Agriculture, Ecosystems and Environment 202 (2015) 90–97

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

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

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ARTICLE INFO

Article history:
Received 21 October 2013
Received in revised form 23 October 2014
Accepted 13 December 2014
Available online xxx

Keywords:
Conservation agriculture
Residue retention
Tillage
Uzbekistan

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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http://dx.doi.org/10.1016/j.agee.2014.12.006
0167-8809/

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).

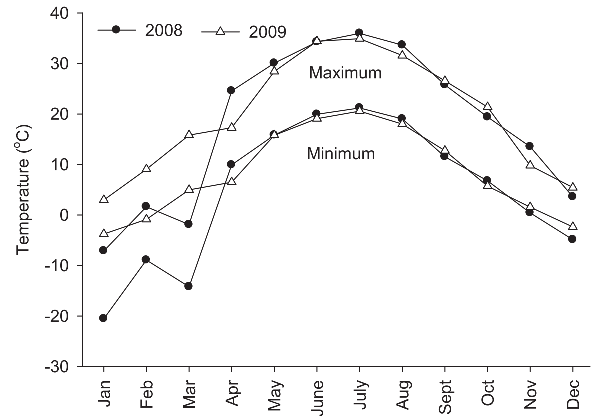

Fig. 1. Average monthly maximum and minimum temperatures in 2008 and 2009 at the experimental site in Urgench (Uzbekistan).

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

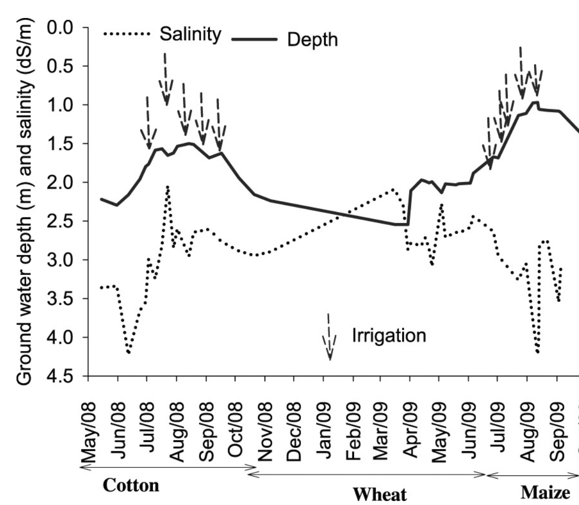

Fig. 2. Groundwater depth (m) and salinity (dS/m)of the fluctuating water table at the experimental site in Urgench May 2008 to October 2009.

(iii) conventional tillage with residue harvested (CT), which corresponded to farmers local practices.

Treatment 'i', PB in combination with RR, constitutes the full CA treatment in our experiment.

Field preparations in October/November, 2007 included deep ploughing, laser-guided land leveling and salt leaching (keeping a 10–12 cm standing water collar for 4–5 days), and an additional leaching in March, 2008. Soil salinity after leaching in the experimental field was <3 dS/m. The size of the experimental field was 3.1 ha. Details of the experiment are reported in Devkota et al. (2013). Cotton was sown as the first crop in May, 2008 and harvested in October, 2008. After this, winter wheat (October, 2008–June, 2009) and maize (June–September, 2009) were grown under the three treatment combinations.

During the first crop cycle, tilled, fresh beds were prepared with a 90-cm spacing between furrows for the PB treatments using a bed maker. The beds were 15 cm high and 60 cm wide at the top; furrows were 15 cm wide. Cotton (*Gossypium hirsutum* L., cv. Khorezm 127) was mechanically seeded at the recommended seed rate of 60 kg ha^{-1} in the center of the beds in early May, 2008. The crop was thinned in 25 days after seeding (DAS) and maintained an average plant density of 45,000 plants ha^{-1}. In CT, cotton was mechanically sown on tilled, flat land with the same spacing and seed rate as under PB.

Since crop residues were unavailable at the onset of the experiment, wheat stover was imported and placed on the surface of both beds and furrows of the residue retention treatments at a rate of 3 t ha^{-1} immediately after seeding cotton.

