Soil & Tillage Research 179 (2018) 86–95

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Effects of ridge tillage and mulching on water availability, grain yield, and water use efficiency in rain-fed winter wheat under different rainfall and nitrogen conditions

Na Li[a], Chunju Zhou[b], Xiao Sun[a], Jianyuan Jing[a], Xiaoxiao Tian[a], Linquan Wang[a,*]

[a] College of Natural Resources and Environment, Northwest A&F University, Yangling, Shaanxi 712100, China
[b] College of Life Sciences, Northwest A&F University, Yangling, Shaanxi 712100, China

ARTICLE INFO

Keywords:
Leaf chlorophyll
Loess soil
Conservation tillage

ABSTRACT

Tillage practices which improve water availability and water use efficiency (*WUE*) are beneficial for rain-fed agriculture. However, there is little consensus about the effects of ridge tillage and mulching, combined with different rainfall and N fertilization conditions, on water status and productivity in winter wheat fields. The current study aimed to investigate the effects of ridge tillage and mulching on water availability, grain yield, and *WUE* in rain-fed winter wheat under different rainfall and N conditions. A three-year field experiment was conducted during 2011–2014 following a split-split plot design. The experiment included two humid growing seasons (2011–2012 and 2013–2014) and one dry growing season (2012–2013). Nitrogen application rates were 0 and 180 kg N ha^{-1}. Tillage systems included conventional tillage (CT, as control), stalk mulching (SM), film mulching (FM), ridge tillage without mulch (RT), ridge tillage with film on ridges (RTf), and ridge tillage with film on ridges and stalk in furrows (RTfs). Results showed that averaged across growing seasons and N treatments, ridge tillage and mulching decreased evapotranspiration by 8.3%–16.2%, and increased grain yield and *WUE* by 4.2%–15.2% and 16.7%–36.8% compared with CT, respectively. Ridge tillage and mulching tended to increase grain yield especially when rainfall was deficient, and tended to increase *WUE* especially when N supply was deficient. Spike number per hectare and grain number per spike made significant contributions to grain yield when all three yield components were considered. Ridge tillage and mulching tended to increase mass-based and area-based canopy moisture during regreening (stage 6 in Feekes scale, late Feb–early Mar) to grain-filling stage (middle May) which was positively correlated with grain yield. Lower leaf area index (*LAI*) in ridge tillage and mulching treatments led to grain yield loss, but the loss was alleviated by greater total chlorophyll in flag leaves. Overall, ridge tillage and mulching improved water availability, grain yield, and *WUE* in rain-fed winter wheat, especially when N and rainfall were deficient.

1. Introduction

Climate change could potentially threaten world food security (Wheeler and von Braun, 2013). Especially under these conditions, crop production is highly dependent on freshwater supply. Drought and periodical rainfall shortage (such as shortage at anthesis) limit grain yields and water use efficiency (*WUE*) in cereal crops such as winter wheat, especially in rain-fed regions (Seddaiu et al., 2016). With limited freshwater resources and high irrigation costs, large areas of wheat are planted under rain-fed conditions. Therefore, it is important to improve water availability and *WUE* in rain-fed winter wheat with water saving and conservation practices (Liu et al., 2016).

As tillage practices affect soil properties such as soil structure and moisture, negative effects of drought and periodical rainfall shortage will be alleviated by improved tillage practices (Liu et al., 2013). Rainfall harvesting techniques such as ridge tillage have been proposed to increase soil water content by enhancing infiltration (Liu et al., 2014); while mulching techniques such as plastic-film mulching have been proposed to improve water availability in soils, mainly by reducing evapotranspiration (Diaz-Hernandez and Salmeron, 2012). Ridge tillage and mulching also affect other soil properties besides moisture, such as soil temperature and mineralization, which further affect crop traits such as leaf area index and grain yields (Liu and Wiatrak, 2012; Shi et al., 2012). Previous studies showed that ridge tillage and

---

Abbreviations: CT, conventional tillage; SM, stalk mulching; FM, film mulching; RT, ridge tillage without mulch; RTf, ridge tillage with film on ridges; RTfs, ridge tillage with film on ridges and stalk in furrows; *WUE*, water use efficiency; *LAI*, leaf area index

[*] Corresponding author.

