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Effects of plastic mulch on the radiative and thermal conditions and potato growth under drip irrigation in arid Northwest China

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ABSTRACT

Drip irrigation and plastic-film mulch are useful water-saving tools for potato (*Solanum tuberosum* L.) production in arid Northwest China. Effects of the radiative and thermal conditions produced by the plastic-film mulch on potato growth can be positive or negative. The objective of this study is to know how radiative and thermal conditions and potato growth are affected by the two most commonly used plastic-film mulches (transparent and black) to efficiently use the positive effects of the plastic-film mulch. Field experiments were conducted at the experimental station located in Wuwei, Gansu Province to explore the effects of transparent mulch (TM), a non-mulched check (NM), and black mulch (BM) on the net radiation (R_n), soil heat flux (G), soil temperature, and potato growth under surface drip irrigation during different plant development stages in 2014 and 2015. Results indicated that the daily integral R_n in the BM treatment was greater than in the TM treatment, while the amplitude of G in the BM treatment was lower than in the TM treatment. The BM treatment had 3.0 and 3.9 °C greater maximum mulch surface temperature than the TM treatment and had greater longwave radiation on the canopy emitted from the mulch surface. The differences in R_n, G, and soil temperature among the treatments diminished with plant canopy enlargement. The potato plant height rankings were BM > TM > NM. The BM treatment had 26% higher jumbo plus large tuber yield than the TM treatment in 2014. Compared with the BM treatment, the TM treatment had the similar potato yield but 9% and 8% less evapotranspiration in 2014 and 2015. The results suggested that the black plastic-film mulch was more suitable for large potato tuber production, while the transparent plastic-film mulch was favorable for water-saving.

1. Introduction

Potatoes are sensitive to both water and heat stress. Tuber yield, grade, and quality are reduced by inadequate or excessive soil water (Shock et al., 2007). Heat stress affects both plant top and tuber growth and development (Marinus and Bodlaender, 1975; Van Dam et al., 1996; Hijmans, 2003). Potato haulm growth is fastest in the air temperature range of 20–25 °C; whereas, the optimal range for tuberization and tuber growth is 15–20 °C (Rykaczewska, 2015) or 16–18 °C (Kooman et al., 1996; Kar and Kumar, 2007; Paul et al., 2014). The optimum air temperature for leaf photosynthesis in potato has been reported to be about 24 °C as leaf photosynthetic rate decreases rapidly with increasing air temperature (Wolf et al., 1990). High air temperature stress reduces tuber yield by limiting tuber induction and development through reduced photosynthesis and carbon portioning to growing tubers (Reynolds and Ewing, 1989; Van Dam et al., 1996; Gangadhar et al., 2014). High soil temperature during the subsequent stages of plant development can lead to malformed tubers (such as cracks and secondary tuber growth) and tubers sprouting in the soil before harvest (Gangadhar et al., 2014; Rykaczewska, 2015). High soil temperature can reduce tuber internal quality by decreasing tuber specific gravity (Zommick et al., 2014) and decreasing Vitamin C and protein content (Wang et al., 2011). The abiotic stress of heat and drought often happen simultaneously in many areas of the world, accounting in part for the far lower average global potato yield (19 t/ha) than its potential yield (120 t/ha) (Haverkort and Struik, 2015). Therefore, it is important to avoid heat and water stress to achieve high yields of high quality tubers.

Plastic-film mulch is popular in potato cultivation in Northwest China, where the potential crop evapotranspiration is far greater than rainfall and water resources for irrigation are seriously limited. The advantages of using plastic-film mulch may include reduced water loss

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from the soil, increased soil temperature of cold soils limit growth, and improved root nutrient uptake (Kasirajan and Ngouajio, 2012). As a promising water-saving measure, plastic-film mulch in combination with drip irrigation is already used in Northwest China potato production (Wang et al., 2009, 2011; Yang et al., 2017; Zhang et al., 2017). Drip irrigation can be used to modulate soil water status while retaining soil aeration, another important environmental factor affecting potato growth.

Plastic-film mulch can affect the above-ground and the below-ground radiative and thermal conditions, including solar radiation (Liakatas et al., 1986; Ham and Kluitenberg, 1994), latent heat flux and sensible heat flux (Ham et al., 1991; Ding et al., 2013), soil heat flux (Liakatas et al., 1986; Ham and Kluitenberg, 1994; Bonachela et al., 2012), and soil temperature (Decoteau et al., 1988; Cavero et al., 1996; Chellemi et al., 1997; Liu et al., 2009; Hou et al., 2010). The potential positive and negative effects of plastic-film mulch may explain the seemingly contradictory potato tuber yield results from the use of plastic-film mulch in different climatic regions or even from the same region during different growing seasons (Wang et al., 2009; Hou et al., 2010).

To efficiently use the positive effects of plastic-film mulch while avoiding its disadvantages, it is imperative to know how radiative and thermal conditions in a potato field are affected by the two most commonly used plastic-film mulches (transparent and black plastic-film mulches). The effects of plastic-film mulch on radiative and thermal conditions are dominated by the thermal and optical properties of plastic-film mulch. The plastic-film mulch effects on the radiative and thermal conditions can vary dramatically during different plant growth stages because progressively more of the mulch is covered by the plant canopy as it grows and the coverage diminishes as the canopy matures and senesces (Li et al., 1999; Hou et al., 2010).