Winter wheat (*Triticum aestivum* L., cv. Krasnodar 99) was relay seeded into the standing cotton at the recommended seed rate of 200 kg ha^{-1} on October, 2008. The crop was harvested on June 16, 2009. In PB, wheat was seeded in rows at a distance of 22.5 cm (4 rows on each 90-cm bed) with double disk seed openers. In CT, seeds were broadcasted manually into the standing cotton after a single cultivation. This was followed by a second cultivation to cover the seeds. Average plant density was 400 plants m^{-2} in both tillage methods. In the RR treatment, cotton stalks of about 7 t ha^{-1} were chopped (about 12–15 cm length) and equally distributed on the surface of both beds and furrows in the 1st week of November, 2008. In the RH treatments, all cotton stalks had been cut at ground level and removed from the plots.

After wheat harvest, all stover was uniformly spread over the RR plots, but removed from the RH plots. Hybrid maize (*Zea mays*) 'Maldoshki' was sown with a double disc seed opener with 45 cm × 45 cm spacing on June 28, 2009. Maize was harvested as grain in September, 2009. In CT, maize was sown after three cultivations followed by rough leveling, whereas under PB, no soil tillage occurred aside from the drilling in narrow bands for seed and fertilizers. During the maize cycle, about 10 t ha^{-1} wheat crop residues were retained on the surface of the RR treatment.

During the entire crop growing season, cotton was irrigated five times (totaling 450 mm ha^{-1} as furrow irrigation); wheat was irrigated six times (totaling 477 mm ha^{-1} as furrow irrigation in PB and 538 mm ha^{-1} as flood irrigation in CT); and maize was irrigated five times (totaling 628 mm ha^{-1} as furrow irrigation in PB and 814 mm ha^{-1} as flood irrigation in CT). More details are reported elsewhere (Devkota et al., 2013). The average salinity level (electrical conductivity, ECe) in the irrigation water was 1.1 dS/m.

Following cotton seeding, salinity levels were mapped across all plots with a portable EC- meter to identify all slightly saline areas (ranging from 2.3–2.7 dS/m). Next, these were selected randomly within each treatment and monitored from the cotton season of 2008 onwards till the end of the study. Soils were sampled at fixed points throughout the three crop seasons. For each treatment,

