Field Crops Research 225 (2018) 130–140

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Effects of sub-soil plastic film mulch on soil water and salt content and water utilization by winter wheat under different soil salinities

Mingming Zhang[a,b], Baodi Dong[a,*], Yunzhou Qiao[a], Hong Yang[a,b], Yakai Wang[a,b], Mengyu Liu[a]

[a] Key Laboratory of Agricultural Water Resources, Hebei Laboratory of Agricultural Water-Saving, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang, 050021, China
[b] University of Chinese Academy of Sciences, Beijing, 100049, China

ARTICLE INFO

Keywords:
Mulch
Soil water
Soil salinity
Soil evaporation
Winter wheat
Water use efficiency

ABSTRACT

Winter wheat yields in dryland saline soils are limited by water shortages and soil salinity. Mulching is one approach to ameliorate water deficit and salt stress. A two-year field experiment was conducted in North China's Bohai Lowland Plain to evaluate the effects of sub-soil plastic film mulch on soil moisture, soil salinity, and water use efficiency of winter wheat (*Triticum aestivum* L.) under three levels of soil salinity. The results showed that mulching significantly increased soil moisture in the top 20 cm of soil by up to 33.1% at the seedling stage and decreased salinity by up to 73.7% in topsoil, compared with no-mulch. Mulching also reduced evaporation by 27.3 mm and increased transpiration by 34.1 mm (average over two years). Plants in the mulch treatment showed higher aboveground biomass than those in the control group and had a similar harvest index. Compared to no-mulch, the average grain yield for the two years was 1579, 1743, and 2377 kg ha^{-1} greater under mulching under salinity levels of 1‰, 2‰, and 3‰, respectively, and the corresponding values of water use efficiency for yield were 27.6%, 40.4%, and 96.6%. Sub-soil plastic film mulch significantly inhibited soil evaporation and salt accumulation, promoted aboveground biomass, and increased grain yield and water use efficiency in dryland saline soil compared with no-mulch. Furthermore, the higher the soil salinity level, the more mulching suppressed soil salinity and improved water utilization by crops compared with no-mulch.

1. Introduction

Dryland crop production is the main source of staple food for most densely populated areas, such as China, India, and sub-Saharan Africa (Daryanto et al., 2017). However, in arid and semi-arid regions, soil salinity and water deficit have severely restricted the development of agriculture. Saline soil is widespread throughout the world, occupying about 36 million ha in China, and is one of the most important types of low-yield soils in China (Huo et al., 2017; Yang, 2008).

China is the world's largest producer of wheat (Daryanto et al., 2016). Dryland wheat accounts for 55–60% of the wheat planting area in China. However, dryland areas experience water loss through runoff and evaporation, with up to 70%–80% of rainfall being lost; this loss represents a quarter to half of the total water consumed by winter wheat crops (Zhao, 2013). In addition, unevenly distributed precipitation, high evaporation, and a shallow groundwater table all increase soil salinity (Dong et al., 2010; Lei et al., 2001).

The Bohai Lowland Plain, located in North China, is a coastal area that is important in terms of economic development and agricultural potential. Winter wheat (*Triticum aestivum* L.) is one of the most important crops in this area and is grown on about 734,000 ha here (Ju et al., 2016). This crop is sensitive to salinity in its early growth and development, especially during the emergence and early seedling stages (Jiang et al., 2012). The proportion of 1.0–3.0 g L^{-1} brackish water in shallow groundwater in this region is 40.8%, and 3.0–5.0 g L^{-1} brackish water accounts for 8.7% (Zhou et al., 2010). Due to increased exploitation of shallow fresh and brackish water, the area of the 3.0–5.0 g L^{-1} brackish water has increased (Liu et al., 2017). In the Baohai Lowland Plain, soil salinity in the 0–60 cm soil profile varies from 0.4 g kg^{-1} to 5.0 g kg^{-1}, with soil salinity of 1.0–3.0 g kg^{-1} and 3.0–5.0 g kg^{-1} accounting for 55.8% and 0.7% of the total area, respectively (Wang et al., 2012b). Due to the large amount of evaporation and low precipitation in spring and fall, the heavy precipitation in summer, and the dry and cold weather in winter, soil salt changes throughout the year, generally accumulating in spring and fall, leaching in summer, and stabilizing in winter (Liu et al., 2010). Soil salinity

