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Water use efficiency of irrigated cotton in Uzbekistan under drip and furrow irrigation

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ABSTRACT

The main goal of this research was to measure cotton water use, and to determine irrigation water scheduling parameters associated with optimal seed-lint yield and irrigation water use efficiency, which are poorly understood in the Central Asian Republic of Uzbekistan. A cotton (*Gossypium hirsutum* L.) field experiment with drip irrigation in comparison to furrow (conventional) irrigation was conducted on a deep silt loam soil (Calcic Xerosol) at the Central Experiment Station of the Uzbekistan National Cotton Growing Research Institute at Tashkent in 2003, 2004 and 2005. To investigate irrigation scheduling, the field capacity (F_C) index was adopted, which was 0.30 $m^3\ m^{-3}$ in this soil. Irrigations were scheduled when soil water in the root zone was depleted to specific fractions of F_C, e.g., 70% of F_C, for each of three main plant growth periods (germination–squaring; squaring–flowering; beginning of maturation–maturation). Crop water use, which we here define as the sum of transpiration and evaporation, was established using the soil water balance approach on a weekly basis. Soil profile water content was determined using a neutron moisture meter (NMM), which was calibrated in polyvinyl chloride (PVC) access tubes for each differing soil layer. Under drip irrigation and the optimal mode (70–70–60% of F_C) of irrigation scheduling, 18–42% of the irrigation water was saved in comparison with furrow irrigated cotton grown under the same condition; and irrigation water use efficiency increased by 35–103% compared with that of furrow irrigation. Seed-lint cotton yield was increased 10–19% relative to that for furrow irrigated cotton. The irrigation scheduling rule developed here should be considered an improved practice for drip irrigated cotton that is applicable to irrigated Calcic Xerosols of Uzbekistan.

1. Introduction

Agriculture in Uzbekistan was and still is the largest sector in Uzbekistan's economy. Cotton and wheat are the major crops in Uzbekistan followed by maize, vegetables and fruits. About 60% of the country is (semi-) desert with only 4 million ha of irrigated area in the country of 447,000 km^2 surface area. With annual rainfall of 100–300 mm, Uzbekistan's climate is that of the dry mid-latitude desert, with a continental climate that is characterized by hot summers and cold winters. Thus, agricultural production in the country, like in the whole of Central Asia, is predominantly based on irrigation, which

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makes irrigation water supply and management the major factors limiting crop yields in the region.

Water, used for hydro-electric generation and irrigation, is supplied by two major river systems: the Amu Darya and Syr Darya, which also supply the neighboring countries of Kyrgyzstan, Tajikistan, Afghanistan, Turkmenistan and parts of Kazakhstan. Although water supply was formerly centrally arranged, since independence in 1991 these Central Asian countries have continued their dispute on meeting their individual and increasing water demands. Since then, lack of water has gradually devastated the irrigation-dependent cotton, winter wheat and other major crop production. In addition, lack of water has engendered the ecological catastrophe within the Aral Sea Basin, at the tail end of the river systems of Uzbekistan and Kazakhstan.

Approaches to dealing with water scarcity include efforts to improve crop water use efficiency (WUE) by changing irrigation methods (furrow, drip, sprinkler, etc.), applied amounts (deficit irrigation), crops, tillage practices, and other management methods. When the crop cannot be changed due to its economic importance, which is the case with cotton in Uzbekistan, then changes in irrigation methods and management are key to improving WUE. Water use efficiency may be calculated as units of dry yield per unit land area (Y, kg m^{-2}) divided by units of water consumed by the crop per unit land area (ET, $m^3\,m^{-2}$, usually reported as mm) to produce that yield, or:

$$\mathrm{WUE} = \frac{Y}{\mathrm{ET}} \qquad (1)$$

where WUE is in kg m^{-3}, and ET is crop evapotranspiration, which can be expressed as a depth of water (m). Another key parameter for evaluating cropping system efficiency is the irrigation water use efficiency (IWUE, kg m^{-3}):

$$\mathrm{IWUE} = \frac{Y - Y_D}{I} \qquad (2)$$

where Y is dry yield under the irrigated condition, Y_D the dry yield (kg m^{-2}) under dryland (no-irrigation) conditions, and I is the irrigation water applied (m).

