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Soil loosening on permanent raised-beds in arid northwest China

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Abstract

Poor lateral water infiltration into permanently raised beds (PRB) can reduce crop yield and water use efficiency (WUE) in dryland agriculture. Especially for densely planted crops the reduced soil moisture affects seedling emergence and causes slow crop growth. Soil loosening with three different types of cutters was tested to overcome this problem of wide PRB in this study. A field experiment with five treatments (traditional tillage, bed without soil loosening, bed with soil loosening by two-edge cutter, bed with soil loosening by flat cutter and bed with soil loosening by V-shaped cutter) was conducted in the Hexi Corridor, northwest China, on spring wheat in 2005 and 2006. The effects of soil loosening and the performances of the three cutters were assessed based on 2 years of soil moisture, bulk density, temperature, spring wheat growth, yield, WUE, power and fuel consumption data. Soil loosening significantly increased lateral water infiltration and thus improved soil water content by 3–8% to 100 cm depth and soil temperature by 0.2–0.4 °C to 30 cm depth compared to beds without soil loosening on sandy-loam soil in 100 cm wide bed systems. Furthermore, bulk density at 10–20 cm depth was about 7.4% lower for bed with soil loosening treatments than for bed without soil loosening. The best results were achieved by the V-shaped cutter, which at a slight additional fuel consumption of 0.46–0.84 l ha^{-1} offered the greatest benefits to spring wheat yield and WUE. Spring wheat yields increased by 5% and WUE improved by 38% compared to traditional tillage due to higher soil moisture and temperature, lower bulk density and faster growth. The improvements in WUE have tremendous implications in the arid areas of northwest China where agriculture relies heavily on irrigation, but water resources are scarce. We conclude therefore that soil loosening by V-shaped cutter is an efficient way to remove poor water infiltration, and significantly improve yield and WUE for wide beds under PRB farming system in arid areas of northwest China.

Keywords: Permanent raised-beds; Soil loosening; Water infiltration; Water use efficiency; Spring wheat; Arid areas

1. Introduction

Agriculture in the arid Hexi Corridor of northwest China, where rainfall is less than 200 mm per year, relies heavily on irrigation. Maintaining or improving water use efficiency is extremely important because the limited water resources available for irrigation mainly come from a mountain glacier (Kang et al., 1996). Many water-saving techniques have been tested to ensure the sustainable development of agriculture. Furrow irrigation of permanent raised-beds (PRB) has been adopted widely in arid areas of northwest China. Compared with the traditional flat till, flood irrigation farming systems, PRB is a contemporary farming practice involving bed planting, furrow irrigation, and controlled traffic. PRB requires keeping the beds and furrows permanently in the same position and only repairing the bed every year before the next crop is planted (Sayre and Moreno, 1997; Singh, 2003). Permanent raised-beds are effective in increasing water use efficiency (WUE) (Wang et al., 1999, 2002), reducing compaction of the cropping zone,

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and managing crop residues on the bed (Talukder et al., 2002). PRB has been shown to improve mechanical and chemical weed control, facilitate zero-tillage, and reduce tractor power requirements (Ren et al., 2001; Timsina and Connor, 2001; Hulugalle and Daniells, 2005).

Recent research results have promoted the development and extension of PRB farming system all over the world. Francois et al. (1999) developed a new cropping system to manage water under PRB in Thailand for an Asian rice-based system. Hobbs et al. (2000), Humphreys et al. (2004) and Kukal et al. (2005) systematically researched PRB farming systems in the rice–wheat systems of the Indo-Gangetic plains of southern Asia, while Ockerby and Fukai (2001) studied the management of rice grown on raised beds with continuous furrow irrigation in northern Queensland, Australia. In more arid environments, Wang et al. (2004a) compared PRB and traditional tillage for winter wheat from 1998 to 2002 in northern China.

Wheat (including both spring and winter habit wheat) is the most popular cereal crop in northwest China, especially in Hexi Corridor. In PRB farming systems, 100 cm wide beds systems for wheat planting are the most common because of the dimensions of tractor and harvester wheel spacing. Furthermore, in the same field, wide beds decrease traffic lanes in comparison with narrow beds, which enhances cropping zones and land use efficiency.

A major problem in wide beds is that irrigation water is difficult to laterally infiltrate from the furrow to the center of the bed, where crop water requirements are therefore often not met. Zhang et al. (2005) tested water infiltration on sandy-loam soil in 1.0 m wide bed planting system with furrow irrigation. The results showed that with 90 mm of irrigation water, wetting front required about 290 min to horizontally infiltrate from furrow to the center of bed, while it already reached near 100 cm depth under the furrow in vertical, so only less than 20% of irrigation water was stored in the center of bed. Poor lateral water infiltration in wide beds can therefore adversely affect crop germination, growth and yield. Wang et al. (2004b) reported that on loamy soils non-uniform lateral infiltration into beds wider than 75 cm reduced plant available water in the center of the beds. The lack of water in the center had a negative effect on winter wheat seedling emergence, lowering yield by 5% and decreasing water use efficiency by 6% compared to beds with less than 75 cm furrow-to-furrow distance. In the Hexi Corridor, Wu (2006) demonstrated that yield and center row yield of spring wheat in 70 cm wide beds (three rows) was about 10 and 23% higher than in 100 cm wide beds (five rows), respectively. Deng et al. (2005) and Ma and Wang (2005) also found that narrow bed planting systems had the advantages of higher water content and spring wheat yield in center rows compared to 100 cm bed planting system. The more uniform distribution of irrigation water in beds ranging from 70 to 90 cm width also provides more flexibility for gravity irrigation, efficient management of fertilizer, and easier handling of high levels of crop residues (Sayre et al., 2005).

The irrigation problems of wide beds in PRB farming systems have been known for some time, but few studies on ways to remove poor lateral water infiltration have been conducted. In this paper, the results of a project funded by the Australian Centre for International Agricultural Research (ACIAR) on the use of soil loosening to facilitate water penetration from the furrow to the center of the bed are reported. A soil loosening cultivator, equipped with three kinds of bed cutters designed to open a layer with macro-pores at the bottom of the bed, was tested. The aim of the study was to identify whether soil loosening improves uniform water infiltration into the bed, and if there was a positive effect on yields and water use efficiency in the Hexi Corridor of northwest China. The study also assessed which shape of cutter is most suitable cutter for soil loosening.

2. Materials and methods

2.1. Site and climatic conditions

The experiment was conducted at GAAS (Gansu Academy of Agricultural Science) water-saving research station (latitude 38°50′N, longitude 100°10′E), Zhangye city situated in the Hexi Corridor of northwest China, for two crop cycles in 2005 and 2006. Zhangye is located in warm–temperate arid region at 1200–1700 m above sea level. According to the statistics of Zhangye Weather Station, the normal annual precipitation is 146 mm. Mean annual pan-evaporation is around 2390 mm, 16 times greater than annual precipitation. The annual mean air temperature is about 7.3 °C, with an absolute maximum of 39.1 °C (July) and an absolute minimum of 27 °C (January). Accumulated temperature of ≥10 °C is about 3088 °C during an average of 169 frost-free days per year. The single crop cycle consists of spring wheat, sown in March and harvested in July, and irrigated in middle of April, May and June, respectively. In the experimental plots the soil was a sandy-loam, low in organic matter and slightly alkaline (Table 1).