* Corresponding author at: Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang, Hebei, China. Tel: +86 311 85825949; Fax: +86 311 85815093.
E-mail addresses: zhangmingming13@mails.ucas.ac.cn (M. Zhang), dongbaodi@126.com (B. Dong), qiaoyunzhou@sjziam.ac.cn (Y. Qiao), yanghong215@mails.ucas.ac.cn (H. Yang), wangyakai.01@163.com (Y. Wang), mengyuliu2016@126.com (M. Liu).

https://doi.org/10.1016/j.fcr.2018.06.010
Received 15 February 2018; Received in revised form 21 June 2018; Accepted 21 June 2018
0378-4290/

reduces the value of soil resources, causes great losses to crop production, and poses a threat to the environment (Shao et al., 2016). Most saline soils will become unproductive and abandoned if the soil salinity is not solved effectively (Wu et al., 2008). Crops face the dual challenges of salinity and drought in saline soils (Zhao et al., 2016). The soil salinity not only has osmotic effects on plants but also often creates a water-deficit environment, creating physiological drought (Zhang et al., 2017). With the increase of irrigation water salinity, the yield of winter wheat decreased. Wheat yield decreased by 7%–13% when the irrigation water salinity was 2–3 g L^{-1}, and decreased by 13–24% when the salinity was 3–5 g L^{-1} (Shang et al., 2009; Qiao et al., 2007). Therefore, effective techniques for controlling soil salinity and increasing water use efficiency of wheat are needed to cope with these challenges.

Agronomic management measures should be focused on reducing unprofitable water loss due to soil evaporation, maintaining the beneficial physical properties of soil, and maintaining soil salinity within an acceptable range for plant growth (Bezborodov et al., 2010). Mulch film has been utilized since 1978 in China (Zhou et al., 2009), and is an important agricultural technique. Nationwide, the use of mulch film has increased wheat grain production by 33.2% (Liu et al., 2014). Plastic mulch conserves water in areas where irrigation is limited or not available and protects emerging crops from low spring soil temperatures (Zhou et al., 2009). Mulching can retain soil water content and increase soil temperature, thereby improving the crop yield (Du et al., 2016; Ju et al., 2016), as well as decreasing soil evaporation, increasing soil moisture efficiency, improving the physical characteristics of the soil, reducing salt damage to crops, accelerating crop germination and growth, and increasing the water use efficiency of crops (Gong et al., 2017; Li et al., 2013; Zhang et al., 2011; Zhao et al., 2016). The effectiveness of mulch film varies, depending on the type of soil conditions, climate, and the interactions between these factors (Han et al., 2014). Qin et al. (2015) also reported that the effects of plastic mulching strongly depend on environmental conditions. Plastic mulching effect performed better at relatively low temperature, tended to decrease with an increase in the availability of water, and tended to increase with N input (Qin et al., 2015). However, they did not specifically focus on the combined effects of soil mulching and salinity in wheat yield. Therefore, it is important to quantitatively examine the effect of this water-saving strategy with different soil salinities.

In recent years, sub-soil plastic film mulch has been used widely in Northwestern China to reduce soil evaporation and maximize rain-fed wheat production. In the past, the use of plastic mulch was expensive and labor-intensive, requiring annual installation. The recent introduction of a rotary-filming-soil covering seeder has made the process more affordable and allowed shallow rotary tillage, paving plastic mulch, covering soil, punching, and seeding operations to proceed simultaneously. However, few studies have examined the effects of this new mulch model on soil moisture, salinity dynamics, and winter wheat growth in saline soils under rain-fed conditions. Thus, the main objective of the present study was to measure the effects of sub-soil plastic film mulch on soil moisture and salinity dynamics as well as on winter wheat yield and water utilization under different soil salinities. Our results from a dryland region can be applied to quantitatively evaluate the value of sub-soil plastic film mulch in other semi-arid regions that are severely affected by drought and soil salinity.

