Agricultural Water Management 152 (2015) 243–250

Contents lists available at ScienceDirect

Agricultural Water Management

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

# Soil salinity management on raised beds with different furrow irrigation modes in salt-affected lands

M. Devkota[a,b,*], R.K. Gupta[c], C. Martius[b,d], J.P.A. Lamers[b], K.P. Devkota[e], K.D. Sayre[f], P.L.G. Vlek[b]

[a] International Maize and Wheat Improvement Center (CIMMYT), Kathmandu, Nepal
[b] Center for Development Research (ZEF), Walter Flex-Str. 3, 53113 Bonn, Germany
[c] Borlaug Institute for South Asia/CIMMYT, NASC Complex, CG Block, Pusa, New Delhi, India
[d] Center for International Forestry Research (CIFOR), Bogor, Indonesia
[e] International Rice Research Institute (IRRI), DAPO Box 7777, Manila, Philippines
[f] International Maize and Wheat Improvement Center (CIMMYT), Texcoco, Mexico

ARTICLE INFO

*Article history:*
Received 27 December 2013
Accepted 17 January 2015
Available online 14 February 2015

*Keywords:*
Salt-leaching
Raised beds
Furrow irrigation
Uzbekistan

ABSTRACT

Mismanagement of irrigation water and the ensuing secondary salinization are threatening the sustainability of irrigated agriculture especially in many dryland regions. The permanent raised-bed/furrow system, a water-wise conservation agriculture-based practice, is gaining importance for row- and high value-crops in irrigated agriculture. However, because of additional surface exposure and elevation, raised beds may be more prone to salt accumulation especially under shallow water table conditions. A field study was carried out in 2008 and 2009 in the Khorezm region, Central Asia, to investigate the effect of three furrow irrigation methods on salt dynamics of the soil and the performance of the cotton crop on the raised bed-furrow system. The irrigation methods compared included (i) Conventional furrow irrigation wherein every furrow was irrigated (EFI) at each irrigation event; (ii) Alternate skip furrow irrigation (ASFI where one of two neighbouring furrows were alternately irrigated during consecutive irrigations events; and (iii) Permanent skip furrow irrigation (PSFI) during which irrigation was permanently skipped in one of the two neighbouring furrows during all irrigation events. For salinity management with PSFI a 'managed salt accumulation and effective leaching' approach was pursued.

The EFI method increased salt accumulation on the top of the raised beds. In contrast, the PSFI method allowed an effective salt leaching from the top of the raised beds. After leaching, salinity on top of the beds under PSFI was reduced to <3 dS m$^{-1}$ compared to 5–6 dS m$^{-1}$ under ASFI and EFI indicating an effective leaching with the PSFI method. Raw cotton (*Gossypium hirsutum* L., cv. Khorezm 127) yield was higher under the PSFI (2003 kg ha$^{-1}$) method having yield increases of 984 kg ha$^{-1}$ (96% higher) and 787 kg ha$^{-1}$ (64% higher) than under EFI (1216 kg ha$^{-1}$) and ASFI (1019 kg ha$^{-1}$) methods, respectively. Better crop performance with PSFI was linked with the lesser salinization of the raised beds and a larger salt free root zone before the leaching events. In addition, the PSFI method reduced irrigation water demand contributed thus to minimizing secondary soil salinization. Thus, PSFI could be an effective method to manage the salt under raised beds in salt-affected irrigated arid regions.