Cotton water use and WUE can be affected by irrigation method and amount. Several studies have found that drip irrigation increased lint yields and WUE by large amounts compared with those from sprinkler or surface irrigation (Smith et al., 1991; Bordovsky, 2001; Janat and Somi, 2002; Kamilov et al., 2003). Colaizzi et al. (2005) found that drip irrigation produced significantly larger yield and WUE than did spray or low energy precision application (LEPA) in 1 of 2 years; but, WUE values, which ranged from 0.152 to 0.194 kg m^{-3}, were not appreciably different for full irrigation and deficit irrigation at 75% of the full amount. Howell et al. (2004) found larger WUE for deficit (half the full amount) sprinkler irrigated cotton in only 1 of 2 years. Values of WUE ranged from 0.144 to 0.219 kg m^{-3} in the latter study, and water use ranged from 578 to 775 mm while lint yield ranged from 0.65 to 1.31 Mg ha^{-1}. Water use in the Colaizzi et al. (2005) study ranged from 410 to 725 mm and lint yield ranged from 0.78 to 1.15 Mg ha^{-1}. Both the Colaizzi et al. (2005) and Howell et al. (2004) studies were in the High Plains of Texas.

Grismer (2002) reported that lint yields averaged 1.33 Mg ha^{-1} for Upland and 1.08 Mg ha^{-1} for Pima in the Central Valley of California for fully irrigated cotton, which is slightly larger than yields from the well-irrigated cotton fields in Texas. The same California study reported that maximum WUE values were in the range of 0.19–0.21 kg m^{-3}, also similar to top end values in the Texas High Plains, which have a much shorter growing season. Ayars et al. (1999) reported data that showed on average a larger WUE (0.30–0.33 kg m^{-3}) for drip irrigated cotton in the Central Valley of California than for furrow irrigated cotton (0.23–0.32 kg m^{-3}), but results may have been biased by different crop coefficients used for the drip irrigation scheduling. In the survey of Grismer (2002), drip system WUE values were typically >0.21 kg m^{-3} and sometimes >0.30 kg m^{-3}.

Prior to this study, investigation of cotton irrigation scheduling and WUE under irrigation water deficiencies and different irrigation application methods had not been conducted in Uzbekistan. Given the contrary and possibly biased WUE results of studies done in California, Texas and elsewhere, it is important to discover if there are important improvements in WUE related to irrigation method and management under conditions in Uzbekistan. The main objectives of this research were to (i) measure cotton water use, yield and WUE under full and deficit irrigation, (ii) compare these for drip and furrow irrigation methods, and (iii) determine irrigation water scheduling parameters associated with larger yield and irrigation WUE.

2. Materials and methods

The field experiment was conducted at the Central Experiment Station of Uzbekistan's National Cotton Growing Research Institute (41°42′N, 69°49′E, 625 m elevation above mean sea level) in 2003, 2004 and 2005 near Tashkent, the capitol. The soil, a silt loam Calcic Xerosol in the FAO taxomony, is known in the Russian taxonomy still used in Uzbekistan as an old irrigated typical sierozem; and it has a silt loam texture that is uniform with depth (Table 1) (Shamsiev, 2003). The water table is >15 m deep, ensuring an automorphic type of soil formation.

As a starting point for investigations of irrigation scheduling, we adopted as an index the field capacity (F_C), which was 0.30 $m^3\,m^{-3}$ in this soil (Shamsiev, 2003). Irrigations were scheduled when soil water content in the root zone was depleted by the crop to specific fractions of F_C (e.g., irrigation at 70% of F_C) for each of the three main plant growth periods defined below. The experiment was carried out in three replicates and comprised two irrigation scheduling treatments with drip irrigation, and one treatment with furrow irrigation (the conventional control) for comparison. The drip irrigation system, comprising one line of surface drip tape in every other inter-row, was installed in the field after completion of early season inter-row cultivation. Each treatment consisted of scheduling irrigation at specific percentages of F_C during each of three plant growth periods as follows:

1. 65–65–60% of F_C (drip irrigation)
2. 70–70–60% of F_C (drip irrigation)
3. 70–70–60% of F_C (furrow irrigation)