Agricultural and Forest Meteorology 263 (2018) 107–117

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

The effects of rotating conservation tillage with conventional tillage on soil properties and grain yields in winter wheat-spring maize rotations

Yujiao Zhang[a,b], Shulan Wang[a], Hao Wang[a], Fang Ning[a], Yuanhong Zhang[a], Zhaoyang Dong[a], Pengfei Wen[a], Rui Wang[a], Xiaoli Wang[a,*], Jun Li[a,*]

[a] *College of Agronomy, Northwest A&F University, Yangling 712100, China*
[b] *School of Agriculture, Yunnan University, Kunming 650504, China*

ARTICLE INFO

Keywords:
Conservation tillage
Conventional tillage
Dryland agriculture
Grain yield
Soil properties
Tillage rotation

ABSTRACT

Intensive tillage in conventional tillage systems reinforces water stress effects on crop growth, limiting yields from dryland agriculture. Conservation tillage can reduce soil evaporation and conserve more soil water in fields, but long-term, mono-conservation tillage may lead to low crop yields. The rotation of conventional tillage with conservation tillage may offset some of the defects generated by the mono-tillage practices of either conventional or conservation tillage, improve crop yields and provide better soil conditions. A long-term tillage rotation experiment (2007–2016) was established to assess the effects of rotating conservation tillage with conventional tillage on soil water and crop productivity in a winter wheat-spring maize rotation field in Heyang County, Shaanxi Province, a typical semi-arid region of the Loess Plateau, China. Four tillage treatments were applied over ten years, as follows: ST/CT (subsoiling was performed during the first year then rotated with conventional tillage in the second year), CT/NT (conventional tillage during the first year and then rotated with no-tillage in the second year), NT (no tillage applied in any year) and CT (conventional tillage applied annually). Compared with CT and NT, the CT/NT rotation significantly decreased the soil bulk density and increased the soil porosity in the 0–60 cm soil layer after ten years ($P < 0.05$). The CT/NT and ST/CT rotations increased the minimum soil temperature during the wheat growth season and decreased the maximum soil temperature during the maize growth season. In fallow periods, the mean soil water storage and soil water content values for the CT/NT rotation were 8.7% and 4.8–10.1% higher than those of the CT treatment, respectively. The CT/NT rotation consumed more soil water during the winter wheat growth season and less soil water during the spring maize growth season compared to the NT and CT treatments. Over ten years, the ST/CT rotation produced higher crop yields (winter wheat: 5231 kg ha^{-1}, spring maize: 8388 kg ha^{-1}), while the CT/NT rotation had a higher WUE (winter wheat: 15.5 kg ha^{-1} mm^{-1}, ST/CT: 20.6 kg ha^{-1} mm^{-1}) than either NT or CT alone. The CT/NT rotation also had an increased straw yield (mean value: 9952 kg ha^{-1}) and economic profit (6776 yuan ha^{-1}). Moreover, the CT/NT and ST/CT rotations provided an optimal SOC distribution in the 0–60 cm soil layer. With respect to comprehensive productivity, the CT/NT rotation provided relatively better soil conditions and crop yields during the winter wheat-spring maize rotations. We recommend using the CT/NT rotation as the optimal tillage system for the sustainable production of crops under conditions of semi-arid agricultural production in the Loess Plateau of China.

1. Introduction

Water shortage is the primary limiting factor for crop production in the rainfed farming systems of semi-arid areas (Debaeke and Aboudrare, 2004). The Loess Plateau is one of the primary rainfed and semi-arid areas for crop production in China, and it always suffers from severe water stress (Chu et al., 2016). These stress effects are reinforced by the current conventional tillage (CT) practices, which include the post-harvest removal or burning of crop residues and plowing (Zhang et al., 2016). Intensive soil disturbances, residue removal or burning as part of the conventional tillage practices throughout the entire crop season leads to accelerated soil erosion, environmental pollution, and soil degradation, and it affects ecosystem functions (Choudhury et al., 2014; Montgomery, 2007). This approach often creates a dry, loose bed of fine soil particles (Schillinger et al., 2007). Moreover, the intensive tillage in the conventional tillage system, combined with bare soil

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

https://doi.org/10.1016/j.agrformet.2018.08.012
Received 11 December 2017; Received in revised form 10 August 2018; Accepted 18 August 2018
0168-1923/

surfaces, leads to a shallow arable layer and a thickened subsurface soil layer. Thus, this practice has resulted in a compact and closed plow pan, which hinders the circulation of soil water, fertilizer and heat in the deep soil layer (He et al., 2006; Wu et al., 2014). As a result, the fields become "waterlogged" fields when the rainfall is ample and experience drought when rainfall is inadequate. Consequently, this tillage approach aggravates the water stress and drought effects, resulting in unstable, low crop yields in the Loess Plateau. Thus, improving the soil water status is the key to maintaining high, stable crop yields in the Loess Plateau, particularly during winter wheat production.

