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Buried straw layer plus plastic mulching reduces soil salinity and increases sunflower yield in saline soils

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ABSTRACT

Soil salinization is a major limitation to high crop yield in saline soils of the Hetao Irrigation District of Inner Mongolia, China. As such, people are forced to use better and more effective approaches to soil management due to scarcity of freshwater and the adverse effects of climate. A three-year field experiment was conducted to investigate the effects of buried straw layer and plastic film mulch on soil moisture, soil salinity and sunflower (*Helianthus annuus* L.) yield in saline soils. Four field management practices were designed: bare ground (BG), plastic mulch (PM), buried maize straw layer (12 t ha^{-1}) at a depth of 40 cm (SL), and combined application of plastic mulch and straw layer burial (PM + SL). Soil water at the 0–40 cm layer was higher under SL and PM + SL than under BG and PM within 45 days after sowing (DAS) but the reverse occurred thereafter. Compared to PM and BG, both SL and PM + SL significantly decreased the salt content of the upper 40 cm depth at sowing. Furthermore, PM + SL invariably decreased the salt content throughout the growth period of sunflower. In contrast, SL and PM moderately increased the salt content during the later growth period. Compared with BG, SL significantly decreased salt accumulation in the off season. Over the three years, the highest seed and biomass yield, 100-seed weight and head diameters of sunflower were obtained from the PM + SL plots. The average seed yield (3198 kg ha^{-1}) under PM + SL exceeded the yields under BG, PM and SL by 51.9, 5.9 and 35.7% respectively. Therefore, PM + SL may be an efficient practice for reducing soil salinity and increasing sunflower yield in the Hetao Irrigation District and other similar ecological areas.

1. Introduction

Soil salinization is one of the major causes of declining agricultural productivity in numerous arid and semiarid regions throughout the world (Qadir et al., 2000). High salinity has been a significant threat to the sustainable development of agriculture (Mondal et al., 2001; Bakker et al., 2010). The Hetao Irrigation District, located in northwest China, has an irrigated land area of 570,000 ha. Approximately half of the irrigated land in this area has saline-alkali problem. High evaporation rate, limited rainfall and shallow groundwater table contribute to the increase in soil salinity (Lei et al., 2011). It was reported that most of the saline soils in the area will eventually become totally unproductive and possibly abandoned if the salinity problem could not be resolved immediately and effectively (Wu et al., 2008).

As a salt-tolerant crop, sunflower is one of the most important crops in this region. Nevertheless, its germination, emergence, and early growth are very sensitive to soil salinity (Katerji et al., 1994, 1996). Salt accumulation in the root zone is the main cause of yield decline. Irrigation with water from the Yellow River is the most readily available strategy for reducing salinity in saline fields (Feng et al., 2005). However, excessive irrigation without appropriate drainage systems raises the groundwater table. Thus, this management option can potentially cause salt accumulation in the root zone, with a negative effect on crop productivity (Sharma and Minhas, 2005; Qadir et al., 2009). In recent years, the amount of water for irrigation coming from the Yellow River has reduced significantly, thus creating a conflict between water shortage and salinity control in this region (Lei et al., 2011). Therefore, new techniques should be developed to address these challenges.

Soil and water management approaches should aim to reduce unproductive water losses associated with evaporation from soil surfaces, increase soil moisture storage, maintain soil salinity levels within acceptable crop production limits, enhance soil organic matter inputs and nutrient availability, and maintain soil physical properties in the root zone (Bezborodov et al., 2010).

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Mulching of the soil surface using various materials (e.g., crop residue, plastic film, sand, or gravel) can reduce evaporative water loss and help to reduce salt accumulation within the shallow soil depth (Pang et al., 2010; Li et al., 2013). Agele et al. (2010) showed that plastic film mulching improved soil moisture, increased soil temperature, root and shoot biomass, and leaf area development of sunflower. Similarly, Li et al. (2013) demonstrated that plastic mulching could serve as a water vapor barrier against evaporation losses, increase soil moisture storage, and enhance biological activity. In addition, returning crop residues or applying straw mulches to the soil surface could improve soil quality and productivity through favorable effects on soil properties (Lal and Stewart, 1995). The beneficial effects of straw or residue mulch on soil organic carbon, water retention, and ratio of water-stable aggregates have been highlighted in previous studies (Havlin et al., 1990; Duiker and Lal, 1999). In a long-term field study, Mulumba and Lal (2008) found that placing crop residues on soil surface shaded the soil, increased available water, and enhanced soil aggregate stability.