E-mail address: linquanw@nwsuaf.edu.cn (L. Wang).

https://doi.org/10.1016/j.still.2018.01.003
Received 10 June 2017; Received in revised form 16 December 2017; Accepted 12 January 2018

mulching increase yields and *WUE* in rain-fed crops (Liu and Siddique, 2015; Wang et al., 2016), while stalk mulching also enhances soil quality (Kahlon et al., 2013). Overall, application of improved tillage practices (such as ridge tillage and mulching) is beneficial for sustainable development of rain-fed agriculture.

The southern Loess Plateau is a major winter wheat production region in China, with drought and periodical rainfall shortage as major limiting factors. High rainfall variability and evaporation lead to an imbalance between water supply and plant water demands, which then result in lower grain yields (Yang et al., 2017; Seddaiu et al., 2016). To alleviate the negative effects of drought and periodical rainfall shortage on crop production, ridge tillage and mulching have been proposed to rain-fed regions (Liu et al., 2014; Wang et al., 2016). For example, Zhang et al. (2011) reported a combination of ridge tillage and mulching, i.e., ridge tillage with film on ridges and stalk in furrows (RTfs), is an efficient measure to increase crop yield and improve soil fertility in the Loess Plateau of China.

Although ridge tillage and mulching provide an opportunity of sustainably enhancing crop productivity in rain-fed regions, performances of these techniques are inconsistent in different regions and growing seasons, partly due to influences from other factors such as rainfall and fertilization (Wang et al., 2016). For example, film mulching has more notable effects on soil water content and crop yield when water supply is deficient (Diaz-Hernandez and Salmeron, 2012; Wang et al., 2016), while mulching treatments have more significant effects on *WUE* when supplied with deficient N (Li et al., 2015). Therefore, factors such as rainfall and N fertilization should be considered when investigating the performances of ridge tillage and mulching. However, for rain-fed winter wheat in the southern Loess Plateau, there is little consensus about the effects of ridge tillage and mulching on water availability, grain yield, and *WUE* under different rainfall and N conditions.

The study aimed to: i) assess the effects of ridge tillage, mulching, and their combination on water availability, grain yield, and *WUE* in rain-fed winter wheat under different rainfall and N conditions; ii) elucidate the mechanism of improvements in grain yield and *WUE* in ridge tillage and mulching treatments, based on data of yield components, water availability, leaf area index, and leaf chlorophyll.

2. Materials and methods

2.1. Site and materials

Before the current study, a wheat (*Triticum aestivum* L.) - maize (*Zea mays* L.) rotation had been conducted for two years (Oct 5th, 2009–Oct 7th, 2011) without fertilization and without irrigation. The current three-year field experiment was conducted during 2011–2014 wheat growing seasons, i.e., Oct 8th, 2011–Jun 7th, 2012 (244 d); Oct 6th, 2012–May 27th, 2013 (234 d); and Oct 9th, 2013–Jun 6th, 2014 (241 d). While between wheat growing seasons, i.e., Jun 8th, 2012–Oct 5th, 2012 and May 28th, 2013–Oct 8th, 2013, maize was planted without fertilization and irrigation. The experimental site was located in Yangling (34°17′ N, 108°04′ E; 520 m ASL), in the southern Loess Plateau of China. The mean annual precipitation is about 550–600 mm, with about 200–250 mm occurring during the wheat growing season; the annual mean temperature is about 13 °C. During 2011–2012, 2012–2013, and 2013–2014 wheat growing season, rainfall totaled 242.9, 191.8, and 266.7 mm; daily air temperature averaged 8.2 °C (lowest: −7.0 °C; highest: 25.3 °C), 8.0 °C (lowest: −7.3 °C; highest: 26.0 °C), and 8.3 °C (lowest: −6.0 °C; highest: 24.5 °C), respectively (Fig. 1). The soil was classified as an Anthropic Torrifluvents Entisol (Soil Survey Staff, 2014). Selected properties of the top layer (0–20 cm) were: bulk density 1.33 Mg m^{-3}, clay content 165 g kg^{-1}, silt content 517 g kg^{-1}, sand content 318 g kg^{-1}, organic C 9.83 g kg^{-1}, total N 0.88 g kg^{-1}, total P 0.59 g kg^{-1}, total K 1.86 g kg^{-1}, inorganic N 7.02 mg kg^{-1}, Olsen P 8.63 mg kg^{-1}, available K 130.61 mg kg^{-1}, soil pH (1:2.5 soil:water, w:v) 8.3, and field capacity 244 g kg^{-1}. The groundwater depth was 25–40 m.

