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Optimizing use of Water for Cotton Production using Evapotranspiration-based Irrigation Scheduling Technique in the Fergana Valley, Uzbekistan

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Abstract: Irrigated agriculture is the backbone of Central Asian economies and efficient irrigation management is of crucial importance to the sustainable crop production. The ET-based irrigation scheduling method has potential to replace subjective daily water management decisions at Water Users Association level with crop water demand-based decisions to improve on-farm water-use efficiency. Results from a two year study conducted in Fergana Valley of Uzbekistan showed that there can be a 25-34% saving of water without any significant change in yield when irrigation is applied using the ET-based scheduling method. The pilot plots are representative of 38% of irrigated area in Fergana Valley (241,407 ha). If this methodology is widely adopted by the WUAs, large amounts of water can be saved which can be diverted for horizontal expansion of agriculture or for other purposes such as supporting ecosystem services.

Key words: Evapotranspiration, cotton, Uzbekistan.

Irrigated agriculture is the backbone of Uzbekistan's economy (Yusupov *et al*., 2012). Efficient irrigation water management is of crucial importance to the sustainable crop production in the country. 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) has 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 resulted in significantly reduced crop yields in most part of the country (Reddy *et al*., 2012).

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 techniques such as evapotranspiration (ET)-based irrigation scheduling, drip irrigation, and crop monitoring sensors. At present, Central Asian farmers, including those in Uzbekistan, use the Soviet era-developed method of irrigation

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which divides the irrigated areas in nine Hydro Module Zones (HMZ). Each HMZ has a set of crop–specific recommendations for irrigation based the soil characteristics (thickness of soil layers, soil texture) and depth of groundwater table. These recommendations have not been revised against changes in cultivars and fluctuations in groundwater table during 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.

The main goal of this study was to test the use of ET-based irrigation scheduling for improving water-use efficiency of cotton in Uzbekistan.

Materials and Methods

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 at 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:

$$ET_c = ET_r \times K_c \times K_s \quad ...(1)$$

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.

Study area

Field experiments were conducted in two provinces of Uzbekistan (Fergana and Andijon) within the Fergana Valley where winter wheat and cotton are predominantly grown. Cotton is the most important crop in terms of irrigated area and production in Central Asia, mainly

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

Farm	Hydro module zone	Soil characteristics (soil depth and texture)	Ground water table	Crop	
				Type	Area (ha)
WUA "Tomchikuli", Marhamat District, Andijon Province, Uzbekistan					
Davlat Ganimat	I	Shallow (0.2-0.5 m) loamy and clay on sandy gravel deposits and deep sandy loam and light loam	≥3 m	Cotton	32
				Wheat	34
				Wheat	30
WUA "Qodirjon Azamjon", Kuva district, Fergana Province, Uzbekistan					
Qahramon Davlat Sakhovati	II	Medium (0.5-1.0 m) depth, loamy and clay on sandy gravel deposits and gypsum, deep sandy loam and light loam	≥3 m	Cotton	32
				Wheat	33
				Wheat	22
Toshpulatov Ganijon Shuhrat	VIII	Deep (≥ 1 m) light- and medium-loam, homogeneous, heavy loam, lightened texture (transient to coarser texture) to the bottom	1-2 m	Cotton	14
				Wheat	13
				Wheat	1

* HMZ: Hydro Module Zone.

Table 2. Location and size of experimental plots

Farm	Hydro module zone	Width of the experimental site (m)		Length of the experimental site (m)		Total area of the experimental site (ha)	
		Traditional irrigation	ET-based irrigation	Traditional irrigation	ET-based irrigation	Traditional irrigation	ET-based irrigation
Davlat Ganimat	I	9	11	30	30	0.027	0.033
Qakhramon Davlat Sakhovati	II	9	9	30	30	0.027	0.027
Toshpulatov Ganijon Shukhrat	VIII	9	9	30	30	0.027	0.027

in Uzbekistan (FAS USDA, 2002; FAO, 2004). Excessive water is often applied to furrow irrigated cotton in Central Asia (Horst *et al*., 2005, 2007). Three dominant HMZs were identified for conducting irrigation experiments with cotton crop. 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. Only portions of farmers' fields were used for the study (Table 2).

