Soil & Tillage Research 153 (2015) 20–27

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Impact of tillage practices on nitrogen accumulation and translocation in wheat and soil nitrate-nitrogen leaching in drylands

Hongguang Wang [a,b], Zengjiang Guo [a,c], Yu Shi [a,*], Yongli Zhang [a], Zhenwen Yu [a]

[a] Key Laboratory of Crop Ecophysiology and Farming System, Ministry of Agriculture, College of Agronomy, Shandong Agricultural University, Tai'an 271018, China

[b] Key laboratory of Crop Growth Regulation, Hebei Province, College of Agronomy, Hebei Agricultural University, Baoding 071000, China

[c] Polytechnic College, Hebei University of Science and Technology, Shijiazhuang, Hebei Province 050000, China

ARTICLE INFO

Article history:
Received 15 July 2014
Received in revised form 6 February 2015
Accepted 7 March 2015

Keywords:
Tillage practice
Wheat
Nitrogen accumulation
Nitrate-nitrogen leaching
Economic benefit

ABSTRACT

Although the effects of tillage practices on soil properties and root growth is well studied, how they affect nitrogen accumulation and translocation in wheat in dryland regions is poorly understood. Here, the impact of different tillage practices, namely, strip rotary tillage (SR), strip rotary tillage after subsoiling (SRS), rotary tillage (R), and rotary tillage after subsoiling (RS), on nitrogen accumulation and translocation, grain yield, and economic benefit in wheat and soil nitrate-nitrogen leaching in drylands was studied over three wheat growing seasons from 2009 to 2012. The results showed that compared with R, nitrogen accumulation amount under SRS increased by 36.8% from jointing to maturity in 2009–2011 and by 12.9 and 16.4% from sowing to maturity in 2009–2010 and 2010–2011, respectively. Post-anthesis nitrogen accumulation, its contribution rate to grain and nitrogen accumulation in grains at maturity under SRS were 48.3, 31.3 and 12.7% higher, respectively, compared to that under R in 2009–2010. On the other hand, nitrate-nitrogen accumulation under SRS in 0–60 cm soil layers was lower in comparison to that under SR and R, which suggested that SRS promoted absorption of nitrate-nitrogen in soil layers by wheat. However, no significant difference in nitrate-nitrogen accumulation in the 60–200 cm soil layers was observed between SR and R. Average grain yield, nitrogen production efficiency and economic benefit were all the highest under SRS at 598.78 g m^{-2}, 39.9 kg kg^{-1} and 8350.8 RMB ¥ ha^{-1}, respectively, over the study period. Therefore, we propose that SRS is the optimal tillage practice for wheat production in this region.

1. Introduction

Implementation of conservation tillage, which comprises tillage, no-tillage, subsoiling, mulching and other field activities, results in significant water conservancy, increase in production and income, and ecological improvements (Riksen and Goossens, 2005; Bhatt and Khera, 2006; Wang et al., 2007; Mohanty et al., 2007). Studies have shown that no-tillage can increase soil aggregates and nutrient content at soil surfaces (Paustian et al., 2000; Blanco-Canqui and Lal, 2004; Lampurlanes and Cantero-Martinez, 2006). Subsoiling has also been shown to increase the nitrogen content of large-sized microaggregates (Wang et al., 2010). A large number of studies on drylands have shown that subsoiling leads to better grain yield and water use efficiency than conventional ploughing. However, conflicting results have been reported on the impact of no-tillage on wheat yield (He et al., 2006; Li et al., 2006; Jin et al., 2007; Lei et al., 2008). The results of a study conducted in the drylands of western Henan Province showed that compared with ploughing, wheat yield increased under no-tillage and subsoiling tillage by 21.1% and 29.4%, respectively. Compared to ploughing in the dryland region of the Weibei Plain, wheat yield increased under no-tillage and subsoiling by −0.8% and 6.3%, respectively. Thus, results to date indicate that subsoiling tillage improves wheat production in drylands. However, very few studies have focused on optimizing subsoiling with strip rotary tillage in field conditions.

In the farmland ecosystem of drylands, a large amount of nitrate-nitrogen exists in the soil (Li and Li, 2000; Ferguson et al., 2002). It has been reported that in a wheat continuous cropping system, 180 kg ha^{-1} of nitrogen fertilizer is applied every year. The

Abbreviations: SR, strip rotary tillage; SRS, strip rotary tillage after subsoiling; R, rotary tillage; RS, rotary tillage after subsoiling; ET, evapotranspiration; WUE, water use efficiency.

* Corresponding author at: Key Laboratory of Crop Ecophysiology and Farming System, Ministry of Agriculture, College of Agronomy, Shandong Agricultural University, 61 Daizong Road, Tai'an 271018, Shandong, China. Tel.: +86 538 8241484.
E-mail address: shiyu@sdau.edu.cn (Y. Shi).

http://dx.doi.org/10.1016/j.still.2015.03.006
0167-1987/

Table 1
Rainfall and ≥0 °C accumulated temperature at various growth stages during the 2009–2012 growing seasons of wheat.

