Evapotranspiration-based Irrigation Scheduling for Cotton Growing in Fergana Valley to Improve Water-use Efficiency

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Irrigated agriculture is the backbone of Uzbekistan's economy (Yusupov et al., 2012). Therefore, efficient irrigation water management is of crucial importance to the sustainable crop production in Uzbekistan. Two major rivers in the Central Asia Region, Amu Darya and Syr Darya, supply a major portion of the water required for irrigated crop production in Uzbekistan. One of the major sources of water for these Rivers is glaciers in their basins. Between 1957 and 2000, water stocks in these glaciers reduced by more than 25% and it is projected that most of the small glaciers may disappear by 2025 effectively reducing the total stock by 25% (Yusupov et al., 2012). This situation is expected to worsen when countries located upstream use their potential share of water from these two Rivers.

Since independence, Uzbekistan has made significant efforts including institutional reforms to implement integrated water resources management (IWRM) to maintain and improve irrigation capacity. The definition of IWRM is *"coordination of development and management of water, land and other resources for maximizing economic returns and social welfare with no compromise of the environment (GWP, 2000)"*. As per IWRM guidelines, Water Users Associations (WUA) have been formed at secondary canal levels to manage allocated bulk water locally and equitably. The WUAs are organized in a top-down, hierarchical structure using power and resources of the State. Their formation was a much-needed step in the right direction for better irrigation management at farm level (Zavgordnyaya, 2006). However, lack of transparency and equity in local water use still remains an issue due to weak management and governmental structures hindering improved water management at the field scale. This situation combined with waterlogging and salinity problems has affected significantly crop yields (Reddy et al., 2012).

Major irrigated crops in Uzbekistan are cotton, winter wheat, and rice. Intensive cotton and rice production on irrigated lands during the past several decades has led to increased salinity and waterlogging, degrading soil quality significantly and beyond recovery in some parts of Uzbekistan, e.g. Aral River Basin. Efforts are now being made by Uzbekistan's government and several international donor agencies to promote diversified crop production systems to alleviate these problems. Irrigated cotton production has been reduced from 2 million ha (50% of all irrigated land) in the late 1980s to 1.2 million ha in 2013. Total water use has decreased by 20% to 51 billion m^3 since the 1980s and irrigation water use has reduced by 40% since the 1990s to 10,500 m^3/ha.

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Although Uzbekistan maintained its irrigation capacity and made significant efforts that include institutional reforms since independence, soil quality in irrigated agricultural systems is deteriorating at an alarming rate mainly due to salinity and waterlogging problems. Most of the state-funded efforts are on improving and modernizing hydraulic structures and canals. Although, these efforts are much needed for better water management at a regional scale, there is a need for equal and simultaneous effort to improve irrigation water management at field and farm levels through adoption of water-saving technologies such as evapotranspiration (ET)-based irrigation scheduling, drip irrigation, and crop monitoring sensors. At present, Fergana Valley farmers use the Soviet period-developed method of irrigation which divides the irrigated areas in Hydro Module Zones (HMZ). Each HMZ has a set of crop–specific recommendations for irrigation based on the soil type and depth of groundwater table. These recommendations have not been revised against changes in cultivars and fluctuations in groundwater table during the past decades. The ET-based irrigation scheduling method has the potential to replace subjective daily water management decisions at WUA level with crop water demand-based decisions to improve water use efficiency while reducing salinity and waterlogging problems.

Evapotranspiration-based Irrigation Scheduling

Evapotranspiration (ET) is defined as the measure of total water demand through evaporation from soil and transpiration by plants. Crop ET (ET_c) is a measure of water requirement of a particular crop being grown on the soil surface. Therefore, the ET_c can be used in daily irrigation scheduling programs, water demand models, and other applications (Marek, et al., 2010). The accuracy of ET_c values is highly dependent on characterization of site location and representation of topography, wind obstructions, buildings, roads, hills, drainage and waterways. It can be estimated as:

$$ET_c = ET_r \times K_c \times K_s \qquad (1)$$

where ET_r is the ET rate from a reference crop usually alfalfa or grass, K_c is a crop coefficient that varies by crop development stage (ranges 0 to 1), and K_s is a water stress coefficient that also ranges from 0 to 1. Crop coefficient is the ratio of ET_c to the ET_r. According to Allen et al. (1998), K_c represents an integration of the effects of four characteristics that distinguish a given crop form the reference crop: (1) crop height (affects aerodynamic resistance and vapor transfer), (2) canopy-soil albedo (affects R_n), (3) canopy resistance (to vapor transfer), and (4) evaporation from soil. K_c is directly derived from studies of the soil-water balance determined from cropped fields or from lysimeters. K_c values are estimated under optimal agronomical conditions, i.e. no water stress, disease, weed/insect infestation, or salinity issues. A K_s value of 1 can be assumed for fully irrigated conditions. The ET_r can be accurately calculated from meteorological data such as solar radiation, air temperature, wind speed, and relative humidity recorded from weather stations. The ASCE Standardized ET equation (Allen et al., 2005) is one of the widely adopted methods for estimating ET_r.

Goal and Objectives

The main goal of this field research is to test and demonstrate the use of evapotranspiration-based irrigation scheduling for improving water-use efficiency of cotton in Uzbekistan. This will be achieved by: (i) measuring water use by cotton, its yield, and its water use efficiency (WUE) under full irrigation, and (ii) compare these for evapotranspiration-based irrigation and WUA-prescribed irrigation scheduling methods.

Materials and Methods

Study Area

Field experiments were conducted in two provinces of Uzbekistan (Fergana and Andijon) and one province of Tajikistan (Sogd), all within the Fergana Valley where winter wheat and cotton crops are predominantly grown. Within each province, one WUA was selected. In Uzbekistan, within each WUA boundary, six dominant HMZs were identified for conducting irrigation experiments with winter wheat and cotton. Only one HMZ was selected in Tajikistan's part of the Fergana Valley due to constraints related resources availability. However, the selected HMZs account for more than 805 of the irrigated lands in the Fergana Valley. Table 1 presents detailed information on fields selected in each of the three WUAs in the Fergana Valley for irrigation experiment. Figure 1 illustrates the location of experimental sites in the Fergana Valley.

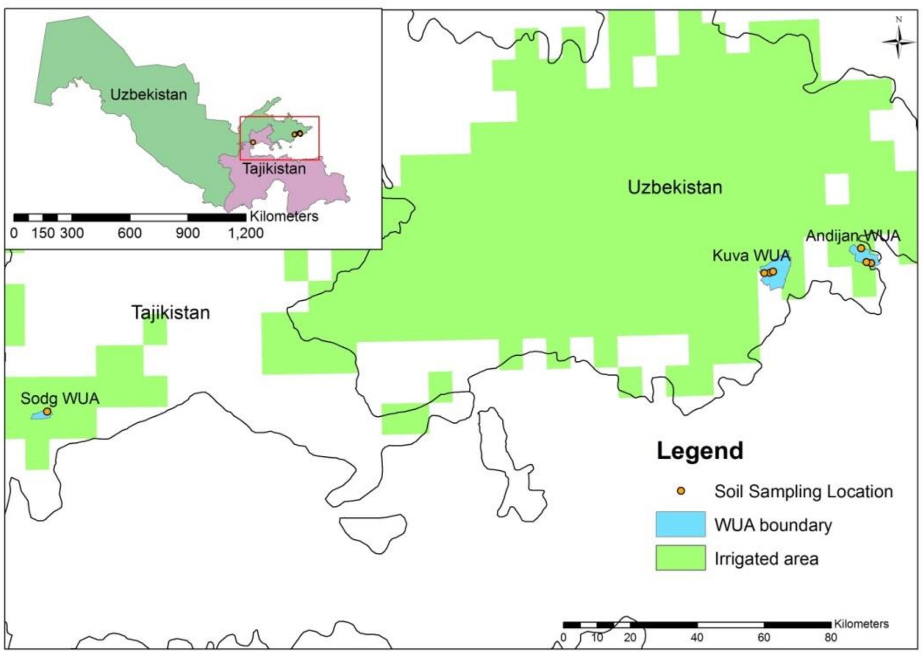

Figure 1: Location of the three WUAs where the study is being conducted.

Table 1. Characterization of selected fields for irrigation demonstration experiment during 2015 growing season.