In Andijon Province, the farm *Davlat Ganimat* was selected as a pilot site, which was located in the territory of Water Users Association *Tomchikuli* in Markhamat District. The farm was located in the first (I) hydro module zone, where the soil texture has the following characteristics: sandy loam on clay alluvial deposits, strong sandy loam and light loam; the water table is ≤3 m. In Fergana Province, two farms were selected as pilot sites in the two different hydro module zones (II and VIII). The first site, *Qodirjon Azamjon*, was located in the territory of Water Users Association in Kuva District. Another farm, *Qakhramon Davlat Sakhovati* was located in the second (II) hydro module zone, where the soil texture is represented by loamy and clayey on sandy gravel deposits; strong sandy loam and light loamy; with the water table of ≤ 3 m. Detailed soil physical properties are presented in Table 3.

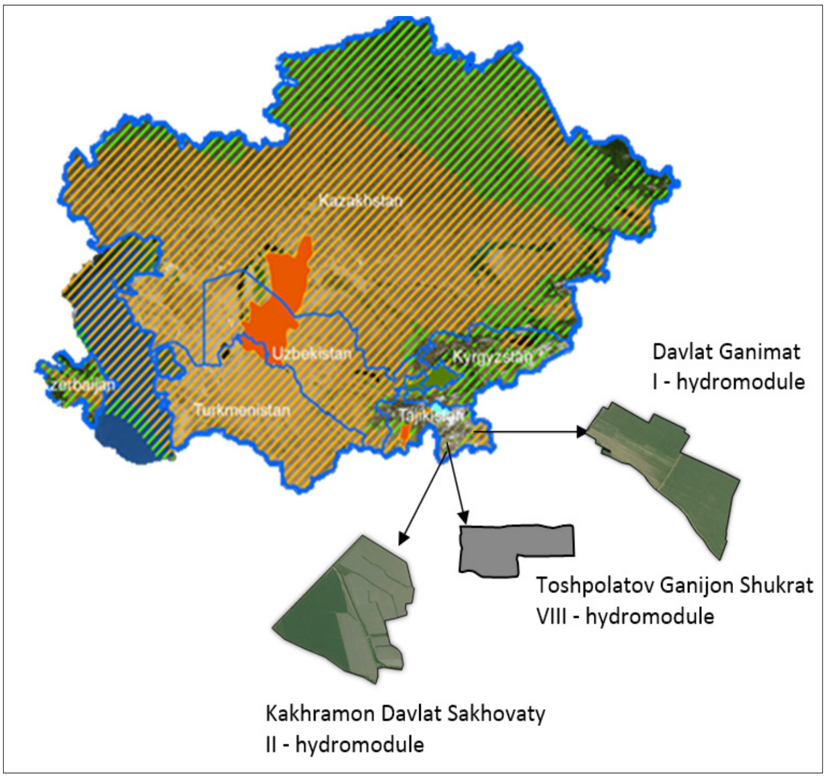

Fig. 1. Location of study sites within Fergana Valley.

Table 3. Soil physical properties at the sites in the three hydro module zones

Hydro module zone	Soil layer	Layer (cm)	Soil layer thickness (cm)	Soil texture	Sand (1-0.05 mm) (%)	Clay (<0.001 mm) (%)	Silt (0.05-0.001 mm) (%)	Hydraulic conductivity, m day^{-1}	BD* g cm^{-3}	FC* m^3 m^{-3}	PWP* m^3 m^{-3}
I	1	0-13	13	Loam	35%	25%	41%	0.072	1.308	0.281	0.112
I	2	13-31	18	Loam	34%	26%	40%	0.072	1.675	0.340	0.136
I	3	31-65	34	Clay Loam	30%	29%	41%	0.072	1.581	0.295	0.118
I	4	65-96	31	Loam	33%	23%	44%	0.072	1.605	0.281	0.112
I	5	96-117	21	Loam	36%	23%	41%	0.072	1.640	0.287	0.115
I	6	117-134	17	Loam	28%	25%	47%	0.072	1.613	0.283	0.113
I	7	134-150	16	Clay Loam	29%	31%	40%	0.072	1.651	0.283	0.113
II	1	0-25	25	Loam	49%	15%	36%	0.606	1.713	0.323	0.129
II	2	25-45	20	Loam	51%	16%	33%	0.606	1.544	0.341	0.137
II	3	45-60	15	Loam	50%	15%	36%	0.606	1.454	0.308	0.123
II	4	60-73	13	Loam	36%	21%	42%	0.606	1.460	0.324	0.130
II	5	73-113	40	Sandy Loam	55%	17%	28%	0.606	1.473	0.315	0.126
II	6	113-122	9	Sand	97%	2%	1%	0.606	1.380	0.295	0.118
II	7	122-131	9	Loamy Sand	78%	5%	18%	0.606	1.593	0.341	0.136
II	8	131-150	19	Sand	95%	2%	3%	0.606	1.378	0.295	0.118
VIII	1	0-20	20	Sandy Loam	56%	14%	30%	0.277	1.739	0.256	0.102
VIII	2	20-47	27	Loam	50%	16%	35%	0.277	1.583	0.285	0.114
VIII	3	47-90	43	Sandy Loam	53%	16%	31%	0.277	1.393	0.253	0.101
VIII	4	90-125	35	Loam	43%	16%	41%	0.277	1.602	0.286	0.114
VIII	5	125-150	25	Loam	42%	17%	40%	0.277	1.602	0.286	0.114

