Improving Water Use Efficiency Through Innovative Technologies in Irrigation and Agriculture in the Fergana Valley

V.A. Dukhovny, Sh. Mukhamedjanov, A. Mukhamedjanov, V. Nangia

TASHKENT - 2015

Project executors

Viktor Dukhovny - SIC ICWC	Director SIC ICWC, overall project management
Shukhrat Mukhamedjanov - SIC ICWC	Project management
Vinay Nangia	ICARDA
Prasanna Gowda	USDA-ARS
Tulkun Yuldashev	ICARDA
Rustam Sagdullaev - SIC ICWC	Project assistance
Azamat Mukhomedjanov - SIC ICWC	Regional hydro technical expert
Maraim Mirzaliev	Fergana Province field executor
Ismail Ganiev	Fergana Province field hydro technician
Qurbon Sharipov	Fergana and Andijon Province field agronomist
Jamoliddin Akhmedov	Fergana Province field adviser
Avaz Akhunov	Andijon Province field executor
Abdurakhim Urinov	Andijon Province field hydro technician
Husanboy Pozilov	Andijon Province field adviser

Abbreviation

WUA	Water User Association
GWT	Groundwater Table
CW	Cipoletti Weir
TW	Thomson Weir
SW	SANIIRI Weir
HMZ	Hydromodule Zone
DS	Demonstration Site
DW	Drainage Well

Table of Content

Background	5
Organization of demonstration sites: preparatory work	6
Demonstration sites in Andijon Province	7
Demonstration sites in Fergana Province	7
Morphological description of the main soil profiles	8
Organization of experimental sites, equipping and technique of project work	11
Installation of small meteorological stations	12
Equipping of experimental sites	13
Technique of project work	13
Results of project work and their assessment	14
Soil moisture assessment	14
Assessment of the experimental site irrigation	18
Phenological observations at the experimental sites	20
Agro-technical assessment at the experimental sites	22
Workshops and publications	22

Background

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) 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 (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 the Uzbekistan 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 late 1980s to 1.2 million ha in 2013. Total water use has decreased by 20% to 51 billion m^3 since 1980s and irrigation water use has reduced by 40% since 1990s to 10,500 m^3/ha.

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 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.

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.

Weather station network-based irrigation demand forecasting

Real-time weather conditions-based modeling of crop growth can predict whether the soil is drying and the plant is water-stressed or not. If no rain is forecast for the following short-term period, the informed farmer would decide to irrigate in such situations.

The research proposed here is to have a network of weather stations that transmit weather data needed to run the crop models for different dominant crops to the central server. The models would predict if there is sufficient soil moisture depletion and crop water stress requiring irrigation. Then the server would advise WUA water managers to irrigate their clients' crop in the coming days.

Such an approach was tried during the Soviet times using a network of tensiometers and was very popular amongst the famers then. Revival of such a service using weather station-based forecasting has a high probability of acceptance amongst the farming communities. The USDA is already providing such data over its website for farmers in the Texas Panhandle area, and was a viable partner for execution in the Fergana Valley.

Three demonstrations fields were selected. In these fields the work related to water-use efficiency was done during 2014. Since September 2014, for adaptation of new approaches, by using the small weather stations and the crop model, seven pilot sites with different soil conditions and hydromodule zones were selected (Table 1). In these seven pilot sites (fig. 1) the efforts were undertaken to determine physical and chemical

characteristics of the soils. These parameters are necessary for adaptation of the crop model and for planning of irrigation regime at the WUA and farm levels.

During 2015, it was planned to implement the adaptation of these two models in the three provinces in the Fergana Valley. But due to budget cuts, the work plan had to be changed, and only the results of the field work related to irrigation with the help of small weather stations at three pilot sites in two provinces are presented in this report.

Objective

To develop a management system for transfer of innovative technologies that ensures efficient use of irrigation water at the Water User Association (WUA), farm and field level.

Experiment design

At each location, irrigation experiment was conducted in three replicates and 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 is depleted by the crop to 70% of FC. Amount of irrigation applied was measured using flow meter at both supply and tail end of the furrow. Crops were 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). Two weather stations, one each is installed within two 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 being used in Equation 1 to estimate cotton water use.

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):

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

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 a weather station installed specifically for this experiment. The ET value from equation were 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 and winter wheat were calculated by summing the daily crop water use. Finally, WUE was calculated and compared between two irrigation scheduling methods.

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.

Establishment of demonstration sites

Preparatory work

The main objective of this part of work was to show an advantage of using the irrigation management method, which is based on accurate calculations using the climate data, over the commonly used methods where irrigation planning is based on indirect indicators showing soil and plant conditions. Organization of demonstration sites within the framework of this project provides a practical demonstration (with the opportunity to study at these sites) of the efficiency of irrigation water use, water use management and agricultural operations at the field level in a timely manner. The demonstration sites were selected in two provinces of the Fergana Valley (Fergana and Andijon Provinces of Uzbekistan) where both wheat and cotton crops were sown. Demonstration fields were selected according to hydromodule zones, as in Central Asia and the CIS the irrigation rates for different crops are set considering both climatic zones and soil reclamation conditions, with their division into the so-called hydromodule zones (fig 1).

Each site was selected considering its representativeness in regards to the water management and other conditions for agricultural production in given zone. In the Fergana Province, two farms - Qakhramon Davlat Sakhovati and Tashpulatov Ganijon Shukhrat were chosen in the territory of WUA Qodirjon Azamjon. In the Andijon Province, one farm - Davlat Ganimat was chosen in the territory of WUA Tomchikuli (fig 1).

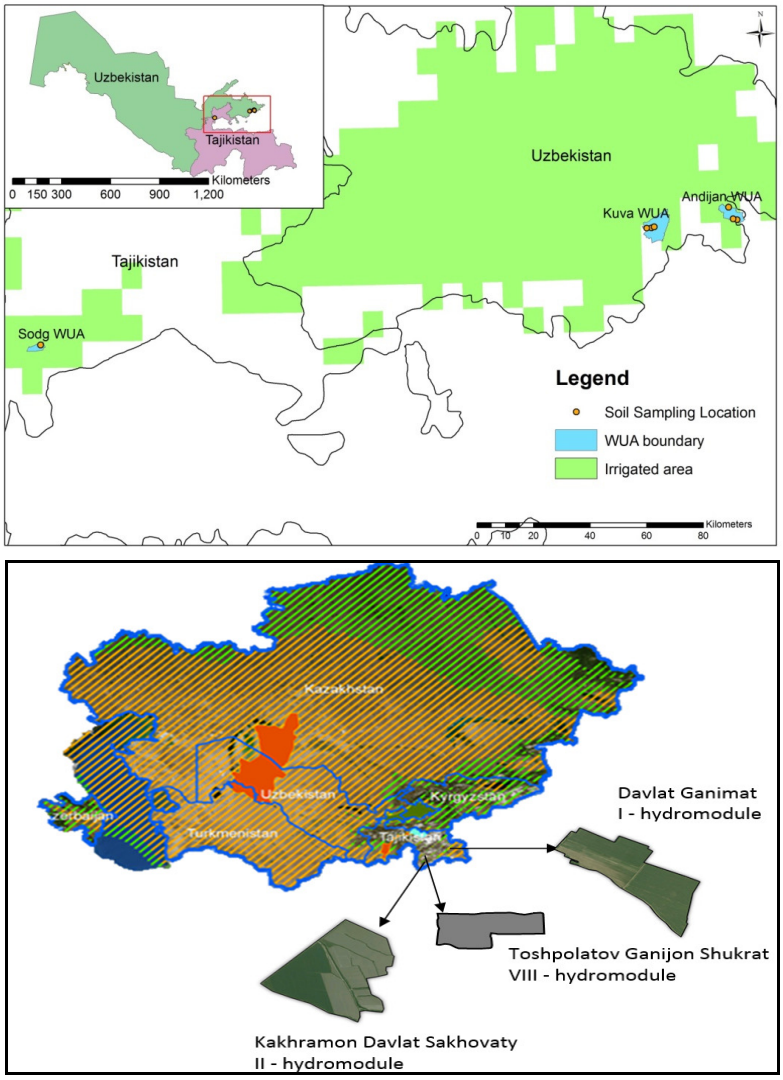


Figure 1: Location of study sites within Fergana Valley.

Demonstration sites in Andijon Province

In Andijon Province, one farm was selected as a pilot site, which is located in the territory of Water Users Association Tomchikuli in Markhamat District.

- The farm, Davlat Ganimat, is located in the first (I) hydromodule zone, where the soil texture is: shallow (0.2-0.5 m) sandy loam on clay alluvial deposits, strong sandy loam and light loam; the water table is ≤ 3m) (Table 1).

In 2015, cotton was planted on 32 hectares and winter wheat in 34 hectares at this site. The farm has 67.1 hectares of land in total. The main source of irrigation is the canal K-4b. The cropping patterns in Davlat Ganimat farm in 2014 was – cotton: 32 hectares of which the demonstration field area was 17.5 ha (where a small experimental site was organized); winter wheat: 34 hectares, of which the demonstration field area was 17.7 hectares (where a small experimental site was organized), and onions: 1 hectare.