Conservation tillage practices, including straw mulch, reduced tillage and no tillage, could improve the soil water conservation and water use efficiency (WUE), with minimal soil disturbances (Wang and Shangguan, 2015). Numerous studies (Hou et al., 2012; Verhulst et al., 2011) have suggestedthat conservation tillage technologies, such as no tillage, reduced tillage and straw mulching, can improve WUE and simultaneously reduce seasonal evapotranspiration. For example, no-tillage can conserve more soil water by increasing water infiltration and decreasing evaporation (Wagger and Denton, 1992). Subsoiling can enhance root growth and improve soil water infiltration (Hou et al., 2012) while increasing the amount of water that is available to the crop (Mohanty et al., 2007). However, long-term mono-conservation tillage may not always be able to satisfy the key needs of farmers, such as increases in crop production and soil quality and the capacity to control weeds and reduce production costs (FAO, 2008). For example, annual subsoiling was not found to markedly enhance the soil water content, crop yields or WUE (Zhang et al., 2009). Reduced tillage often increases the soil bulk density in the top soil layer (10–20 cm) in the absence of plowing; this density leads to a reduction of the air-filled pore space (Václav et al., 2013), which is not beneficial for crop growth. Moreover, although reduced or no tillage has no significant effect on the grain yield during the first 3 years, the grain yield decreased during subsequent years, while conventional tillage produced higher yields (Arvidsson et al., 2014; Brenna et al., 2014). Thus, proper cultivation management techniques to increase soil water and WUE are essential for sustainable crop production in this area (Lu et al., 2016).

Numerous short-term studies have found that using a conservation tillage rotation can enhance the soil properties and increase the soil water status and yields of dryland agriculture (He et al., 2007; Qin et al., 2008). A study in northern China by He et al. (2007) suggested that conservation tillage coupled with subsoiling could significantly improve the grain yields and WUE of winter wheat over the long term. Ma et al. (2015) also indicated that subsoiling at an interval of 3 years improved the soil moisture content in the 100 cm–160 cm soil layer before sowing when compared with plowing for 6 years. These studies all focused on the effects of conservational tillage rotations over a short period. However, for most years, the conventional tillage practice has also been found to produce higher crop yields than no tillage or subsoiling. Regardless of water conservation management efforts, conventional tillage could yield better agronomic and economic responses than conservation tillage (Sime et al., 2015). Under similar water conservation management conditions, conventional tillage enhanced the agronomic responses of maize to a greater degree than conservation tillage. In addition, it appears to be difficult for farmers to change from conventional tillage to conservation tillage within a short period of time.

The rotation of conventional tillage with conservation tillage may offset the defects produced by the mono-tillage practices of either conventional or conservation tillage and help growers achieve sustainable crop yields, and rotation may improve soil conditions compared to conservation tillage alone. In addition, rotations between conventional and conservation tillage may be more easily accepted by farmers. However, the rotation between conservation and conventional tillage has rarely been reported. The suitability of conservation tillage practices should first be locally assessed, before their extensive application in any particular region (Su et al., 2007). A site-specific system that rotates conventional tillage with conservation tillage is indispensable for mitigating severe water stress in the Loess Plateau. Simultaneously, a rotation between conventional and conservation tillage could also undo many of the positive effects on soil conditions and crop production produced by monoculture tillage systems, for either conservation or conventional tillage. Specifically, the effects of rotating conventional and conservation tillage on farming systems are not yet clearly understood. A previous study (Zhang et al., 2017) on the Loess Plateau indicated that no tillage rotated yearly with subsoiling improved soil conditions and increased crop yields compared to no tillage rotated with subsoiling every two years. With this in mind, a long-term experiment (2007–2016) was established in a field in Heyang County, Shaanxi Province, a typical semi-arid region in the Loess Plateau in China, to assess the effects of tillage rotation on agricultural ecosystem productivity. In this paper, four tillage treatments were applied as follows: ST/CT (subsoiling was applied during the first year and rotated with conventional tillage in the second year), CT/NT (conventional tillage was used in the first year and rotated with no-tillage in the second year), NT (no tillage applied in any year) and CT (conventional tillage annually), to explore the optimal rotation between conservation and conventional tillage in the Loess Plateau. Our objectives were to assess the long-term effects of these tillage practices (ST/CT, CT/NT, NT and CT) on the soil properties, water storage and grain yields to select an optimal tillage system for crop production under semi-arid agricultural production conditions.

2. Materials and methods

2.1. Study site description

This study was performed over ten crop growing seasons (from September 2007 to June 2016) on the Loess Plateau, China. The research station is located in Ganjing Town (35°19′ N, 106°4′ E), Heyang County, Shaanxi Province, China, which is characterized by a temperate, semi-arid, continental monsoon climate at an altitude of 877 m. Over the last 30 years, the annual mean temperature was 11.5 °C and the total yearly frost-free period was 210 days. The mean annual precipitation was 526 mm, and the evaporation was 1833 mm. The annual precipitation was uneven, and 60% of the total precipitation was distributed over the summer season (July, August, and September), which deviated from the winter wheat growth season. The monthly precipitation measurements and temperatures recorded during this ten-year experiment (2007–2016) are shown in Fig. 1.

Before the experiment, continuous spring maize was planted, and conventional tillage with crop residue removal was applied after the crop harvest every year. 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. The soil properties and nutrient conditions, measured at a soil depth of 0 to 60 cm before this experiment, started in 2007 are shown in Table 1.

2.2. Experimental design and treatments

The experiment began in September 2007. The research plots were established on a previous continuous maize-planted field. Three tillage practices were applied for ten years (2007–2016) during this experiment: no tillage (NT), subsoiling (ST), and conventional tillage (CT). All tillage practices were applied after both winter wheat and spring maize harvests. For the NT practice, the crop straw was chopped and spread evenly over the surface of the experimental plots following the harvest of the previous crop using a combine harvester. For the ST practice, the crop straw was left on the soil surface as mulch, and the soil was then subsoiled to a depth of 30–35 cm at intervals of 60 cm using a subsoiler with adjustable wings (Nong haha 1SZL-250 Machinery Co. Ltd., Hebei,