*BD: Bulk density; FC: Field capacity; PWP: Permanent wilting point.

Irrigation experiment design

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

Daily grass reference ET (ET_o) required for estimating crop water use was calculated using the ASCE Standardized ET equation (Allen *et al.*, 2005). Three weather stations, one each was 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 was obtained from a weather station installed at each experiment location.

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

$$ET_c = P + I + F - R - \Delta S \quad ...(2)$$

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 was obtained from the weather station installed specifically for this experiment. The ET value from equation was adjusted if it was different from that calculated using Equation 2. The change in the storage volume was 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 was also equipped with ET gages for comparing their estimate of ET with the weather station-based equation method. Seasonal crop water use for cotton was calculated by summing the daily crop water use. Finally, WUE was calculated and compared between two irrigation scheduling methods.

Data collection protocols

Soil moisture measurements were taken every 5 to 7 days during April and May months when the ET losses were moderately-high but from June, readings were taken every day. Observers took readings at each 15 cm interval up to depth of 1.5 m. Observations were taken at each experimental site in three replications by three points in the fields for traditional irrigation and ET-based irrigation. Water table measurements were taken every day starting June month only in the farm Toshpulatov Ganijon Shukhrat (HMZ VIII), where water table in vegetation period rises up to 1 m and above. In other two farms, the water table is typically below 3 m from surface and does not influence the rooting zone. Weirs were installed at each experimental site to measure water delivery and outflow and to calculate irrigation rate. These measurements started with the beginning of irrigation. Every day, after the irrigation started, the level was measured at the weir's scale and logged. Further, water delivery was calculated based on weir measurements. Phenological stages of cotton were recorded at experimental sites to assess growth and development of plants. The measurements were carried out every 15 days. Climatic data on air temperature (max. and min.), air humidity, precipitation and wind speed were downloaded automatically from meteorological station. Access to data from the meteorological station was provided through installed data transmitters and cellular communication.

Results and Discussion

Phenological observations

Cotton was planted in April at selected sites: two irrigation methods were compared during the vegetation growth - traditional (farmer's practice) and ET-based irrigation method (Table 4). There were no significant differences in the phenological observations made between treatments in all three hydro module zones (Fig. 2).

Irrigation application rates

There was a significant saving of water using the ET-based irrigation scheduling method (Table 4). A 33.8% water was saved at HMZ I site, 25.2% at HMZ II site and 34.3% at HMZ VIII site by switching from conventional irrigation to ET-based irrigation scheduling method.

