

Effects of Different Plastic Mulching Methods on Soil Water, Temperature and Nitrate Accumulation in a Dryland Winter Wheat Field

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Abstract

This study has investigated the effects of two different plastic mulching methods on soil water, temperature, and nitrate (NO₃-N) accumulation in a dryland winter wheat field after one-year experiment. The drought-resistant wheat (*Triticum aestivum*) variety *Chang-8744* was grown by (i) furrow planting with ridge mulching, (ii) bunch planting with flat mulching, and (iii) conventional flat planting without mulching (or control). Results showed that dryland winter wheat effectively utilized soil water down to 2 m depth, mainly in the first 140 cm. Plastic mulching increased the evapotranspiration during wheat growing season and mostly r flat plastic mulching, by ~18% over the value recorded in the control plots. Soil temperature of the 20-40 cm-layer was higher than the one recorded at 5-10 cm depth during seedling-overwintering stages. Ridge plastic mulching and flat plastic mulching increased soil temperatures at 5 cm, 10 cm, and 40 cm depths during seedling-overwintering stages with reference to the control (no mulching), then lowered them at the same depths during reviving-ripening stages. Residual NO₃-N was always detected in the soil after harvesting irrespective of the mulching method. It was mainly concentrated in the first -60 cm accounting for ~50% of soil NO₃-N accumulation within the 2-m profile. The highest soil NO₃-N accumulation occurred under flat plastic mulching, which represented ~107% of the mean value of the remaining treatments. Finally, flat plastic mulching showed the greatest effects on soil water, temperature, and NO₃-N accumulation in dryland wheat field.

Keywords: evapotranspiration, soil temperature

1. Introduction

Dryland winter wheat is one of the major staple crops in China's Shanxi Province, which is a typical rainfed agricultural area. Winter wheat production in this area is constrained by the uneven distribution of precipitation (~500 mm yearly) and its inconsistency with the water requirement of wheat. Therefore, effectively harvesting rainwater, preserving soil moisture, and coupling water with fertilizers is critical for stable production of rainfed winter wheat.

In recent years, mulching techniques have been widely promoted and applied as an important measure to increase soil temperature, preserve soil moisture to ensure optimum crop yields in the rainfed agricultural areas of northern China (Li et al., 2001; Gao et al., 2005; Debashis et al., 2008; Chen et al., 2010). A previous study found that the water consumption (*i.e.*, evapotranspiration) of plastic mulching was significantly higher than that of no mulching during the growing season in Lanzhou, Gansu (Yang et al., 2015). Plastic mulching showed a remarkable effect on harvesting rainfall and effectively increased soil water content in the surface layer in Wuchuan, Inner Mongolia (Wang et al., 2013). Additionally, plastic mulching markedly enhanced crop utilization of soil water in the deep layer in Yangling, Shaanxi (Wang et al., 2004).

Many studies have indicated that plastic mulching can affect the variation in soil temperature. Plastic mulching resulted in an obvious temperature rise in the Jungar Banner of Inner Mongolia; the largest temperature difference was found at 10 cm and 20 cm depths, with a temperature increase of ~2.5 °C (Li et al., 2010). Compared with the control (no mulching), plastic mulching also showed a common effect of increasing soil temperature in Yuzhong, Gansu (Cheng et al., 2016). With regard to soil nitrate (NO₃-N) accumulation, the highest NO₃-N concentration was found at the 0-10 cm depth under plastic mulching treatment in Dingxi, Gansu

(Zhang et al., 2011). Soil NO₃-N concentration was influenced by plastic mulching within a range of 0-80 cm in the loess highland area of northwest China (Wang et al., 2015).

There exist regional differences in the effects of plastic mulching on soil water, temperature, and NO₃-N accumulation in dryland wheat fields due to different environmental conditions. In the present study, field experiments were conducted during 2014-2015 in a rainfed agricultural area of southern Shanxi, China that aimed at assessing variations in soil water, temperature, and NO₃-N concentration under two different plastic mulching methods. The results would provide reference data for the high yield and stable production of dryland winter wheat in southern Shanxi, China.

2. Materials and Methods

2.1 Experimental Site

The experiment was carried out during 2014-2015 in a dry highland wheat area of Dongliang Village, Liujiayuan Town, Hongtong County, Linfen City, Shanxi Province, China. This area has a warm temperate continental monsoon climate with an average annual sunshine of 2419 h. The effective accumulated temperature was 3326.9 °C and the average annual temperature 12 °C. The frost-free period lasted 180-210 days, with the average annual rainfall of ~500 mm. The experimental site's soil was calcareous cinnamon with a medium loam texture. The chemical characteristics of the topsoil before planting are shown in Table 1.