Farm	HMZ*	Soil texture	Ground Water Table	Crop	
				Type	Area (ha)
WUA "Tomchikuli", Marhamat District, Andijon Province, Uzbekistan					
Davlat Ganimat	I	Thin (0.2-0.5 m) loamy and clayey on sandy gravel deposits and strong sandy loam and light loamy	≤ 3m	Cotton	32
				Wheat	34
Mirzahmat Sahovati	VI	Heavy loam and clayey, homogeneous, different-textured, layered	2-3m	Cotton	31
				Wheat	43
E. Ergashev	IX	Heavy loam and clayey, homogeneous, different-textured, layered	1-2m	Cotton	40
				Wheat	30
WUA "Qodirjon Azamjon", Kuva district, Fergana Province, Uzbekistan					
Qahramon Davlat Sahovati	II	Medium (0.5-1.0 m) loamy and clayey on sandy gravel deposits and strong sandy loam and light loamy	≤ 3m	Cotton	32
				Wheat	33
Qurbonov Temur	IV	Sandy and loamy, and thin- and medium-loam and clay	2-3m	Cotton	25
				Wheat	22
Toshpulatov Ganijon Shuhrat	VIII	Light- and medium-loam, homogeneous, heavy loam, relieved to the bottom	1-2m	Cotton	14
				Wheat	13
WUA "Chashma", J. Rasulov district, Sogd Province, Tajikistan					
Parij Kammuna	III	Thick (1 m or more) medium, heavy clay and clayey	≤ 3m	Cotton	8
				Wheat	1

* HMZ: Hydro Module Zone

Irrigation Experiment Design

At each location, an irrigation experiment is being conducted in three replicates and two irrigation scheduling methods: (i) evapotranspiration-based irrigation scheduling and (ii) WUA-prescribed irrigation scheduling. Both irrigation scheduling methods are designed to apply full irrigation with the furrow method. For implementing ET-based irrigation scheduling, field capacity (FC) of soils in the experiment plots were measured. Irrigation will be scheduled when soil-water content in the root zone is depleted by the crop to 70% of FC. Amount of irrigation applied is measured using flow meter at both supply and tail ends of the furrow. Cotton will be planted and harvested in accordance with local agricultural and crop management practices.

Daily grass reference ET (ET_o) required for estimating crop water use is calculated using the ASCE Standardized ET equation (Allen et al., 2005). Three weather stations, one for each site, are installed within three selected WUAs (Table 1). Efforts were made to find a suitable location that represents weather conditions with the WUA boundary and near one of the fields selected for irrigation experiment for easy maintenance purposes. The weather data required for calculating ET_o is being obtained from a weather station installed at each experiment location. Crop coefficients for different stages of cotton, developed by KRASS (a national partner in this project), is to be used in Equation 1 to estimate cotton water use.

Photo 1: (a) TDR access tube for measuring soil-water content at different depths, (b) and (c) team collecting soil samples for soil characterization and determination of physical and chemical properties, and (d) team studying a historic HMZ map for selected Water User Association.

Crop water demand or ET calculated using grass reference ET and crop coefficients will be compared with ET derived using the soil water balance equation (Ibragimov et al., 2007):

$$ETc = P + I + F - R - \Delta S \qquad (2)$$

where ET is the crop water use, P is the precipitation, I is the irrigation, F is flux across the lower boundary of the root zone, R is the sum of runoff and run-on, and ΔS is the change in soil water content in the soil profile. Precipitation data is obtained from a weather station installed specifically for this experiment. The ET value from equation will be adjusted if it is different from that calculated using Equation 2. The change in the storage volume is calculated using soil water content measured using TDR sensors (IMKO PRIME PICO TDR system, Germany) installed at a depth of 30, 60, and 90 cm. Finally, each experiment site is also equipped with ET gages for comparing their estimate of ET with the weather station-based equation method.

Seasonal crop water use for cotton will be calculated by summing the daily crop water use. Finally, WUE will be calculated and compared between two irrigation scheduling methods.

Expected Benefits

Prior to this demonstration experiment, comprehensive investigation on efficiency of WUA-prescribed irrigation scheduling against widely used ET-based irrigation scheduling in Fergana Valley had been limited. This experiment, while demonstrating the efficacy of ET-based irrigation scheduling services, provides crop coefficients for cotton and winter wheat grown in seven predominant HMZs. In addition, the data collected as part of this experiment can be used to conduct crop modeling to evaluate the effects of climate change on water availability and water demand in the Fergana Valley. Irrigation and water use efficiencies calculated using this experiment can be used to compare their relative performance with other cotton and winter wheat producing nations in Central Asia and around the world.

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