Cotton and Winter Wheat Irrigation Scheduling Improvements in Uzbekistan

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Abstract

Investigations of water use (evapotranspiration or ET) and irrigation scheduling of furrow irrigated winter wheat (*Triticum aestivum L.*) and of drip irrigated cotton (*Gossypium hirsutum, cv. Akdarya-6*) were conducted at the Central Experiment Station of the Uzbekistan Cotton Growing Research Institute (UNCGRI) on a deep silt loam soil in 2000, 2001, and 2002. Water use was established using the soil water balance approach on a weekly basis. Deep measurements of the soil profile water content were accomplished using soil moisture neutron probes (SMNP), which were calibrated in polyvinyl chloride (PVC) access tubes for the soil and each soil horizon. Water use was measured by the soil water balance method. Soil water measurements were compared with percentages of field capacity to determine irrigation rates and times during the growing season. The results revealed that drip irrigation of cotton under the given circumstances improved water use efficiency and seed-cotton yield. Under drip irrigation, the optimal mode of cotton irrigation scheduling was to irrigate at 70%, 70%, and 60% of field capacity during each of the three major growth stages, respectively. This mode saved 35% of the irrigation water in comparison with surface irrigated cotton grown under the same condition. Seed-cotton yield was increased by 21% relative to the surface irrigated cotton. Optimal development and high crop productivity of winter wheat was reached when irrigations were scheduled at soil moisture levels of 75, 75, and 60% of field capacity during the three major crop growth stages, respectively. More irrigation did not result in additional yield from the crop.

Key words: Neutron Scattering, Calibration, Drip Irrigation, Profile Water Content, Crop Water Use, Seed Cotton Productivity, Microirrigation

Introduction

Sixty percent of Uzbekistan is (semi-) desert. Almost all agricultural production is due to irrigation on approx. four million hectares, which makes irrigation water supply and management the prevailing factors limiting crop yields in the country. Cotton and wheat are the major crops, followed by corn, alfalfa, sugar beet, vegetables and fruits. With annual rainfall of 110 to 220 mm, Uzbekistan's climate is that of the dry mid-latitude desert, which is characterized by hot summers and cold winters. Agriculture in Uzbekistan was and still is the largest sector in Uzbekistan's economy.

Two major river systems: the Amu-Darya and Syr-Darya, supply all the water used for hydro-electric power generation and most of the water used for irrigation. There are some groundwater wells also used for irrigation.

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These two rivers also supply the neighboring countries of Kyrgyzstan, Tajikistan, Afghanistan, Turkmenistan and parts of Kazakhstan. Since 1991, these Central Asian countries have continued a dispute on meeting increasing water demands. Since then, lack of water has gradually devastated the irrigation-dependent cotton, winter wheat and other major crop production. In addition, lack of water has engendered the ecological catastrophe within the Aral Sea Basin, at the tail end of the river systems of Uzbekistan.

Investigation of crop water scheduling in relation to lack of irrigation water has only recently been conducted in Uzbekistan. Also, winter wheat production, which was small before the 1990s, has recently become second only to cotton in cropped land area. Cotton – winter wheat rotations are the subject of much current study; and we have recently reported results of our wheat research in a Workshop devoted to this topic (Kamilov et al., 2002). The main goal of this research was to measure cotton and winter wheat water use in Uzbekistan, and to determine irrigation scheduling parameters associated with optimal yield and irrigation water use efficiency.

Materials and Methods

Field experiments on cotton and winter wheat were conducted at the Central Experiment Station of Uzbekistan's Cotton Growing Research Institute in 2000, 2001, and 2002 at Tashkent. The soil is an old irrigated typical gray soil, a medium loam; and the water table is more than 15-m deep (automorphic type of soil formation).

As a starting point for investigations of irrigation scheduling, we adopted the field capacity (F_C) index, which was 0.298 m^3 m^{-3} over the root zone of this soil. Irrigations were scheduled when soil moisture in the root zone was depleted by the crop to specific fractions of F_C (for instance, irrigation at 70% of F_C) for each of the three main plant growth periods defined below.