Yield and water productivity

Insignificant differences in yields were observed between the two methods of irrigation-4011 vs. 3985 kg ha^{-1}, 3975 vs. 4579 kg ha^{-1} and 3968 vs. 3500 kg ha^{-1} for HMZ I, II and VIII for conventional and ET-based irrigation scheduling method, respectively (Table 5). This suggests that the yields are already close to the

Table 4. Irrigation schedule for cotton at the experimental site

HMZ I				HMZ II				HMZ VIII			
Traditional		ET-based		Traditional		ET-based		Traditional		ET-based	
Date	mm	Date	mm	Date	mm	Date	mm	Date	mm	Date	mm
18-Apr	28.5	23-Apr	35.3	3-Jun	132.7	3-Jun	105.3	10-Jun	121.7	10-Jun	108.0
19-Jun	114.3	24-Jun	78.8	29-Jun	121.0	30-Jun	91.7	3-Jul	130.7	5-Jul	99.7
8-Jul	12.5	13-Jul	74.6	14-Jul	130.3	17-Jul	93.7	20-Jul	124.0	23-Jul	95.3
20-Jul	128.2	20-Jul	84.1	2-Aug	139.3	5-Aug	93.0	4-Aug	129.7	6-Aug	104.0
5-Aug	14.6	5-Aug	86.0	20-Aug	113.7	23-Aug	93.0	18-Aug	113.0	-	-
Total	541.7		358.8		637.0		476.7		619.1		407.0

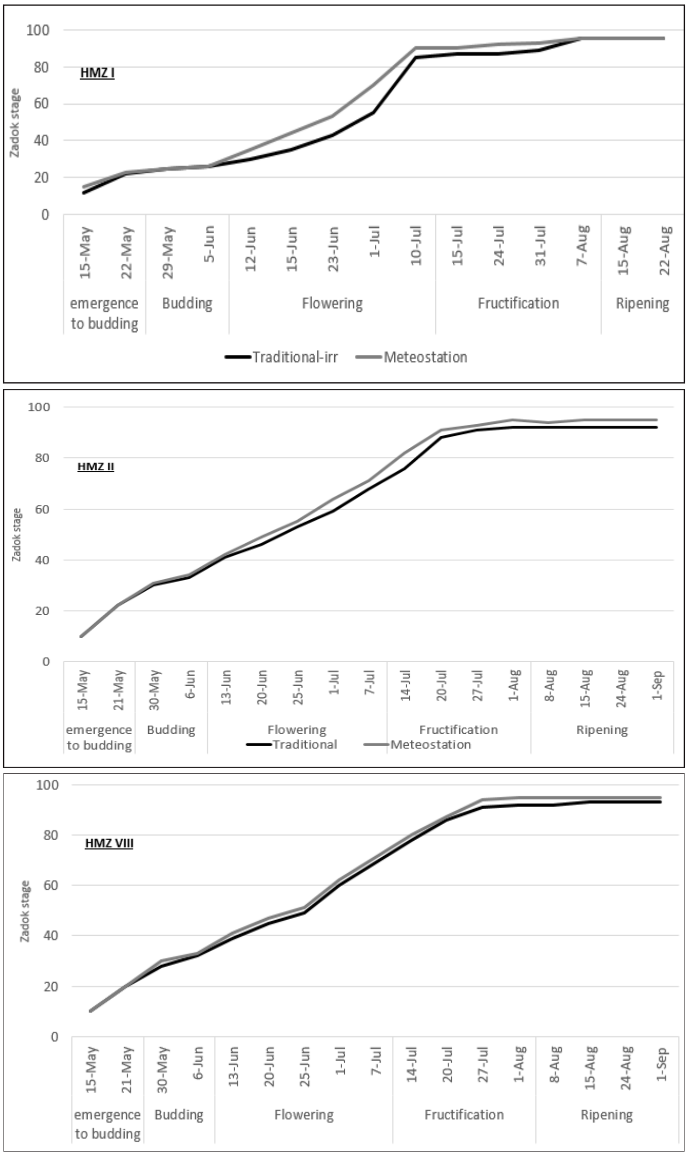

Fig. 2. Comparison of phenological growth stages between traditional and ET-based irrigation treatments for the three hydro module zones.

achievable levels at the respective locations and that other agronomic practices (such as cultivar, planting date, fertilization, field preparation, etc.) maybe of consideration for achieving even higher yields. Also, it suggests that the ET-based irrigation scheduling method does not

Table 5. Comparison of yield and water productivity under conventional and evapotranspiration-based irrigation method for cotton and wheat crop in Fergana Valley area in Uzbekistan

HMZ*	Water applied (mm)		Yield (kg ha^{-1})		Water productivity (kg ha^{-1} mm^{-1})	
	Conventional irrigation	ET-based irrigation	Conventional irrigation	ET-based irrigation	Conventional irrigation	ET-based irrigation
I	541.7	358.8	4011	3985	0.74	1.11
II	637.0	476.7	3975	4579	0.62	0.96
VIII	619.1	407.0	3968	3500	0.64	0.86

* HMZ I: Sandy loam soil with ≤3 m groundwater table depth; HMZ II: deep sandy loam and light loam soil with ≤3 m groundwater table depth; HMZ VIII: light and medium loamy, heavy loamy with light texture in deeper layers, 1-2 m groundwater table depth.