Demonstration sites in Fergana Province (Kuva District)

In Fergana Province, two farms were selected as pilot sites in the two different hydromodule zones (II and VIII), which are located in the territory of Water Users Association Qodirjon Azamjon in Kuva District.

- The farm Qakhramon Davlat Sakhovati is located in the second (II) hydromodule zone where the texture of soil is: medium (0.5-1.0 m) loamy and clayey on sandy gravel deposits and strong sandy loam and light loamy; the water table is ≤ 3m) (Table 1).

Table 1 Characteristics of the selected demonstration sites in the Fergana Valley

Farm	HMZ*	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	≤ 3m	Cotton	32
				Wheat	34
WUA Qodirjon Azamjon, Kuva district, Fergana Province, Uzbekistan					
Qahramon Davlat Sahovati	II	Medium (0.5-1.0 m) depth, loamy and clay on sandy gravel deposits and gypsum, deep sandy loam and light loam	≤ 3m	Cotton	32
				Wheat	33
Toshpulatov Ganijon Shuhrat	VIII	Deep (≥ 1 m) light- and medium-loam, homogeneous, heavy loam, lightened texture (transient to coarser texture) to the bottom	1-2m	Cotton	14
				Wheat	13
				Wheat	1

In 2015, the structure of cropped area in Qakhramon Davlat Sakhovati was – Cotton: 32 hectares, of which the demonstration field area is 19 hectares (where a small experimental site was organized). Winter wheat: 33 hectares, of which the demonstration field area is 1 hectare. The farm has 65 hectares of the land. The farm "Toshpulatov Ganijon Shukhrat" is located in the eighth (VIII) hydromodule zone, where the texture of soil is: light - and medium loam, homogeneous, heavy loam; the water table is 1-2m (Table 1). In 2015, the structure of cropped area of Toshpulatov Ganijon Shukhrat was – Cotton: 13 hectares (where a small experimental site was organized); winter wheat: 14 hectares (where a small experimental site was organized).

Morphological description of the main soil profiles

For crop modeling, detailed analysis of soil characteristics of different soil layers from the surface down to 1.5 meters (color, texture and root residues; transition of horizons, humidity and mechanical composition) was performed:

Uzbekistan, Ferghana Province, Kuva District, WUA "Qodirjon Azamjon"

Farm Qakhramon Davlat Sakhovati

Capacity genetic horizon, cm	Morphological Characteristics
Ap 0-25	Plough layer, dark grey, dark yellowy-brown (10 YR 4/6), moisty, structure fine-granular (pulvered structure), fluffy consistence (a knife penetrates up to 7 cm), well-structurized, medium-textured loam, plant remains (roots), graded transition to the next horizon
A2 25-45	Subsurface layer, grey, dark yellowy-brown (10 YR 4/6), moisty, structure fine-granular (pulvered structure), puddled structure a knife penetrates up to 6.5 cm), medium-textured loam, plant remains (roots), sharp transition to the next horizon

Capacity genetic horizon, cm	Morphological Characteristics
B1 45-60	Yellowy-brown (10YR 6/8), moisty, structure fine-graded (pulvered structure), firm consistency, (a knife penetrates up to 4 cm), heavy clay loam, fine root remains included, sharp transition
B2 60-73	Dark brown (7.5YR 5/6) reddish, spotted (10R 4/8, 3/6), moisty, structure finely nutty structure, firm consistence, less consistent (a knife penetrates up to 5 cm), heavy clay loam, fine root remains included, graded transition.
B3 73-113	Greyish, brown (7.5YR 5/4) with rusted brown stains, moisty, structure nutty structure, finely nutty structure, coarse clay, firm consistency (a knife penetrates up to 3.5 cm), heavy clay loam, fine root remains included, sharp transition to the next horizon
B4 113-122	Multicolored sand, alluvium, moisty, structure granular, less consistent than previous layer (a knife penetrates up to 7.0 cm), arenaceous sandstone, coarse sand, sharp changes
B5 122-131	Yellowy-brown (10YR 5/6) , moisty, structure finely nutty structure, coarse clay, firm consistency (a knife penetrates up to 6.5 cm), fluffy consistence , clayish, sharp transition to the next horizon
B5 131-150	Multicolored: light brown and pink-grey(7.5 YR 6/4, 7/2), light-yellowy-brown (10YR 6/4), moisty, structure granular, more consistent than the previous layer (a knife penetrates up to 4.5 см), coarse sand and alluvium soils

Farm Toshpulatov Ganijon Shukhrat

Capacity genetic horizon, cm	Morphological Characteristics
Ap 0-20	Plough layer, dark grey, dark yellowy-brown (10 YR 4/6), moisty, structure fine-granular, grained, firm consistency (a knife penetrates up to 4-5 cm), heavy clay loam, plant remains (roots), graded transition to the next horizon.
A2 20-47	Subsurface layer, grewy, dark yellowy-brown (10 YR 4/6), moisty, structure fine- nutty structure, coarse clay, grained (pulvered structure), firm consistency (a knife penetrates up to 2.5 cm, clay, plant remains (roots), graded transition to the next horizon.
B1 47-90	Yellowy-brown (10YR 5/8), moisty, sticky soil (shokhak), structure grained, fine- nutty structure, finegrained (pulvered structure), firm consistency, less consistent (a knife penetrates up to 3.5 см), heavy clay loam, clayish, fine root remains included, graded transition
B2 90-125	Dark brown(7.5YR 5/6), moisty, structure grained, fine-granular, nutty structure, firm consistency, less consistent (a knife penetrates up to 4 см), clayish, graded transition
B3 1 25-150	Dark yellowy-brown (10YR 4/6), moisty, structure crumbly soil, firm consistency (a knife penetrates up to 4 cm), medium-textured loam, clayish

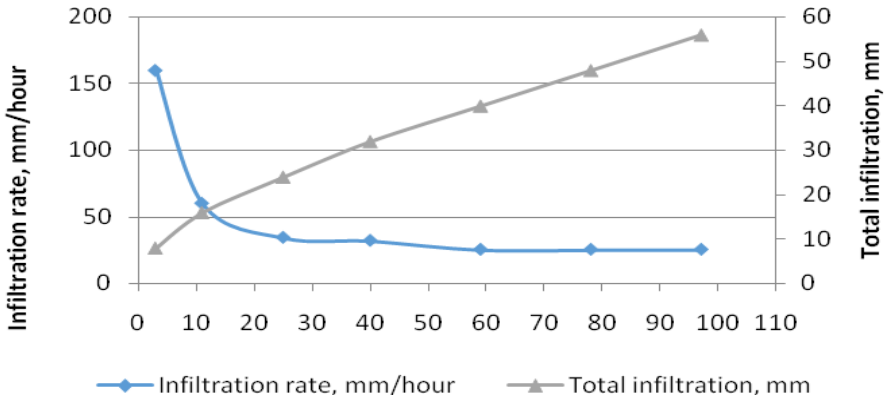
Uzbekistan, Andijon Province, Markhamat District, WUA Tomchikuli

Farm Davlat Ganimat

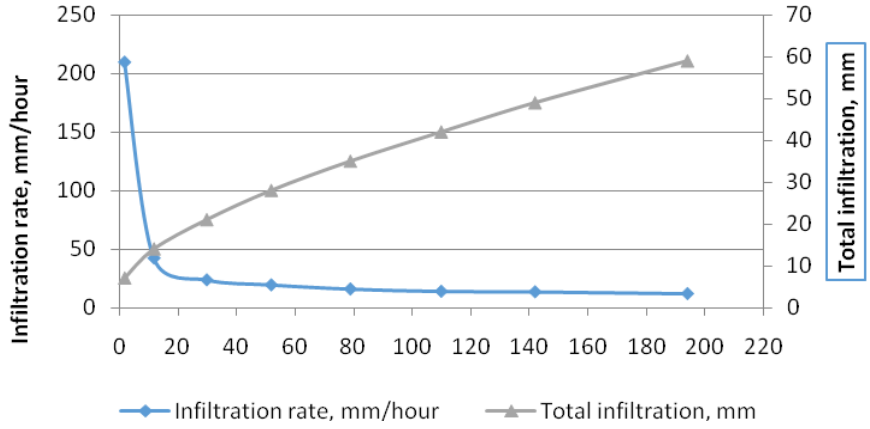
Capacity genetic horizon, cm	Morphological Characteristics
Ap 0-13	Plough layer, dark-grey, dark -yellowy-brown (10 YR-4/6), moisty, structure coarse- nutty structure, nutty structure, finely nutty structure, grained, fluffy consistency (a knife penetrates up to 7 cm), well-structurized, clay, plant remains (roots), graded transition to the next horizon.
A2 13-31	Subsurface layer, grey, dark-yellowy-brown (10 YR 4/6), moisty, structure crumbly, fine crumbly, coarse-nutty structure, nutty, firm consistency (a knife penetrates up to 4 cm), clay, plant remains (roots), sharp transition to the next horizon.
B1 31-65	Yellowish-red and dark brown (5YR-5/6, 7.5YR-5/6), moisty, structure grained, finely nutty structure, nutty structure, fine crumbly, firm consistency (a knife penetrates up to 5 cm), clay, few plant roots, graded transition
B2 65-96	Dark brown (7.5YR 5/8), moisty, structure pulvered structure, grained, coarse-grained, nutty structure, coarse-nutty structure, firm consistency, more consistent (a knife penetrates up to 4.5 cm), clay, few plant roots included, graded transition
B3 96-117	Dark brown (7.5YR 5/6), moisty, structure fine crumbly, coarse nutty structure, nutty structure, finely nutty structure, coarse clay, grained, firm consistency (a knife penetrates up to 5 cm), clay, no plant roots, graded transition
B3 117-134	Dark brown (7.5YR-5/8), moisty, structure coarse nutty structure, nutty structure, finely nutty structure, coarse clay, more firm consistency (a knife penetrates up to 3.5 cm), heavy clay loam, no plant roots, graded transition
B3 134-150	Yellowish-red (5YR 5/8), moisty, structure mean-crumbly, fine crumbly, nutty structure, finely nutty structure, coarse clay, firm consistency (a knife penetrates up to 4.0 cm), heavy clay loam, no plant roots