The experiments with cotton were carried out in three replicates and comprised two irrigation scheduling treatments with drip irrigation, and one treatment with surface irrigation for comparison. The drip irrigation system, comprising one line of surface drip tape per row, was installed in the field after completion of early season inter-row cultivation. Each treatment consisted of scheduling irrigations at specific percentages of F_C during each of three plant growth periods as follows:

1. 65-65-60% of F_C (drip irrigation)
2. 70-70-60% of F_C (drip irrigation)
3. 70-70-60% of F_C (conventional irrigation)

where the first of the three levels of F_C (e.g., **65**-65-60%) was used from germination to squaring stage of the crop; the second level (e.g., 65-**65**-60%) was used from squaring to the flowering-fruiting stage; and the third level (e.g., 65-65-**60**%) was used during maturation of cotton bolls. Each replicated plot was 240 m^2 (4.8 m by 50 m). Irrigation water quantity applied through drip irrigation was measured by an in-line propeller-type flow meter. Water quantity for the surface irrigation treatment and runoff were measured using the weir of Chippoletty. Fertilizer was applied at rates of 200 kg ha^{-1} N, 140 kg ha^{-1} P, and 100 kg ha^{-1} K. All other cultural practices were conducted similar to the common practices in the area.

The experiments with winter wheat were carried out in three replicates and comprised four treatments. Each treatment consisted of scheduling furrow irrigations at specific percentages of F_C during each of three plant growth periods as follows:

1. 65-65-60% of F_C
2. 70-70-60% of F_C
3. 75-75-60% of F_C
4. 80-80-70% of F_C

where the first of the three levels of FC (e.g. **65**-65-60%) was used from germination to shooting stage of the crop; the second level (e.g. 65-**65**-60%) was used from shooting to the milk-wax stage of grain ripeness; and the third level (e.g. 65-65-**60**%) was used from the milk-wax stage to full grain ripeness. Plot area in the experiments was 240 m^2 (4.8 m by 50 m). Irrigation water quantity used for each treatment was measured with a weir (Weir of Chippoletty). Fertilizer was applied at rates of 200 kg ha^{-1} N, 140 kg ha^{-1} P, and 100 kg ha^{-1} K. Water use was measured by the soil water balance method.

Considering ET as crop water use, P as precipitation, I as Irrigation, R as the sum of runoff and runon, F as flux across the lower boundary of the soil profile (control volume), and ΔS as change in soil water stored in the profile, we know that the soil water balance must sum up to zero:

$$ET + \Delta S + R - P - I - F = 0 \qquad (1)$$

where the sign conventions are as given in Evett (2002), including the conventions that (1) ET is taken as positive when water is lost to the atmosphere through transpiration and/or evaporation, and (2) ΔS is positive when soil water storage increases over the season. Re-arranging this equation gives the crop water use or ET as:

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

A key thrust of our investigations was the measurement of soil profile water content. For this purpose we used the SMNP (Campbell Pacific Nuclear International, model Hydroprobe-503DR1.5), which was calibrated for each soil and soil horizon. Calibration of the SMNP was performed using methods described in Evett and Steiner (1995) and Hignett and Evett (2002). For calibration, PVC access tubes were installed in the field to 2.0-m depth, in two replicates in each of two plots of 10 square meters each. A wet site plot was irrigated to field capacity to below the 2-m depth using irrigation water. A non-irrigated plot was prepared as the dry site by crop and field management during the preceding season. Volumetric water content of the soil profiles was measured by volumetric/gravimetric methods for comparison with count ratios measured with the SMNP. Calibration equations were calculated for the important soil layers. These were used for determination of profile water content and thus calculation of irrigation rates and times for cotton during the growing season. Measurements of volumetric water content of the soil profile were conducted twice a week and in two replicates during the experiments by SMNP to 2-m depth and for each 20-cm soil layer separately. Before each measurement, a standard count (C_S) of the SMNP was determined in five replicates.

Results and Discussion

SMNP Calibration

Reasonably precise calibration equations were obtained for all soil horizons. The root mean squared error (RMSE) of regression ranged from 0.010 to 0.014 m^3 m^{-3} (Table 1). Distinctly different soil horizons were identified. Also, due to nearness to the surface, equations for the 10-cm depth were different in slope from equations for deeper layers. The old irrigated gray soil of Tashkent Province is uniform in texture, ranging from silt to silty clay loam throughout the profile, and is probably derived from loess, either in place or in alluvial deposits.

