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Application of Surface and Groundwater to Produce Cotton in Semi-Arid Uzbekistan

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ABSTRACT

The transition from territorial water management to the basin principle and the establishment of on-farm water consumer associations were pursued to improve irrigation water management in Uzbekistan. Despite the fact that these new institutions were introduced about a decade ago in a top-down fashion, they could not live up to expectations and address the problem of water mismanagement and scarcity without involving some innovative technological tools. A new method called *subirrigatciya*, i.e. the combined use of surface and groundwater, for irrigating cotton was piloted in the Khorezm region. The research findings reveal that this environmentally safe and clean technique can be used to moisturize the plant-root zone, increase crop productivity, minimize water scarcity problems, and improve the ecosystem as well as the socio-economic conditions in the region. The results indicate that the best case scenario was obtained at pre-irrigation soil moisture of 70-80-60% in a 0-3-0 irrigation scheme with an irrigation rate of 2200 m^3/ha. In these circumstances, cotton yield reached 4280 kg/ha. It is suggested that the *subirrigatciya* method needs considerable attention among scientists as water scarcity becomes more severe. However, additional research is needed to verify the findings.

Keywords: cotton, groundwater, irrigation, soil moisture, *subirrigatciya*, surface water

INTRODUCTION

History of irrigation development in Uzbekistan

The Republic of Uzbekistan is considered one of the oldest regions in the world that practices irrigated agriculture. According to research conducted by the famous historian Bartold and the archaeologist Yakubovskiy, construction of canals in Uzbekistan began as early as in the mid-2nd millennium BC (Bartold 1965). The original farming was based on natural river flows, and especially in delta areas, from which water was diverted to irrigation canals (*ibid*). For instance, Khorezm oasis, which was developed by artificial irrigation, had been named by ancient Chinese people - "Kanguy", i.e. edge of the canals (Gulyamov 1957). Ancient Greek historians also noted that Tashkent (the current capital) was surrounded by large irrigation and drainage canals already in the 2nd and 3rd centuries AD (Tolstov 1969). This was also recorded by Arab geographers: in the times of Shash (Tashkent oasis), there were about 50 villages surrounding orchard and vineyards of which some of them Biskent (Piskent), Farekent (Parkent) and Zarekent (Zarkent) have survived to this date (Gulyamov 1955).

Moreover, in the preface to his book "Kitab al-djabr val muqabala", the famous medieval mathematician and astronomer Muhammed ibn Mussa al-Khorezmiy wrote that his mathematics were needed to "measure the earth and dig canals" (Rosen 1831). It is important to emphasize that from the end of 8th century and especially during the 10th through 12th centuries, there were already some active Central Asian scientists who created special schools in mathematics, astronomy, and irrigation (Gulyamov 1955). In addition, skillful irrigation engineers of the 9th-11th centuries were acknowledged by the famous scientist Al-Beruniy's books (*ibid*). For instance, in his book "the monuments of past generations", he mentioned the location of water sources and artificial fountains as well as the construction of irrigation canals and the slopes on the hillside. Abu Abdullah Khorazmiy, a scientist who lived in the 10th century in Khorezm, devoted a special chapter to the water and irrigation engineering of the Merv oasis in his "Mavatih Al-Ulum" glossary (Gulyamov 1957).

The main scientific and technical achievement in the development of irrigation in the lands of ancient Uzbekistan came in the beginning of 20th century, when Uzbekistan became part of the Soviet Union and a dual-purpose land reclamation system was created. The main purpose was to create deeper canals to store water in the condition of slow water flow that occurred in certain times and lift it using various water-lifting technologies (e.g. "chigir"). The deep canals also served the purpose of draining the remaining water from irrigation fields, in order eventually to limit the rise of groundwater table and reduce soil salinity (Andrianov 1969).

To support growth in the economy of the former Soviet Union, the agency working on irrigation and land reclamation activities was involved in the expansion of irrigated areas. The agency concentrated on more effective use of agricultural machineries, rebuilding of irrigation systems, and creation of different engineering types of irrigation systems. Furthermore, the existing water supply infrastructure and large-scale irrigation systems were developed and improved (Tolstov 1962).

