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Influence of different plastic film mulches and wetted soil percentages on potato grown under drip irrigation

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ABSTRACT

Potato (*Solanum tuberosum* L.), an important food crop of Northwest China, is commonly grown using transparent plastic film mulch for water conservation since both irrigation water and precipitation are scarce. In order to improve production efficiency, field experiments were conducted at Shiyanghe Experimental Station, China Agricultural University, Wuwei, Gansu Province, China using plastic mulch and drip irrigation to study the influence of two typical plastic mulches (transparent and black) and three wetted soil percentages on potato root distribution, evapotranspiration, tuber yield and quality, and water use efficiency (WUE) in 2014 and 2015. Using a wetted soil percentage of 55%, three soil surface treatments were tested: transparent plastic mulch, black plastic mulch, and a non-mulched check. With the transparent plastic mulch, three wetted soil percentages 35%, 55%, and 75% were evaluated. The soil retained moisture better in the mulched treatments than in the non-mulched treatment. As the plant canopy increased, the differences diminished. Potato grown without plastic mulch developed more roots than potato grown with mulch. The soil water fluctuations in the top of the bed with black plastic mulch were greater than with transparent plastic mulch. Potato grown with either plastic mulch had greater yield and WUE than potato grown without plastic mulch. Potato grown with transparent plastic mulch had 10% and 7% greater WUE in 2014 and 2015, respectively than potato grown with black plastic mulch but the differences were not statistically significant. For different wetted soil percentages, the irrigation frequency was higher with the 35% wetted soil treatment than with 55% or 75%. The irrigation at 35% principally only affected the soil water in the upper soil in contrast to the 55% or 75% treatments. The 35% wetted soil treatment had more root development in 2015. Potato evapotranspiration increased as the wetted soil percentage increased. The 75% wetted soil treatment had significantly more evapotranspiration than the 35% wetted soil treatment in 2015. The 35% wetted soil treatment had the highest WUE, 17% and 25% higher than the 75% wetted soil treatment in 2014 and 2015, respectively. The 35% wetted soil percentage irrigation regime combined with transparent plastic mulch merits wider testing for potato production in arid Northwest China.

1. Introduction

Potato (*Solanum tuberosum* L.) is an important food crop of Northwest China where both irrigation water and precipitation are scarce. Plastic film mulching can save water (Li et al., 2004), modify the soil temperature (Hou et al., 2010; Filipović et al., 2016) and accelerate plant growth (Qin et al., 2016; Fan et al., 2016). Drip irrigation can save water and increase crop yields by delivering frequent, small amounts of water directly to the vicinity of the plants' roots (Darwish et al., 2003). The combination of drip irrigation with plastic mulch has proven benefits for potato (Wang et al., 2009, 2011), cotton (*Gossypium hirsutum* L.) (Zhou et al., 2012), and maize (*Zea mays* L.) (Qin et al., 2016) production in Northwest China.

Spatiotemporal changes in soil water not only affect soil temperature, soil aeration, and solute transport but also crop root growth and distribution (Feddes et al., 1976; Michelakis et al., 1993; Pivonia et al., 2004). The root distribution has great impact on soil water dynamics (Müller et al., 2016). Soil water distribution over time effects crop evapotranspiration, water use efficiency, yield, and quality. Potato is especially sensitive to soil water (Lynch et al.,

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1995; Fabeiro et al., 2001; Onder et al., 2005; Shock et al., 2007), soil temperature (Marinus and Bodlaender, 1975; Van Dam et al., 1996; Kar and Kumar, 2007), and soil aeration (Crawford and Braendle, 1996). The most favorable soil environment for potato growth consists of moist soil with small soil matric potential (SMP) variations (Wang et al., 2007; Shock and Wang, 2011), moderate soil temperature, and good soil aeration.

Both plastic mulch and drip irrigation profoundly influence soil environment, especially through spatiotemporal changes in soil water. Plastic film mulch increases soil temperature, improves root nutrient uptake, reduces water loss from the soil (Kasirajan and Ngouajio, 2012), and increases the soil water content in the upper soil (Liu et al., 2009; Gao et al., 2014). Different colored plastic film mulches have different thermal and optical properties, which in turn affect crop growth, yield, quality, and WUE. Reports on colored plastic film mulch have provided contradictory results. Crop yield with transparent plastic mulch can be greater than with black mulch (Yaghi et al., 2013; Chang et al., 2016), or it can be lower (Ruiz et al., 1999; Anikwe et al., 2007; Liu et al., 2016). Plastic mulch can reduce tuber specific gravity (Wang et al., 2011) or have no effect on the specific gravity (Rykbost and Cetas, 1977).

The wetted soil percentage which is the area wetted as a percent of the total irrigated area is a parameter used in drip irrigation system design (Keller and Karmeli, 1974). Appropriate wetted soil percentage can reduce soil evaporation and promote favorable soil aeration. Wetted soil percentages that are too low may cause water stress, while wetted soil percentages that are too high may cause soil water deep drainage, resulting in low water and fertilizer use efficiency and groundwater contamination. Different wetted soil percentages require different irrigation frequencies and result in different soil water regimes. The irrigation regime affects potato root growth, yield, quality, and WUE (Shock et al., 2007; Wang et al., 2011; Carli et al., 2014). The higher irrigation frequency of a small soil volume can reduce preferential water transport through macropores and increase fertilizer use efficiency as soluble nutrients are held more effectively in a smaller soil volume (Clothier and Green, 1994). Frequent and small irrigations can also result in higher root length density and root weight density (Wang et al., 2006). Moreover, frequent irrigation during early tuber development can significantly increase specific gravity and starch content, while decreasing protein content (Günel and Karadoĝan, 1998). The determination of a suitable wetted soil percentage for potato production could increase yields while conserving water.