Infiltration rate at the demonstration sites

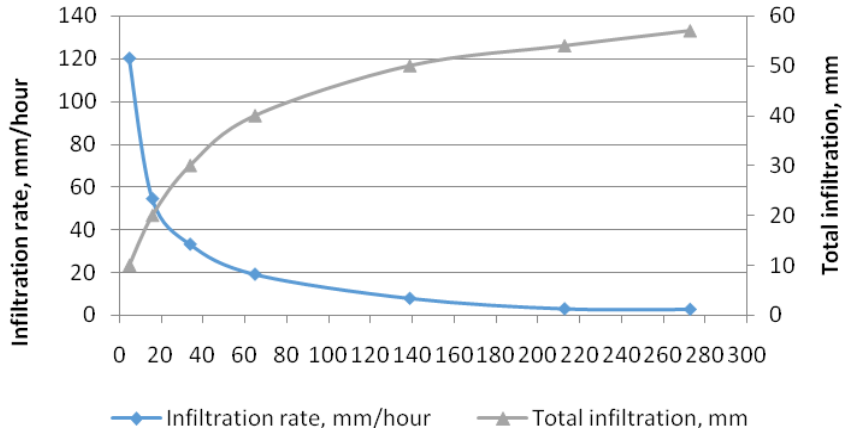
Data was obtained on soil infiltration rate in all the selected field sites of seven hydromodule zones of the Fergana Valley. Analysis of the data shows that out of seven sites, the two fields from the farm Davlat Ganimat in Andijon Province and the farm Parij Kommuna in Sogd Province of Tajikistan have very low permeability in these areas and the values of the infiltration rate are very small - 3.0 and 3.9 mm/hour, respectively. The highest values of the infiltration rate were obtained on the site of the farm E. Ergshev in Andijon Province. In Fergana Province, the infiltration rate values were 11.5; 25.3 and 26.3 mm/hour, respectively. Judging by the infiltration rate, we can conclude that the two sites have very firm soil consistency, one site has very light soils and three other sites have medium and light soils.



(a) Fergana Province, Kuva District, Farm Qahramon Davlat Sakhovati



(b) Fergana Province, Kuva District, farm Toshpulatov Ganijon Shukhrat



(c) Andijon Province, Markhamat District, farm Davlat Ganimat

Figure 2: Soil infiltration curves for the three sites at which study was conducted.

Setting-up of experimental sites and data collection protocols

Small experimental sites were established in each of the selected and described above farms. Two fields were selected in each of the farms - Davlat Ganimat (Andijon Province) and Tashpulatov Ganijon Shukhrat (Fergana Province) - one field with winter wheat, and

the second one with cotton. In the farm Qakhramon Davlat Sakhovati (Fergana Province), one field with cotton was chosen only. In each farm, one site was organized to show traditional method of irrigation management (traditional irrigation) and the other site was set for irrigation management on the basis of daily meteorological information and soil moisture data. As irrigation management on the basis of climatic data was made through the usage of total evaporation values, this site was called for convenience as an experimental site with Meteo-based irrigation (Table 2). Thus, we selected five fields with 10 small experimental sites organized within their boundaries (Table 2).

Table 2: Location and size of experimental sites

Farms	Hydromodule zones	Crops	Width of the experimental site, m		Length of the experimental site, m		Total area of the experimental site, hectare	
			Traditional irrigation	ET irrigation	Traditional irrigation	ET irrigation	Traditional irrigation	ET irrigation
Fergana province, Kuva district, Qodirjon Agzamjon WUA								
Qakhramon Davlat Sakhovati	II	Cotton	9	9	30	30	0.027	0.027
Toshpulatov Ganijon Shukhrat	VIII	wheat	9	9	120	120	0.108	0.108
		Cotton	9	9	30	30	0.027	0.027
Andijon Province, Markhamat District, Tomchikuli WUA								
Davlat Ganimat	I	wheat	10	10	30	30	0.03	0.03
		Cotton	9	11	30	30	0.027	0.033

Installation of meteorological stations

For organization of irrigation management on the basis of climatic data in farms of Tashpulatov Ganijon Shukhrat in the Fergana Province and Davlat Ganimat in the Andijon Province, small meteorological stations were installed for collection of data on all meteorological parameters (air temperature, humidity, solar radiation, precipitation, and wind speed). The meteorological station in the farm Tashpulatov Ganijon Shukhrat is installed in a cotton field at a distance of 50 meters from the field border, while in the farm Davlat Ganimat the station is installed on the border of winter wheat field. There are no high plants and trees within the distance of 50 meters from the meteorological stations.

Solar battery and data transmitter

Meteorological station in farm Davlat Ganimat in Andijan Province

The following works were undertaken at each experimental site:

- water accounting using weirs helps to record the applied rates and mode of water delivery to and outflow from irrigated fields (based on flow rate and duration of irrigation);
- observations on soil moisture through installed moisture gauging devices;
- observation on growth and development of plants in phenological sites; and
- gathering of climatic parameters which were downloaded automatically via the cellular network-based internet connectivity

Equipping of the experimental sites

Installation of water weirs

In the experimental site of Davlat Ganimat, six weirs (three for cotton and three for wheat) were built to measure water delivery to and outflow from the fields. In the sites with meteo-based irrigation, weirs were built only at the inlet (one weir for cotton and one weir for wheat), and in these sites irrigation was planned through furrows without outflow. In the traditional irrigation sites, weirs were built at the inlet to measure water delivery (one weir for cotton and one weir for wheat) and at the outlet to measure outflow from the fields (one weir for cotton and one weir for wheat). For the experimental fields in the farm Tashpulatov Shukhrat, six weirs were installed by the same scheme as was described for the farm Dawlat Ganimat for cotton and wheat. For the experimental site in the Qakhramon Davlat Sakhovati, three weirs were built for cotton only by the same scheme as was described for the farm Dawlat Ganimat.

Installation of soil moisture measurement equipment

Each experimental site was equipped with a soil moisture TDR sensors (IMKO PRIME PICO TDR system, Germany). The TSR system consists of tubes and the device for measuring moisture. Three tubes for three measurements were installed up to a depth of 1.5 meters in each field.

Technique of project work

Phenological stage observation areas were demarcated in each field for plant observations: 1 m x 1 m with 12 plants for cotton fields and 1 m x 1 m with 200-300 plants for winter wheat fields.

Field operations of the project were based on monitoring of all necessary parameters related to irrigation, climate and growth of crops. Time and frequency of measurements were set for data acquisition from the devices established in every experimental site. Each captured and measured value was recorded in a logbook for further assessments and calculations.

Monitoring of soil moisture

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 from moisture meters installed in the fields. Observers took readings at each 15 cm interval up to depth of 1.5 m. Observations taken in each experimental site in three replications by three points in the fields for traditional irrigation and Meteo-based irrigation.

Monitoring of water table

Water table measurements were taken every day starting June month only in the farm Toshpulatov Ganijon Shukhrat, where water table in vegetation period rises up to 1 m and

above. In other two farms, the water table is below 3 m from surface and does not influence the root zone.

Measurements of water delivery to the experimental sites
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 watering. Every day, after the watering began, the level was measured at the weir's scale and logged. Further, water delivery was calculated based on weir measurements.

Phenological observations
Phenological stages of winter wheat and cotton were recorded at experimental sites to assess growth and development of plants. The measurements were carried out every 15 days.

Monitoring of climatic data from meteorological stations
Climatic data on air temperature (max and min), air humidity, precipitation and wind speed were downloaded automatically from meteorological station through the Internet. Access to data from the meteorological station was provided through installed data transmitters and cellular communication.

Results of project work and their assessment

Assessment of soil moisture

The measured soil moisture are presented for farms located in two different hydromodule zones (HMZ): the farm Toshpulatov Ganijon Shukhrat - VIII (HMZ) and the farm Davlat Ganimat - I (HMZ). The estimation of soil moisture made it possible to establish the dynamics in different periods of cotton growth, depending on the depth of the root zone and of irrigation. As can be seen from the graphs (figs. 3 and 4), the soil moisture was sufficient for plant growth in both farms from April till the end of May and remained at the level of 20% in the farm Tashpulatov Ganijon Shukhrat and was within 18-19% in the farm Davlat Ganimat.

