Agricultural Water Management 203 (2018) 376–384

Contents lists available at ScienceDirect

Agricultural Water Management

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

The influence of rotational tillage on soil water storage, water use efficiency and maize yield in semi-arid areas under varied rainfall conditions

Shulan Wang[a], Hao Wang[a], Yuanhong Zhang[a], Rui Wang[a], Yujiao Zhang[a], Zonggui Xu[b], Guangcan Jia[a], Xiaoli Wang[a], Jun Li[a,*]

[a] College of Agronomy, Northwest A&F University, Yangling, Shaanxi 712100, China
[b] College of Forestry, Northwest A&F University, Yangling, Shaanxi 712100, China

ARTICLE INFO

Keywords:
Soil water storage
Rotational tillage
Water depletion
Crop production
Water use efficiency

ABSTRACT

The implementation of rotational tillage with straw mulching during a fallow period seems to be an effective management strategy to help store water for spring-sown crop. A site-specific field study was conducted according to rainfall conditions to determine the effect of rotational tillage on soil water regime, water use efficiency and grain yield in semi-arid region on the loess plateau of China. Six tillage practices were tested: NT/ST rotation (no-tillage was applied in the first year and rotated with sub-soiling in the second year), ST/CT rotation (sub-soiling was applied in the first year and rotated with conventional tillage in the second year), CT/NT rotation (conventional tillage was applied in the first year and rotated with no-tillage in the second year), NT (no-tillage was applied every year), ST (sub-soiling was applied every year), CT(conventional tillage was applied every year). The results showed that the rotational tillage increase average SWS (soil water at sowing) by 5.2 mm in dry years, 0.8 mm in normal years, and 13.2 mm in humid years when compared to CT. Soil water depletion was consistent with rainfall totals, and the lowest depletion value recorded in the NT/ST and followed by NT treatment. The grain yield was positively related with rainfall, and average grain yields for three rainfall conditions were ranked as NT/ST > CT/NT > ST/CT > ST > NT = CT, while the soil water use efficiency (WUE) was ranked in the order of NT/ST, > CT/NT > ST, ST/CT > NT > CT. Grain yields of rotational tillage NT/ST, ST/CT and CT/NT are higher than the yield of NT by 6.5%–12.0%, higher than the yield of ST by 1.7%–7.0%, and 7.6%–13.2% higher than CT, respectively. Hence, rotational tillage could improve soil water storage, thus significantly increasing crop grain yield and water use efficiency. The method could have important applications in semi-arid areas.

1. Introduction

Rain-fed cropland covers approximately 80% of the total cultivated land in semi-arid areas, which are also an important cereal production area, in China (Chen et al., 2015; Hou et al., 2012a, 2012b). Maize (Zea mays L.) is most typically cultivated in this region, but grain yield remains stagnant due to water stress and seasonal agricultural drought owing to low and erratic rainfall, high runoff water losses and high evaporation (Sharma and Abrol et al., 2011). Relative studies have indicated that plastic film mulching had positive advantages in increasing water moisture, while it also resulted in environmental problems (Chen et al., 2015).

Tillage practices seem an effective approach to sustainable development, but excessive soil tillage (i.e., moldboard plowing) applied with conventional tillage strongly influences soil properties, and result in lower water and nutrient availability (Kumar et al., 2013), leading to unstable and declining crop yield (Hou et al., 2012a, 2012b; Chan and Heenan, 2005). Conservation tillage such as no-till and reduced tillage and sub-soiling with straw mulching promise as an approach to managing and improving crop production and water use efficiency.

No-till (NT) practice with straw mulching in the surface could minimize the disruption of the soil structure and reduce soil erosion and runoff, thereby increasing soil water capacity and water use efficiency (Sharma and Abrol et al., 2011). Sub-soiling can eliminate soil compaction of the subsoil layer by increasing soil structure and improving infiltration and water storage, thereby increasing the drought-resilience and crop yield (Ma and Yu et al., 2015). However, other studies demonstrated the negative impacts of long-term annual tillage practice. For example, long-term NT adoption may increase soil bulk density, decrease seed germination and emergence, and thereby increase weed overgrown and crop yield reduction (Tian et al., 2016). Sub-soiling has little effect on plant growth and no effect on grain yield over three

* Corresponding author.
E-mail address: junli@nwsuaf.edu.cn (J. Li).

https://doi.org/10.1016/j.agwat.2018.03.007
Received 5 February 2017; Received in revised form 26 February 2018; Accepted 4 March 2018
0378-3774/

cropping seasons (Ma et al., 2015).

Nevertheless, relative studies reported that the adoption of soil rotational tillage at an appropriate time is to be a promising approach for overcoming some of the disadvantages caused by continuous single tillage (Hou et al., 2012a, 2012b; López-Fando et al., 2007). He et al. (2006) found that NT coupled with sub-soiling practice can increase crop yields and WUE in semi-arid areas of northern China. He et al. (2007) and Qin et al. (2008) showed that the sub-soiling efficacy could persist approximately 4 years, and the combination of a 2 or 4-year NT and 1-year sub-soiling could minimize soil compaction and improve soil physical and chemical changes which caused by annual sub-soiling practice. Therefore, tillage practices during fallow period have certain storage effect. However, current information is limited due to the regularity of water storage, grain yield and WUE to an interval of varying tillage in the semi-arid region.

As indicated by the literature, straw mulching associated with conservation tillage seems promising for maintaining or improving soil water storage and yield. However, limited information is available on the tepid response of the combination of rotational tillage during fallow period and straw mulching on soil water storage and grain yield, especially in different annual rainfall conditions. In this study, we focused on the effects of tillage practices during fallow on soil water storage and grain yield of the semi-arid region at different rainfall conditions. The aim is to identify promising approach on water conservation and yield.