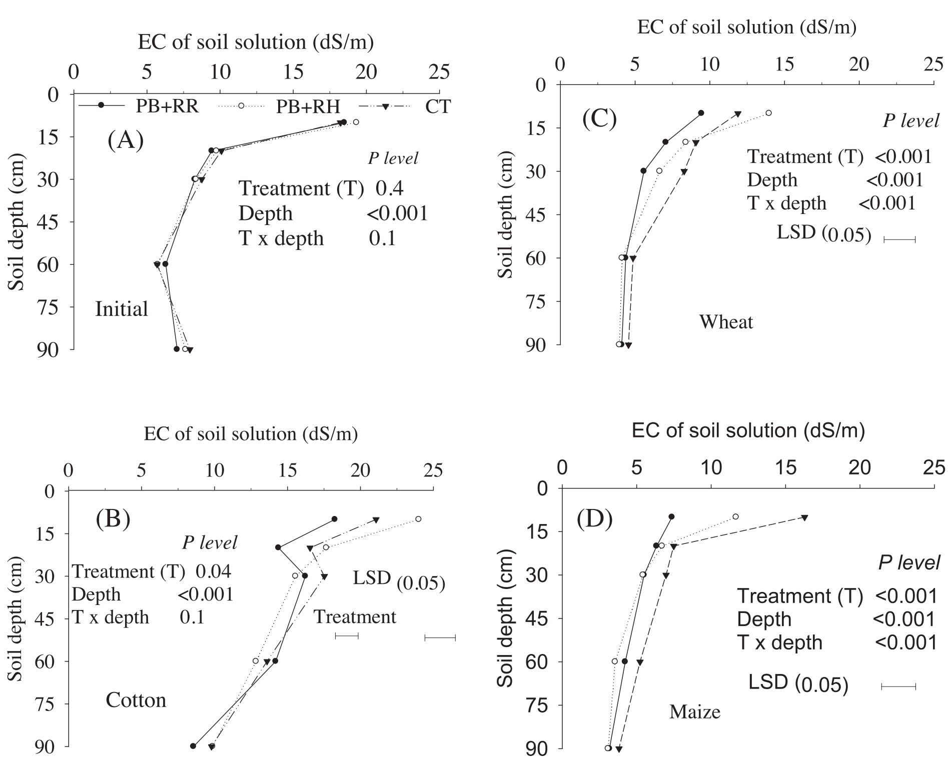

Fig. 3. Soil salinity dynamics expressed as EC of soil solution (dS/m) at pre-experiment stage and during the different crop seasons at different soil depths (10, 20, 30, 60 and 90 cm) as affected by tillage method and crop residue level. Legend: PB + RR = bed planting with residue retention, PB + RH = bed planting with residue harvested and removed, and CT = conventional tillage. The horizontal bars indicate the least significant difference (LSD) between treatment and soil depth (b) and interaction between treatment and soil depth (c and d).

three plots of 600 m^2 in size each were selected. Within each plot, two points were identified on the basis of the aforementioned salinity criteria, resulting in a total of six replications for each treatment.

2.3. Soil sampling and analysis

Soil was sampled from the predetermined sampling points with six replications for each treatment to monitor soil salinity dynamics. In PB, soil was sampled at two locations: at the top of the bed and at the center of the furrow. Soils were sampled from 0–10, 10–20, 20–30, 30–60, and 60–90 cm soil depths, one day before irrigation and at each harvest. In total, 17 samples were taken at each location during the entire duration of the study. Samples were analyzed for soil moisture content according to Gardner et al. (2001) (Eq. (1)) and electrical conductivity (EC_p), which is the EC of 1:1 ratio of water to soil paste. The gravimetric soil moisture content (θd) was converted to volumetric moisture percent (%) by multiplying moisture content with bulk density of the respective soil layers. The EC_p was converted to an EC of soil water content (dS/m) while using the formula derived from Rengasamy (2010) (Eq. (2)).

$$\text{Soil gravimetric moisture content}(\theta d) = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}} \quad (1)$$

$$\text{EC of field soil water(dS/m)} = \frac{(\text{EC of 1 : 1 soil} - \text{water} \times 100)}{\text{\%field soil water content}} \quad (2)$$

2.4. Statistical analysis

The analysis of variance of soil salinity under different treatments over time was conducted using the repeated measures option of the GenStat Discovery v 4. The treatment means were separated by Fisher's protected LSD (least significant difference (P = 0.05)).

3. Results

3.1. Soil salinity dynamics over the soil profile

Significant changes in soil solution salinity were observed in the top 30 cm soil throughout the entire study period (Fig. 3). Compared to the pre-experiment level, the EC of the soil solution was increased in all treatments during the cotton season (Fig. 3B), while it decreased during the wheat (Fig. 3C) and maize seasons (Fig. 3D). The effect of tillage and residue level on soil solution salinity reduced with increasing soil depth.

During the cotton season, the EC of the soil solution in the top 30 cm increased compared to pre-experiment level by 48% under PB + RH, by 50% under CT and by 23% under PB + RR (Fig. 3B). However, in the following wheat season, the EC of the soil solution was significantly reduced compared to the cotton growing period at all soil depths for all treatments. Under wheat, the EC of the soil solution in the top 90 cm soil decreased by 53% in PB + RH, by 57% in PB + RR and by 50% in CT compared to the cotton season (Fig. 3C). Compared to pre-experiment values, salinity in the wheat season in the top 30 cm was decreased by 59% under PB + RR, by 32% under PB + RH and by 19% under CT. During maize cropping, the EC of the soil solution level in CT was higher than in PB + RR and PB + RH at all soil depth (Fig. 3D). Compared to the wheat season, the EC of the soil solution in the top 10 cm at maize harvest was increased by 37% in CT, however this was slightly lower in PB + RR and PB + RH. Similarly, in comparison to the pre-experiment value, the EC of the soil solution at the end of the maize season was decreased over the entire soil depth for all treatments. Fig. 3D).