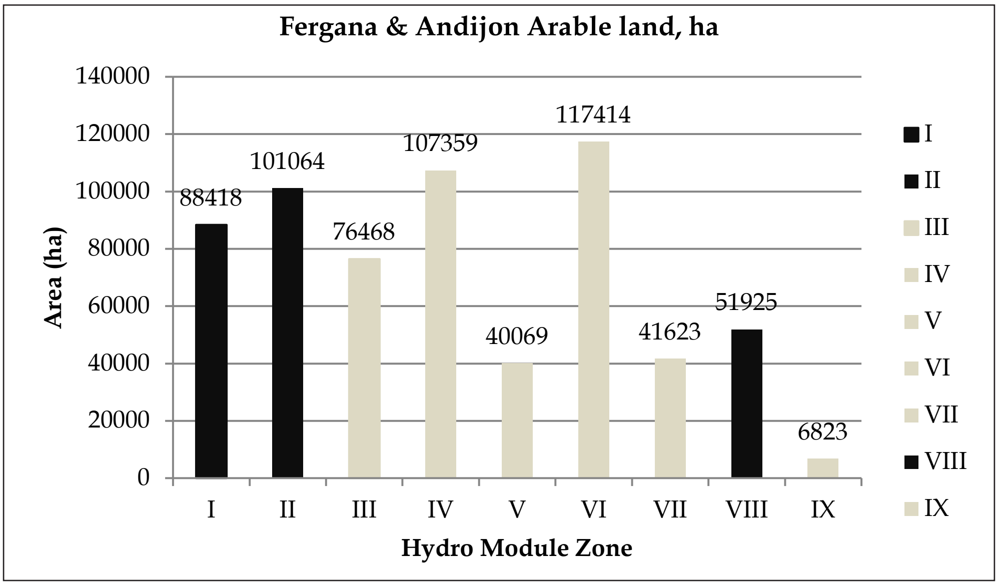

Fig. 3. Area under different hydro module zones in Fergana and Andijon Provinces of Uzbekistan.

cause any moisture stress to crop that may have led to decrease in crop yields.

Water productivity (yield/water applied) is a good indicator of effectiveness of water usage. Since there was a significant saving of water without any adverse impact on the crop yield, water productivity increased when irrigation method was changed from traditional to ET-based scheduling method (Table 5). Water productivity increased by 50, 52 and 34% respectively for HMZ I, II and VIII when irrigation method was changed from traditional to ET-based scheduling.

Fig. 3 presents the total area in Fergana and Andijon Province under each of the nine hydro module zones. HMZ I has a total area of 88,418 ha, HMZ II has 101,064 ha and HMZ VIII has 51,925 ha which are respectively 14%, 16% and 8.2% of the total arable area of 631,163 ha in the two provinces. If our field research results are outscaled, a total of 241,407 ha can save a substantial amount of water that can be diverted for either horizontal expansion of agriculture or for other uses such as for supporting ecosystem services and for increasing discharge into the Aral Sea.

Conclusions

Irrigated agriculture is the backbone of Central Asian economies and efficient irrigation management is of crucial importance to the sustainable crop production. The ET-based irrigation scheduling method has potential to replace subjective daily water management decisions at Water Users Association level with crop water demand-based decisions to improve on-farm water-use efficiency. Results from a two year study conducted on cotton crop at Fergana and Andijon Provinces in Fergana Valley of Uzbekistan showed that there can be a 25-34% saving of water without any significant change in yields when irrigation is applied using the ET-based scheduling method. This led to an overall increase in water productivity by 34-50%. The pilot plots are representative of 38% of irrigated area in Fergana Valley (241, 407 ha). If this methodology is widely adopted by the WUAs, large amounts of water can be saved which can be diverted for horizontal expansion of agriculture or for other purposes such as supporting ecosystem services.

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