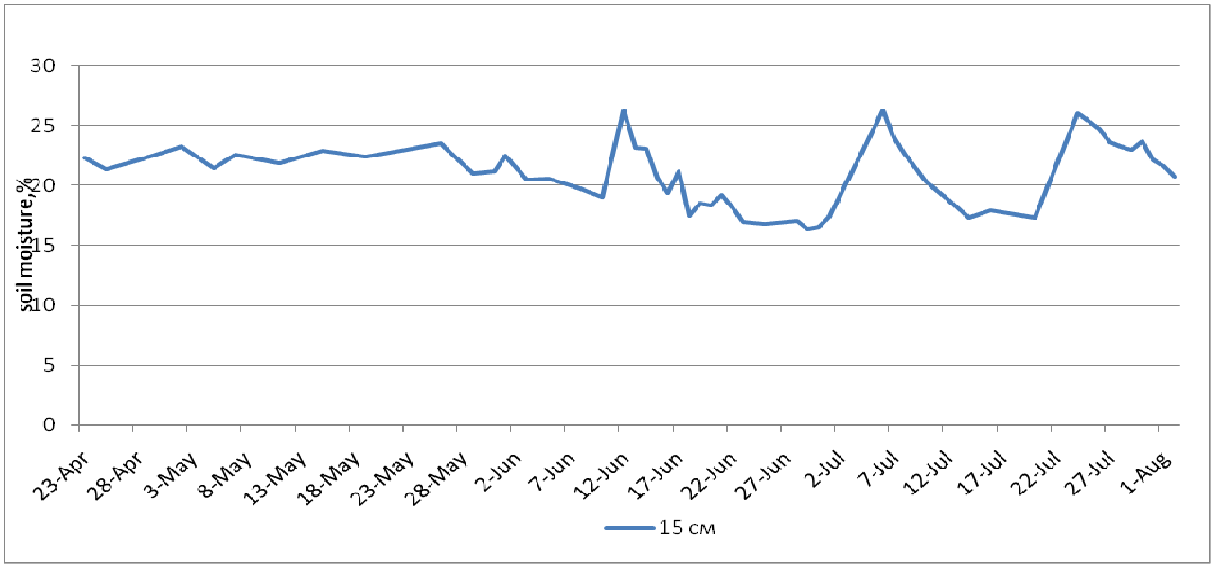


Figure 3. Soil moisture at the depth of 15 cm in the farm Toshpolatov Ganijon Shukhrat

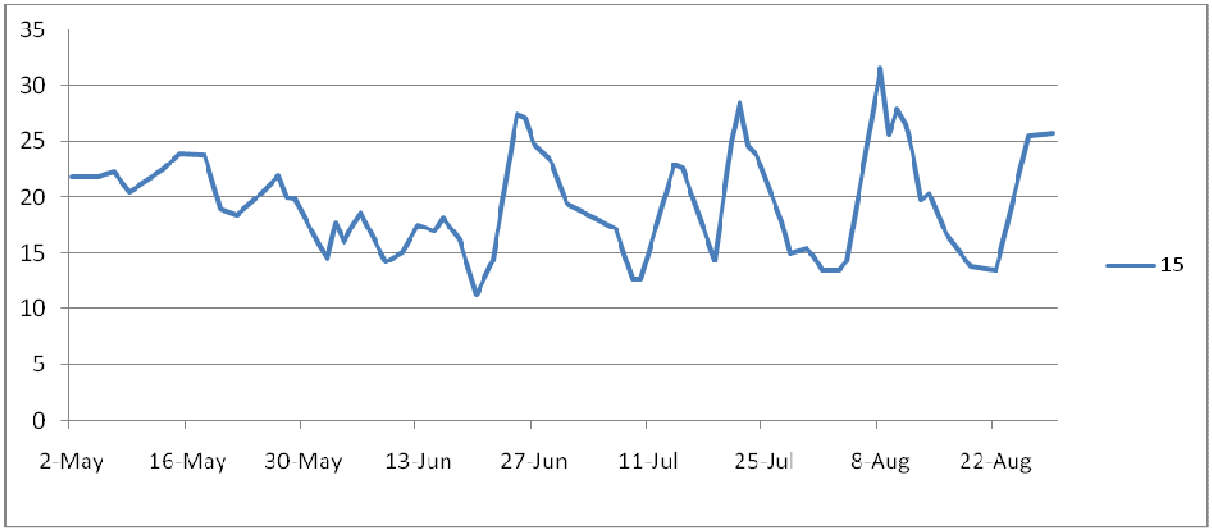


Figure 4. Soil moisture at the depth of 15 cm in the farm Davlat Ganimat

The effect of irrigation on soil moisture change is obvious almost in the entire depth of the root zone up to 100 cm. However, more clearly it is observed near to the surface of the root zone, and though there is also an influence in deeper 60-70 cm, it shows no such abrupt up and down fluxes as on the surface of the root zone. At the same time, it should be noted that the trend is not the same for all hydromodule zones. For example, for the VIII-hydromodule zone, with closely bedded groundwater, wide fluctuations in the soil moisture are observed because of irrigation only at a depth of 15-30 cm, and in deeper horizons soil moisture is almost flat. This means that the effect of groundwater reaches 45 cm from the soil surface and irrigation events have their effect only on additional increase in moisture (Figs. 5 and 6).

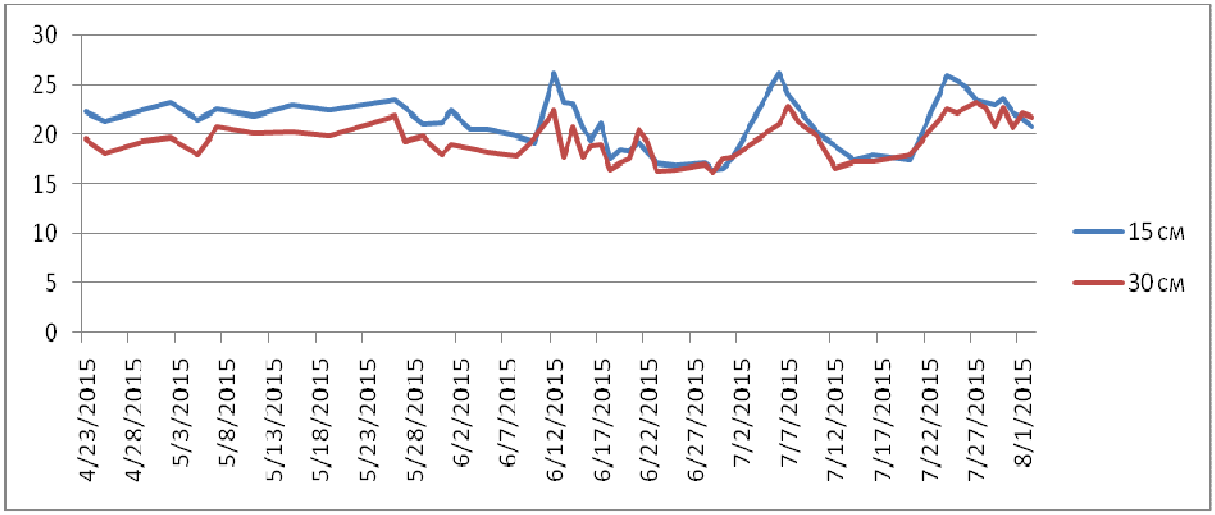


Figure 5. Changes in soil moisture at the depth of 15-30 cm in the VIII- hydromodule zone

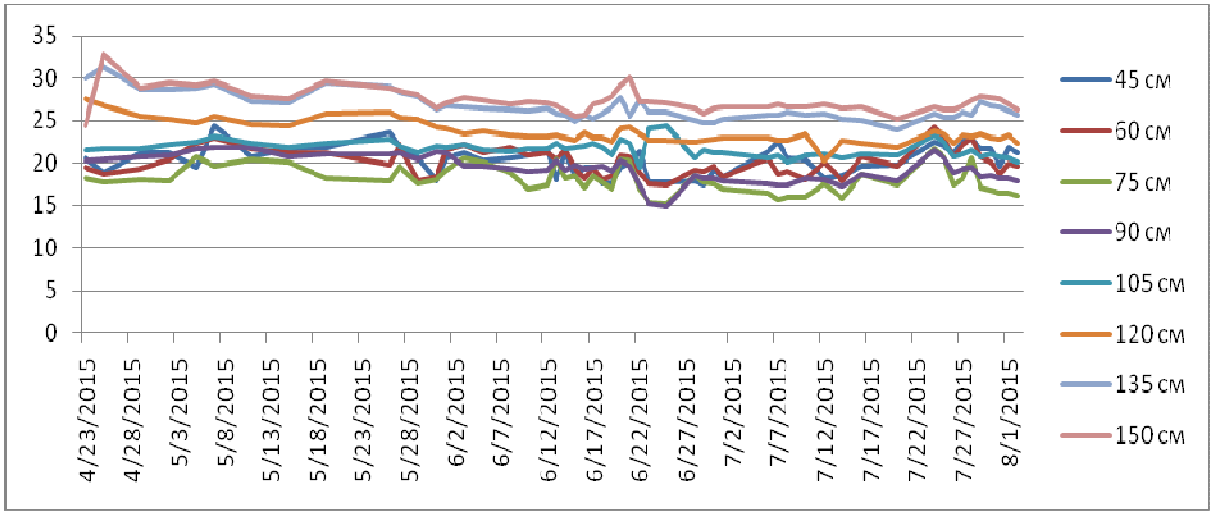


Figure 6. Changes in soil moisture at the depth of 45-150 cm in the VIII hydromodule zone

In case of hydromodule zone I with deep groundwater, the trend is somewhat different. The effect of irrigation is felt down to a depth of 60 cm and in these horizons it is clearly seen as an abrupt rise in moisture during irrigation and as an abrupt fall between irrigation events (Fig. 7). Going deeper in the root zone, wide fluctuations of the soil moisture are not observed, particularly, between irrigation events the soil moisture does not fall below 20% starting from a depth of 75 cm. Whereas at a depth of 100 cm and deeper, the soil moisture is kept within 25-26%.