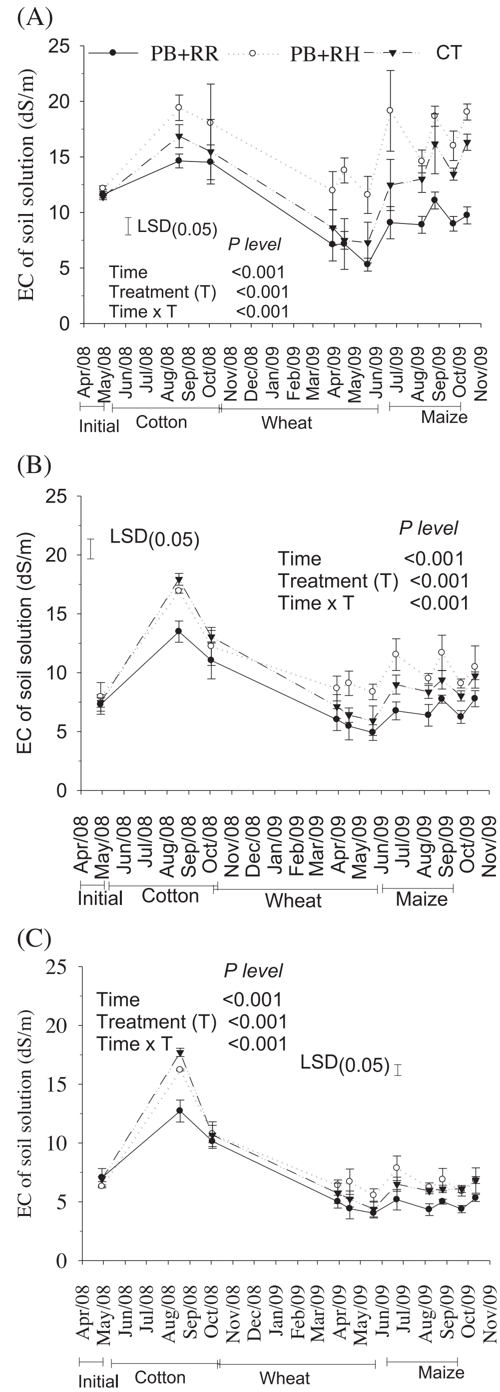

Fig. 4. Soil salinity dynamics in raised beds over time, expressed as EC of soil solution (dS/m) in (a) top 10 cm soil, (b) top 30 cm soil profile and (c) top 90 cm soil as affected by tillage method and crop residue level in a cotton-wheat-maize system. Legend: PB + RR = bed planting with residue retention, PB + RH = bed planting with residue harvested and removed and CT = conventional tillage. Bars represent standard error. LSD is the least significant difference of time and treatment.

3.2. Salt dynamics in raised beds

The salinity of the soil solution in the top 10 cm soil of the raised beds with residue removal was higher than for the other two treatments over the entire study period. However, an effect of mulching on soil solution salinity was observed already at the end of the cotton season (i.e., after one cropping seasons): the EC of the soil solution level under PB + RR was already lower than under PB + RH and CT (Fig. 4A). After the three crop cycles, the EC of the soil solution (dS/m) in the 10 cm topsoil were 19.1 dS/m in PB + RH, 16.1 dS/m in CT, and 9.8 dS/m in PB + RR, which was 61% higher in PB + RH and 36% higher under CT. But it was reduced by 18% under PB + RR when compared to the initial level. These results indicate that, the rate of soil solution salinity increase on top of the beds can significantly be reduced by a crop residue mulch. A removal of crop residues from the top of the raised beds can raise the EC of soil solution on top of the beds over the levels found under CT. Similar trends were observed for the top 30 cm soil (Fig. 4B).

