Agricultural Water Management 201 (2018) 299–308

Contents lists available at ScienceDirect

Agricultural Water Management

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

Effects of tillage and mulching measures on soil moisture and temperature, photosynthetic characteristics and yield of winter wheat

Yonghui Yang[a,b,*,1], Jinli Ding[c,1], Yunhong Zhang[a,1], Jicheng Wu[a,b,*], Jiemei Zhang[a,b], Xiaoying Pan[a,b], Cuimin Gao[a,b], Yue Wang[a,b], Fang He[a,b]

[a] Institute of Plant Nutrition & Resource Environment, Henan Academy of Agricultural Sciences, Zhengzhou 450002, China
[b] Yuanyang Experimental Station of Crop Water Use, Ministry of Agriculture, Yuanyang 453514, China
[c] College of Geography and Tourism, Zhengzhou Normal University, Zhengzhou 450044, China

ARTICLE INFO

Article history:
Received 10 August 2017
Received in revised form 6 November 2017
Accepted 9 November 2017
Available online 24 November 2017

Keywords:
Straw mulching
Film mulching
Soil moisture and temperature characteristics
Winter wheat (*Triticum aestivum L.*)
Photosynthetic characteristics
Yield

ABSTRACT

In order to find out the appropriate measures for soil water preservation and wheat yield increase, a three–year field experiment was conducted in Yuzhou Experimental Station of Water Saving Agriculture in the west of Henan Province, China, during the growing seasons of 2014–2015, 2015–2016 and 2016–2017 to study the effects of different tillage modes and soil mulching measures on dynamics of soil moisture and temperature, photosynthetic characteristics and yield of winter wheat (*Triticum aestivum L.*). The results showed that straw coverage and film mulching measures under the conventional tillage and no tillage modes increased soil moisture by 4.4%–27.3%,13.4%–41.8% and 6.2%–46.7%, 2.4%–80.2%, respectively. The treatments of soil surface coverage measures under both conventional tillage and no tillage modes at tillering stage increased the temperature of soil layer at 10 cm and 15 cm depth by 9.1%–18.2% and 10.0%–40.0% in 2014–2015, while mulching measures under the conventional tillage obviously increased soil temperature at wintering stage but decreased soil temperature at booting and mature stages in 2016–2017. However, mulching measures under no tillage mode reduced soil temperature in shallower layer during seedling establishment stage in the three–year period of 2014–2017. Moreover, the two mulching measures raised net photosynthetic rate (Pn) and water use efficiency (WUE) of functional leaves under the conventional tillage mode and reduced transpiration rate (Tr) at the filling stage. Except straw coverage measures under no tillage in 2015–2016, the combination of mulching measures under no tillage reduced Pn, Tr and WUE of wheat leaves at filling stage as compared to those without mulching measures. Under the conventional tillage mode, straw coverage increased wheat yield by 6.4%–9.3%, mainly due to the increase in the number of grains per panicle. Under no tillage mode, both straw coverage and mulching measures reduced wheat yield to different extents and film mulching measures was more effective than straw coverage. The combination of conventional tillage and straw mulching resulted in a yield of 8425.9–8888.9 kg hm^{-2}, so this combination was recommended as the optimal treatment under the conditions set in this study.

1. Introduction

Water stress is one of the important and unfavorable factors influencing the growth and development of crops. Water deficiency has caused agricultural loss as high as $8 billion annually in the world. Shortage of water resources has become a global problem limiting agricultural development (Wang et al., 2016; Qin et al., 2015). Wheat (*Triticum aestivum L*) is one of the most important food crops in the world. China is ranked in the first place in term of wheat production and consumption. The cultivated area for wheat is 21.33–30.67 million hectare, accounting for 19.57%–22.07% of the total cultivated area for crops in China (Qin et al., 2015). HuangHuai region is suitable for producing strong and moderate gluten wheat grains. This region is one of the most important wheat–production regions in China and annually has 15.30 million ha of cultivated area for wheat. The highly efficient development of wheat with high yield and good quality is of strategic significance for ensuring food

* Corresponding authors. Present address: Institute of Plant Nutrition, Agricultural Resources and Environmental Science, Henan Academy of Agricultural Sciences, 116 Garden Road, Zhengzhou 450002, China.

E-mail addresses: yangyongh@mails.qucas.ac.cn (Y. Yang), wujc2065@126.com (J. Wu).

[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.agwat.2017.11.003
0378-3774/© 2017 Published by Elsevier B.V.

safety in China. However, the unbalance of precipitation supply and demand for crops is the main factor limiting agricultural productivity in this region. For winter wheat, it is critical to meet water requirement at the period (4–5 months) of jointing stage, booting stage and filling stage. However, precipitations in these periods only account for 1/5–1/4 of demanded water of winter wheat, and water deficiency can be as high as approximately 200 mm (Xu et al., 2014). Moreover, due to the consecutive rotary cultivation practice, the cultivation layer of field soil has become shallower and shallower, and soil physicochemical properties, including soil gas/air permeability, ventilation and soil water permeability, have become poorer and poorer, which significantly reduce soil productivity, seriously limit high output of crops, and further aggravate the contradiction between water demand and supply. This issue has become the spot light drawing the attentions of the agricultural researchers (Li et al., 2015; Xu et al., 2015).