Intensive use of new lands led to the increase of the water scarcity and poor quality of irrigation water in the middle and lower reaches of Amudarya and Syrdarya rivers. This eventually led to Aral Sea shrinkage and degradation of the environmental situation in the Aral Sea zone (Andrianov 1969).

The irrigation systems developed in the middle of the 20th century were ineffective, and that resulted in certain changes in the natural environment which later contributed to the rise of groundwater levels (Hamidov *et al.* 2007a). Since this is an arid zone, the rising groundwater led to in-

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Research Note

creased salinity and reduced land productivity in Uzbekistan. The presence of saline lands in the country, now covering about 50% of irrigated lands, is due mainly to naturally occurring salinity as well as from secondary salinity, the latter caused by rising saline groundwater (Qadir *et al.* 2009). Construction and maintenance of horizontal and vertical drainage systems were carried out in the late 20th century in order to avoid these adverse impacts to land productivity.

To carry out this research, the Khorezm region has been selected because the region is severely affected by groundwater salinization as well as geographic proximity to the ecological catastrophe area, i.e., the shrinking Aral Sea. Despite the fact that the average irrigation water consumption per 100 kg of cotton is 675.7 m^3/year (including, irrigation and leaching) and for wheat is 430.2 m^3 in the region, agricultural crop yields remain too low (Statistical Department 2010). This can be explained by the fact that approximately 128 000 hectare (ha) in the region is slightly (about 50%), 96 000 ha (or about 35%) moderately, and 33 000 (about 12%) ha severely salinized (Hamidov 2007).

Transition from territorial water management principle to the basin principle, establishment of on-farm water users associations, and introduction of irrigation service fees have slightly reduced the problems associated with water scarcity and deterioration of land reclamation. However, many potential solutions for water conservation have yet to be adequately examined. In particular, the *subirrigatciya*, *a* combined use of surface and groundwater for irrigation of cotton, winter wheat and other crops, is an efficient, but currently forgotten method of irrigation that was anciently used in the Khorezm oasis. The method of *subirrigatciya* can provide tangible benefits if appropriate research is carried out to determine its usefulness in irrigation practices.

The study area is located in the Shavat district, Khorezm Region, the northwest part of Uzbekistan, supplied by the lower reaches of Amudarya River (100 meters above sea level), which is the major water source for all water sectors in Khorezm. The region covers an area of about 6,100 km^2 and is spread between 40.49 and 41.97 N and 60.21 and 62.18 E of the Greenwich meridian, or about 245 km south of the shrinking Aral Sea (**Fig. 1A**).

The Amudarya River supplies water for the whole Khorezm Region and in the last years, the water amount has been tremendously reduced because of intensive upstream utilization of the river (Djalalov *et al.* 2005). The river provides irrigation water for 276.5 thousand ha of which more than 12% are severely saline. The Khorezm Region accounts for 15% of Uzbekistan's river water withdrawals. Water withdrawal for agriculture in turn accounts for 94% of all water withdrawals in the Khorezm Region (Schieder and Wehrheim 2004).

The region has become particularly vulnerable to short and long-term droughts, and during the 2000 and 2001 growing seasons drought resulted in major crop failures (World Health Organisation [WHO] 2001). Consequently, during above-mentioned period, the agricultural Gross Domestic Product (GDP) for the Khorezm Region has become one of the lowest in Uzbekistan (Djalalov *et al.* 2005). Moreover, the socio-economic and public health situation in the region has been worsening due to geographical proximity of the region to the ecologically degraded Aral Sea (Khamzina *et al.* 2006).

Khorezm borders with the Autonomous Republic of Karakalpakistan in the north and east, with Turkmenistan in the south and west, with the Bukhara region in the south and east. The population of the Khorezm Region is 1.3 million people, 24% of which reside in towns and the density is equal to 217.4 people per km^2 (Gulomov *et al.* 2001). About 80% of Khorezm's population resides in rural areas and is engaged in cotton production, which is the main cultivated crop for that region, followed by winter wheat, rice and other crops.

