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Managing soil salinity with permanent bed planting in irrigated production systems in Central Asia

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ABSTRACT

Land degradation due to water logging and its influence on secondary soil salinization processes pose a major threat to the sustainability of irrigated agriculture in the semi-arid production ecologies of Central Asia. In rainfed conditions, conservation agriculture (CA) practices, i.e., reduced tillage, residue retention and crop rotation, have proven to have substantial scope for arresting or reversing soil degradation. Previous research findings suggest that CA can be beneficially applied to irrigated croplands as well, but influences on salinization processes are insufficiently documented. This study investigates the effect of CA practices on soil salinity dynamics in irrigated production systems in the Khorezm region, Uzbekistan, Central Asia. The study was conducted under a cotton-wheat-maize rotation system, typical for the region, from 2007 to 2009 with two tillage methods ('CA' – permanent raised beds (PB); conventional tillage (CT)) combined with two residue levels (residue harvested (RH); residue retained (RR)). Compared to pre-experiment levels, salinity in the top 30 cm soil increased significantly during cotton (May–October), while a negligible change occurred during wheat (October–June) and maize (July–September) season. In absence of crop residues, soil salinity on top of the beds increased compared to CT without crop residue retention. When retaining crop residues, the soil salinity under PB was reduced by 32% in the top 10 cm and by 22% over the top 90 cm soil profile compared to CT without crop residue retention. Thus, PB + RR seems a promising option to slow down on-going soil salinization in salt-affected agro-ecologies such as those in the irrigated arid lands of Central Asia.

1. Introduction

Soil salinity is a serious threat to global agriculture (Zhang et al., 2007). About 20% of the world's cultivated area and nearly 50% of the irrigated croplands are affected by soil salinity (Zhu, 2001). Dryland regions, which mostly depend on irrigation for crop production, are even more vulnerable to soil salinity (Brady and Well, 2008). About 1–2% of the irrigated areas in dryland regions become unsuitable for crop production for some fraction of the year due to salinity (FAO, 2002). In irrigated agriculture, salt comes to the fields with the irrigation water and, when not leached out, accumulate in the soil profile through evaporative water loss, a process that removes the soil water but concentrates salts in the topsoil (secondary salinization).

In Uzbekistan, intensive soil tillage is typically coupled with full residue removal and inefficient irrigation water management (Tischbein et al., 2012). Common consequences of these practices include a dispersion of soil aggregates, reduction in soil organic matter, and a rise of groundwater tables, which in turn leads to increased evaporation loss and salinity levels in soils (Egamberdiev, 2007; Lal et al., 2007). Furthermore, the generally shallow groundwater levels that are common during cropping periods in various regions of Uzbekistan (<1 m, i.e., above the critical limit for secondary salinization) are caused by heavy irrigation of virtually all crops including rice coupled with inadequate drainage systems (Ibrakhimov et al., 2011). The combination of these practices has increased secondary soil salinization of the irrigated croplands in Uzbekistan (Forkutsa et al., 2009b).

Soil salinity affects crop growth, yield and quality, and hence the sustainability of irrigated agriculture (Razzouk and Whittington, 1991; Dong et al., 2008). Mitigation or coping measure can be

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achieved through appropriate soil and water management practices, or through crop breeding advances (Ayers and Westcot, 1985; Dong et al., 2008). Suggested management practices include irrigation at night to reduce evaporation loss (Rhoades et al., 1992; Rhoades, 1999), pre-sowing seed treatments to enhance germination even under saline conditions, improved cultivation methods such as sowing on raised beds (Egamberdiev, 2007; Sayre, 2007; Bakker et al., 2010), increased seed rates (Minhas, 1998), increased application of nitrogen and potassium fertilizers (Minhas, 1996; Tanji and Kielen, 2002), and mulching the soil surface with crop residues (Egamberdiev, 2007; Pang et al., 2009; Bezborodov et al., 2010) or plastic (Dong et al., 2008). Recent research findings demonstrated that conservation agriculture (CA) practices, i.e., reduced tillage, residue retention and appropriate rotation, can influence the location and accumulation of salts by reducing evaporation and upward salt transport in the soil (Brady and Well, 2008).

Among the CA practices, raised bed planting is gaining importance for row-spaced crops in many parts of the world (Sayre, 2007). Raised beds are reportedly saving 25–30% irrigation water, increasing water use efficiency (Sayre and Hobbs, 2004; Hassan et al., 2005; Malik et al., 2005; Choudhary et al., 2008; Ahmad et al., 2009) and providing better opportunities to leach salts from the furrows (Bakker et al., 2010). However, under saline conditions, increased salt accumulation on top of the beds has been reported by Choudhary et al. (2008) due to the upward movement of salts through capillary rise in response to evaporation gradients. Also surface mulching with crop residues has been identified as a promising management option to combat soil salinity, as it can decrease soil water evaporation, increase infiltration and regulate soil water and salt movement (Tian and Lei, 1994; Pang and Xu, 1998; Li and Zhang, 1999; Pang, 1999; Li et al., 2000; Huang et al., 2001; Deng et al., 2003; Qiao et al., 2006).

