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Effects of mulching and nitrogen on soil temperature, water content, nitrate-N content and maize yield in the Loess Plateau of China

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ABSTRACT

In the semi-arid region of the Loess Plateau in China, the use of alternative field management practices is essential for sustainable agriculture. The purpose of this study was to investigate the effect of mulching and fertilization on the soil temperature, soil water content, soil nitrate-N content and grain yield of maize. The experiment was conducted over three consecutive years and used randomly assigned field plots with five replicates. The six treatments consisted of no fertilizer without plastic film (CK), no fertilizer with plastic film (ZM), basal fertilizer without plastic film (BN), basal fertilizer with plastic film (BM), basal and top dressing without plastic film (BTN) and basal and top dressing with plastic film (BTM). The soil temperature of the 10-cm mulching treatment was significantly higher than that of the no-mulching treatment, and the average soil temperature of the mulching treatment increased by 2.3 °C before July and nearly 1.2 °C after July. The soil water content in the mulching treatment was significantly higher than that in the no-mulching treatment at 0–60 cm, which was not significantly different from the 140–200 cm depth. The trend in the soil nitrate-N content distribution revealed symmetrical shapes along the center of the furrows, and the standard symmetrical distribution reduced gradually with an increase in soil depth under the plastic film mulching conditions. The soil nitrate-N content under basal fertilizer was 1.65 times higher than that without fertilizer at 0–10 cm at 36 days after sowing. The soil nitrate-N content in the topsoil was reduced from 48.67 to 30.77 mg/kg after 58 days. We found that plastic film mulching with basal fertilizer increased maize yield by 10.61%, 9.48%, and 15.36%, and top dressing increased the yield by 16.61%, 20.94%, and 12.24% over the three consecutive years. A treatment involving plastic film mulching, basal fertilizer and top dressing is recommended. Further studies are required to investigate the effect of mulching on increased soil temperature, soil water content and soil nitrate-N content, which simultaneously affect yield, and to determine the effects on the field microclimate.

1. Introduction

The success of agriculture in keeping pace with the population explosion has been depended on hybrid crops varieties, fertilization, irrigation and innovations in field management (Godfray et al., 2010). In particular, plastic film mulching has proven to be one of the most effective methods to increase water use efficiency and grain yield in dry farming agricultural areas (Fisher, 1995; Wang et al., 2009). The advantages of plastic film mulching have been reported since the middle of the last century, and the technique has reduced harvest time by up to nine days (Andrew et al., 1976) and has almost doubled grain yield (Hopen, 1964). Studies have indicated that mulching is conducive to crop growth by improving the soil water content and soil temperature in dryland agriculture (Cook et al., 2006). Mulching also has the benefit of improving soil physical conditions, including the protection of topsoil stability (De Silva and Cook, 2003). A higher soil temperature and better soil moisture increase seed fertility and individual plant yield under plastic film mulching (Zhou et al., 2009). Studies have demonstrated that the benefits of plastic mulching result from the adjustment of the soil environment caused by an increase in soil temperature and a reduction in evaporation, weed competition, soil compaction, and soil erosion. These changes in the soil environment are good for crop root growth, and the stronger ability of

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roots results in increased absorption of water and nutrients, which improves plant growth rates (Clark et al., 2003).

On the Loess Plateau, the field management practice of plastic film mulching has been extensively applied to crop production (Wang et al., 2009; Zhang et al., 2011). Maize yield has been increased by plastic film mulching for two major reasons. First, plastic film mulching reduces soil evaporation by intercepting the steam that is released when water moves from deeper soil layers to the topsoil by capillarity and maintains the stability of the topsoil water content, which increases crop transpiration. Second, plastic film mulching increases the soil temperature through the greenhouse effect, which absorbs solar radiation above the mulching and reduces heat loss, improving crop production.

Increased yield in response to plastic film mulching not only results in improved soil water content and increased soil temperature but also directly changes soil biological characteristics and fertility (Grassini et al., 2009; Liu et al., 2013). The soil nitrate-N content is an important indicator of soil fertility and productivity (Reeves, 1997). In the semi-arid region of Tunisia, nitrogen (N) fertilization was shown to increase durum wheat production under dry conditions with poor water supply (Barron et al., 2003; Latiri-Souki et al., 1998). However, grain yield may be reduced with the excessive application of N fertilizer. In addition, N fertilization should be modulated because excessive N fertilization can pose a danger to the environment and is wasteful in terms of economic efficiency (Morell et al., 2011). The variation in crop yield response to fertilizer application, which occurs because of unstable precipitation and differences in the fertilizer rate and disposal of crop residues, might result in loss of fertilizer under traditional farming systems (Wang et al., 2010). Thus, it is important to quantify the relationship between N fertilization and the vertical distribution of the soil nitrate-N content.