The region is characterized by shallow and saline groundwater. A review of the literature indicates that with

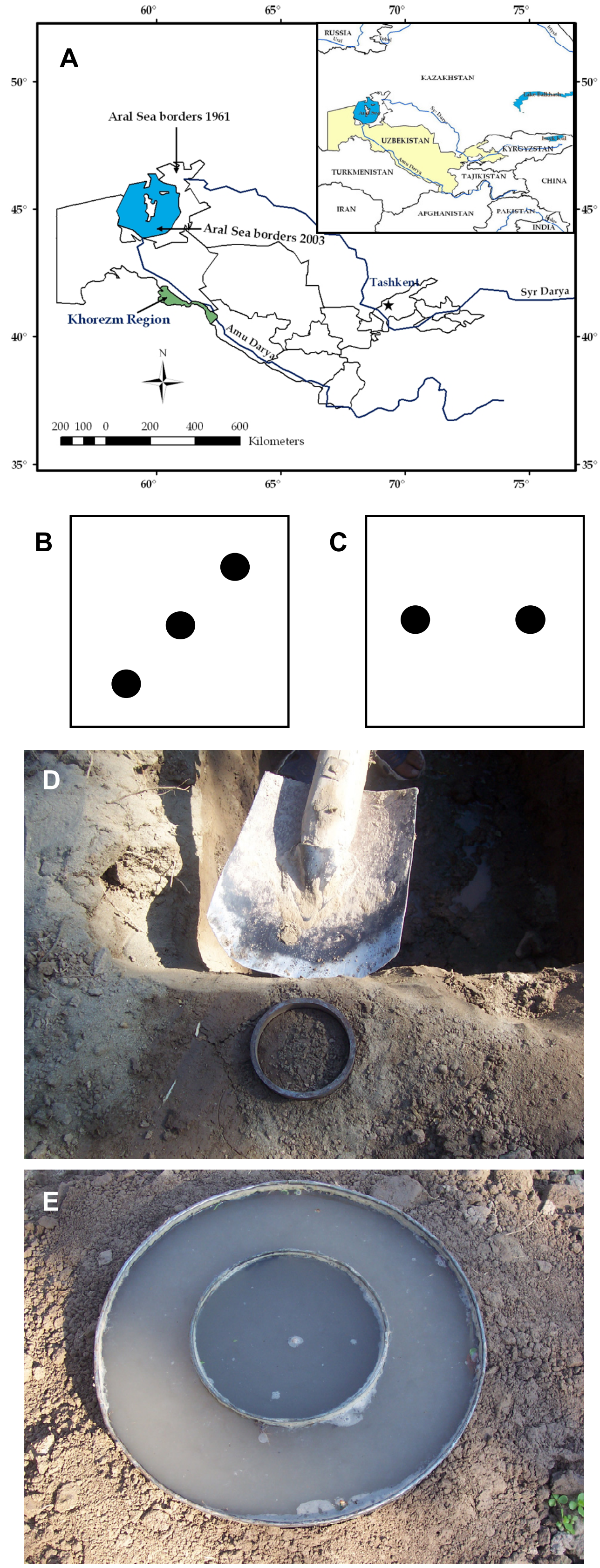

Fig. 1 (**A**) Location of the study region. (**B**) Soil sampling before planting. (**C**) Soil sampling after vegetation. (**D**) Determination of soil bulk density using a core sampler and a shovel. (**E**) Determination of infiltration rate in the investigated field.

groundwater at a depth of 1-1.5 m and with less than 2 g/l salt content, about 60% of cotton's water demand was met by groundwater (Suvonov 2010). This suggests the appropriateness of combined use of surface and groundwater resources for irrigating agricultural crops during vegetation period.

Experience of *subirrigatciya* method by other scientists

Subirrigatciya is a way of maintaining the level of less saline groundwater table at a certain depth, moisturizing upper layers of soil through capillary rise (Suvonov 2010). Research studies carried out by Radjabov and Mahmudov (1983) showed that the largest water loss from the groundwater occurs when the level of the groundwater remains at the 3 m or deeper whereas the lowest loss when groundwater level is close to the surface. The use of groundwater by plants also depends on the depth of groundwater, which gradually increases from level of 1 m to below 3 m (*ibid*).

Recent research findings from Hamidov *et al.* (2007b) indicate that maintaining groundwater table at a depth of between 1-2 m was the best for plant development in Khorezm region. Notably, when water table remained at a depth of 1 m or less, it negatively affected plant development due to the high level of salt content in the groundwater, which eventually led to reduction in crop yields.