Findings on mulching effects on thermal conditions and plant growth reported in the literature are contradictory. The transparent plastic-film mulch use results in higher soil temperature than the black mulch as shown for taro grown in southeastern Nigeria (Anikwe et al., 2007), watermelon grown in Croatia (Ban et al., 2009) and southwestern Mexico (Farias Larios and Orozco Santos, 1997), and cucumber grown in Syria (Yaghi et al., 2013). Meanwhile, the black plastic-film mulch produces higher soil temperature than the transparent plastic-film mulch as shown for potato grown in Spain (Ruiz et al., 1999, 2002; Baghour et al., 2003) and watermelon grown in Croatia (Romic et al., 2003). Some crop yields with black mulch are higher than with transparent mulch such as taro (Anikwe et al., 2007) and potato (Ruiz et al., 1999); whereas, other crop yields with black plastic-film mulch are lower than with transparent plastic-film mulch such as watermelon (Farias Larios and Orozco Santos, 1997) and cucumber (Yaghi et al., 2013). Black plastic-film mulch is better than the transparent plastic-film mulch for high yield in some years, while the transparent plastic-film mulch is better in other years at the same place (Ban et al., 2009). The yield with transparent plastic-film mulch is even lower than without mulch (Ruiz et al., 1999). These results suggest that the plastic-film mulch effects on radiative and thermal conditions are complex and it is more difficult to know how the dramatically-changed radiative and thermal conditions affect crop yield due to the difficulty in separating these mulching effects from other environmental influences.

Plastic-film mulch is known to increase soil temperature on potato (Ruiz et al., 1999, 2002; Baghour et al., 2003; Wang et al., 2009; Hou et al., 2010), but to our knowledge, there are few reports that present a thorough investigation of the plastic-film mulch effects on radiative and thermal conditions and its influence on drip-irrigated potato growth during different growth stages. The purpose of this experiment was to determine: 1) the effects of the two main standard plastic-film mulches (transparent and black) on radiative and thermal conditions in potato under surface drip irrigation during potato's five typical developmental stages in Northwest China, 2) how potato growth is affected by the two different plastic-film mulches and 3) which plastic-film mulch should be chosen for potato production.

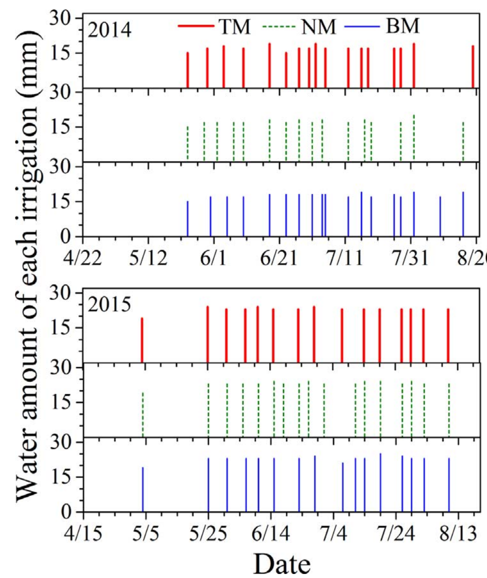

Fig. 1. The date and water amount of each irrigation for the different mulch treatments: transparent mulch (TM), non-mulched check (NM), and black mulch (BM) in 2014 and 2015.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted at the Shiyanghe Experimental Station (N 37°52′, E 102°50′, altitude 1581 m), China Agricultural University, Wuwei, Gansu Province, on the border of Tenger Desert in 2014 and 2015. The station is located in a typical continental temperate climate zone with a mean annual sunshine duration over 3000 h, mean annual air temperature of 8 °C and a frost free growing season of 150 d. The region has mean annual precipitation of 164 mm, mean annual pan evaporation of 2000 mm measured by a Class A evaporation pan, and limited water resources. The groundwater table varies between 25 and 30 m depth. The soil is sandy loam with mean soil bulk density 1.53 g/cm^3 at 0–1.0 m depth.

2.2. Experimental design

Experiments were carried out from April to August in 2014 and 2015. Three soil surface treatments were tested: 1) transparent plastic mulch (TM) with a film thickness of 0.008 mm, 2) a non-mulched check (NM), and 3) black plastic mulch (BM) with a film thickness of 0.008 mm. For the mulched treatments, the entire surface of each potato bed was covered with mulch. The treatments were replicated three times using a randomized complete block design.

2.3. Agronomic practices

Each plot was 6 m long and 5.6 m wide, containing 7 beds in north-south orientation (0.8 m wide and 0.2 m high). In the center of the beds, 30 g seed potatoes (cv. Kexin No.1, Inner Mongolia Minfeng Potato Industry Co., Ltd., Ulanqab, China) were planted every 30 cm. Holes 8 cm in diameter were punched through the film and the seed potatoes were placed 15 cm deep.

In 2014, the potatoes were planted on 22 April and harvested on 21 August. Before planting, 101 kg/ha N and 259 kg/ha P_2O_5 were applied. After planting, an additional 84 kg/ha N and 117 kg/ha K_2O were applied through the drip irrigation system on three dates: 40% on 10