Nodules and veins of $CaCO_3$ were noted during sampling at depths of >70 cm. Since the soil is a uniform silt loam, the different calibration curve for depths >70 cm is probably due to the increase in $CaCO_3$ concentration. Similar effects of calcium minerals on SMNP calibration slopes have also been noted in the semi-arid Great Plains of the United States, where slopes were likewise lower for soil layers rich in $CaCO_3$ (Evett and Steiner, 1995; Evett, 2000). The effect is probably due to the presence of oxygen in these minerals, which is relatively effective in causing thermalization of fast neutrons. The lowered calibration slope values would be expected in this case because the presence of oxygen would increase the concentration of thermal neutrons and thus increase neutron counts without the presence of water.

Table 1. Calibration equations for soil moisture neutron probe (SMNP) for Tashkent. Equations are in terms of volumetric water content (θ, $m^3\ m^{-3}$) and count ratio (C_R). Measurements were at 20-cm increments between depths noted below.

Location	Depth (cm)	Equation	r^2	RMSE* ($m^3\ m^{-3}$)
Tashkent #H390104791**	10	$\theta = 0.013 + 1.1752C_R$	0.989	0.011
	30 – 70	$\theta = -0.176 + 0.3759C_R$	0.958	0.014
	90 – 170	$\theta = -0.039 + 0.2463C_R$	0.911	0.010

* RMSE is root mean squared error of regression.

** The # sign denotes the SMNP serial number.

An example of data gathered with the SMNP for crop water use determination is illustrated. Water content remained well below the maximum allowed by the soil porosity, which was calculated from measured bulk density (Fig. 1). Application of the soil water balance equation, using measured irrigation, rainfall and soil water content changes, allowed calculation of water use for the season.

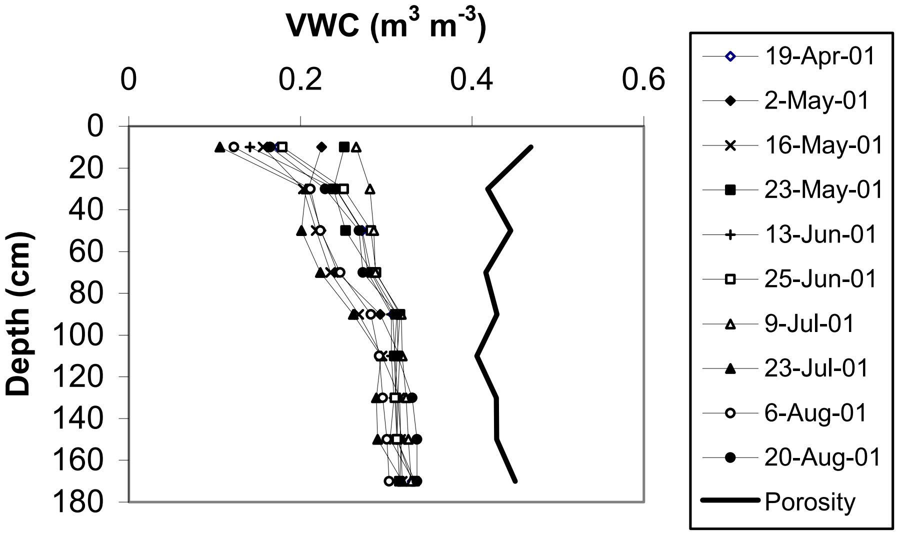

Figure 1. Evolution of profile volumetric water content (VWC) at the UNCGRI, Tashkent during the cotton irrigation season in 2001.

Crop water use and yield

The sum of runoff and runon (R) and the flux (F) were assumed to be zero for the soil of Tashkent Province and, therefore, the soil water balance equation gave the crop water use as:

$$ET = -\Delta S + P + I \quad (3)$$

Precipitation data (P) were taken from the Meteorological Station of the Institute, which is located at the Central Experiment Station. During the cotton vegetation season, precipitation was 64 mm, 27 mm, and 102 mm in 2000, 2001, and 2002, respectively. During the wheat experiment periods (October – June) precipitation was 249 mm and 716 mm in 2000-2001 and 2001-2002, respectively.