## 1. Introduction

The expansion of irrigated agriculture in Central Asia has increased the water demand and use up to 12000–14,000 m$^3$ ha$^{-1}$ yr$^{-1}$ (Nazirov, 2005). But the productivity of the drylands in this region is still constrained by frequent water shortages and continuous deteriorations in water quality due to reduced water flows in the Syr- and Amu-Darya rivers and the steady increase in the volumes of drainage water discharged back into these river systems (Qadir et al., 2009). In turn, average salt accumulation rate (5.3 t ha$^{-1}$ yr$^{-1}$) in the Syr-Darya Basin is 5–10 times higher than in the Indus Basin (Qureshi et al., 2008). In addition to the deterioration in irrigation water quality and excessive water allowances for leaching soil salinity problems in the Syr Darya basin are rooted in poor on-farm water management practices. Consequently, crop production in the lower reaches of the Syr-Darya Basin seriously suffers from secondary salinization and associated

* Corresponding author at: CIMMYT International, P.O. Box: 5186, Singh Durbar Plaza Marg, Kathmandu, Nepal. Tel.: +977 1 4269564, 4269567; fax: +977 1 4229804.
*E-mail address:* m.devkota@cgiar.org (M. Devkota).

http://dx.doi.org/10.1016/j.agwat.2015.01.013
0378-3774/

water logging problems due to a congestion of the field drainage networks.

Conservation agriculture (CA)-based practices, that involve minimal field traffic and tillage, adequate residue retention on the soil surface and economically diversified crop rotations, can significantly influence the upward transport of soluble salts and their re-distribution in the soil profile (Brady and Well, 2008). Amongst the CA practices, raised bed planting is gaining importance including for row crops (Sayre, 2007) also due to water savings of 25–30% and increased water use efficiencies (Sayre and Hobbs, 2004; Hassan et al., 2005; Malik et al., 2005; Choudhary et al., 2008; Devkota et al., 2013).

Although residue retention in permanent raised beds has great potential to reduce soil salinity in salt-affected areas (Devkota, 2011; Devkota et al., 2015), crop residues are not always available in sufficient quantities for mulching in Central Asia due to the high demands as feed and biofuel (Kienzler et al., 2012). In the absence of sufficient crop residues, irrigation frequency, amount and method of irrigation are known to collectively determine the quantity, status, and distribution of salts in soils (El-Swaify, 2000). When irrigation water is applied to the furrows on every side of the bed, it allows salts to leach down from the furrows (Bakker et al., 2010). But the evaporation of water during the drying periods results in salt accumulation on the tops and side slopes of the raised beds (Richards, 1954). Such salt movement to the centre of the bed may damage (young) plants seeded there (Brady and Well, 2008). With the permanent skip furrow irrigation (PSFI) method, salts are 'pushed' across the bed from the irrigated side of the furrow, where plants are located, to the dry side without plants. This management of root zone salinity improves emergence, stand establishment and finally crop yields in saline fields (Meiri and Plaut, 1985). However, Holland et al. (2007) underlined that too rapidly advancing irrigation water in furrows, may reduce the time for salt dissolution and a consequent salt removal from the root zone compared to flood irrigation (Scotter, 1978). Thus, benefits of raised-furrow irrigation system can be reaped when accumulated salts are effectively leached out from the raised beds, or if permanent raised beds can be used in combination with residue retention on the soil surface to markedly reduce evaporation from the surface of the beds. We hypothesized that salts accumulated in dry furrows can be leached out efficiently, if their redistribution (between the irrigated and dry sides of the beds) can be minimized/prevented during leaching events. This can be reached by a 'managed salt accumulation and leaching' approach with the objective to direct salt concentrations away from the plant roots by applying irrigation water very rationally and targeted. In addition, this procedure allows higher levels of salt to accumulate without damaging crops, as salts are "pushed" across the bed from the irrigated side of the furrow, where plants are located, to the dry side without plants. During irrigation/leaching events irrigation water therefore first applied to the permanently irrigated furrow and thereafter to the skipped dry furrows to leach down the accumulated soluble salts. This watering sequence will prevent the accumulated salts in the dry furrows from moving laterally towards the irrigated furrows. As a result, salinity on this sites of the beds remain lower. This hypothesis was field tested by comparing the effects of three furrow irrigation methods on salt distribution, salt leaching and crop performance under raised bed cultivation in the irrigated, arid lands of Uzbekistan, Central Asia.

