Agriculture, Ecosystems and Environment 251 (2018) 67–77

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Research paper

Conservation agriculture based on crop rotation and tillage in the semi-arid Loess Plateau, China: Effects on crop yield and soil water use

Lei Sun[a,c], Shulan Wang[b], Yujiao Zhang[b], Jun Li[b,*], Xiaoli Wang[b,*], Rui Wang[b], Wei Lyu[b], Ningning Chen[b], Qian Wang[b]

[a] College of Forestry, Northwest Agriculture & Forestry University, Yangling, Shaanxi 712100, China
[b] College of Agronomy, Northwest Agriculture & Forestry University, Yangling, Shaanxi 712100, China
[c] Department of Landscape & Engineering, Heze University, Heze, Shandong 274015, China

ARTICLE INFO

Keywords:
Cropping system
Tillage
Yield
Water use efficiency
Soil water

ABSTRACT

In the semi-arid Loess Plateau region, water stress is the main limiting factor for rainfed agriculture; thus, conservation agriculture has been proposed to address this problem in these areas. Since 2007, a middle- to long-term experiment was established in Heyang County, Shaanxi, a region typical of the Loess Plateau, to evaluate the impact of no-tillage (NT), subsoiling tillage (ST) and conventional tillage (CT) on crop yield, water use, and soil water dynamics for winter wheat (*Triticum aestivum* L.) continuous cropping (WWC), spring maize (*Zea mays* L.) continuous cropping (SMC), and spring maize-winter wheat rotation cropping (MWR) systems. The highest four-year average wheat yield amounting to 5958 kg ha^{-1} was attained in MWR-ST, while the highest maize yield advantage averaging 772 kg ha^{-1} was obtained in SMC-NT. There were no significant differences in evapotranspiration (ET) and soil water storage (SWS) at the sowing/harvest stage among all treatments, but the relative greater average SWS before sowing was maintained under conservation tillage practices. The highest water use efficiency (WUE) reaching 10.0 kg ha^{-1} mm^{-1} for wheat in MWR and 20.3 kg ha^{-1} mm^{-1} for maize in SMC was obtained under ST treatment, while the significant WUE advantage of NT compared with CT was only obtained in SMC. At key growth stages, the higher soil water content (SWC) in the 0–200 cm soil profile was maintained in the conservation tillage and MWR system for wheat but in the conservation tillage and SMC system for maize. The longer-duration fallows did not produce a better effect on SWS at the sowing stage, while the reduction of soil disturbance enhanced SWS compared with CT.

In summary, tillage, cropping system, and their interaction effect produced significant effects on crop production and soil water status, and the above findings might be helpful to draft appropriate management strategies to realize optimal crop yield based on water use.

1. Introduction

The semi-arid Loess Plateau region, spanning 6.2×10^5 km^2 in northwestern China, is crucially important for Chinese arid agriculture (Ren et al., 2016). The area of rainfed cropping systems is approximately 25 Mha, accounting for more than 80% of the arable land (Zhang et al., 2014). Due to the scarcity and temporal variability of precipitation, as well as the high evaporation of more than 1500 mm, water stress has been a main limiting factor for crop production in these areas (Fengrui et al., 2000).

Winter wheat (*Triticum aestivum* L.) and spring maize (*Zea mays* L.) are the primary cereal crops in these regions. With the constraint of water and the frost-free window, the main cropping system is one harvest per year (continuous spring maize [SMC] and continuous winter wheat [WWC]) and sometimes two harvests in double years (spring maize-winter wheat rotation [MWR], Fig. 1). To maximize soil water storage (SWS), traditionally, conventional tillage (CT, e.g. plowing and harrowing), straw/stubble removal and fallow were usually scheduled after the harvest of previous crops (Su et al., 2007). Long-term of CT deteriorates the chemical and physical properties of farmlands and furthermore causes serious sustainability problems such as soil erosion and productivity decline (Govaerts et al., 2006; Wang et al., 2012).

Extensive studies have been focusing on the ecological, agronomic, and economic effect of conservation agriculture (Syswerda and Robertson, 2014; Gonzalez-Sanchez et al., 2015), which integrates three main elements: minimal soil disturbance, organic matter cover over the soil, and crop rotation. Because of the diversity of ecological

* Corresponding authors.
E-mail addresses: junli@nwsuaf.edu.cn (J. Li), nwwangxl@nwsuaf.edu.cn (X. Wang).

http://dx.doi.org/10.1016/j.agee.2017.09.011
Received 19 April 2017; Received in revised form 14 September 2017; Accepted 16 September 2017

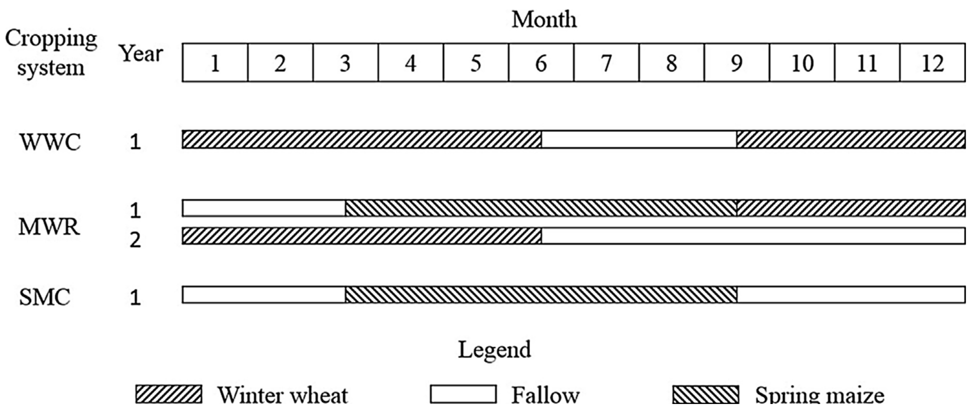

Fig. 1. The rotation schemes for winter wheat and spring maize in three main cropping systems in the Loess Plateau.