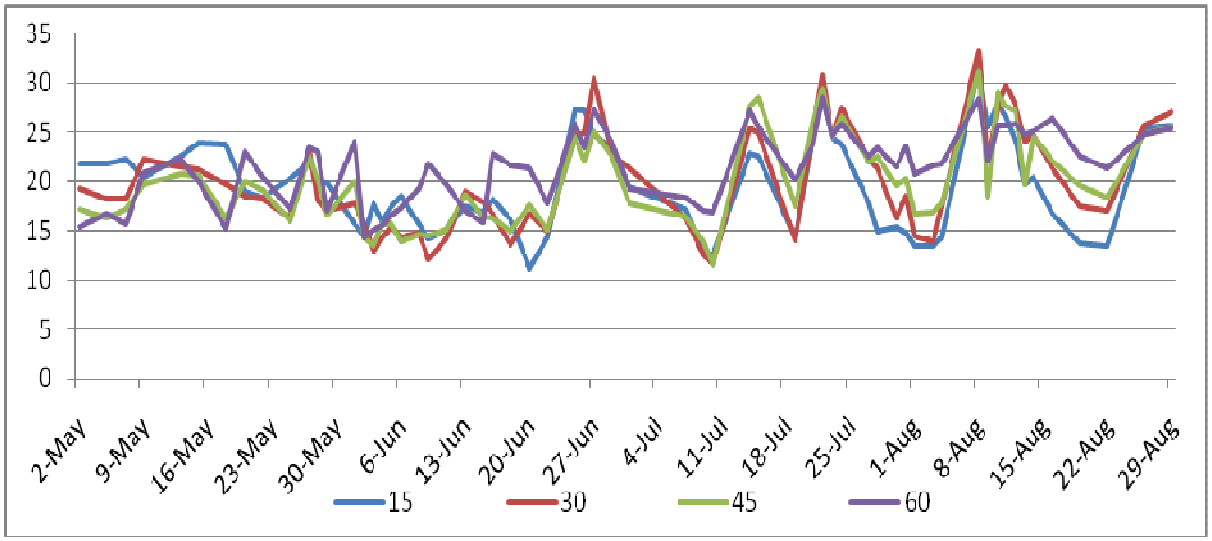


Figure 7. Changes in soil moisture in the root zone at a depth of 15 to 60 cm in the farm Davlat Ganimat

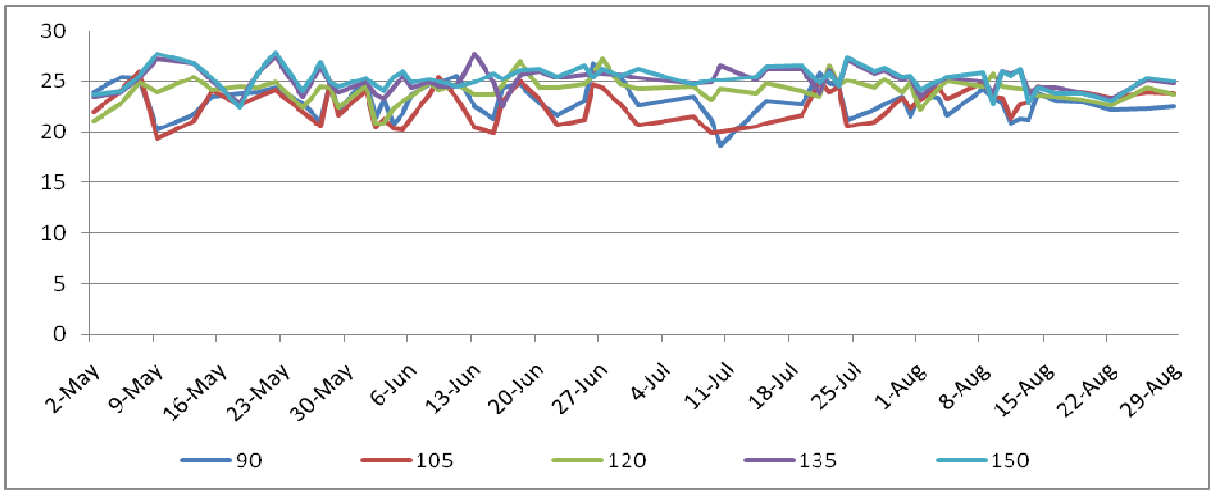


Figure 8. Changes in soil moisture in the root zone at a depth of 90 to 150 cm in the farm Davlat Ganimat

The abovementioned statement is supported by the analysis of soil moisture on the days before watering, after watering and in 5-6 days after the watering event. As the graphs show (figs. 9 and10), the soil moisture is subjected to change up to a depth of 60-75 cm after watering in VIII-hydromodule zone, while in I-hydromodule zone the sensitivity to watering events is observed down to a depth of 100 cm and no noticeable change in the moisture is observed in deeper horizons (Figure 9 and 10).

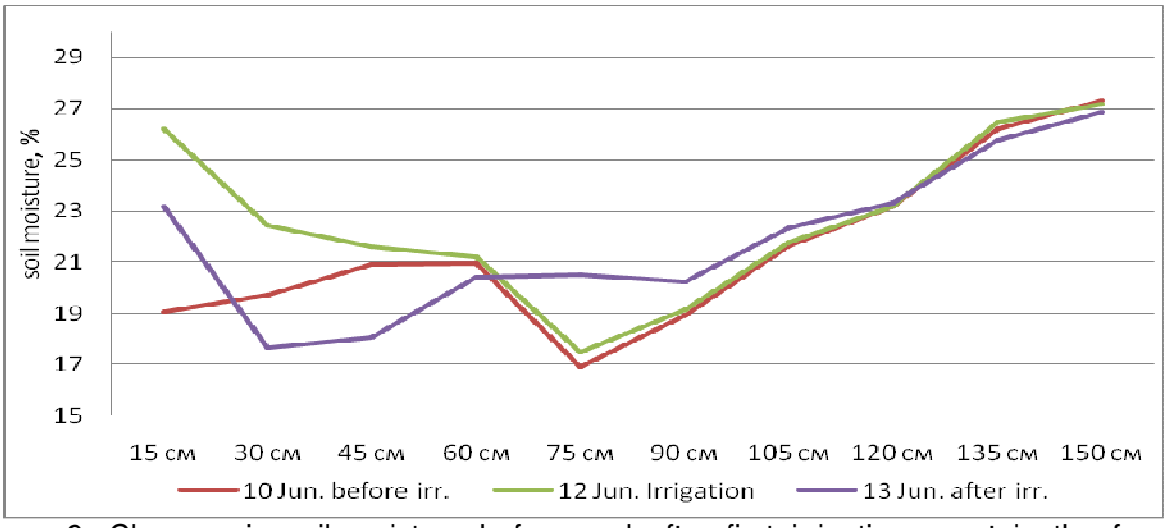


Figure 9. Changes in soil moisture before and after first irrigation event in the farm Toshpolatov Ganizhon Shukhrat