Table 1. Chemical characteristics of the topsoil before planting

Year	Organic matter g/kg	Total N	NO ₃ -N mg/kg	Available P	Available K	Cation exchange capacity	pH
2014	14.52	0.77	8.63	12.23	198.14	48.27	7.84

2.2 Experimental Design

Three treatments were applied in the experiment including (i) control *i.e.* conventional flat planting without plastic mulching, (ii) furrow planting with ridge plastic mulching, and (iii) bunch planting with flat plastic mulching, with four replications. The experiment was arranged in a randomized complete block design. The elementary plot area was 470 m². All fertilizers were applied once as basal fertilizers before sowing, and no irrigation was applied during the growing season of wheat. The drought-resistant wheat (*Triticum aestivum*) variety *Chang-8744* was sown at a rate of 150 kg/hm² during September 30-October 1, 2014 and harvested on June 7, 2015 for estimation of the whole plot yield (Gao et al., 2016).

For the control, conventional flat planting was conducted with shallow rotary tillage 13 cm deep before sowing; after breaking the clods and flattening of the soil, seeds were sown with a row spacing of 20 cm. For the ridge mulching, ridges were covered with plastic film and seeds were sown in 30 cm-width furrows at the side of the plastic film; seeds were sown in two rows spaced 20 cm apart, with a ridge width of 35 cm. For the flat mulching, the whole ground was covered with flat plastic film fixed with an overlying layer of soil approximately 0.5-1 cm thick; seeds were sown to 3-5 cm depth, in rows spaced 15-16 cm apart and bunches spaced 12 cm apart; the plastic film was 120 cm wide each lane, with 7-8 rows per lane.

2.3 Soil Physicochemical Analysis

Soil samples were collected down to 2 m depth at 20 cm intervals before sowing (September 23) and after harvesting (June 7) during the growing season of 2014-2015. Three parallel samples were taken for each treatment. For soil NO₃-N analysis, 5 g of fresh soil sample was weighed and transferred into 50 mL of 0.01 mol/L CaCl₂ and oscillated for 30 min. The NO₃-N concentration in the extracts was measured using an AA3 continuous flow analyzer (Brown rupee, German). Additionally, soil water content was measured by the oven drying method (105 °C, 12 h).

NO₃-N accumulation (kg/hm²) = Soil depth (cm) × Bulk density (g/cm³) × NO₃-N concentration (g/kg)/10.

Soil water content = (Quality of aluminum box and soil sample before drying – Quality of aluminum box and soil sample after drying)/(Quality of aluminum box and soil sample after drying – Quality of dry empty aluminum box) × 100 %.

Evapotranspiration (mm) = Soil water storage in the 2-m profile before sowing – Soil water storage in the 2-m profile at harvesting + Effective precipitation during the growing season of wheat.

Temperature loggers (TidbiT v2 Temp, Hobo, USA) were installed at 5 cm, 10 cm, 20 cm, and 40 cm depths to collect data automatically and continuously. Temperatures were recorded at a frequency of 1 h.

2.4 Data Analysis

The experimental data were analyzed using Excel and DPS statistical software.

3. Results

3.1 Effects of Different Plastic Mulching Methods on Soil Water Content

Soil water content within the 2-m profile of different treatments generally decreased after harvesting compared with values recorded before sowing (Figure 1); this indicated that winter wheat growth could absorb soil water up to a depth of 2 m. The different treatments showed greater effects on soil water content at 0-140 cm depth, while no major effects were observed at 140-200 cm depth. In particular, flat plastic mulching resulted in the largest reduction in soil water content at 0-140 cm depth (6-9%). The surface soil water content in the flat plastic mulching plots decreased after harvesting, probably because only 95.90 mm of precipitation fell during the wheat growing season and was absorbed for crop growth, thus resulting in the relatively low soil water content in the surface layer at harvest.