The interaction (tillage × mulching) effect on salinity changes in the top 90 cm were less pronounced over the entire study period (Fig. 4C). Similar to the situation in the top 10 cm and top 30 cm soil depths, salinity levels in the top 90 cm under PB + RR were consistently lower than under PB + RH and CT.

3.3. Salt dynamics in furrows

Irrespective of treatment and crop, the soil solution salinity levels in the furrow were significantly lower compared to the values on the bed over the top 10 and 90 cm soil profiles. During the wheat season, the salinity levels in the top 10 cm of the furrow were equal under both mulch practices, e.g., 4.2 dS/m during the growing season and 9.1 dS/m at harvest. Only after the wheat season, i.e., with the increased residue cover on the field surface, the salinity level in RR furrows was 16–38% lower than in RH furrows (Fig. 5A). In the top 90 cm, the salinity level was 11% higher ($P < 0.001$) under RR furrows compared to the RH furrow during the wheat season. During the maize season, salinity level in both RR and RH furrows did not differ over the 90 cm soil profile (Fig. 5B).

3.4. Salt dynamics combined over beds and furrows

According to the salinity dynamics on top of the beds, PB + RR had consistently lower ($P < 0.05$) salinity levels, when averaged over bed and furrow, than PB + RH and CT in all soil depths (Fig. 6). Up to the wheat season (i.e., after two cropping seasons) the EC of the soil solution level in the top 30 cm and 90 cm profile was similar in PB + RH and CT. However, during the third (maize) season, the averaged salinity level in the top 30 cm soil in PB (bed

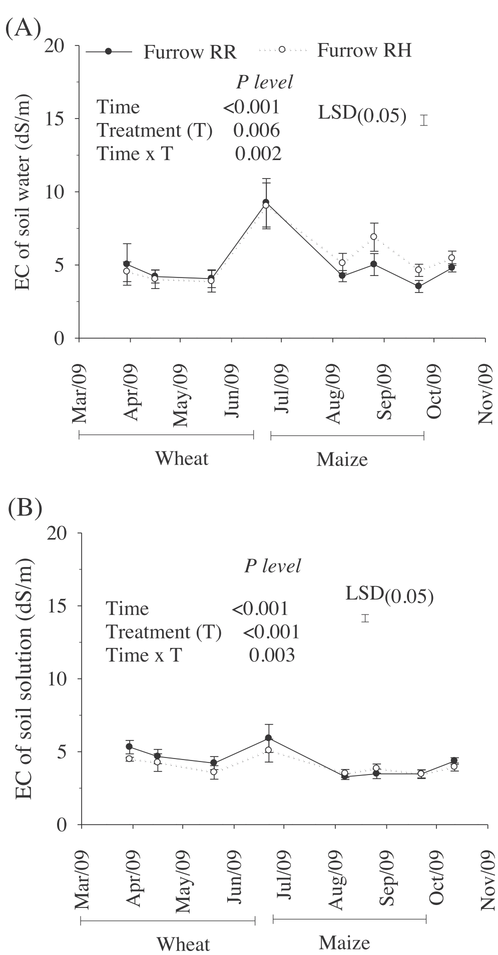

Fig. 5. Soil salinity dynamics in furrows over three cropping periods expressed as EC of soil solution (dS/m) in (a) top 30 cm soil and (b) top 90 cm soil; as affected by crop residue level in cotton-wheat-maize system. Legend: RR = residue retention and RH = residue harvested and removed. Bars represent standard errors. LSD is the least significant difference of time and treatment.