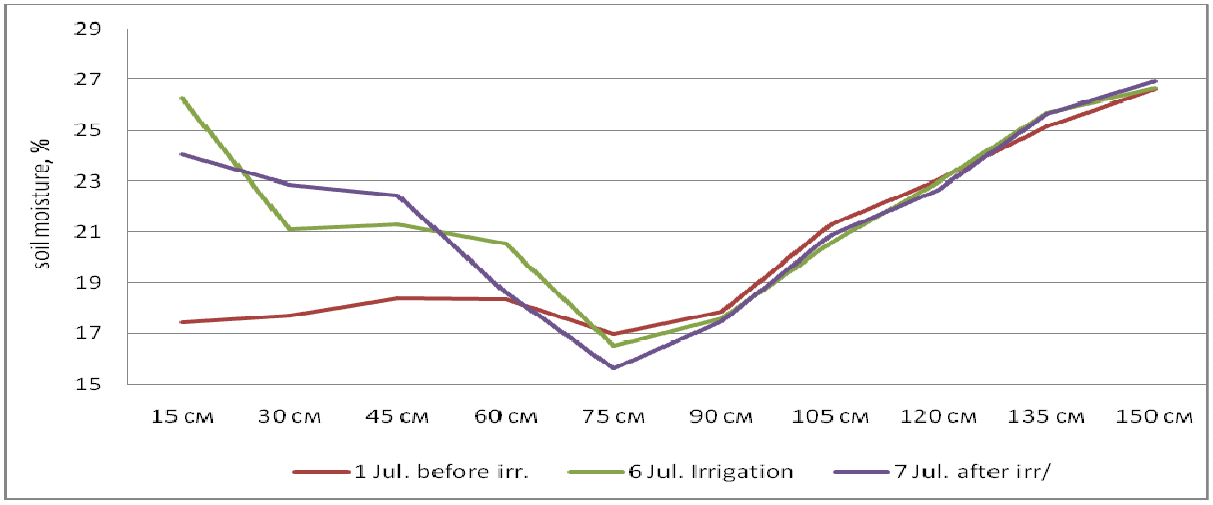


Figure 10. Changes in soil moisture before and after second irrigation event in the farm Toshpolatov Ganizhon Shukhrat

The effect of irrigation over the entire depth of the root zone is obvious; however, in VIII-hydromodule zone, groundwater at a depth of 170 cm contributes to the root zone, and thus below 75 cm the soil moisture is high between irrigation events. In I-hydromodule zone, the water table is below 3 meters from the soil surface. Consequently, we observe changes in moisture at a depth of 100 cm as well.

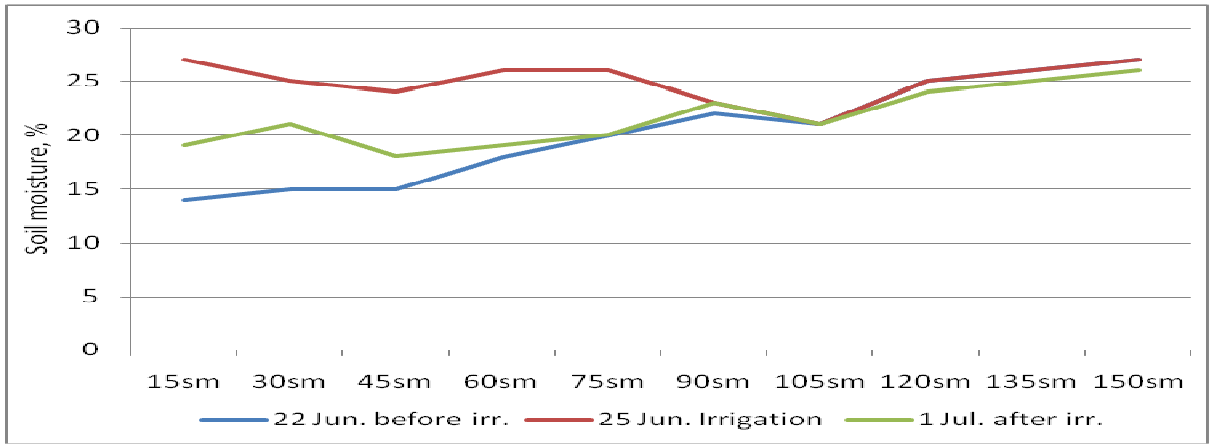


Figure 11. Changes in soil moisture before and after first irrigation event in the farm Davlat Ganimat

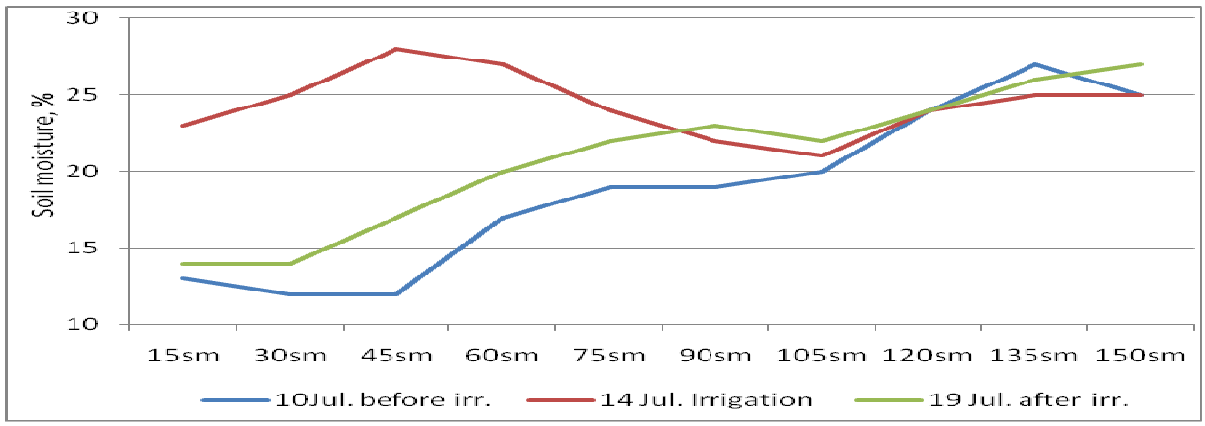


Figure 12. Changes in soil moisture before and after second irrigation event in the farm Davlat Ganimat

Thus, it follows from the analysis that for the irrigated experimental sites, the most active zones of moisture variation are the upper layers of the root zone from 15 cm to 60 cm in the period of intense irrigation. In the deeper horizons, the soil moisture is not subjected to large changes. However, it should be kept in mind that this is valid for a period of intense irrigation only.

Assessment of the experimental site irrigation

Irrigation in the experimental sites was performed in two ways - traditional irrigation and irrigation based on the data from the meteorological station and the soil moisture measurements. Tables 3 and 4 and figures 13 and 14 show that irrigation performed on the basis of meteorological parameters give high efficiency for both wheat and cotton crop. In the experimental plot under winter wheat in I-hydromodule zone, irrigation rates were quite low for the meteorological parameters based irrigation than in the case of traditional irrigation, given that the dates and number of irrigation events are the same in both cases.

Table 3: Irrigation schedule for winter wheat in the project experimental site

	I-hydromodule - Andijon Province, farm Davlat Ganimat			VIII-hydromodule, Fergana Province, Tashpolatov Ganijon Shukhrat			
Date	**Traditional irrigation**	**Date**	**Meteo-based irrigation**	**Date**	**Traditional irrigation**	**Date**	**Meteo-based irrigation**
	m^3/ha		**m^3/ha**		**m^3/ha**		**m^3/ha**
17-Mar	970	17-Mar	753	14-Mar	935		
20-Apr	1090	20-Apr	565	16-Apr	910	25-Apr	909
11-May	990	11-May	708	18-May	1075		
30-May	1085	30-May	788	30-May	1188	30-May	1013
Total	**4135**		**2814**		**4108**		**1922**

The irrigation rate of winter wheat in the case of the meteorological parameters based irrigation was 1271 m^3/ha less than that in the traditional irrigation.

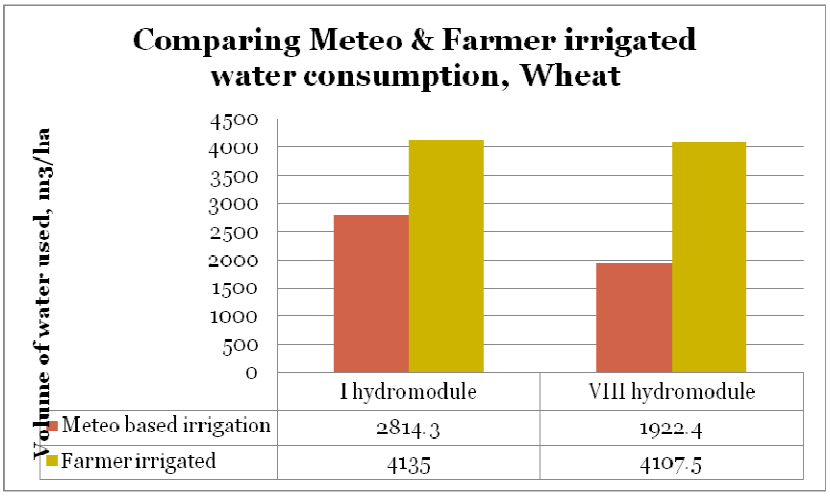


Figure 13 Water consumption of winter wheat in experimental sites

For the experimental site of winter wheat in VIII-hydromodule zone, the depth of irrigation events is two times less in case of meteorological parameters based method than under the traditional method of irrigation. As a result, the irrigation rate of winter wheat in the first case is 2186 m^3/ha less than that in the traditional irrigation method.

As to irrigation of cotton, there is also a significant decrease in irrigation rates in all experimental sites. This was mainly due to the difference in watering depths between the traditional irrigation method and the meteorological parameters based irrigation method.