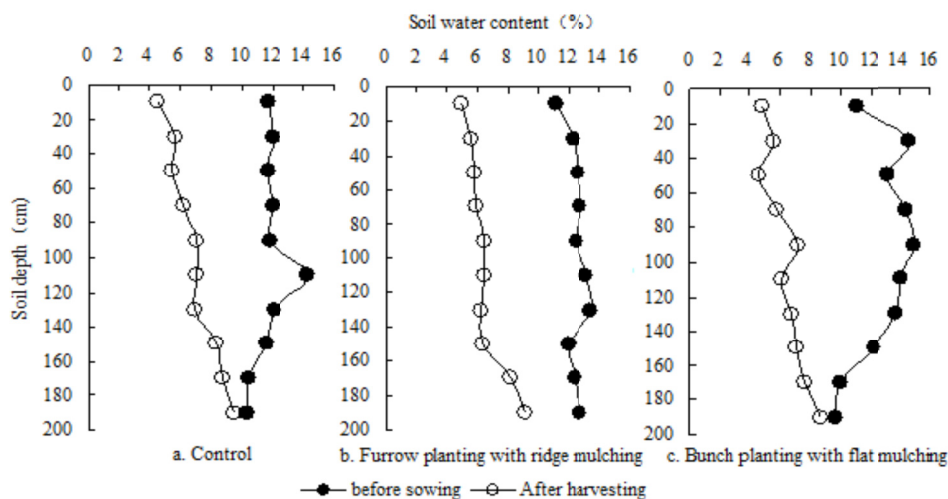


Figure 1. Effect of different plastic mulching methods on soil water content in the 0-200 cm profile

Note. a. Control (before sowing: ●); Control (after harvesting: ○); b. Furrow planting with ridge mulching (before sowing: ●); Furrow planting with ridge mulching (after sowing: ○); and c. Bunch planting with flat mulching (before sowing: ●); Bunch planting with flat mulching (after sowing: ○).

3.2 Effects of Different Plastic Mulching Methods on Soil Evapotranspiration

Estimates of the evapotranspiration of the control, ridge plastic mulching, and flat plastic mulching treatments were 235.08 mm, 266.30 mm, and 277.69 mm, respectively. This result indicated that soil evapotranspiration increased with plastic mulching. Significant increases were detected in both the ridge plastic mulching and flat plastic mulching compared to control (no mulching). In fact, ridge plastic mulching increased the evapotranspiration by ~13% and flat mulching by ~18%. These results indicated that following plastic mulching, the consumption of soil water was conducive to downward root growth of the crops and the absorption of soil water in the deep layers.

3.3 Effects of Different Plastic Mulching Methods on Soil Temperature

In mulched plots, soil temperature ranged from 6.1 to 10.4 °C in November and gradually decreased from December to January, followed by a rebound in February and then a peak in June. At 5 cm and 10 cm depths, the soil temperature of flat plastic mulching plots was higher than those of ridge plastic mulching and non-mulched plots during the period of November-February (overwintering stage); the mean temperature increases were 0.3-0.9 °C at 5 cm depth and 0.3-0.8 °C at 10 cm depth. The soil temperature of the control plots increased compared with those of mulched plots during March-June; mean temperature increases at 5 cm and 10 cm depths were 0.1-0.8 °C and 0.1-0.7 °C in March (reviving stage), and 0.9-1.7 °C and 0.9-1.6 °C during April-June

(jointing-ripening stages), respectively. At 20 cm soil depth, soil temperature of the control increased by 0.6 °C in November-February and by 0.4 °C in March, whereas the soil temperature of flat mulched plots increased by an average of 0.9 °C during April-June compared to mean value of the remaining treatments. At 40 cm soil depth, the soil temperature under flat mulching increased by 0.7 °C during November-February and by 0.2 °C in March, while the soil temperature of control treatment increased by an average of 0.8 °C during April-June compared with the remaining treatments. Thus, bunch planting with flat plastic mulching had a significant effect on heat preservation in the deep soil layer (40 cm) during the overwintering stage; in the middle-late growth stages of wheat with increasing air temperature, the no mulching treatment showed the greatest temperature-increasing effect, while the plastic mulching treatments exhibited a temperature-reducing effect.