2. Materials and methods

2.1. Experimental site

The experiment was conducted during the winter wheat growing seasons in 2015–2016 and 2016–2017 under rain-fed conditions in the Nanpi Eco-Agricultural Experimental Station of Chinese Academy of Sciences (116°40′E, 38°00′N; elevation, 11 m). Nanpi Station lies in the low plain near Bohai Sea in the North China Plain and has a warm, temperate, semi-humid, continental monsoon climate. It is representative of coastal lowland plain areas with water deficit and saline soil. The main crops in this area are wheat, corn (*Zea mays* L.), and cotton (*Gossypium hirsutum* L.), along with some oil crops, vegetables, and fruits. A winter wheat–summer corn rotation is the main cropping system in this area and was implemented in the fields in this study. The mean annual rainfall is 480 mm, with more than 70% of the precipitation concentrated in June to September. The mean annual temperature is 12.3 °C. The region receives 2938.6 average hours of sunshine a year, 5592.3 MJ cm^{-2} in annual average radiation, and 4232 °C in total accumulated temperature units. The average annual rainfall during the winter wheat growing season for 20 years (1996–2016) in the study area was 125 mm. During the present study, the first and second growing seasons received 114.1 and 86.2 mm of precipitation, respectively. According to the method described by Fu et al. (2014), 2015–2016 and 2016–2017 were considered a normal year and a drought year, respectively. Weather data were obtained from the weather station at the experimental site. The monthly total precipitation and mean temperature are shown in Fig. 1.

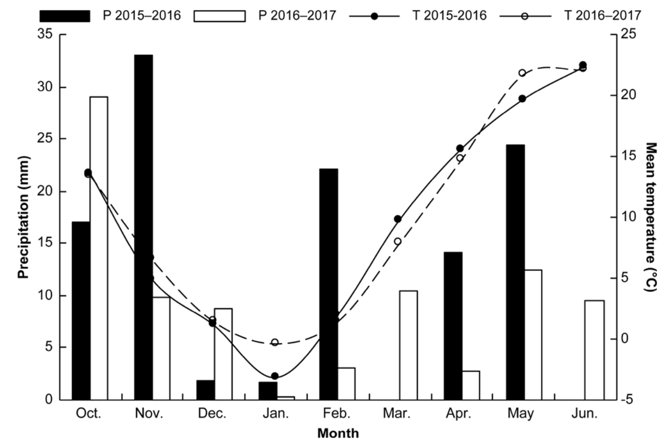

Fig. 1. Monthly precipitation (P, mm) and temperature (T, °C) from 2015 to 2017 during winter wheat growing seasons.

The soil at the study site is light loamy soil with mild salinity. The 0–30 cm layer of the soil contained 15.36 g kg^{-1} organic matter, 71.86 mg kg^{-1} available nitrogen, 20.88 mg kg^{-1} available phosphorus, and 120.54 mg kg^{-1} available potassium. The average soil bulk density was 1.40 $g{\cdot}cm^{-3}$ and field capacity was 0.34 (m^3 m^{-3}) for a 2-m profile. Detailed soil physical properties are listed in Table 1.

2.2. Experimental design

A field experiment was carried out during the winter wheat growing seasons for 2015–2017 using a randomized block design with three replicates. The experiment included 6 treatments combining two levels of planting patterns and three levels of soil salinity. The planting pattern treatments included no-mulch (M0) and sub-soil plastic film mulch

Table 1
Soil physical properties at the experimental site.

Soil depth (cm)	Percentage of particle content (%)			Soil texture classification
	< 0.002 mm	0.02–0.002 mm	2–0.02 mm	
0–10	3.0	36.9	60.1	Sandy loam
10–20	1.6	37.5	60.9	Sandy loam
20–40	2.4	35.2	62.4	Sandy loam
40–60	1.7	42.3	56.0	Sandy loam
60–80	2.3	49.5	48.2	Silty sandy loam
80–100	2.4	53.4	44.2	Silty sandy loam
100–120	1.4	41.4	57.2	Sandy loam
120–140	1.3	42.5	56.2	Sandy loam
140–160	1.4	39.1	59.5	Sandy loam