Burying a straw layer in soil also has potential positive effects on soil water and salt management (Sembiring et al., 1995; Tumarbay et al., 2006; Wang et al., 2012). Straw layer serves as a salt accumulation barrier, inhibiting the movement of salts from the subsoil and/or shallow groundwater to the topsoil (Qiao et al., 2006a; Chi et al., 1994). In simulation studies, Cao et al. (2012) and Tumarbay et al. (2006) demonstrated that applying straw layer limited grounder water evaporation and reduced salt built-up in the topsoil. During irrigation, a buried straw layer improved the water storage capacity of the topsoil by retarding the infiltration rate (Zhang et al., 2010; Wang et al., 2011). Since the straw layer extends soil water residence time in the layer above, it might maximize the dissolution of soluble salts in the soil as the water moves down the profile, thus improving the salt leaching efficiency (Zhang et al., 2009). Other benefits of straw layer buried deeply in a saline soil as reported by other researchers include reductions in soil pH and bulk density and increases in soil organic matter, and plant earliness (Zhao et al., 2003; Li et al., 2009; Fan et al., 2012; Wang et al., 2012).

Currently, plastic film mulching has been widely used to increase sunflower yield in saline soils. However, burying a straw layer in the soil or combining straw layer burial with plastic film mulching is rarely performed in salt-affected fields. Also there is scanty information on the comparative effects of straw layer burial and plastic film mulching with the same crop in an irrigated saline soil. Therefore, a three-year field trial was conducted to explore the effects of burying straw layer and mulching with plastic film on sunflower production. We hypothesized that the dynamics of soil moisture and salinity, and their distribution in the soil profile as well as sunflower yield and yield components would be affected by burying a straw layer.

2. Materials and methods

2.1. Study area and site characterization

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 Wuyuan County, Inner Mongolia, China.

The study area has a typical arid continental climate that is very cold in winter with little snowfall and very dry in 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 of 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 of 1.5–1.8 g L^{-1}. The experimental soil was silty loam with a pH of 8.8 and contained 11.1 g kg^{-1} organic matter, 35.6 mg kg^{-1} available N, 6.4 mg kg^{-1} available P and 161 mg kg^{-1} available K at the 0–10 cm layer.

The daily precipitation and pan evaporation data during the sunflower growing seasons are provided in Fig. 1. The total precipitation during the experimental period was 54.5 mm in 2011 (27 May–24 September), 238.6 mm in 2012 (5 June–3 October), and 64.8 mm in 2013 (2 June–30 September), accounting for 68.7, 64.3 and 59.0% of annual precipitation, respectively. The first and third seasons were drier than average (145.2 mm) for the corresponding period of the previous 10 years, whereas the second season was wetter. There were four heavy rainfall events (daily precipitation intensity > 20 mm) before 60 DAS in the second season. Although no irrigation was applied during the growing period of each season, abundant rain water was received in the trials in the wet year.

Pan evaporation also varied greatly among the three experimental seasons (Fig. 1). The total pan evaporation was 1330.9 mm in 2011, 1019.1 mm in 2012, and 1238.2 mm in 2013. Daily fluctuations in pan evaporation were large, ranging from 1 mm to 26 mm. Generally, the pan evaporation declined during the experimental period, and a higher evaporation occurred during the first half of the growing season. Therefore, more water loss to evaporation occurred in the early experimental period.

2.2. Experimental design and filed management

Experiment was conducted in field micro plots from October 2010 to October 2013. The field with an area of 48 m^2 (6 m × 8 m) was divided into three blocks; each block had four treatments,

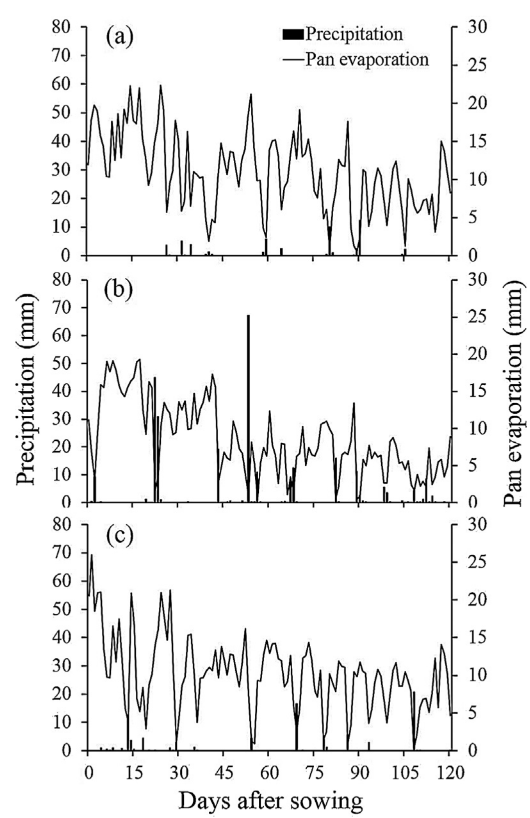

Fig. 1. Daily precipitation and pan evaporation during the growing period of sunflower in 2011 (a), 2012 (b) and 2013 (c).