2. Materials and methods

2.1. Site description

The experimental was established in 2007 at a tableland ((35°19′54.45″N latitude, 110°05′58.35″E longitude; altitude 877 m) site, located in Heyang county, Shaanxi Province, China, during 2007–2016. The experimental fields are level and the soil is classified as middle loam based on the FAO/UNESCO Soil Classification (FAO, 1993). All the fields had been plowed for several years at the start of the experiment in 2007, and the soil in 0–20 cm layer had a pH of 8.2, an SOC of 9.94 g kg^{-1} , a soil total nitrogen content of 0.74 g kg^{-1} , a soil total phosphorous content of 0.59 g kg^{-1}, and an available potassium content of 110.6 g kg^{-1}. The soil bulk density was 1.43 g cm^{-3} and soil porosity was 46.76%.

The study area is characterized by a semi-arid and continental monsoon, with an average annual temperature of 11.5 °C, and a potential evaporation of 1832.8 mm. Average annual sunshine is approximately 2528.3 h. The climate data were obtained from the weather station located at the experimental station.

The rainfall conditions were divided based on the drought index (Guo et al., 2012), and partial information used in this paper are listed in Table 1. The drought index (DI) for rainfall was calculated using the following equation to assess variations and status in rainfall among different years:

$$DI = (P - M)/\sigma$$

where P is the annual rainfall, M is the average rainfall, and σ is the standard error for rainfalls. DI is used to distinguish among the wet (DI > 0.35), normal ($-0.35 \le DI \le 0.35$), and dry ($DI < -0.35$) years. Similarly, the DIs for (fallow rainfall (FSR) and growing season rainfall (GSR) were calculated to assess variations and status in seasonal rainfall among different years.

According to the rainfall totals during growth stages, the year 2013 and 2015 were identified as dry planting seasons, 2008, 2009 and 2014 were identified as normal planting seasons, and 2010, 2011, 2012 and 2016 were identified as wet planting seasons. In this study, we chose year 2013 to represent a dry year, 2014 as a normal year and 2016 as a humid year

2.2. Experimental design and treatments

A homogeneous area of 2025 m^2 was selected in 2007 for the establishment of the experimental plots. The experimental area was a randomized block design with three replications. Each plot was 5 m wide and 22.5 m long. In this study, six tillage treatments were applied in the fallow period of spring maize field. NT (no-tillage) was applied every year, ST (sub-soiling was applied every year), CT (conventional tillage was applied every year), NT/ST rotation (no-tillage was applied in first year and rotated with sub-soiling in second year), ST/CT rotation (sub-soiling was applied in first year and rotated with conventional tillage in second year), CT/NT rotation (conventional tillage were applied in first year and rotated with no-tillage in second year).

In every season, tillage was conducted after the harvest of previous crops according to the designed patterns. In the CT treatment, the soil was tilled to 20–25 cm depth using a tractor-mounted moldboard plow, and the crop straws were returned and buried into the arable layer. The straws were retained evenly on the plot surface as mulch under NT and ST. For ST treatment, the soil was sub-soiled to a depth of 30–35 cm by a sub-soiling chisel, with its adjustable wings being set to intervals of 60-cm distance between their terminal tines. Soil disturbance was avoided under NT until sowing, and ST can also be defined as conservation tillage, for the field surface suffered little disturbance with this treatment.

A common spring maize variety Zhengdan 958 was sown in middle or late April, the local popular sowing time. For NT and ST, maize was drill seeded at a plant density of 5.3 plants m^{-2}, while for CT, sowing with the same plant density was conducted using a rotary cultivator seeder. The distance within and between rows of maize was 30 cm and 60 cm, respectively. The one-time application of the full amount of fertilizer was conducted by broadcast before sowing with rates of 150 kg N $ha^{\cdot -1}$,120 kg P_2O_5 $ha^{\cdot -1}$ and 90 kg K_2O $ha^{\cdot -1}$. The fertilizer types for N, P_2O_5 and K_2O were urea, ammonium phosphate and potassium sulfate, respectively. The harvest of maize was performed in the first fortnight of September. After the scheduled tillage, the field was kept fallow until the seeding of next maize season in next April.

For all treatments, weeds were controlled by spraying chemical herbicides before crop emergence and at the initial fallow stage, as well as by hand one to two times in the growth season based on visual estimates of weed populations.

Table 1
Annual rainfall, fallow rainfall (FSR), and growing season rainfall (GSR) between 2008 and 2016.

Year	Annual rainfall (mm)	DI for annual rainfall	Rainfall conditions	GSR (mm)	DI for GSR	Rainfall conditions	FSR (mm)	DI for FSR	Rainfall conditions
2008	518.3	−0.05	Normal	392.1	0.31	Normal	137.7	0.22	Normal
2009	521.5	−0.02	Normal	394.6	0.34	Normal	105.7	−0.53	Dry
2010	553.6	0.26	Normal	470.3	1.08	Wet	116.2	−0.28	Normal
2011	710.5	1.60	Wet	483.3	1.21	Wet	85.2	−1.01	Dry
2012	517.2	−0.06	Normal	451.2	0.89	Wet	217.2	2.08	Wet
2013	349.9	−1.49	Dry	293.0	−0.66	Dry	56.4	−1.68	Dry
2014	626.7	0.88	Wet	394.7	0.34	Normal	119.9	−0.20	Normal
2015	495.6	−0.24	Normal	280.3	−0.78	Dry	127.4	−0.02	Normal
2016	501.5	−0.19	Normal	400.2	0.39	Wet	165.6	0.87	Wet