Studies conducted by Baumann (1961) on the use of groundwater by plants revealed that when groundwater was at a depth of around 1 m, alfalfa used about 73-80% of its total water demand through groundwater capillary rise. The groundwater uptake was up to 30% at a depth of 2 m, and only 11-12% at a depth of 3 m. It was found that winter wheat used groundwater for 20% of its total water demand when groundwater was at a depth of 1 m during the initial period of vegetation, and up to 50% during its further development process. The study also confirmed that when the groundwater table remained at the 3.5 m level or deeper, it was difficult to observe any crop groundwater intake.

Mirzajonov and Urazmetov (1997) stated that this *subirrigatciya* technique is environmentally friendly and clean. If correctly used, remnants of agricultural chemicals (e.g. nitrogen, phosphorus, potassium and other micro and macro elements) which are usually applied to combat plant diseases, may remain in the area. Chemicals will not run into rivers, at the risk of causing environmental and human health problems. Mirzajonov and Urazmetov (1997) also highlighted that reducing the number of crop irrigation can lower the use of human labor and agricultural mechanization (*ibid*). The latter may help to conserve machinery fuel and lubricants (Ragab and Amer 1986).

Therefore, the main aim of this research was to test *subirrigatciya* practices in Khorezm region in order to develop water-saving irrigation technology. If successful, the research will help farmers to be aware of effective tools for continuing their agricultural practices in case of water deficit in the lower reaches of Amudarya River. The research could thereby contribute to the improvement of environmental conditions of the area.

MATERIALS AND METHODS

A pilot field investigation took place in 2009 at the territory of the "*Toji Islam*" farm in Shavat district of Khorezm with the aim to test effectiveness of *subirrigatciya* and establishment of water saving techniques for cotton irrigation. Field investigations were carried out in two treatments: 1) control treatment, i.e. traditional supply of water to cotton field, and 2) cotton irrigation under pre-irrigation soil moisture content of 70-80-60%. *Subirrigatciya* practice was used in the latter treatment using Soyuz NIHI (1983) method. The pilot production unit (PPU), where the investigation took place, is an area of 8 ha located in the primary zone with an open-drain of 1.6-1.8 m in depth. Khorezm-127 variety of cotton seed was planted in this pilot area in early April 2009[1].

The climatic conditions of the Shavat district are characterized by dry air and intense solar radiation, causing high evaporation. The annual evaporation rate from surface water averages between 1000-1200 mm, greatly exceeding annual precipitation by almost 10-15 times. The district is primarily distributed by meadow-alluvial soil content with slightly- to moderately-salinized soil and relatively shallow (h = 1.3-1.6 m) saline groundwater. In accordance with the climatic and soil morphological characteristics, the PPU may represent up to 40% of the territory of Khorezm. Artificial lifting of the level of saline groundwater was carried out in order to create a *subirrigatciya* regime, which was achieved by constructing hydraulic structures at the heads of drains serving PPU territory.

At the observation location, soils were sampled by horizon (stratification) in three places to describe the soil profile (**Fig. 1B**). Three 1m deep pits were dug, representing the beginning, middle, and ends of the experimental site. Samples were collected from 5 soil layers (0-20, 20-40, 40-60, 60-80, 80-100 cm) using an auger to analyse soil physical and chemical properties. These samples were collected twice during vegetation period: before planting and in the end of vegetation season. For the samples collected before planting, the mean value was used. For the samples collected at the end of the vegetation season, soil samples were taken in two fields: one from control site and another from *subirrigatciya* site (**Fig. 1C**).

All samples were subject to laboratory analysis to determine soil content for soluble salts, humus and gross forms of nutrients using Machigin's (1963) method. These analyses were completed at the Central Laboratory of the Uzbek Research Institute of Cotton Growing.

Determination of soil moisture was carried out to a depth of 1 m for each 0-20 cm layers before each irrigation practice. The soil moisture at the non-saline wilting point (WP) and at the field capacity (FC) was determined using gravimetric method and was calculated directly at the field (Beltrao *et al.* 1996; Ben Asher *et al.* 2002).

Soil bulk density

Soil bulk density and water infiltration rates were determined to understand the region's soil characteristics and to identify the soil water movements.