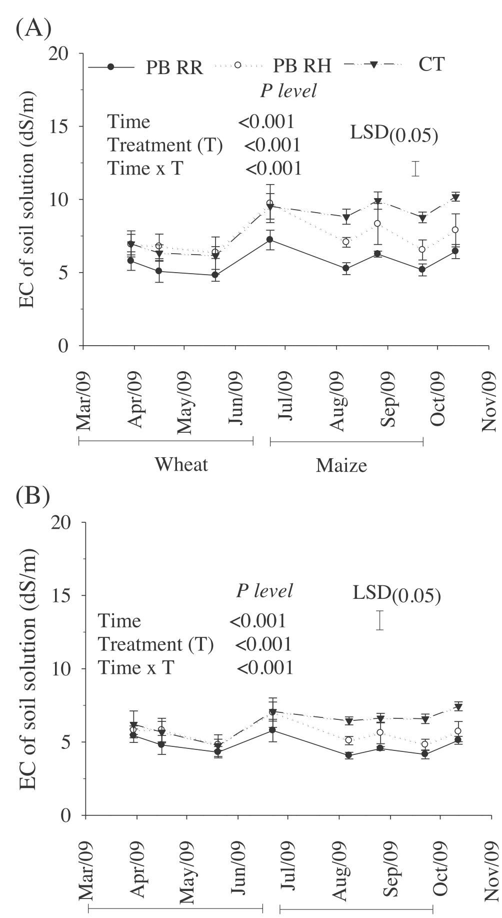

Fig. 6. Soil salinity dynamics expressed as EC of soil solution (dS/m) averaged over bed and furrow in (a) top 30 cm and (b) top 90 cm soil depth; as affected by tillage method and crop residue level in a cotton-wheat-maize rotation system. Legend: PB + RR = bed with residue retention, PB + RH = bed with residue harvested and removed and CT = conventional tillage. Bars represent standard error. LSD is the least significant difference of time and treatment.

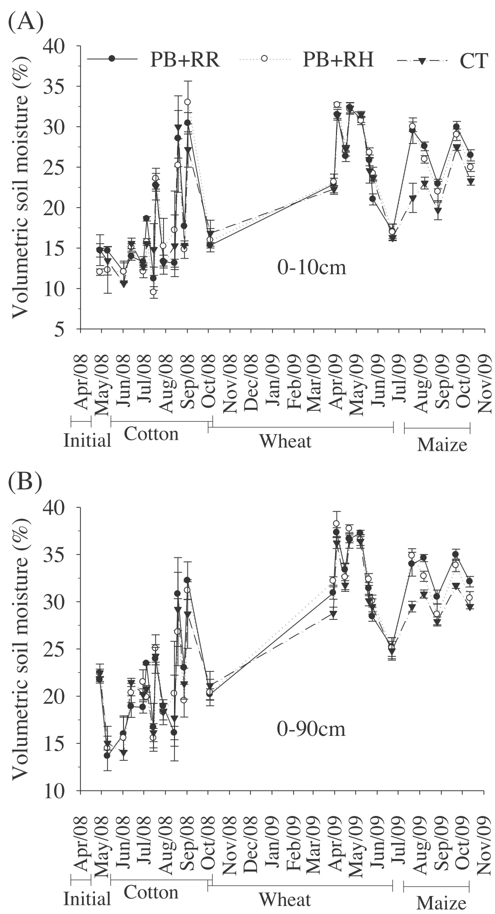

Fig. 7. Soil moisture level expressed as volumetric moisture (%) in (A) top 10 cm and (B) top 90 cm soil; as affected by tillage method and crop residue level in cotton, wheat, maize in rotation. PB + RR = bed with residue retention, PB + RH = bed with residue harvested and removed, and CT = conventional tillage. Bars represent standard error.

plus furrow) was lower in both, RH (by 15–20%) and with RR (by 35–40%) compared to the CT treatment (Fig. 6A).

With respect to the entire 90 cm soil depth, the treatment effect on salinity level over time was not as large as for the top 30 cm. Nevertheless, the effect of tillage and residue retention on salinity in the top 90 cm soil showed a similar trend to that in the top 30 cm in both crop seasons (Fig. 6B).

3.5. Soil moisture dynamics

Volumetric soil moisture content in the top 10 and 90 cm soil during cotton and wheat cultivation was not affected by soil tillage or by mulching (Fig. 7). However, during the maize season, PB showed higher ($P < 0.05$) soil moisture contents than CT, both before and after irrigation events. Irrespective of time, soil moisture in the top 90 cm soil was higher by 9% in PB (average moisture 33%) compared to CT (average moisture 30%), while in PB, RR increased soil moisture content by 3% compared to RH. Similarly, in the top 10 cm soil moisture in PB was 17% higher than under CT. Residue retention in PB increased moisture content by 3–5% compared to RH (Fig. 6A).