and socioeconomic contexts, yield variability (Carmona et al., 2015; Kuhn et al., 2016) or even yield decline restricts the wide adoption of NT (Brouder and Gomez-Macpherson, 2014). Some yield-restricted problems (e.g., soil compaction and nutrient immobilization) might be solved by "reduced tillage" practices such as subsoiling tillage [ST] (Lopez-Garrido et al., 2014; Wang et al., 2006), which can reduce soil disturbance than CT but increase it than NT. In addition, in some cases, NT decreased crop yield after the conversion from CT in the initial years while it increased it subsequently (Soane et al., 2012), so long-term studies on the economic and ecological effect of different tillage practices are necessary. Currently, though straw incorporation in these regions has become the most popular practice along with the progress of mechanization and the innovation of energy consumption in daily life, CT is still a prominent tillage practice, where the straws and stubbles are incorporated into the soils, so organic matter is not thoroughly covered over the ground in this area.

Previous studies confirmed that the conversion from monoculture to crop rotation was positive for increasing crop yield (Laik et al., 2014). Reasonable and diversifying crop rotations are helpful to maintain biodiversity above and in the soil, contribute nitrogen to the soil/plant system, avoid plant diseases and insect pests, improve soil physical properties, and increase water availability and WUE (Kassam et al., 2009; Kirkegaard and Ryan, 2014). However, most of the rotation systems involve legumes, and comparisons between cereal crop rotation and their monocultures are relatively few. Furthermore, an interaction effect between tillage and rotation was found to significantly impact crop yield (Fischer et al., 2002a; Martin-Rueda et al., 2007).

Fallow is traditionally considered to increase soil water storage, facilitate weed control, organic material mineralization and nutrient release (Aase and Pikul, 2000; Fengrui et al., 2000). In the semi-arid Loess Plateau region, the fallow period of WWC was longer compared with MWR by three months for wheat (three months vs. no fallow, Fig. 1), while for maize, the fallow period MWR was longer compared with SMC by three months (10 months vs. 7 months). Therefore, the usual hypothesis is that before sowing, more soil water storage was obtained in WWC and MWR for winter wheat and spring maize, respectively, and further improved wheat and maize yields would be produced in WWC and MWR, respectively.

According to the authors' knowledge, few studies on the effects of cereal crop rotation, tillage and the rotation-tillage interaction in this semi-arid area have been reported in the literature. Long-term studies of these factors will be of importance to the improvement of soil water use efficiency and crop yield in that agroecosystem.

With this in mind, a middle- to long-term experiment was established in a field of Heyang county, Shaanxi province, a region typical of the semi-arid Loess Plateau, to assess the effects of cropping system and tillage on agroecosystem productivity. Our objectives were to (i) assess the long-term effects of tillage practices (NT, CT, and ST) and cropping systems (WWC, MWR and SMC) on crop yield; (ii) compare the different influences of tillage and cropping systems on SWS, evapotranspiration (ET), and water use efficiency (WUE); (iii) observe soil water dynamics under different treatments in the growth and fallow periods; and (iv) evaluate the relationship between yield and the aforementioned water variables and draft appropriate management strategies to realize optimal crop yield.

2. Material and methods

2.1. Experimental site

The field experiment was conducted at the Heyang Dryland Agricultural Research Station, Ganjing Town (latitude 35°33′N; longitude 110°08′E; altitude 900 m), Heyang County, Shaanxi Province, China (Fig. 2). The site is located in the southeast of the Loess Plateau region where the climate is semi-arid and continental monsoon, with a 30-year average annual precipitation of 538 mm, concentrated from July to September, and displaying great inter- and intra-annual variability. According to Guo et al. (2012), three annual precipitation types (normal, dry, and wet) on the growth or fallow period scale were distinguished based on the drought index, and some of the information used in this paper is listed in Table 1. The annual average temperature is 10.5 °C, with a frost-free period of 180-190 days. The temporal distributions of monthly precipitation and monthly mean temperature during 2007–2015 are shown in Fig. 3. The average annual sunshine duration, aridity index and evaporation are 2528.3 h, 1.5 and 1832.8 mm, respectively. The meteorological data were obtained from the nearest weather station, which was approximately 1 km away. The experimental fields are level and the soils derived from loess are Cumuli-Ustic Isohumosols (Chinese Soil Taxonomy). The soils contain 27% clay, 39% silt, and 34% sand and have weak cohesion, good water-storage capacity and negligible drainage below 2 m. Several basic properties of topsoil (0–20 cm) before the experiment onset are presented in Table 2.

2.2. Experiment design and management

The experiment initiated on 15 September 2007 was a split plot design (Fig. 2) with three replicates from south to north, with cropping systems (SMC, WWC, and MWR) assigned to main plots and three tillage treatments (CT, ST, and NT) assigned to subplots. Each plot only underwent one type of tillage within a planting season according to the above designed sequence. All plots were 5 m in width and 22 m in length (110 m^2) with a 60-cm interval between adjacent blocks.

2.2.1. Tillage management

Prior to the research, spring maize had been continuously cropped in this site under F2 and CT practice for 3–4 years. In 2007, one season of maize was cultivated in the experimental field using CT and no fertilizer, and after the harvest, the experiment commenced with the scheduled first tillage. In every season, tillage was conducted after the