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# Effects of straw mulch and buried straw on soil moisture and salinity in relation to sunflower growth and yield

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ABSTRACT

Salt accumulation in the root zone can be controlled by reducing the upward movement of salts and evaporation in arid areas of China. This paper aimed to examine the effects of the combined application of straw mulch and buried straw layer on soil moisture, soil salinity and growth of sunflower (*Helianthus annuus* L.) plants. A three-year field experiment was conducted in the Hetao Irrigation District, Inner Mongolia, China. Three field management practices were studied: deep tillage with no mulch (CK), deep tillage with straw mulch (SM) and combined application of straw mulch and burying of a maize straw layer (12 t $ha^{-1}$) at a depth of 40 cm (SM + SL). Except in the second half of the first growing season, soil moisture at the 0–40 cm depth was higher with SM + SL and SM than CK. Also the topsoil (0–20 cm) moisture during the early growth period under SM + SL was higher than that under SM by 1.6–9.9% in 2011 and 1.6–3.4% in 2013, but the value for SM + SL was 2.1–10.4% higher than that for SM during the whole growth period of 2012. Compared with SM, the topsoil salinity under SM + SL decreased by 5.4–23.0% in 2011, 0.7–19.8% in 2012 and 4.5–31.6% in 2013 but these two mulch treatments moderately increased the soil salinity in the subsoil (20–40 cm) layer compared with CK. Furthermore, SM + SL promoted sunflower growth, as indicated by taller plants and greater leaf area index. The highest sunflower shoot biomass was always obtained from the SM + SL treatment. Averaged across the three years, SM + SL increased the shoot biomass by 4.8% compared to SM and 20.8% compared to CK. The SM + SL may be an effective saline soil management practice in the Hetao Irrigation District and other similar ecological areas.



## 1. Introduction

Salinity has severely restricted global agriculture in arid and semiarid regions. At present, this stress is becoming even more prevalent as the intensity of land use increases throughout the world (Meloni et al., 2003; Dong et al., 2008, 2009). The Hetao Irrigation District, located in northwestern China, has an irrigated land area of 570,000 ha, and approximately half of the irrigated cropland is saline soil (Feng et al., 2005). Irrigation through Yellow River water plays an important role in crop production and agricultural development in this area. To reduce soil salinity and increase crop yields, flood irrigation has always been used. However, inappropriate irrigation and drainage systems have resulted in rising groundwater levels, which have the potential to trigger salt accumulation in the soil profile and have a negative effect on crop production (Sharma and Minhas, 2005; Qadir et al., 2009). In addition, limited precipitation, high evaporation and inadequate soil and water management have contributed to an increase in salinity. Therefore, effective techniques for controlling soil salinity and increasing water productivity should be developed to cope with these challenges (Dong et al., 2010a,b).

Sunflower (*Helianthus annuus* L.) is one of the most important economic crops in this area. Although sunflowers are classified as a salt-tolerant crop, they are also sensitive to salinity in the growth and development stages, especially during the emergence and early seedling stages. Reducing root zone salinity is one beneficial strategy to improve sunflower emergence and stand establishment in saline fields. Under conventional tillage regimes, several techniques, such as inorganic fertilisers, soil amendments, and mulching with different materials, have been used to increase sunflower yields (Qadir et al., 2000; Chen and Dong, 2008). However, these field practices have always followed abundant water input. Conversely, mismanagement of fertiliser and water applications results in salt accumulation (Darwish et al., 2005). The sunflower root system is dense in the upper 20 cm of the soil layer, with a trend toward rooting downward (Hu et al., 2013). Therefore, maintaining soil salinity levels within acceptable crop production limits in this

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layer should be the primary goals of soil and water management (Bezborodov et al., 2010).

Mulching with different materials has been demonstrated to reduce water evaporation (Li et al., 2013; Pabin et al., 2003), improve fallow efficiency and increase the amount of stored soil water available for plant use (Wang et al., 2001), and reduce salt build-up in the soil (Pang et al., 2010). Based on field experiments, Mulumba and Lal (2008) reported that crop residues placed on the soil surface shade the soil, reduce unproductive water evaporation, and enhance available water capacity, moisture retention and aggregate stability. Deng et al. (2006) reported that mulching with crop residues improved water-use efficiency by 10–20% as a result of reduced soil evaporation and increased plant transpiration. Carter (1998) observed that mulching results in higher soil moisture during the entire crop growth period and provides the best opportunity for increasing crop productivity. Havlin et al. (1990) and Lal and Stewart (1995) showed that returning crop residues to the soil has a beneficial effect on building soil organic carbon, which thereby improves soil quality and productivity.

A deeply buried straw layer in the soil serves as a water and salt transport barrier, inhibiting the movement of salts from the subsoil and shallow groundwater to the topsoil during the water evaporation process (Chi et al., 1994; Tumarbay et al., 2006). Based on field study results, Zhang et al. (2009) and Li et al. (2012) reported that straw layer burial enhanced salt leaching and controlled salt accumulation in the root zone. Other benefits of burying a straw layer deep in the soil have also been reported by other researchers, such as a reduction in soil pH, a decrease in particle density and improvement in plant earliness (Fan et al., 2012; Zhao et al., 2003). In addition, the straw layer burial promoted soil physical and chemical properties (Yang and Chen, 2000; Wang et al., 2012; Li et al., 2009).