4. Discussion

Salt dynamics in soils result from the interaction between soil, water, and management practices (El-Swaify, 2000). Groundwater level below the root zone are one of the most important factors influencing soil salinity dynamics in irrigated arid croplands, such as in the study region (Forkutsa et al., 2009b). Groundwater levels are affected by management practices; soil type; methods, strategies and efficiencies of irrigation and drainage; and characteristics of the aquifer (Ibrakhimov et al., 2011). The use of agricultural practices that reverse or at least decelerate soil salinization is essential for sustainable irrigated crop production.

After irrigation, water moves through the soil and the soluble salts present in the profile dissolves and leads to an increased salt concentration in the groundwater (Hillel, 2002). Irrespective of the treatment effect, soil solution salinity during the cotton season was highest followed by the maize and wheat seasons. During the cotton and maize season irrigation for the respective crop and also due to the impact from the surrounding, intensively irrigated rice fields, the ground water table and salinity increased significantly (Fig. 2) compared to the wheat season. The numbers of irrigation event were the same during the cotton and maize seasons, but more water was applied to maize. Frequent irrigation events with higher amounts (in total 4454 m^3 ha^{-1} in cotton and 6285 m^3 ha^{-1} in PB and 8146 m^3 ha^{-1} in CT in maize, (Devkota et al., 2013) could have helped leaching the salts from the soil profile as evidence by the higher salt concentrations in the groundwater compared to the cotton season. This situation resulted in low salt concentrations in the soil water during the maize season compared to the cotton season.

If soil water evaporates it leaves the salts behind, which subsequently accumulate on the surface (Bakker et al., 2010). This explains the soil salinization in the study region which was more pronounced in the top 10 cm in all treatments – near to the surface – than in the top 90 cm soil profile (Fig. 4), indicating in particular that managing secondary salinization is a major challenge. Subsurface soil above the phreatic water table merely acts as transmission zone for the salty water, accumulating salts in the surface soil, primarily through evaporation. The present field study brings out two distinct salinization processes taking place during the cotton and maize growing seasons. Results of the field study bring out the importance of groundwater table and its salinity, number and amount of irrigation water and its application method, and residue management practices in salinization of root zone during cropping seasons. Crop residues retained on the soil surface shade the soil, and in turn serve as a water vapor barrier against evaporation losses (Sauer et al., 1996; Jalota and Arora, 2002), reduce surface runoff, and increase infiltration (Huang et al., 2005; Mulumba and Lal, 2008). Mulched crop residues therefore decrease the upward movement of groundwater driven by evaporation and upward salt-movement from deeper soil layers to the root zone (Deng et al., 2003; Qiao et al., 2006). The decreased soil salinization rate under PB + RR, compared to CT and PB + RH, indicated a significant beneficial effect of crop residue mulching after three cropping cycles.

Nevertheless, the amount of crop residue retention required to fully benefit from this effect remains an open question. In a study of salt dynamics under mulching and different water quality treatments in Central Asia, Bezborodov et al. (2010) reported an approximately 20% increase in surface soil salinity, after three crop seasons, of the non-mulch treatments compared to a surface mulching with 1.5 t ha^{-1} wheat residues under conventional tillage. Although these levels are indicative, more research in the irrigated areas of Central Asia is needed to this key aspect given the relatively high decomposition rates for crop residues in this region (Lamers et al., 2010) as well as regarding the competition of various types of crop residues for alternative uses such as feed (Kienzler et al., 2012).

The findings indicated PB + RR as a suitable alternative strategy to manage soil salinity in salt-affected, irrigated croplands. However, the higher salinity level under PB + RH after three cropping cycles compared to CT indicated also that a continuous removal of residues under PB could worsen soil salinity under PB compared to the current conventional practices. Huang et al. (2001) reported a reduced salt content in the top 30 cm soil and smaller reductions in salt content in the 30–60 cm soil depth than in those of the overlying layers when soil was mulched with wheat straw. The findings of the present study together with that of Huang et al. (2001) confirm the effect of a surface mulch with crop residues up to the 30 cm soil depth. Below this depth, the effect of crop residues on salinity was negligible, at least during the first three cropping cycles.