Previous studies have been conducted to quantify N removal and mulching in maize site-specific field experiments, mainly at research stations. Very few have attempted to investigate the relationships between N removal and mulching and soil water and nitrate-N contents across widely varying field environments, especially in high-yielding systems (Cai and Sharma, 2010; Knoth et al., 2013; Li et al., 2013; Miriti et al., 2012). This study evaluated the feasibility of using alternative field management practices to contribute towards food security and sustainable agriculture. Therefore, the aim of the study was to evaluate the effect of plastic film mulch on the vertical distribution of soil temperature, soil water contents, and soil-N content in a maize crop on the Loess Plateau of China.

2. Materials and methods

2.1. Experimental site

The field experiment was conducted at the Changwu Experimental Station (35°12′N, 107°40′E and altitude 1206 m) on the Loess Plateau in Changwu county of Shaanxi Province, China. The climate is temperate semi-arid with a mean annual air temperature of 9.1 ± 2.3 °C, a mean monthly maximum temperature of 22 °C (July) and a mean monthly minimum temperature of −7 °C (January). The average annual sunshine duration is 2230 h with more than 171 frost-free days. The mean annual precipitation from 1990 to 2012 was 571 ± 74 mm, of which approximately 55% fell during the growing season between July and September. The rainfall during the experimental period was measured using an automatic weather station (Changwu experimental station meteorological observatory, WS-STD1, England) at the experimental site. According to the USDA textural classification system, the soil has a silty loam texture, which is derived from loess with a deep and even soil profile. Soil sample was dried at room temperature (75 °C) in the laboratory to a constant weight and sieved (2 mm) to eliminate coarse soil particles. Soil acidity (pH) was measured in an aqueous soil extract in de-ionized water (1:2.5 soil:water). Bulk density was measured by the core method, using cores that measured 3 cm in diameter, 10 cm in length, and 70.68 cm^3 in volume. Field capacity at 33 kPa was determined using a pressure-membrane extraction apparatus. Soil organic matter was determined using the Walkley–Black method (Antonio et al., 2010). The topsoil (0–80 cm) is 35% clay, 62% silt, and 3% sand with a pH of 8.3, and has a bulk density of 1.28 g/cm^3, a field capacity of 24.5% cm^3/cm^3, an organic matter content of 11.8 g/kg, a total nitrogen content of 0.81 g/kg, an available phosphorus content of 14.2 g/kg, an available potassium content of 145.8 g/kg and an inorganic nitrogen content of 4.12 g/kg.

2.2. Experimental design

In this experiment, six treatments were designed and applied: (1) a flat plot (8 × 4 m) with no basal fertilizer, no top dressing and no mulching (CK); (2) plastic film mulching with no basal fertilizer and no top dressing (ZM); (3) basal N (80 kg/ha) and P (80 kg/ha) (Murungu et al., 2011) with no top dressing and no mulching (BN); (4) plastic film mulching and basal N (80 kg/ha) and P (80 kg/ha) with no top dressing (BM); (5) basal N (80 kg/ha) and P (80 kg/ha) and top dressing N (80 kg/ha) with no mulching (BTN); and (6) plastic film mulching with basal N (80 kg/ha) and P (80 kg/ha) fertilizer and top dressing N (80 kg/ha) (BTM).

The experiment was laid out using a randomized block design with five replications; each plot was 8 m long and 4 m wide. The entire experimental area was ploughed and leveled each year during the three-year period over which the experiment was conducted. Following dividing and ridging of 30 experimental plots, basal fertilizers (80 kg N/ha and 80 kg P/ha) were mixed in the soil for the BN, BM, BTN, and BTM treatments. Maize was planted at a 30- cm row and 60-cm line spacing, and a sketch showing the width direction arrangement is presented in Fig. 1. Mulching was laid over the soil surface layer of the ridges, 80 cm wide and 0.008 mm thick (Yonggu suye Co., Ltd., Shaanxi, China).

The maize breed (*Zea mays* L., cv. ‘Liyu 18’) was sown on 22 April 2010, 26 April 2011, and 21 April 2012, using a hole-sowing tool (3-cm diameter). Top dressing N (80 kg ha^{-1}) fertilizer was applied in late June (BTN, BTM). The maize crop was harvested on 17 September 2010, 21 September 2011, and 18 September 2012. After harvest, the plastic film was gathered and recycled by the manufacturer. Traditional tillage in dry farming areas of northern China involves mouldboard ploughing (motorized) to a depth of 16–18 cm, followed by a sequence of harrowing, smoothing, rolling, and hoeing.

2.3. Sampling and measurements

Soil temperature measurements (*N* = 3 repeated three times per treatment)

- A batch of rectangular geothermometers (Jingda Thermal Instruments, Wuqiang County, Hebei Province, China) was placed in the middle of a ridge and furrow in every treatment plot at depths of 0, 5, 10, and 20 cm.
- On bright sunny days, the soil temperature (Dwyer et al., 1990) was recorded hourly from 08:00 to 20:00, i.e., on 26 June 2010 (65 days after sowing), 29 June 2011 (64 days after sowing), and 22 June 2012 (62 days after sowing).
- For three consecutive field seasons, the soil temperature was recoded at nearly 15-day intervals from sowing to harvesting.