Most previous works have concentrated on the beneficial effects of the individual use of straw mulch or buried straw layer on soil moisture, salinity and crop production. However, studies have rarely addressed the effects of combining straw mulch and straw layer burial on soil moisture and salinity dynamics and crop growth in saline soils. Currently, tillage machine for burying straw layer have been designed and are widely used in China (Wang et al., 2011; Zhao et al., 2013). Thus, the main objective of the study was to determine the effects of combining straw mulch and buried straw layer on soil moisture and salinity dynamics as well as sunflower growth and yield.

## 2. Materials and methods

### 2.1. Experimental area

Field experiments were conducted from October 2010 to September 2013 at the experimental station of the Management Department of Yichang Irrigation Sub-district (41°04′N, 108°00′E, 1022 m ASL) in the Hetao Irrigation District, Inner Mongolia, China. The study area has a typical arid continental climate that is very cold in the winter with little snowfall and very dry in the summer with little rainfall. The mean annual precipitation in the region is approximately 170 mm, occurring mainly between July and August. The mean annual evaporation is approximately 2068 mm, being 11 times the value of annual rainfall. The annual average temperature is 8.1 °C, with monthly averages ranging from 23.76 °C in July to 10.08 °C in January (Wu et al., 2008). The groundwater table at this site varied from 1.2 to 2.6 m, with a salt concentration ranging from 1.5 to 1.8 g $L^{-1}$. The soil texture is silt loam with severe salinization. The main physico-chemical properties of the pre-experiment soil are presented in Table 1.

**Table 1**
Soil properties of the pre-experimental soil in the study site collected at 0–40 cm depth.

| Soil properties | Soil depth (cm) | | | |
|---|---|---|---|---|
| | 0–10 | 10–20 | 20–30 | 30–40 |
| Sand (%) | 34.09 | 35.75 | 36.22 | 37.38 |
| Silt (%) | 51.92 | 53.76 | 53.46 | 55.38 |
| Clay (%) | 13.99 | 10.49 | 10.32 | 7.24 |
| Bulk density (g $cm^{-3}$) | 1.45 | 1.47 | 1.49 | 1.47 |
| Organic matter (g $kg^{-1}$) | 11.06 | 10.63 | 8.21 | 6.94 |
| Available N (mg $kg^{-1}$) | 35.62 | 31.91 | 30.33 | 29.68 |
| Available P (mg $kg^{-1}$) | 6.36 | 2.03 | 1.03 | 0.88 |
| Available K (mg $kg^{-1}$) | 161.29 | 115.12 | 98.24 | 80.37 |
| Salinity (g $kg^{-1}$) | 4.87 | 2.54 | 2.26 | 2.04 |
| pH ($H_2O$, 1:5) | 8.77 | 8.53 | 8.41 | 8.32 |
| SAR | 6.28 | 3.82 | 3.23 | 3.05 |

### 2.2. Experimental design and implementation

The experiment included three treatments: (i) deep tillage with no mulch (CK), (ii) deep tillage with straw mulch (SM), and (iii) combined application of straw mulch and burying of a straw layer at a depth of 40 cm at the beginning of the experiment (SM + SL). The treatments were arranged into a randomized complete block design with three replications. Each plot measured 4 $m^2$ (2 m × 2 m), and they were insulated by double-plastic sheets buried to a 100 cm depth relative to the soil surface to minimize the effects of lateral water and salt movement between plots. Each plot was surrounded by a concrete panel 40 cm wide and 60 cm high, and the exposed part of panel (approximately 20 cm) was hardened by cement.

After sunflowers were harvested in early October 2010, the upper 40 cm of soil in the SM + SL plot was removed at intervals of 20 cm depth by spade and placed in different positions, and then, the air-dried and chopped maize straw (10–15 cm) was uniformly placed on the bottom to a thickness of approximately 5 cm (equal to 12 t $ha^{-1}$). To guarantee the consistency of test conditions, the upper 40 cm of soil in the CK and SM plots was also dug out as performed in the SM + SL plot, but no straw layer was imposed. Based on the initial soil bulky density, the dug soil of each plot was refilled layer-by-layer and then flattened with a harrow. Afterward, the plots were flood irrigated with Yellow River water in later October (with a salt concentration approximately 0.58 g $L^{-1}$). For each plot, approximately 0.6 $m^3$ of water was applied. The straw layer burying operation was done once at the beginning of the experiment, and no straw layer was laid in the subsequent years.

To leach soluble salts for sunflower germination in each growing season, a second irrigation (0.6 $m^3$ $plot^{-1}$) was applied approximately 10 d before sowing. Considering the severely dry climate in 2011, the plots were covered completely with plastic film to reduce water loss by evaporation after spring irrigation until sowing. At sowing, the plots were ploughed to a depth of 15–20 cm and harrowed by hand when the mellowness of soil was physically acceptable. According to the local fertiliser practice, a compound fertiliser was applied at 180 kg $ha^{-1}$ N (using urea (46% N) plus DAP (diammonium phosphate, 18% N and 46% $P_2O_5$)), 120 kg $ha^{-1}$ $P_2O_5$ (using DAP) and 75 kg $ha^{-1}$ K (using potassium sulphate, 50% $K_2O$). After fertiliser application, the soil surface was leveled.

Sunflower was planted with a row spacing of 60 cm at a density of 49,000 plants per hectare. The sunflower cultivar LD 5009 was manually sown on 28 May 2011, 8 June 2012 and 2 June 2013. For the SM and SM + SL plots, approximately 6 t $ha^{-1}$ of air-dried and chopped maize straw (10–15 cm) was evenly applied to the inter-rows of sunflower after sowing. Neither irrigation nor fertilization was applied throughout the growing season. Sunflowers were harvested on 23 September 2011, 18 September 2012 and 16