High evaporation rates lead to a higher amount of salt accumulation in bare top soils over shallow and saline groundwater tables (Choudhary et al., 2008; Cardon et al., 2010). The hot and dry weather conditions during the cotton and maize season (Fig. 1), and the low ground coverage due to row and spaced planting could have contributed to the increased evaporation in these two crops, hence increased secondary soil salinisation. Remedies to reduce this type of soil salinity should focus on preventing rising groundwater tables by reducing deep percolation through over-irrigation or minimizing the evaporation with the use of ground cover, e.g. by retaining crop residues on the soil surface (Forkutsa et al., 2009b). Although such practices should be applied irrespective of the crop cultivated, some crops demand a higher share in ground coverage than others. For example, wheat usually is more narrowly spaced than cotton or maize, which reduces soil evaporation. Given that groundwater tables during the wheat season were less shallow (Fig. 2), the crop had high ground coverage (leaf area index: 2.0–8.0 $m^2 m^{-2}$) and air temperature were comparatively low (Fig. 1) are all factors that likely reduced evaporation losses from the soil profile during the wheat season compared to cotton (leaf area index: 0.2–3.5 $m^2 m^{-2}$) and maize (leaf area index: 0.07–2.5 $m^2 m^{-2}$) seasons (Devkota, 2011). As a result, these factors contributed to decreased soil salinity during the wheat season (Fig. 3). Since this effect is linked directly to the wheat crop rather than the mulch, the soil salinity level during wheat cultivation was lower in all treatments compared to that in the cotton and maize crops.

Salinity at irrigated soil surfaces increase as the soil dries (Bakker et al., 2010). During maize cultivation, the comparatively higher soil salinity under CT than PB could be related to the low soil moisture content on the top 10 cm as well as in the top 90 cm soil profile (Fig. 7) (Devkota, 2011). Visual observations indicated greater soil cracking in CT, and hence more irrigation water may have entered the soil through by-pass flow without leaching any salts from the surface horizon. Moreover, the bed and furrow configuration on raised bed can provide a steady flow of irrigation water into the furrow and prevents water logging (Bakker et al., 2010), which could have increased the salt leaching from the soil profile in PB as suggested by Sayre (2007). These considerations together indicate that furrow irrigation with raised bed plantings and residue retention is more effective in minimizing soil salinization than CT with flood irrigation.

5. Summary and conclusions

In raised bed systems, soil salinity on top of the beds increases over time in the absence of crop residues on the soil surface compared to the conventional practices. When retaining crop residues, the increase in soil salinity on raised beds was considerably reduced although this depended also on the soil depth. Such a reduction in soil salinization rate will have considerable importance in a region like Central Asia where land degradation due to secondary salinization is widespread, and in particular in Uzbekistan, where more than 50% of irrigated lands suffer from soil salinity. Thus, raised bed planting with residue retention is a promising option to slow down the on-going soil salinization in salt-affected irrigated arid lands.

This study considered only two residue treatments, i.e., residue retained and residue harvested: at the end of the three cropping seasons about 13 t ha^{-1} wheat residues and 6 t ha^{-1} of cotton residues were retained. Retaining all residues after each crop cycle may, however, not be necessary. A partial removal of crop residues would also facilitate the use of residues for other purposes, such as fodder and fuel, which are competing with the need for residue retention uses than for mulch. This requires further studies, particularly in view of competing uses for crop residues as fodder and source of fuel.

Acknowledgements

The research described in this paper was funded by the German Ministry for Education and Research (BMBF; project number 0339970A). Field work was done in the ZEF/UNESCO project “Economic and Ecological Restructuring of Land and Water Use in the Khorezm Region (Uzbekistan): A Pilot Project in Development Research” funded by BMBF.

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