We hypothesized that the synergistic effects of combining raised bed planting with residue retention is more effective than the effect of either of these practices alone for managing salts. The objective of this study therefore was to compare the salt dynamics under conventional and conservation agriculture practices in irrigated arid lands, with a particular emphasis on permanent raised bed planting and residue retention.

2. Materials and methods

2.1. Study area and site description

The study was undertaken from 2007 to 2009 in the research site of a long term project on land and water use in Khorezm region, Uzbekistan, Central Asia (41°32′12″N, 60°40′44″E, and 100 m a.s.l.) (Martius et al., 2012). Cotton is the major summer crop grown in the region covering almost 50% of the cropped area (Djanibekov et al., 2012). Land preparation involving intensive soil tillage (up to 4–5 machinery passes) and poorly managed flood irrigation with low water use efficiencies are common crop cultivation practices in the region (Tischbein et al., 2012). The climate in the region is arid, with long, hot and dry summers and short, very cold winters (Conrad et al., 2012). During the study period, mean minimum and maximum temperatures during the cotton season (May–October) were 16 °C and 30 °C, during the wheat season (October–June) 5 °C and 16 °C and during the maize season (June–October) 17 °C and 32 °C, respectively (Fig. 1). Long-term average precipitation is around 100 mm year^{-1}, mainly falling outside the vegetation growing period, and is greatly exceeded by annual evaporation (342 mm) (Forkutsa et al., 2009a; Conrad et al., 2012). Rainfall received during the cotton, wheat and maize growing seasons were 14.6, 72.6 and 30.4 mm respectively. In addition to precipitation, 450, 477, and 627 mm of canal water was applied as irrigation for production of the cotton, wheat and maize crops grown in raised bed- furrow planting system, respectively (Devkota et al., 2013). As compared with furrow irrigation, conventional flooding method received 11 and 22 percent more canal water, respectively, in wheat and maize crop seasons. The soil in the experimental area has a loamy texture, low organic matter (0.3–0.6%) and moderate range of salinity (2–4 dS/m). The groundwater table in the area is generally shallow (0.75–2.5 m) with depths ranging from 1.5 to 2.2 m during cotton, 1.8–2.5 m during wheat, and 0.7–1.5 m during maize seasons (Fig. 2).

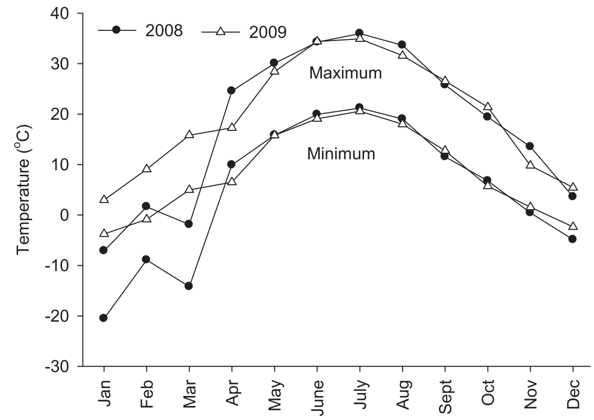

Fig. 1. Average monthly maximum and minimum temperatures in 2008 and 2009 at the experimental site in Urgench (Uzbekistan).

2.2. Experimental treatments and crop management

The study was conducted in a cotton–wheat–maize rotation system, typical for the study region. The treatments considered a combination of two tillage methods (permanently raised beds (PB) and conventional tillage CT)) and two residue retention levels (residue harvested (RH) and residue retention (RR)). The treatments combined were:

(i) permanently raised beds with residue retention (PB + RR),
(ii) permanently raised beds with residues harvested (PB + RH), and

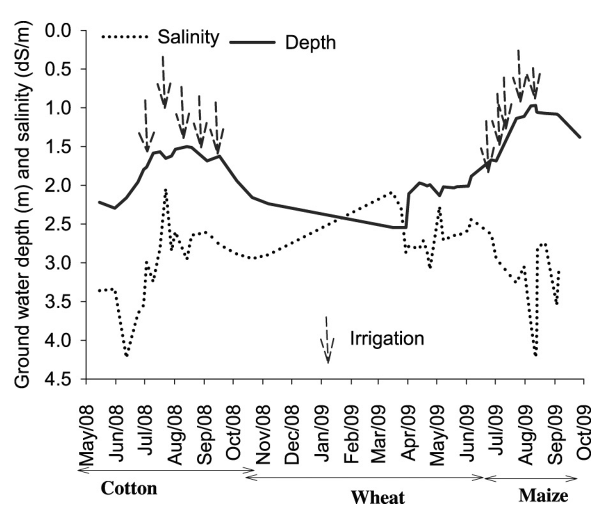

Fig. 2. Groundwater depth (m) and salinity (dS/m)of the fluctuating water table at the experimental site in Urgench May 2008 to October 2009.