Table 4: Irrigation schedule for cotton in the project experimental site

I - hydromodule Andijan province				II - hydromodule, Fergana province				VIII - hydromodule, Fergana province			
Date	traditional irrigation	Date	Meteo based irrigation	Date	traditional irrigation	Date	Meteo based irrigation	Date	traditional irrigation	Date	Meteo based irrigation
	m^3/ha		m^3/ha		m^3/ha		m^3/ha		m^3/ha		m^3/ha
18-Apr	285	23-Apr	353	3-Jun	1327	3-Jun	1053	10-Jun	1217	10-Jun	1080
19-Jun	1143	24-Jun	788	29-Jun	1210	30-Jun	917	3-Jul	1307	5-Jul	997
8-Jul	1250	13-Jul	746	14-Jul	1303	17-Jul	937	20-Jul	1240	23-Jul	953
20-Jul	1282	20-Jul	841	2-Aug	1393	5-Aug	930	4-Aug	1297	6-Aug	1040
5-Aug	1457	5-Aug	860	20-Aug	1137	23-Aug	930	18-Aug	1130	22-Aug	0
Total	**5417**		**3588**	**Total**	**6370**		**4767**	**Total**	**6191**		**4070**

When performing irrigation in the traditional way, the irrigation rate is higher in all sites as compared to the new approach and this difference is from 1829 m^3/ha to 2130 m^3/ha.

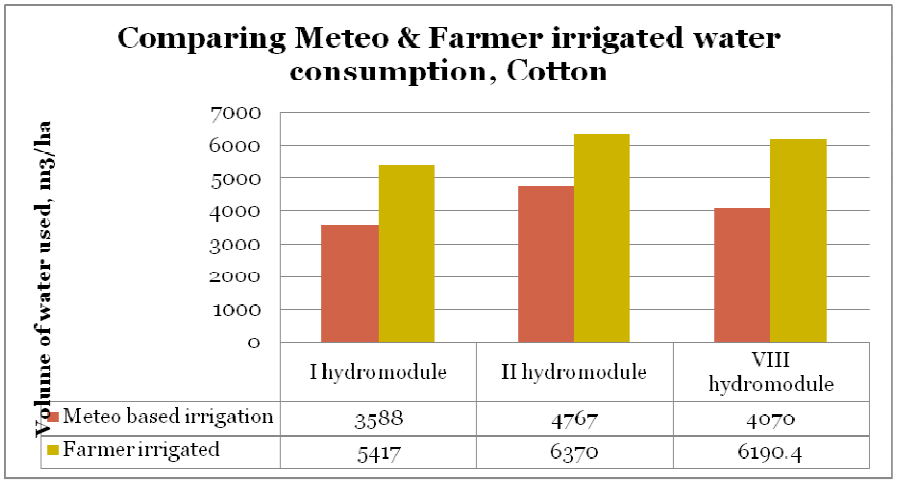


Figure 14 Water consumption of cotton in experimental sites

Thus, by comparing the traditional method of irrigation scheduling with the new method based on use of meteorological parameters and soil moisture, one can conclude that the new approach helps to irrigate crops at optimal rates and significantly reduce the amounts of irrigation water used and increases water productivity.

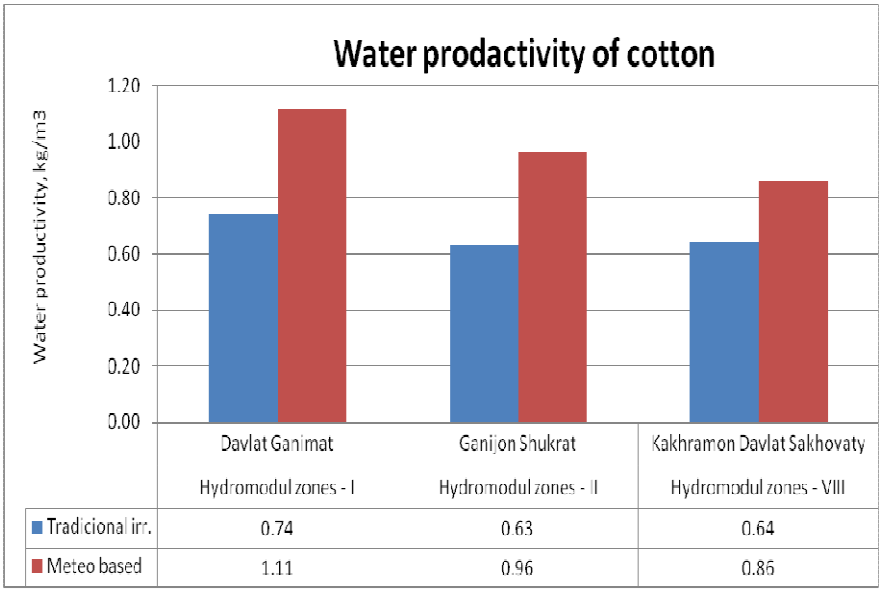


Figure 15 Water productivity of cotton in experimental sites

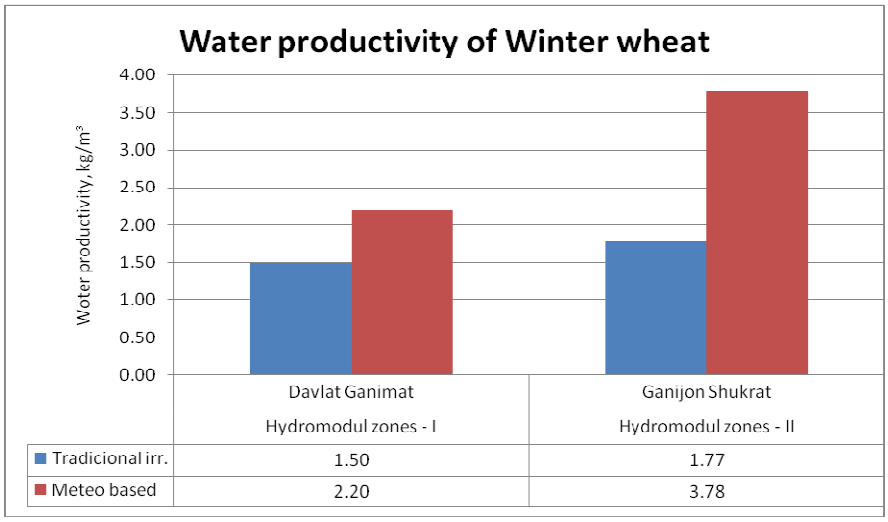


Figure 16 Water productivity of winter wheat in experimental sites

Phenological observations at the experimental sites

The results of phenological observations show no significant differences between the two methods of irrigation (figs. 17 and 18). Some advantage can be hardly seen in the case of irrigation based on meteorological parameters in the farm Davlat Ganimat. Here the height of plants was higher during flowering and fruit formation as compared to traditional irrigation management. Whereas the parameters of growth were similar during sprouting and budding, as well as during ripening.

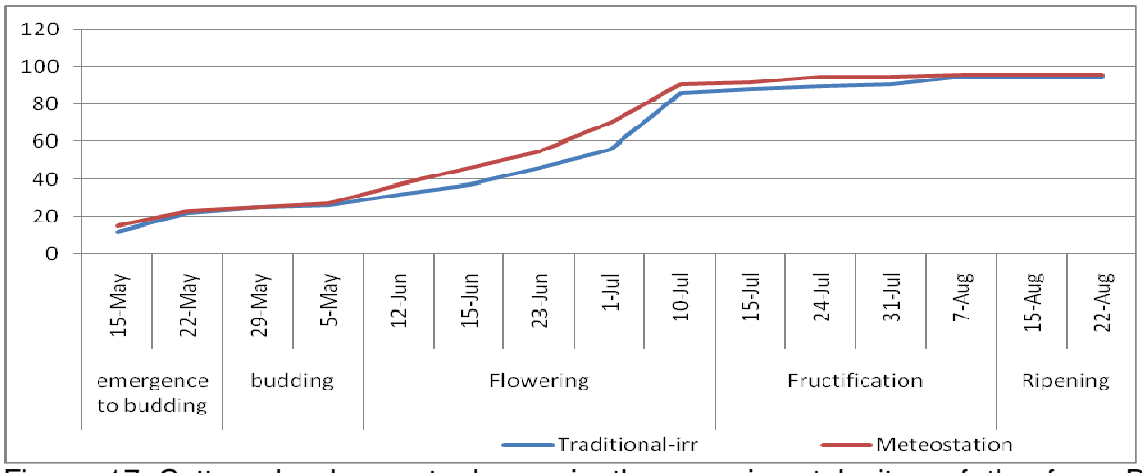


Figure 17 Cotton development phases in the experimental sites of the farm Davlat Ganimat, I-hydromodule zone

In the farm Toshpolat Ganijon Shukhrat, VIII-hydromodule zone, growth and development of plants were the same during the whole season, with some advance in growth during ripening in the meteorological station site.

