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Irrigation Scheduling Study of Drip Irrigated Cotton by use of Soil Moisture Neutron Probe

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Abstract

Investigations of water use (evapotranspiration or ET) and irrigation scheduling 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 the old irrigated typical gray soil (deep silt loam) in 2000 and 2001. 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. Soil water measurements were used for determination of irrigation rates and times for drip irrigated cotton during the growing season. Cotton water use was measured by the soil water balance method. The results revealed that drip irrigation of cotton under the given circumstances improved water use efficiency and seed-cotton yield. Under drip irrigation practices and the optimal mode (70-70-60% of field capacity) of irrigation scheduling, 31 to 39% of the irrigation water was saved in comparison with surface irrigated cotton grown under the same condition. The seed-cotton yield was increased by 21 to 22% relative to the surface irrigated cotton.

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

Introduction

Cotton and wheat are the major crops in Uzbekistan followed by corn, alfalfa, sugar beet, vegetables and fruits. About 60% of the country is (semi-) desert with only four million hectares of the area cropped. 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. Thus, agricultural production in the country, like in the whole of Central Asia, is predominantly based on irrigation, which makes irrigation water supply and management the prevailing factors limiting crop yields in the region.

Agriculture in Uzbekistan was and still is the largest sector in Uzbekistan's economy. Water, used for hydro-electricity generation and irrigation, is supplied by two major river systems: the Amu-Darya and Syr-Darya, which also supply the neighboring countries of Kyrgyzstan, Tajikistan, Afganistan, Turkmenistan and parts of Kazakhstan. Since 1991, these Central Asian countries have continued their 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 not been conducted in Uzbekistan. The main goal of this research was to measure cotton water use in Uzbekistan, and to determine irrigation scheduling parameters associated with optimal yield and irrigation water use efficiency.

Materials and Methods

The field experiment was conducted at the Central Experiment Station of Uzbekistan's Cotton Growing Research Institute in 2000 and 2001 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} in 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 experiment with cotton was 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 was 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.

Cotton 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 convention that ET is taken as positive when water is lost to the atmosphere through transpiration and/or evaporation. 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). 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

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	10	$\theta = 0.013 + 1.1752C_R$	0.989	0.011
#H390104791**	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.

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.

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.

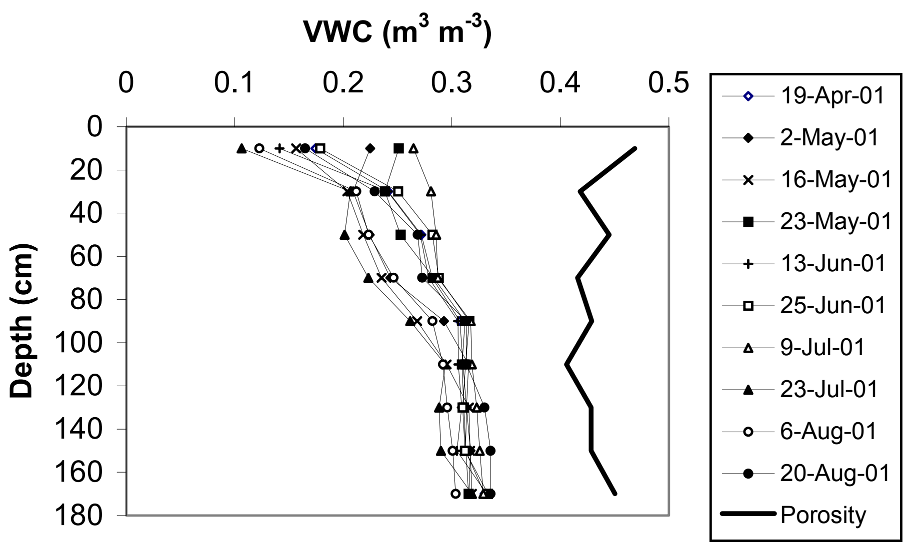

Figure 1. Evolution of profile volumetric water content (VWC) at the UNCGRI, Tashkent during the cotton irrigation season in 2001.

Crop water use

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 and 27 mm in 2000 and 2001, respectively.

Values of change in soil water stored in the profile (ΔS) were calculated with the use of the integral calculus method and data from Table 2. Values of water content at the beginning of each growing season were similar in all treatments and so were lumped across treatments in Table 2.

Table 2. Volumetric water content of the old irrigated typical gray soil at the beginning and the end of vegetation (Tashkent, cotton)

	Volumetric water content (m^3 m^{-3})							
	2000				2001			
		At end of growing season				At end of growing season		
		Drip irrigation		Surface irrigation		Drip irrigation		Surface irrigation
Soil layer (cm)	At crop emergence	65-65-60% F_C	70-70-60% F_C	70-70-60% F_C	At crop emergence	65-65-60% F_C	70-70-60% F_C	70-70-60% F_C
30	0.276	0.222	0.235	0.226	0.284	0.247	0.249	0.238
50	0.295	0.230	0.259	0.261	0.330	0.258	0.312	0.304
70	0.329	0.256	0.270	0.244	0.341	0.303	0.323	0.336
90	0.355	0.293	0.312	0.278	0.344	0.300	0.349	0.341
110	0.347	0.285	0.319	0.301	0.314	0.278	0.311	0.326
130	0.361	0.304	0.325	0.326	0.305	0.280	0.328	0.344
150	0.366	0.315	0.347	0.319	0.316	0.299	0.334	0.352
170	0.373	0.324	0.362	0.335	0.388	0.314	0.334	0.354

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 3).

Table 3. Water use (ET) of cotton in Tashkent.

			2000			2001		
Treatment #	% of F_C Treatments	Irrigation Method	ΔS (mm)	Irrigation (mm)	ET (mm)	ΔS (mm)	Irrigation (mm)	ET (mm)
1	65-65-60%	Drip	105	225	183	76	330	281
2	70-70-60%	Drip	63	250	251	23.4	375	379
3	70-70-60%	Surface	92	410	381	14.6	542	554

Results of the experiment showed that, for drip irrigated treatments, top yield in both years was reached for treatment 2 (Table 4). Treatment 1 was considered to be deficit scheduling of irrigation due to its lower yield. For drip irrigation, additional yield received (average for two years) with treatment 2 (75-75-60% of F_C) in comparison with scheduling of irrigation at 65-65-60% of F_C was 0.43 t ha^{-1} (13.4% increase). Average additional yield for drip irrigation compared with surface irrigation was 0.65 t ha^{-1} (21.7% 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.

Table 4. Irrigation and productivity of cotton at two locations in Uzbekistan

Treatment #	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
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	3.6	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

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 conventional surface irrigation. Therefore, drip irrigation should be further explored as an effective means to control quantity of irrigation water.

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. For two years, scheduling drip irrigation following the 70-70-60% of F_C treatment resulted in saving 31 to 39% of the irrigation water in comparison with surface irrigated cotton grown under the same conditions. Irrigation water use efficiency was increased by 76.4 to 102.8% 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 to 22% relative to the surface irrigated cotton.

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