Values of change in soil water stored in the profile (ΔS) were calculated with the use of the integral calculus method. Values of water content at the beginning of each growing season were similar in all treatments and so were lumped across treatments.

Cotton

Having calculated the ΔS for each treatment of the experiment, we determined the ET for the 0 to 150-cm deep soil control volume (Table 2).

Table 2. Water use (ET) of cotton in Tashkent.

			2000			2001			2002		
Treat-ment #	% of F_C Treatments	Irrigation Method	ΔS (mm)	Irrigation (mm)	ET (mm)	ΔS (mm)	Irrigation (mm)	ET (mm)	ΔS (mm)	Irrigation (mm)	ET (mm)
1	65-65-60%	Drip	105	225	183	76	330	281	-72	298	472
2	70-70-60%	Drip	63	250	251	23	375	379	-47	322	471
3	70-70-60%	Surface	92	410	381	15	542	554	-16	507	624

Results of the experiment showed that, for drip irrigated treatments, top yield in all years was reached for treatment 2 (Table 3). Treatment 1 was considered to be deficit scheduling of irrigation due to its lower yield, which was still larger than that for furrow irrigation. For drip irrigation, additional yield received (average for three years) with treatment 2 (75-75-60% of F_C) in comparison with scheduling of irrigation at 65-65-60% of F_C was 0.38 t ha^{-1} (12.4% increase). Average additional yield for drip irrigation (treatment 2) compared with surface irrigation was 0.60 t ha^{-1} (20.9% increase) using the same irrigation scheduling treatment of 70-70-60% of F_C. Moreover, irrigation water use efficiency was always larger for drip irrigation than for furrow irrigation. Total water use efficiency (Table 4) declined in 2002 when growing season rainfall was the largest (rainfall in the growing season was 64, 27, and 102 mm in 2000, 2001, and 2002, respectively).

Some experiments have shown that drip irrigation does not increase cotton yield relative to well managed surface irrigation (Howell et al., 1987; Bucks et al., 1988). Others have shown that drip irrigation may increase lint yields and water use efficiency by large amounts compared with those from sprinkler or surface irrigation (Bordovsky, 2001; Smith et al., 1991). In our experiment, drip irrigation showed its superiority over surface irrigation applied with conventional methods in Uzbekistan. Therefore, drip irrigation should be further explored as an effective means to control quantity of irrigation water.

Table 3. Yield, irrigation and irrigation water use efficiency of cotton at Tashkent .

Treatment number	Treatment (% F_C)	Irrigation method	Irrigation (m^3 ha^{-1})	Seed cotton yield (t ha^{-1})	Irrigation water requirement per unit yield (m^3 t^{-1})	Irrigation water use efficiency (kg m^{-3})
			Year of 2000			
1	65-65-60	Drip	2250	3.12	721	1.38
2	70-70-60	Drip	2500	3.60	694	1.44
3	70-70-60	Furrow	4100	2.95	1390	0.71
			Year of 2001			
1	65-65-60	Drip	3300	3.29	1003	0.99
2	70-70-60	Drip	3750	3.67	1022	0.97
3	70-70-60	Furrow	5420	3.02	1750	0.55
			Year of 2002			
1	65-65-60	Drip	2980	2.86	1042	0.96
2	70-70-60	Drip	3220	3.15	1022	0.98
3	70-70-60	Furrow	5010	2.65	1891	0.53

Table 4. Yield, water use, and total water use efficiency of cotton Tashkent.

Treatment #	Treatment (% F_C)	Irrigation method	ET (m^3 ha^{-1})	Seed cotton yield (t ha^{-1})	Total water requirement per unit yield (m^3 t^{-1})	Total water use efficiency (kg m^{-3})
			Year of 2000			
1	65-65-60	Drip	1832	3.12	587	1.70
2	70-70-60	Drip	2508	3.60	697	1.44
3	70-70-60	Furrow	3812	2.95	1292	0.77
			Year of 2001			
1	65-65-60	Drip	2810	3.29	854	1.17
2	70-70-60	Drip	3786	3.67	1032	0.97
3	70-70-60	Furrow	5544	3.02	1836	0.54
			Year of 2002			
1	65-65-60	Drip	4720	2.86	1650	0.61
2	70-70-60	Drip	4710	3.15	1495	0.67
3	70-70-60	Furrow	6240	2.65	2358	0.42

