that of the CK and RF treatments. No temperature differences were observed between treatments in the late growth period of maize, probably because full establishment of the plant canopy resulted in minimal temperature increases, due to the presence of the plastic film, when compared with unmulched plots (Liu et al., 2009; Zhou et al., 2009). Therefore, the increase in soil temperature caused by mulching in the early growth period was more important than other factors for improving maize yield in semiarid areas with high altitude.

CONCLUSIONS

In semiarid farmland at high altitude, mulching ridges can increase soil water content in the 0- to 200-cm soil layer when compared with not mulching. The ridge–furrow and plastic-mulching practices did not increase potato crop yield when compared with flat-farming practices, but did increase big tuber yield and the ratio of big tuber yield to total tuber yield. Higher soil temperatures in the plastic-mulching practice were only observed during early growth, with no significant differences observed between treatments during late growth. The longer growing period from seedling emergence to silking for treatments without mulching led to maize failing to reach maturity due to low soil temperatures in the late growing period. The yield of maize was mainly affected by the temperature in May and not by soil water content before sowing in semiarid farmland at high altitude.

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