Nitrogen fertilizer was urea (46.4% N). Phosphorus fertilizer was calcium superphosphate (16% P_2O_5). Plastic film was made of transparent polyethylene, 0.001 cm thick. Maize stalks were cut into pieces before mulching, with selected properties as: average length 3 cm; total N 10.5 g kg^{-1}, total P 13.7 g kg^{-1}, and total K 9.6 g kg^{-1}. Wheat cultivar was *Triticum aestivum* L. 'Xiaoyan 22'.

2.2. Experimental design

Treatments followed a split-split plot design with three replications (Fig. 2), which was suitable for analysis of three factors (Yang et al., 2015). Growing seasons included two humid growing seasons (2011–2012 and 2013–2014) and one dry growing season (2012–2013) (Fig. 1). Tillage systems included conventional tillage (CT, as control), stalk mulching (SM), film mulching (FM), ridge tillage without mulch (RT), ridge tillage with film on ridges (RTf), and ridge tillage with film on ridges and stalk in furrows (RTfs). Nitrogen application rates were 0 (N0) and 180 kg N ha^{-1} (N180). The experiment consisted of 36 plots each growing season, with a size of 4 × 4 m^2 for each plot (Fig. 2).

Plots were plowed using a rotary cultivator to 20 cm depth before sowing. In FM, both film and planted rows were 30 cm wide. In RT, RTf, and RTfs, ridges were 15 cm in height, while ridges and planted rows were both 30 cm wide. In SM, each plot was mulched with stalk at 5.0 Mg ha^{-1}. In RTf, ridges were mulched with film. In RTfs, ridges were mulched with film while planted rows mulched with stalk at 2.5 Mg ha^{-1} (Fig. 2).

Fertilizers were applied before sowing as a basal fertilization. Phosphorus fertilizer was applied at 120 kg P_2O_5 ha^{-1} in all treatments. Nitrogen fertilizer was applied at 180 kg N ha^{-1} in the N180 treatments. In CT and SM, fertilizers were broadcasted and then incorporated into 0–15 cm soil layers; while in other tillage systems, fertilizers were applied by deep-band application to a 15 cm depth under film or ridges (Fig. 2).

After applying fertilizers, wheat was sown to 5 cm depth at 120 kg ha^{-1}. In CT and SM, wheat was sown in planting rows with 20 cm spacing consistent with local growers, while in other tillage systems, with 30 cm spacing, i.e., much wider so as to establish ridges or film mulching (Fig. 2). No side-dress fertilizer or irrigation was applied.

2.3. Sampling and lab analyses

Stem density (*SD*, stems m^{-2}) was determined by counting stems in a 1 × 1 m^2 area in the middle of each plot at grain-filling stage (middle May). Then, 20 stems were randomly collected in each treatment, and leaf area per stem (cm^2 $stem^{-1}$) was measured using ImageJ (Martin et al., 2013). Besides, 10 flag leaves were collected from each plot, cut into pieces, and mixed as a single sample for analysis of total chlorophyll (Fiorini et al., 2016). Leaf area index (*LAI*) was given as:

$$LAI = LAPS * SD * 10^{-4} \quad (1)$$

where, *LAPS* is leaf area per stem (cm^2 $stem^{-1}$); 10^{-4} is used to convert cm^2 $stem^{-1}$ to m^2 $stem^{-1}$.

At maturity (late May–early Jun), a 1 × 1 m^2 area was harvested in the middle of each plot to determine grain yield and spike number per hectare (Yao et al., 2007). Wheat samples were threshed using a cereal thresher. Both straw and grain samples were dried at 105 °C for 30 min, then at 80 °C to a constant weight. Grain yields were adjusted to 14% moisture. Grain number per spike was determined based on data from 20 spikes in each treatment. Thousand grain weight was measured with an automatic counting machine ($n = 3$).

Both at the beginning and the end of each growing season, soil was sampled at 0–200 cm depth (20 cm layer intervals) with a 25-mm