The soil bulk density (BD) was determined using core sampler to test the soil compactness (Blake and Hartge 1986). The soil samples were collected from 20, 40, 60, 80, 100 cm depths using a shovel and core sampler (**Fig. 1D**). A core weight was initially recorded, then soil moisture along with core was recorded, moist soil was placed into the tin cans and transferred to the laboratory, the tin cans and soil were weighed, oven- dried at 105°C for 6 h, cooled in a desiccator and re-weighed. The following equation was used to calculate the bulk density (BD), expressed as g cm^{-3}:

$$BD = \frac{(W - C) * 100}{(100 + A) * V}$$

where: W – soil sample weight (g); C – core weight (g); A – gravimetric soil moisture (%), determined using wet-moist soil and oven-dry weight; V – volume of core (cm^3); r – core radius = 3.75 cm; h – core height = 5 cm.

Water infiltration rate

Infiltration rate was measured by the depth of the water layer (mm) that can enter the soil in one hour (Pankov 1957). A cylinder with the diameter of 22.5 cm was hammered into the soil in the experimental fields. The timber was used to protect the ring from the damage during hammering. The cylinder was kept vertical, so approximately 15 cm was left above the ground. Additionally, a 55 cm-diameter cylinder was constructed around the 22.5 cm cylinder to the same height as the first cylinder. The hessian was placed inside the infiltrometer to protect the soil surface when pouring the water (**Fig. 1E**).

Afterwards, the water was poured into the cylinder and into the space between the two cylinders. The time was recorded to track the infiltration rate. After 4-5 min, the drop in water level in the inner cylinder was recorded and water was added to bring the level back to approximately the original level of the start of the test. The test was continued about 6 h while keeping the water

[1] This particular seed was recommended by researchers of Uzbek Research Institute of Cotton Growing, who annually conduct soil-water analysis of the region and propose certain type of seeds suitable to local conditions.

level the same over the same time interval, but as the time went on the interval between readings was extended (e.g. 20-30 min). Meantime, the infiltration volume was recorded each time water was added. The final infiltration rate (f), expressed as mm h^{-1}, was calculated as follows:

$$f = \frac{(Q * 10)}{(S * t)} * 60$$

where: Q – cylinder water volume (cm^3); t – time differences (min.); S – inner cylinder area (cm^2), determined through equation (Eq. 1); d – inner cylinder diameter = 22.5 cm.

$$S = \frac{\pi * d^2}{4} \quad (1)$$

Statistical analysis

Analysis of variance was performed using Excel version 11 for Windows 2007 (Microsoft Corp.), and least significant differences (LSD) were applied to compare means at $P < 0.05$. Standard error and LSD were calculated.

RESULTS AND DISCUSSION

Results revealed that soil bulk density increased from its original 1.41-1.53 g cm^{-3} to 1.44-1.56 g cm^{-3} in the control plot site. At the stations where the *subirrigatciya* regime was used, soil bulk density gradually reduced to 1.39-1.47 g cm^{-3} (**Table 1**). These results reveal that the field had initially heavy loamy soil, which makes for slow water movement between soil particles and high bulk density. However, soil in *subirrigatciya* resulted in middle loamy, making soil water-holding capacity higher and making water infiltrating into impermeable layers. Furthermore, the water infiltration rate in the soil layers did not change significantly (i.e. from 681.6 m^3/ha or 0.19 mm/min to 648 m^3/ha or 0.18 mm/min), while in the control site it declined substantially from 681.6 m^3/ha or 0.19 mm/min to 576 m^3/ha or 0.16 mm/min. The results indicate that the proposed technology (i.e. *subirrigatciya*) is indeed an effective technology for soil cultivation and for improving irrigation efficiency.

When irrigating cotton with the method of *subirrigatciya* and pre-irrigation soil moisture content remained at 70-80-60% in irrigation scheme 0-3-0 (treatment No.2), a favorable water and soil salinity regime was kept in the plant roots during the growing season, which provided ideal conditions for cotton growth and development. If the coefficient of seasonal salt accumulation in the control was 1.8, in the cases with *subirrigatciya* it was between 1.3-1.5.

In traditional Khorezmian irrigation practices, the amount of nutrients in the groundwater is very high, e.g., the nutrient content increases by 4-6 times per liter of groundwater immediately after irrigation period is finished. However, under *subirrigatciya* practices the nutrient contents increased by only 1.2-1.5 times.