Soil tillage is an important measure for controlling soil water content, fertility, gas/air and heat. Improved tillage measures have been shown to improve soil physicochemical properties and soil water use efficiency (SWUE) (Bottinelli et al., 2017). Many studies have indicated that the protective tillage measures could preserve soil water, increase soil moisture, improve soil quality and increase crop yield, and then benefit for the sustainable development of agricultural production (Bottinelli et al., 2017; Yang et al., 2016; Lampurlanés et al., 2016; Mitchell et al., 2017; Bhatt and Khera, 2006; Shao et al., 2016). For instance, it has been shown that 1) no tillage enhanced soil water-holding capacity and reduced soil evaporation (Lampurlanés et al., 2016); 2) mulching measures was also an effective way to reduce soil water evaporation, drove water moving up from lower layer to the upper layer, where water was available for crops, improved wheat growth and development, and increased crop productivity and WUE (Li et al., 2016); 3) mulching measures under no tillage stimulated the formation of soil aggregates, increased soil nitrogen and carbon contents, and then enhanced the soil microbial activities (Mitchell et al., 2017); and 4) long–term no tillage in the drought region improved the capacity of soil water conservation and storage, enhanced winter wheat's net photosynthesis rate (Pn), transient water use efficiency (TWUE) and the rates of dry matters accumulation and transportation, subsequently coordinated the relationship among various yield components and increased the yield of winter wheat (Wang et al., 2015). Straw–coverage inhibited flag leaves chlorophyll degradation, delayed leaf senescence, improved soil moisture status, optimized the soil root trails and ultimately enhanced the accumulation of dry matters and wheat yield formation in the drought years (Wu et al., 2015). The increased wheat yield by mulching measures was attributed mainly to its resultant increased soil moisture and temperature (Cook et al., 2006) and changes in soil structure and fertility (Zhang et al., 2011). Moreover, mulching tillage enriched soil microorganisms and increased urease activity (Zhao et al., 2002). The effects of mulching measures on soil physicochemical properties were found to be dependent on a number of factors, such as mulch types and quantity, mulching ways and timing etc. (Wu et al., 2011; Kader et al., 2017a; Zhang et al., 2008). Currently, mulching measures and straw coverage are two measures widely applied in agricultural production. Application of mulching measures or straw coverage in the hilly dry land of the west of Henan province where the seasonal drought is seriously improved soil moisture and farm land fertility, stimulated wheat tillering, and increased the number of grains per ear and 1000–grain weight (Wu et al., 2011). Although mulching tillage cost more and was less friendly to environment than straw coverage (Kader et al., 2017a,b), it was superior over straw coverage in improving crop's yield (Zhang et al., 2008).

Currently, a majority of studies have focused on the effects of monoculture or mulching measures on soil physicochemical properties and the agronomic trails of crops. Very few studies have explored on effects of combined tillage modes and mulching measures on SWUE. Moreover, these studies applied shorter treatment duration, which resulted in different effects. Long-term (multiple years) application of same tillage mode can be more reflective for the actual tillage effects (Li et al., 2006). Based on the present studies, we conducted experiments in Yuzhou Experimental Station for Water–Saving Agriculture in the west of Henan province in 2014 to investigate the effects of different tillage modes (conventional tillage and no tillage) and soil surface coverage treatments (straw coverage and mulching measures) on soil moisture and temperature, photosynthetic characteristics and winter wheat yield, aiming to find out the protective tillage mode most suitable for cultivation of wheat with high grain yield and good quality in HuangHuai region and to provide a theoretical basis for food safety production and sustainable agriculture development.

2. Materials and methods

2.1. Experimental location

The experiments were conducted in Yuzhou Experimental Station (34.16°N, 113.15°E, and 150 m above the sea level) of Water Saving Agriculture in the west of Henan province in the three years period of 2014–2017. The region has flat terrain topography with uniform fertility. Soil type is brown loess soil according to the Chinese Soil Taxonomic Classification, and is a kind of soil group under the order of semi–leaching soil. Soil organic matter in cultivation layer was 12.3 g kg^{-1}, total nitrogen was 0.80 g kg^{-1}, water-soluble nitrogen was 47.82 mg kg^{-1}, rapidly available phosphorus was 6.66 mg kg^{-1} and rapidly available potassium was 114.8 mg kg^{-1}. The tillage mode was wheat-maize rotation. Fig. 1 shows the changes in precipitation and atmosphere temperature during wheat growing seasons in the years of 2014–2015, 2015–2016 and 2016–2017.

2.2. Experimental designs

Two factor–fractional split–plot design was applied in this study. The experiment area was divided into 18 plots with three replicates, namely CT, CT + S, CT + M, NT, NT + S and NT + M. The three plots with CT in their names applied the conventional tillage mode (15 cm depth), while the other three plots with NT in their names applied no tillage. The plots CT + S and NT + S were covered with 6000 kg hm^{-2} straw on soil surface, and the plots CT + M and NT + M were covered with entirely plastic mulch. The plots CT and NT without coverage were taken as the controls. The area of each plot was 0.006 ha (6 m × 10 m). The winter wheat (*Triticum aestivum L.*) cultivar Kaimai-18 was used in this study. Its seed were sowed at density of 187.5 kg hm^{-2} in October 10–20 in 2014–2016. Urea (N 46.3%), calcium superphosphate (P_2O_5 12%) and potassium chloride (K_2O 60%) were selected as N, P and K fertilizers, respectively, and applied at the levels of 225 kg hm^{-2} (N), 70 kg hm^{-2} (P_2O_5) and 75 kg hm^{-2} (K_2O), respectively. Among them, 50% of nitrogen fertilizer was applied as the bottom application, and 30% and 20% of nitrogen fertilizer were applied at jointing stage and filling stage as the additional application, respectively. No irrigation was applied during the whole wheat growth period in the three years period of 2014–2017.

2.3. Assay method

2.3.1. Measurement of soil moisture

Soil samples within 0–100 cm layer were collected using soil augers at the tillering stage, jointing stage, booting stage and filling