Winter Wheat

Evapotranspiration (ET) calculated for the 0 to 150-cm deep soil control volume was nearly twice as large in 2002 as in 2001 (Table 5). Some of this may have been due to luxury consumption of water by the crop during the 2001-2002 growing season, which received 716 mm of precipitation, almost three times the amount of precipitation as in the 2000-2001 season. The ET values for the 2000-2001 growing season, ranging from 426 to 492 mm, compare well with values ranging from 424 to 524 mm for irrigated winter wheat grown at Bushland, Texas (Evett et al., 1995). The larger values of ET calculated for the 2001-2002 growing season are excessive and are probably due to unrecorded runoff, which was not measured in the wheat studies, although it was measured in the cotton studies reported here.

Table 5. Water use (ET) of winter wheat in Tashkent.

Treatment number	% of FC treatments	ΔS (mm) 2001	ΔS (mm) 2002	ET (mm) 2001	ET (mm) 2002
1	65-65-60%	33.1	20.4	426	881
2	70-70-60%	28.2	21.2	453	885
3	75-75-60%	24.3	20.5	467	882
4	80-80-70%	21.5	22.0	492	899

Largest yields were reached for treatments 3 and 4, which were concluded as optimal and high moisture mode, respectively (Table 6). Treatments 1 and 2 were considered to be deficit scheduling of irrigations. Additional yield received (average for two years) at the optimal mode (75-75-60% of FC) in comparison with the rigid scheduling of irrigation (65-65-60% of FC) was 0.77 t ha-1 (19.5%).

Table 6. Irrigation and productivity of winter wheat at Tashkent, Uzbekistan

Treatment	Irrigation		Grain Yield		Water requirement per unit yield		Irrigation water use efficiency	
	$m^3\ ha^{-1}$	$m^3\ ha^{-1}$	$Mg\ ha^{-1}$	$Mg\ ha^{-1}$	$m^3\ Mg^{-1}$	$m^3\ Mg^{-1}$	$kg\ m^{-3}$	$kg\ m^{-3}$
% FC	2001	2002	2001	2002	2001	2002	2001	2002
65-65-60	2100	1750	4.01	3.89	5.24	3.89	1.91	2.57
70-70-60	2320	1900	4.58	4.18	5.06	4.55	1.98	2.20
75-75-60	2420	1960	4.99	4.45	4.85	4.4	2.06	2.27
80-80-70	2650	2050	5.01	4.6	5.29	4.46	1.89	2.24

Conclusions

1. Overall, our investigations with cotton conducted in the old irrigated typical gray soil of Tashkent Province showed that calibration of the SMNP was successful and acceptably precise for research objectives. The SMNP was useful for determining water content dynamics of soil profiles, scheduling irrigation during growing seasons, and obtaining accurate data on water use.

2. On average over three seasons, scheduling drip irrigation following the 70-70-60% of F_C treatment resulted in saving 35% of the irrigation water in comparison with surface irrigated cotton grown under the same conditions. Irrigation water use efficiency was increased by 89% compared with that of surface irrigation when scheduling was done using the (70-70-60% of F_C) rule for both. The seed-cotton yield was increased by 21% relative to the surface irrigated cotton.

3. Experimental results of the two years of investigations showed that optimal development and high crop productivity of winter wheat was reached when irrigations were scheduled at soil moisture levels of 75, 75, and 60% of field capacity during the three major crop growth stages, respectively. More irrigation did not result in additional yield from the crop.

Acknowledgements

We gratefully acknowledge support under Technical Cooperation project number UZB/5/002, "*Optimization of Water and Fertilizer Use for Major Crops*", from the International Atomic Energy Agency, Vienna, Austria; support under grant number ZB1-2050, "*Improving Water Use Efficiency/Reducing Salinization in Irrigated Wheat and Sugar Beet Production*", from the U.S. Civilian Research and Development Foundation; and support under Partner Project number P-116, Science and Technology Center Ukraine and USDA-ARS-OIRP.

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