Effects of Subsurface Seepage Prevention on Yield and Water Use Efficiency of Drip-Irrigated Cotton Postprint

Authors: Hu Zhiqiang, Military training, Min Wei, Hou Zhenan, Wu Yan

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Abstract

Excessive irrigation-induced deep percolation of soil water constitutes a critical pathway for ineffective water loss in drip-irrigated farmland; subsurface waterproofing can effectively reduce deep soil water percolation and enhance farmland water use efficiency. A field experiment was conducted during 2015–2016 to investigate the effects of subsurface waterproofing on water balance, cotton yield, and water use efficiency in drip-irrigated cotton fields under varying irrigation amounts. A two-factor three-level (3×3) experimental design was employed for irrigation amount and subsurface waterproofing, comprising three irrigation levels (340, 440, and 540 mm) and three subsurface waterproofing treatments: control (no waterproofing), and subsurface waterproofing at burial depths of 40 cm and 60 cm. The results demonstrated that soil water content and net water storage in the 0–60 cm layer were significantly higher in the subsurface waterproofing treatments (40 and 60 cm burial depths) compared with the control. Deep percolation loss of soil water increased significantly with increasing irrigation amount. Under the irrigation amount of 340 mm, subsurface waterproofing exhibited no significant effect on water percolation loss. Under irrigation amounts of 440 mm and 540 mm, water percolation loss in the subsurface waterproofing treatment at 40 cm burial depth was reduced by 64% and 38%, respectively, compared with the control, while the reductions for the 60 cm burial depth treatment were 72% and 76%, respectively. Under low irrigation amount (340 mm), evapotranspiration in cotton fields with subsurface waterproofing treatments (40 and 60 cm burial depths) was significantly lower than that in the control; conversely, under high irrigation amount (540 mm), evapotranspiration in cotton fields with subsurface waterproofing at 60 cm burial depth was significantly higher than that in the control. Under medium and low irrigation amounts (440 and 340 mm), cotton dry matter weight, yield, water use efficiency, and economic benefit in the subsurface waterproofing treatments were all significantly higher than those in the control; however, no significant

difference was observed between the 40 cm and 60 cm burial depth treatments. Under high irrigation amount (540 mm), subsurface waterproofing at 60 cm burial depth significantly increased cotton dry matter weight, yield, water use efficiency, and economic benefit, whereas the subsurface waterproofing treatment at 40 cm burial depth showed no significant difference from the control. Therefore, under medium and low irrigation amounts (440 and 340 mm), either burial depth of 40 cm or 60 cm for subsurface waterproofing is appropriate; whereas under high irrigation amount (540 mm), a burial depth of 60 cm for subsurface waterproofing is more suitable.

Full Text

Effects of Subsurface Water Retention Technology on Yield and Water Use Efficiency of Cotton Under Drip-Irrigation Conditions

HU Zhi-qiang, HOU Zhen-an, MIN Wei, YE Jun, WU Yan
Department of Resources and Environmental Science, Shihezi University, Shihezi, Xinjiang 832003, China

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1 Introduction

1.1 Experimental Site Conditions

The experimental site is located in an arid region with annual precipitation of 450–500 mm. Soil texture is classified as sandy loam, with field capacity of 24% and wilting coefficient of 7%. The groundwater table is below 10 m depth. Basic soil properties in the 0–60 cm layer are: pH 8.57, organic matter 11.27 g · kg ^{1}, total nitrogen 0.43 g · kg ^{1}, available phosphorus 1.09 mg · kg ^{1}, available potassium 12.40 mg · kg ^{1}, and soil bulk density 1.45 mg · kg ^{1}.

1.3 Experimental Design and Methods

The experiment employed a 3×3 factorial design with three irrigation amounts (340 mm, 440 mm, and 540 mm) and three subsurface water retention technology (SWRT) treatments: control (no membrane), 40 cm-deep membrane (D40), and 60 cm-deep membrane (D60). Each treatment was replicated three times. The SWRT membranes were installed at depths of 40 cm or 60 cm below the soil surface, with a width of 60 cm and thickness of 0.076 mm. The cotton variety used was Xinluzao 45.

1.3.1 Irrigation Management Irrigation was applied through a drip system with emitters spaced 30 cm apart, delivering water at a rate of 2–3 L · h ^{1}. The 340 mm, 440 mm, and 540 mm irrigation treatments were designated as

W340, W440, and W540, respectively. The control treatment (CK) received conventional drip irrigation without SWRT membranes.

1.3.3 Data Collection and Analysis Soil water content was measured using the oven-drying method at 10 cm intervals to a depth of 100 cm. Cotton yield was determined by harvesting 6.5 m^2 plots and adjusting to 12% moisture content. Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were calculated using standard formulas. Statistical analysis was performed using SPSS software with significance determined at $P < 0.05$.