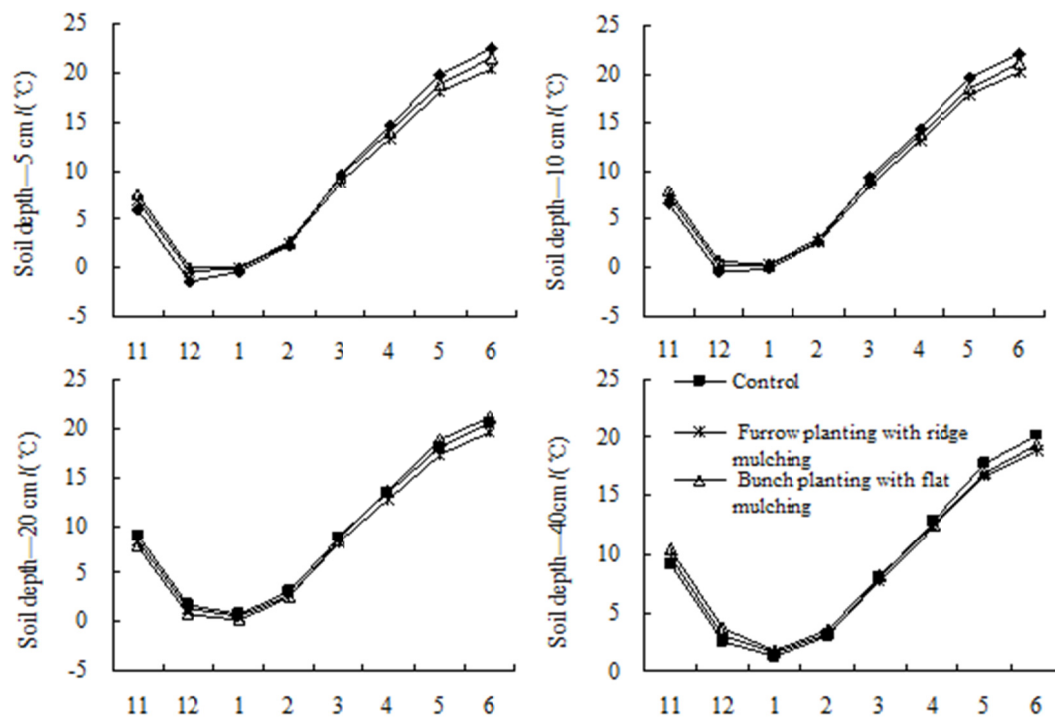


Figure 2. Variation of soil temperature of 0-40 cm topsoil under the two plastic mulching methods and no mulching

3.4 Effect of Different Plastic Mulching Methods on Soil $\text{NO}_3\text{-N}$ Accumulation

Degrees of $\text{NO}_3\text{-N}$ accumulation in the 0-200 cm soil profile varied among different treatments after harvesting compared to amounts of $\text{NO}_3\text{-N}$ observed before sowing (Figure 3). Higher accumulation occurred at -100 cm depth, with little difference at 100-200 cm depth. Maximum $\text{NO}_3\text{-N}$ accumulation ranged from 29.19-32.65 kg/hm^2 at 20-40 cm depth. At 0-60 cm depth, the largest increase in $\text{NO}_3\text{-N}$ accumulation was found under flat plastic mulching, *i.e.* 5.96-7.73 kg/hm^2 , whereas the smallest increase (0.72-4.16 kg/hm^2) was found under ridge mulching, as compared with the corresponding level before sowing. At 60-100 cm depth, the $\text{NO}_3\text{-N}$ accumulation under flat plastic mulching increased by 2.75-5.81 kg/hm^2 compared with the level before sowing, while ridge mulching resulted in the largest increase in $\text{NO}_3\text{-N}$ accumulation (3.88-6.72 kg/hm^2). At depths below 100 cm, soil $\text{NO}_3\text{-N}$ accumulation decreased to different degrees under both ridge plastic mulching and flat plastic mulching, but the relative decrease was larger in the latter treatment, in absolute terms (Figure 3).

Our results showed that following plastic mulching, $\text{NO}_3\text{-N}$ accumulation increased at 0-100 cm- soil depth, while no major difference was found at 100-200-cm soil depth. This may be due to the fact that at the later growth stages of wheat, the roots grew downward and promoted nutrient absorption in the lower soil layers, thus resulting in decreased $\text{NO}_3\text{-N}$ accumulation in the deep soil. By contrast, $\text{NO}_3\text{-N}$ accumulation reached a peak at 20-40 cm depth, which may be attributable to precipitation that caused $\text{NO}_3\text{-N}$ leaching loss from 0-20 cm soil depth and subsequent accumulation toward 20-40 cm soil depth. For the flat mulching, $\text{NO}_3\text{-N}$ accumulation mainly occurred at 0-60 cm depth, while it was slightly decreased at 60-100 cm depth. There was little residual $\text{NO}_3\text{-N}$ at 100-200 cm depth after harvesting, indicating that flat plastic mulching was conducive to nutrient

absorption by wheat from the deep soil; this may be due to the fact that the migration of $\text{NO}_3\text{-N}$ occurred with the movement of water. Following plastic mulching, the increase in crop yields was related to downward root growth of the crops, which could absorb and utilize water and nutrients in the deep soil (Cao et al., 2014).