## 2. Materials and methods

### 2.1. Study area and site description

The study was conducted in the Khorezm region, Uzbekistan (41°32′12′′ N, 60°40‘44“E, and 100 m a.s.l.) in 2008 and 2009. Cotton is the major summer crop grown in the region covering annually almost 50% of the cropped area (Djanibekov et al., 2012). Intensive soil tillage and low irrigation water use efficiencies are common for crop cultivation (Tischbein et al., 2012) which takes place with generally shallow groundwater tables (0.5–2 m). The climate is arid, with long, hot and dry summers and short, very cold winters (Conrad et al., 2012). Long-term average precipitation is less than 100 mm year$^{-1}$ and is greatly exceeded by annual evaporation (Conrad et al., 2012). The soils have a sandy loam to loamy texture, are low in organic matter (0.3–0.6%) and moderate to heavy saline (2–16 dS m$^{-1}$). According to FAO (2003) classification, soils are Calcaric Gleysoils, i.e., meadow soils in the irrigated areas characterized by a shallow saline groundwater table resulting in excessive secondary salinization of surface soil layers.

### 2.2. Experimental set up and treatments

The study was conducted within an on-going experiment demanding a cotton mono-cropping in both years at the Cotton Research Station in the Khorezm region. After conventional tilling, fresh raised beds had been established to seed cotton in the center of 90 cm wide beds, (center of one furrow to the center of the next furrow), in April, in both years. At the 2–4 leaf stage (35–40 days after seeding) a high salinity area was identified in the experiment as evidenced by soil salinity mapping using a portable EC meter (Geonics EM-38). In 2008, the affected area had very few cotton plants, as a result of low germination and survival rates because of the high soil salinity. The average initial soil salinity in the top-30 cm soil of the affected area selected for the case study was more than 12 dS m$^{-1}$. In 2009, the average initial soil salinity in the top 30 cm soil of the selected area was 6–7 dS m$^{-1}$ with a resulting cotton plant density of 4–5 plants per m$^{-2}$.

The irrigation mode experiment was laid out in a complete block design with three irrigation treatments each replicated three times. Each replication consisted of 12 beds with 0.9 m spacing (10.8 m width), and 25 m length in both years. The irrigation included three methods, namely, (i) Every-furrow irrigation (EFI), (ii) Alternating skip furrow irrigation (ASFI) and (iii) Permanent skip furrow irrigation (PSFI). During the EFI which is the conventional furrow irrigation mode, water is applied uniformly to all furrows during each irrigation event (Fig. 1A). With the ASFI method, one of two neighbouring furrows was alternately irrigated during each irrigation event. This implies that in next irrigation event the previously irrigated furrow was kept dry and the other previously dry furrow was irrigated (Fig. 1B). With the PSFI method, one of the two neighbouring furrows was permanently skipped for watering and kept dry until it became desirable to leach the salts out of the root zone for enhancing a healthy growth of crop plants (Fig. 1C).

The treatments in each replication were allocated as shown in Fig. 2. Irrigation treatments were initiated 55 days after seeding (DAS), i.e., at budding stage, in both years. Three irrigation cycles in 2008 and four irrigation cycles in 2009 were applied in each treatment at 10–12 days intervals. The average salinity level in the irrigation water was 1.1 dS m$^{-1}$.

In 2008, ASFI and PSFI treatments received 31 and 32 percent less water, respectively, compared to EFI (Table 1). The amounts of irrigation water was measured using a standard trapezoidal Cipolletti weir combined with a DL/N 70 diver (installed 40 cm in front of the weir crest), which measured water flow through the weir in one-minute intervals. The irrigation time during each irrigation event for each treatment was recorded. The height of water above crest width was measured 4–5 times manually during each irrigation event. The pressure measured by the diver was transformed to height above crest (m) to estimate the discharge (m$^3$ s$^{-1}$) as (Kraatz and Mahajan, 1975):