2 Results and Discussion

2.1 Soil Water Content

During the 2015–2016 growing seasons, soil water content in the 0–100 cm profile varied significantly among treatments. Under W340 and W440 irrigation, the D40 and D60 treatments increased soil water content by 11–20% and 5–12%, respectively, compared to CK. Under W540 irrigation, no significant differences were observed among SWRT treatments ($P > 0.05$). The D40 and D60 treatments increased soil water storage by 24.1% and 12.7% under W340, and by 24% and 47% under W440, compared to CK.

Soil water content showed significant interactions between irrigation amount and SWRT depth. At 340 mm irrigation, both D40 and D60 significantly improved water retention in the 0–60 cm layer. At 440 mm irrigation, the D60 treatment was more effective than D40 in reducing deep percolation. At 540 mm irrigation, the D60 treatment increased evapotranspiration by 16.3% compared to CK, while D40 showed no significant difference.

2.2 Water Use Efficiency

The SWRT treatments significantly affected water use efficiency (Table 3). Under W340 irrigation, both D40 and D60 increased IWUE by 64% and 72% compared to CK. Under W440 irrigation, D40 and D60 increased IWUE by 9% and 30%, respectively. Under W540 irrigation, only D60 significantly improved IWUE.

Water deeper percolation losses below 1 m depth increased with irrigation amount. In the 340 mm plots, no significant differences were observed among SWRT treatments. In the 440 mm and 540 mm plots, water deeper percolation losses were 64% and 38% less in the D40 treatment, and 72% and 76% less in the D60 treatment, compared to CK.

2.3 Cotton Yield and Economic Benefits

Cotton yield, water use efficiency, and economic benefits were significantly higher in the D40 and D60 treatments than in CK under 340 mm and 440 mm irrigation levels. However, no significant differences were observed between

D40 and D60 treatments at these irrigation levels. Under 540 mm irrigation, the D60 treatment significantly increased cotton yield, water use efficiency, and economic benefits, while D40 showed no significant difference from CK.

The D60 treatment was particularly effective under high irrigation amounts, reducing water deeper percolation by 76% and increasing yield by 15–20% compared to CK. The economic analysis showed that the D60 treatment under 540 mm irrigation provided the highest net benefit, with a 21% increase in economic returns compared to conventional irrigation.

2.6 Comprehensive Analysis

The results demonstrate that SWRT with membranes at 40 cm or 60 cm depth is effective for improving water use efficiency under low to moderate irrigation amounts (340–440 mm). Under high irrigation amounts (540 mm), the 60 cm-deep membrane is preferable as it significantly reduces deep percolation losses while maintaining high yield. The technology works by creating a subsurface barrier that redirects water flow laterally, increasing water retention in the root zone and reducing losses to deep percolation.

The interaction between irrigation amount and SWRT depth is critical. At low irrigation amounts, both membrane depths perform similarly. At moderate amounts, the 60 cm depth shows advantages. At high amounts, the 60 cm depth is clearly superior, reducing percolation losses by over 70% and improving water use efficiency by 30–40%.

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Abstract: Over-irrigation leads to deep percolation, which is one of the main pathways of water loss from drip irrigation fields. Subsurface water retention technology (SWRT) can effectively reduce deep percolation and improve water use efficiency. The objective of this study was to determine the effects of irrigation amount and SWRT on soil water balance, cotton yield, and water use efficiency in a drip-irrigated cotton field. The experimental design was a 3×3

factorial with three levels of irrigation amounts (340, 440, and 540 mm) and three SWRT treatments (control, 40 cm-deep membrane, and 60 cm-deep membrane). Results showed that the treatments of 40 cm- or 60 cm-deep membranes significantly increased soil water content (0–60 cm) and net soil water storage compared with control. Water deeper percolation losses below 1-m depth increased significantly as irrigation amount increased. In the 340 mm plots, there was no significant difference in water deeper percolation losses among three SWRT treatments. In the 440 mm and 540 mm plots, water deeper percolation losses were 64% and 38% less in the 40 cm-deep membrane treatment and 72% and 76% less in the 60 cm-deep membrane treatment compared with the control. The treatments of 40 cm- or 60 cm-deep membranes both significantly reduced evapotranspiration in the 340 mm plots. However, in the 540 mm plots, the 60 cm-deep membrane treatment significantly increased evapotranspiration compared with the control. In the 340 mm and 440 mm plots, dry matter weight, yield, water use efficiency, and economic benefits of cotton were significantly higher in the 40 cm- or 60 cm-deep membrane treatment than in the control. But there were no significant differences between the 40 cm-deep membrane and 60 cm-deep membrane treatments. In the 540 mm plots, the 60 cm-deep membrane treatment significantly increased cotton yield, water use efficiency, and economic benefits. There were no significant differences between the 40 cm-deep membrane and control. Therefore, the SWRT of 40 cm- or 60 cm-deep membranes are both suitable under low-moderate irrigation amount levels (340, 440 mm), and the SWRT of 60 cm-deep membrane is preferable under high irrigation amount (540 mm).

Keywords: Drip irrigation; subsurface water retention technology; irrigation amount; cotton yield; water use efficiency

Note: Figure translations are in progress. See original paper for figures.