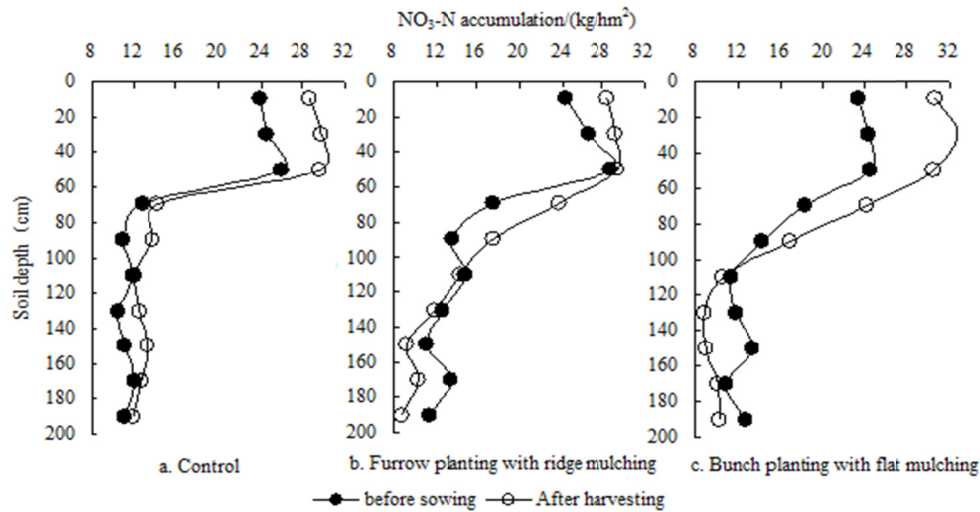


Figure 3. Effects of different plastic mulching methods on $\text{NO}_3\text{-N}$ accumulation in the 0-200 cm soil profile

Note. a. Control (before sowing: ●); Control (after harvesting: ○); b. Furrow planting with ridge mulching (before sowing: ●); Furrow planting with ridge mulching (after sowing: ○); and c. Bunch planting with flat mulching (before sowing: ●); Bunch planting with flat mulching (after sowing: ○).

4. Discussion and Conclusion

This study showed that plastic mulching reduced water evaporation and preserved soil water, which is in agreement with previous research on plastic film mulching. Our results showed that evapotranspiration was mainly concentrated to the top 0-140 cm of the soil under bunch planting with flat plastic mulching in wheat field in south Shanxi. Yang et al. (2011) showed that plastic mulching was conducive to increasing soil water content and promoting the expansion of soil water reservoir capacity. Li et al. (2011), and Ren et al. (2010) showed that under furrow-ridge mulching, natural precipitation was effectively stored and infiltration was enhanced, which significantly increased soil water storage in dryland wheat fields. By comparison, bunch planting with flat plastic mulching contributed to water storage and preservation to a greater degree. He et al. (2010) showed that bunch planting with whole plastic mulching contributed to rainwater harvesting and soil water preservation to a maximized degree. Song et al. (2014) conducted bunch planting with whole plastic mulching in dryland wheat field in a semi-arid area for two consecutive years and found the depth of evapotranspiration extended to 200 cm.

Different mulching techniques can induce variations in soil temperature among other parameters. In fact, plastic mulching reduces soil water evaporation and increase surface soil temperature (Licht et al., 2005; Zhao et al., 2011). Chen et al. (2009) showed that at the overwintering stage, soil temperature in the deep layer was higher than that in the surface layer. This is generally consistent with our results whereby bunch planting with flat plastic mulching had a significant effect on the preservation of soil heat in the deep layer (40 cm) during the overwintering stage. In the present study, it was found that soil $\text{NO}_3\text{-N}$ accumulation in the 2-m profile of plastic mulching treatments increased after harvesting compared to before sowing, but was mainly concentrated 0-100 cm depth. Under bunch planting with flat plastic mulching, $\text{NO}_3\text{-N}$ mainly accumulated at 0-60 cm depth, with little $\text{NO}_3\text{-N}$ residue was found in deep soil layers.

Gao et al. (2005) showed that following plastic mulching, residual $\text{NO}_3\text{-N}$ was mainly concentrated in the 0-100 cm soil layer in wheat field. Chen et al. (2011) reported that soil $\text{NO}_3\text{-N}$ mainly accumulates above 60 cm, while it decreases in deep layers gradually under different ridge-furrow cultivation patterns in the Weibei highland area. Xie et al. (2015) concluded that bunch planting with whole plastic mulching markedly reduces $\text{NO}_3\text{-N}$ accumulation in deep soil.

Although this study only presented the experimental results of one year, the findings were generally consistent with those from other local experimental studies by Li et al. (2011), Xie et al. (2011), Feng (2013), and Zhao et al. (2015) and showed certain trends. All the findings indicated that plastic mulching could improve winter wheat yield, regulate soil temperature, increase soil water, and promote crop absorption and utilization of water and nutrients.

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