Growth stage	Rainfall (mm)			≥0 °C accumulated temperature (°C day)		
	2009–2010	2010–2011	2011–2012	2009–2010	2010–2011	2011–2012
Sowing to pre-winter	57.9	5.0	105.6	559.2	637.4	684.6
Pre-winter to revival	37.7	0.0	12.7	58.2	58.1	92.5
Revival to jointing	35.6	20.0	23.2	377.9	451.0	325.8
Jointing to anthesis	7.9	9.5	25.1	383.1	391.1	487.3
Anthesis to maturity	99.8	71.1	11.6	699.3	739.7	725.7
Sowing to maturity	238.0	105.6	178.2	2077.7	2277.3	2315.9

amount of nitrate-nitrogen accumulation reaches 601 kg ha^{-1} in 100–180 cm soil layers after 15 years. Leaching of residual nitrate-nitrogen into deep soil due to rainfall then causes groundwater pollution (Wang et al., 2006). A field experiment conducted in the Shanxi Province of China found that residual nitrate-nitrogen in the soil leached into deeper soil layers (below 400 cm) after 6 years (Yang et al., 2001). In the drylands of Canada, 123 kg ha^{-1} nitrate-nitrogen were found to have leached away from the top 240 cm soil layers from mid-May to the end of September (Campbell et al., 1984). In addition, the nitrate-nitrogen content in 37% of 311 drinking water samples in the drylands of Western Iran was found to be over 50 mg L^{-1}, and this was attributed to nitrate-nitrogen leaching from agriculture (Jalali, 2005). Therefore, optimizing tillage to reduce nitrate-nitrogen leaching is highly important not only for improving agricultural production but also for protecting the environment.

Soil tillage influences nitrate-nitrogen leaching by regulating soil mineralization and water movement. In addition, it changes the physical and chemical properties as well as the biological environment of the soil, which in turn affect nitrate-nitrogen accumulation (Katupitiya et al., 1997). Matthews et al. (2000) found that tillage produced large surface areas and short diffusion paths in the soil, which then increased nitrate-nitrogen leaching. Consistent with this, no-tillage has been reported to decrease the nitrate-nitrogen concentration in groundwater by decreasing the rate of leaching (Weed and Kanwar, 1996). Halvorson et al. (2001) found that in both one-year cropping system and spring wheat-fallow system, no-tillage reduced nitrate-nitrogen leaching by increasing water use efficiency; compared to conventional and minimum tillage, less nitrate-nitrogen migrated below the root zone and remained in the soil with no-tillage. However, very little is known about the effect of subsoiling with strip rotary tillage on nitrate-nitrogen leaching in the field.

Thus, a large number of studies have been conducted on the impact of conservation tillage on soil nutrient content and wheat grain yield. However, very few studies have focused on the impact of tillage practices on nitrogen accumulation and translocation in wheat. Therefore, this study aimed to determine the wheat yield and water use efficiency to the tillage practices, to examine the impact of tillage practices on nitrogen accumulation and translocation of wheat and to make clear for nitrate-nitrogen leaching under tillage practices in drylands.

2. Materials and methods

2.1. Experimental site

Field experiment was conducted over 3 growing seasons for wheat from 2009 to 2012 in the Village of Bianhe (36°7′N, 118°2′E), Linzi, Shandong Province, Northern China. The area was hilly upland without irrigation, and the experimental field contained calcaric cambisols (FAO classification system). The annual average temperature in this area is 13.0 °C, and the annual average precipitation is 746.8 mm, 60–70% of which occurs in the summer (July–September).

The top 20 cm soil layer of the experimental field contained 11.30 g kg^{-1} of organic matter, 0.90 g kg^{-1} of total N, 74.15 mg kg^{-1} of alkali-hydrolyzable N, 24.02 mg kg^{-1} of available phosphate, and 94.26 mg kg^{-1} of available potassium before sowing in 2009–2010 growth season. The rainfall and ≥0 °C accumulated temperature during various growth stages of wheat are shown in Table 1.

2.2. Experimental design and crop management

In this experiment, the winter wheat (*Triticum aestivum* L.) cultivars Jimai 22 (the most widely planted cultivar in the Yellow and Huai River Valleys), Shannong 16 (a dryland cultivar suited for planting in the high-fertility dryland of Shandong Province) and Yannong 0428 (a dryland cultivar suited for planting in the high-fertility dryland of Shandong Province) were used for the 2009–2010, 2010–2011 and 2011–2012 growth seasons, respectively.

The experiment was conducted during the wheat growing season from 2009 to 2012 with four tillage practice treatments, namely, strip rotary tillage (SR), strip rotary tillage after subsoiling (SRS), rotary tillage (R, conventional tillage), and rotary tillage after subsoiling (RS). The operation procedures for the four tillage practices are listed in Table 2, and the models and manufacturers of the tools used are listed in Table 3. Similar treatments were done in

Table 2
Operation procedure of the four tillage practices.

Tillage practice	Operation procedure
SR	Returning maize straw to the field with the straw returning machine → completing rotary cultivation of sowing row (working depth was approximately 15 cm), base fertilizer application and sowing simultaneous with the 2BMTFS-4-2 multifunctional direct seeder in stubble (the row spacing of 2BMTFS-4-2 multifunctional direct seeder in stubble was designed to be 18 cm + 32 cm, in which the sowing row spacing was 18 cm, so that the area of rotary cultivation covered 36% of the border check's total area).
SRS	Returning maize straw to the field → subsoiling once with the ZS-180 vibration subsoiler (working depth was approximately 38 cm) → completing rotary cultivation of sowing row (working depth was about 15 cm), base fertilizer application and sowing simultaneous with the 2BMTFS-4-2 multifunctional direct seeder in stubble.
R	Returning maize straw to the field → base fertilizer spreading by hand → rotary cultivation two times with rotary cultivator (working depth was approximately 15 cm) → harrowing by hand with a rake → sowing with drill seeder (row spacing was 25 cm).
RS	Returning maize straw to the field → base fertilizer spreading by hand → subsoiling once with the ZS-180 vibration subsoiler (working depth was approximately 38 cm) → rotary cultivating two times with rotary cultivator (working depth was approximately 15 cm) → harrowing by hand with a rake → sowing with drill seeder (row spacing was 25 cm).