The research reported here was conducted to determine: (1) the effects of different plastic mulches and wetted soil percentages on the fluctuations in soil water, potato root distribution, yield, quality, and WUE and (2) both the mulch treatment and the wetted soil percentage that should be used for potato grown with drip irrigation in arid Northwest China.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted at the Shiyanghe Experimental Station, China Agricultural University, Wuwei, Gansu Province in 2014 and 2015 (N 37°52′, E 102°50′, altitude 1581 m). The station is on the border of the Tenger Desert with a typical continental temperate climate. The region has ample sunlight with a mean annual sunshine duration of over 3000 h and a frost free growing season of 150 d. This region has limited water resources with a mean annual precipitation of 164 mm and a mean annual pan evaporation of 2000 mm, measured by a Class A evaporation pan. The average groundwater table fluctuated between 25 and 30 m below land surface. The dominate soil type is sandy loam with a mean soil bulk density of 1.53 g cm^{-3} at 0–100 cm depth.

2.2. Experimental design

Three different wetted soil percentages, the ratio between actual wetted soil volume and total soil volume within a specified soil layer (Keller and Karmeli, 1974; Zur, 1996; Yang et al., 2016), were evaluated using drip irrigation under transparent plastic mulch: 35%, 55%, and 75%. Three soil surface treatments (transparent plastic mulch, black plastic mulch, and a non-mulched check) were studied using drip irrigation with the same wetted percentage of 55%. For the mulched treatments, the surface of each potato bed was entirely covered with mulch 0.008 mm thick. Experiments each year had complete block randomized designs with three replications.

2.3. Agronomic practices

Each plot (6 m × 5.6 m) contained 7 north-south orientating beds (0.8 m wide and 0.2 m high). Pre-sprouted seed potatoes (30 g, cv. Kexin No.1, Inner Mongolia Minfeng Potato Industry Co., Ltd., Ulanqab, China) were hand planted every 30 cm in the center of the beds at a depth of 15 cm. Holes (8 cm in diameter) were punched through the film to plant the seed potatoes and the holes were backfilled with soil that was removed.

In the 2014 growing season, potato seed tubers were planted on 22 April and the crop was harvested on 21 August. Before planting, 259 kg Ha^{-1} P_2O_5 and 101 kg Ha^{-1} N were spread evenly. After planting, 84 kg Ha^{-1} N and 117 kg Ha^{-1} K_2O were applied through the drip irrigation system on three dates: 40% on 10 June, 30% on 23 June, and 30% on 12 July. The Metalaxyl-M mancozeb WG 68% (1.5 kg Ha^{-1} in 300 L of water) was sprayed on 9 June and 20 June for early and late blight control.

In the 2015 growing season, potato seed tubers were planted on 15 April and the crop was harvested on 20 August. Before the planting, 231 kg Ha^{-1} P_2O_5 and 90 kg Ha^{-1} N were spread evenly. After planting, 95 kg Ha^{-1} N and 117 kg Ha^{-1} K_2O were applied through the drip irrigation system on two dates: 50% on 31 May and 50% on 23 June. The Metalaxyl-M mancozeb WG 68% (1.5 kg Ha^{-1} in 300 L of water) was sprayed on 4 June and 16 June for early and late blight control.

2.4. Irrigation system, plastic mulch, and irrigation schedule

Each plot was irrigated by a drip irrigation sub-system, consisting of a sluice valve (Beijing Tianzhu North Butterfly Valve Manufacturing Co., Ltd., Beijing, China), a pressure gauge (Beijing Brighty Instrument Co., Ltd., Beijing, China), and a water meter (Lianyungang Water Meter Co., Ltd., Jiangsu, China). Drip tape (Beijing Luckrain Plastics Co., Ltd., Beijing, China) 0.4 mm thick with a 16 mm inner diameter was placed on the surface of the center of each bed with emitters pointing downward. Drip tapes of each plot were connected to a 16 mm diameter polyethylene (PE) pipe and fixed with soil at the end of beds. The emitter spacing was 0.2 m. The emitter flow rate (Q) was 1.38 L h^{-1} at the operating pressure (H) of 0.1 MPa, with the coefficient of variation 1.99%. The relation between Q and H was: $Q = 0.1055H^{0.5540}$, with $R^2 = 0.9975$.

After the drip irrigation system installation, the plastic film (polyethylene blown film, 1.2 m wide, 0.008 mm thick, Shandong Jining Zhongqu Double Star Plastic Products Factory, Jining, China) was laid tightly on the surface of each mulched bed. The plastic film was fixed in the furrow by covering the edge of the film with 2–5 cm of soil. Each treatment had two tensiometers (Beijing Waterstar Technology Co., Ltd., Beijing, China) in two different plots. The tensiometers were installed at 20 cm depth, directly under the drip