Furthermore, it should be noted that the substances that enter the groundwater are almost entirely used by plant roots with irrigation using the *subirrigatciya* method, leading to the increase of cotton crop yield. From the organic (30 t/ha) and mineral (240 kg/ha of nitrogen, 150 t/ha phosphorus, and 90 kg/ha potassium) fertilizers applied, all the fertilizer was used by cotton plants, as indicated by the corresponding increase in crop productivity.

It is noted that necessary groundwater rise took place in June, when cotton used almost 100% of its total water demand through groundwater uptake, compared to 50% of the crop's total water demand met by groundwater uptake in July, and 7-10% in August. Thus, it is possible to combine groundwater and surface water in irrigating cotton in the northern part of Uzbekistan.

Based on the results, one can summarize that the best pilot production unit was at pre-irrigation soil moisture of 70-80-60%, in irrigation scheme 0-3-0 with irrigation rate at 2200 m^3/ha. Under similar plant density condition, cotton yield was at 4280 kg/ha in *subirrigatciya* treatment, which

Table 1 Soil bulk density in the study site. (Values represent means of bulk density with standard error (SE)).

Soil layers (cm)	Before planting (mean) g cm^{-3}	After harvesting (g cm^{-3})	
		Control treatment	*Subirrigatciya* treatment
0 – 20	1.41 ± 0.03	1.44 ± 0.06	1.39 ± 0.06
20 – 40	1.43 ± 0.07	1.46 ± 0.02	1.41 ± 0.03
40 – 60	1.47 ± 0.03	1.49 ± 0.03	1.45 ± 0.06
60 – 80	1.50 ± 0.04	1.53 ± 0.03	1.46 ± 0.02*
80 – 100	1.53 ± 0.05	1.56 ± 0.04	1.47 ± 0.05*

* Values differ significantly from control treatments at $P < 0.05$

was 630 kg/ha higher than the control treatment.

Some experiments in the Khorezm region have shown that when surface leaching is employed in a situation of shallow groundwater level, it can raise the groundwater level near the surface, resulting in large amount of salts moving from the lower soil strata to the surface layers (World Bank 2002; Djanibekov 2005). Consequently, this strategy increases the risk of resalinization in the plant root zone. Hamidov (2007) stated that instead of applying excessive water to remove soil salts, it is worth to investigate capillary water rise from groundwater, particularly in the case of shallow groundwater levels. In his study, he found that when the groundwater table remained at 108-115 cm depth in Khorezm region, high capillary water rise from a shallow groundwater table significantly contributed to soil moisture conditions and to the biomass production of the little hogweed, *Portulaca oleracea*. Kurambaev (1969) concluded that without irrigation, a high crop (e.g. cotton and wheat) production can be obtained when the groundwater table is at 1-1.2 m depth and only slightly saline. It is evident that very few scientists studied a combined method of use of surface and groundwater to produce cotton. Therefore, this innovative tool requires further attention by the members of scientific community.

To summarize this research work, the Khorezm region was selected to conduct field investigation. The region is located in the lower reaches of the Amudarya River, where salinity of groundwater and soil are highly problematic. On the top of that, climatic conditions do not favor agricultural crops, leading to the absolute necessity of irrigation for agriculture. The climate is considered continental with long hot dry summers, infrequent rains in spring-autumn and very cold temperatures during winter. The region is characterized by meadow-alluvial hydromorphic soils with relatively shallow saline groundwater (h=1.3-1.6 m). Due to these peculiarities of the region as well as recurrent water scarcity problems, the *subirrigatciya* method is proposed to overcome the agricultural challenges of the region. This environmentally friendly and clean technique can be adopted during the vegetation period, allowing an artificial rise of the groundwater table to moisturize plant root systems. Construction of hydraulic structures at the head of existing drainage systems can make this approach possible. As a result of this research, it was possible to solve the surface water shortage through groundwater application.

This paper finds that *subirrigatciya* method is a useful technique to adopt in order to eradicate water shortage problems and thus, deserves significant attention amongst scientists. It is possible to increase cotton productivity through the combined use of groundwater and surface water. However, additional research is needed to verify the findings, particularly for application to different regions of Uzbekistan.

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