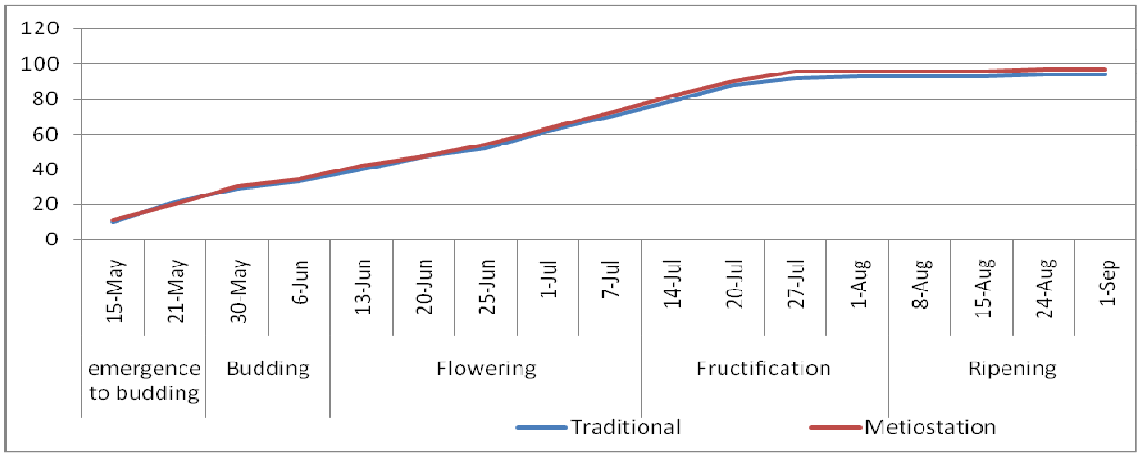


Figure 18 Cotton development phases in the experimental sites of the farm Toshpolat Ganijon Shukhrat, VIII-hydromodule zone

The phase of flowering is an important indicator of plant development. This indicator is highly sensitive to water supply. However, it is difficult to make any judgment from the indicators of flowering for the three hydromodule zones as for quite different hydromodule zones, such as the zones VIII and II flowering dynamics is almost similar, while for the zones close in terms of gradation, such as the hydromodule zones I and II the flowering curves are markedly different (figs. 19-21).

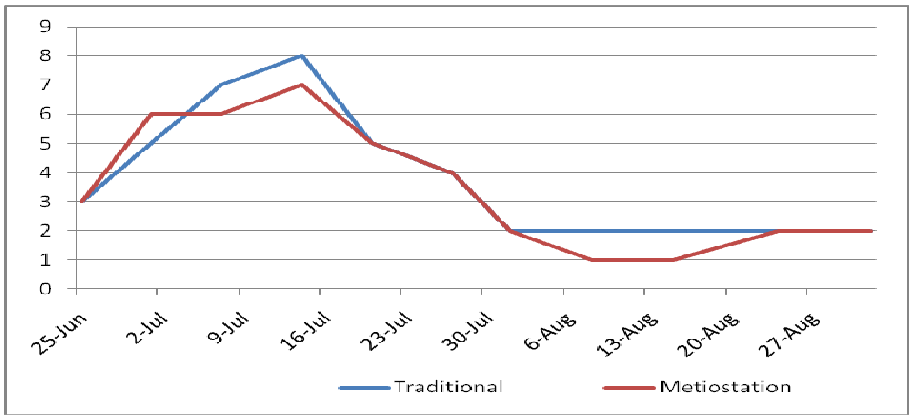


Figure 19 Cotton flowering in the farm Toshpolat Ganijon Shukhrat, VIII-hydromodule zone

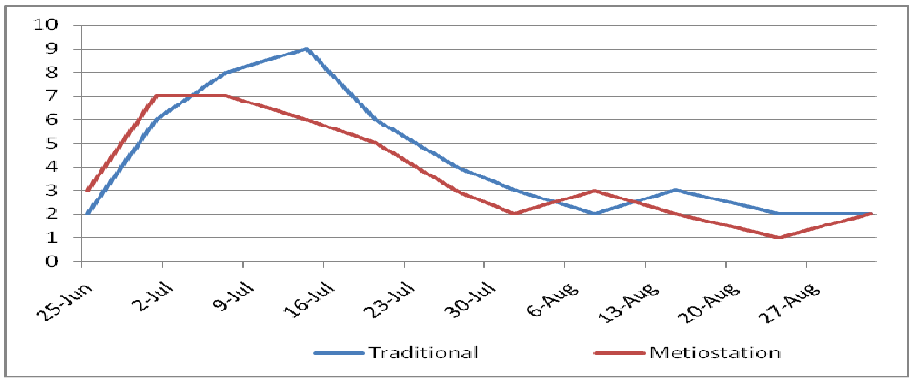


Figure 20 Cotton flowering in the farm Kakhramov Davlat Sahovati, II-hydromodule zone

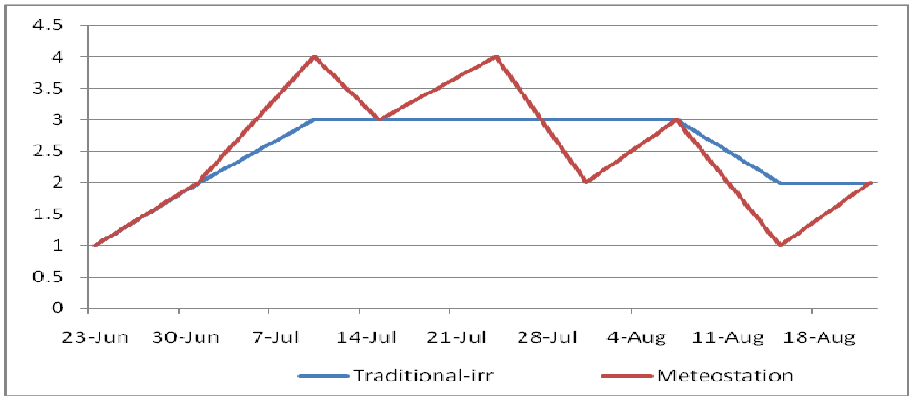


Figure 21 Cotton flowering in the farm Davlat Ganimat, I-hydromodule zone

Analysis of phenological observations shows that irrigation methods did not have any significant effect on development and fruit formation.

Agronomic assessment of the experimental data

Agronomic operations are key to achieving good crop harvests. Timely and appropriate application of fertilizers is also important. In addition, cultivation operations of land are of no less importance. As Table 5 shows, phosphorus and nitrogen are the main fertilizers applied in the region. Most of fertilizers applied are ammonium nitrate (up to 400 kg per hectare) and then carbetamide. The latter is applied in April and June under cotton and in March under winter wheat, while phosphorus is applied mainly during autumn plowing and in spring. Ammonium nitrate is applied in the midst of growth and development in order to support sustainability of plants, i.e. in June and July for cotton and in April for winter wheat.

Table 5 Agronomic assessment in the experimental sites

Operations	Crop	Unit per hectare	Toshpolat Ganijon Shukhrat	Qahramon Davlat Sahovaty	Davlat Ganimat
Seeds	cotton	kg/ha	49	50	55
	wheat	kg/ha	250	-	270
Fertilizer	cotton	kg/ha	650	638	575
	wheat	kg/ha	880	-	900
Carbamide	cotton	kg/ha	150	150	300
	wheat	kg/ha	230	-	200
Ammonium nitrate	cotton	kg/ha	400	400	100
	wheat	kg/ha	250	-	500
Phosphorus	cotton	kg/ha	100	62.5	100
	wheat	kg/ha	400	-	200
Potassium	cotton	kg/ha	-	25	75
	wheat	kg/ha	-	-	-
Harvest	cotton	kg/ha	**3900**	**4100**	**4000**
	wheat	kg/ha	**7272**	**-**	**6200**

Workshops and publications

Based on the conducted experimental work and its results, two workshops were held for farmers, workers from WUAs and staff of water management organizations in July and November, 2015. The workshops focused on irrigation using the meteorological parameters from small meteorological stations installed in the farm Toshpolat Ganijon Shukhrat, Fergana Province and the farm Davlat Ganimat, Andijon Province.

Field workshop was organized in July. The workshops brought together 30 farmers, WUAs' workers and regional administration. Use of meteorological station and moisture gauging devices were demonstrated to the participants. The participants also were acquainted with the experimental design of the sites, where we studied irrigation, which was planned with the usage of meteorological data on evaporation, air temperature and the soil moisture. The experiment arose much interest among both farmers, who saw a possibility to determine time of irrigation more accurately with this new approach, and WUA's workers and regional administration who expressed a wish to implement such approach among all farmers in the region.

A number of workshops were held at provincial level in Fergana and Syrdarya Provinces for the staff from WUAs and provincial and regional water-management organizations in November. These workshops were organized with the support of the Uzbek Ministry for Agriculture and Water Resources. The workshops in Fergana Province brought together 110 people from Fergana, Andijon and Namangan Provinces, and 60 persons from Tashkent, Syrdarya, Djizak, and Samarkand Provinces participated in the workshop in Syrdarya Province.

Overarching conclusions

Fergana Valley farmers still use the Soviet era method of irrigation which divides the irrigated areas in hydromodule 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.

A study was conducted in which farmer fields falling under HMZ I, II and VIII were selected. The fields were split into two – one receiving irrigation using traditional HMZ method and the other receiving irrigation based on the weather station-based ET and soil moisture data. Results from the two year study indicate that there can be a saving of approx. 25-35% saving of water in cotton crop and 32-53% saving in winter wheat crop without any loss of productivity if the weather station-based irrigation advisory system is adopted in the three HMZs. Similar levels of savings can be expected for the other zones which could not be studied for lack of sufficient financial support.