11 - IMPROVEMENTS ON FURROW IRRIGATION FOR SLOPING LANDS

K. M. Kulov[1], A. J. Atakanov[1], P. M. Jooshev[1], N. J. Sharshekeev[1]

Abstract: One environmental aspect that characterizes some irrigated areas located in the Osh Oblast is their steep slope values (0.02-0.03). So the main task of the carried out studies was the increase of irrigation application efficiency aimed at controlling the amount of non-beneficial water use in irrigation. It was achieved on the basis of definition of optimal parameters for furrow irrigation in relation to existing specific conditions and using of operation planning and scheduling models for irrigation of crops. For 3 years of studies, tests were conducted for 12 different options on cotton irrigation and 8 options of wheat irrigation. To assess water resources-saving technologies, the irrigation study results are analyzed for the evenness of moistening along the furrow length, irrigation runoff at end of furrows, and erosion characteristics. The account of water delivery to irrigated fields was made at the head of water intake by Cipoletti weirs and at the tail of outfall furrows by Thomson weirs. Soil humidity observation was carried out using a neutron probe and the thermostatic-weighing method. Based on the analysis of cotton field research results, considering technological, economic and ecological perspectives, it is concluded that furrow lengths shall vary within the limits of 120 to 150 m, the furrow distances should be set equal to 1.2 m and furrow discharges in the range 0.15 to 0.2 l/s.

Keywords: Furrow irrigation, Irrigation under steep slope conditions, Irrigation recommendations.

Introduction

Irrigated agriculture in the Kyrgyz part of Fergana Valley is located in intermountain hollows and valleys at various elevations, so under different natural climatic conditions, even within the area of one district or irrigation system. The main part of agricultural area of the Kirghiz part of Fergana Valley is located at 700-1500 m above sea level, and the upper limit of agriculture

---

[1] Kyrgyz Scientific and Research Institute of Irrigation (KSRII), 4^a Toktonaliev st. Bishkek, The Kyrgyz Republic. Email: kulov@elcat.kg

reaches 2800 m. The climate of the area is sharply continental, with great daily temperature fluctuations and non-uniform precipitations. The summer is very dry, with only 11% of annual precipitations during June - August. Therefore, agricultural production on the most part of the areas can be made only with irrigation.

Presently many farmers who have come into agriculture from other fields of activity have no sufficient knowledge on the land improvement field, and not fully use the opportunities of irrigated agriculture because they do not follow the recommended agro technical methods and modes of the irrigation technology adequate to agricultural crops irrigation. The low level of irrigated agriculture inevitably leads to ecological unbalance and disruption of the environment, with the occurrence of negative processes such as irrigation erosion, salinity and waterlogging and significant decreasing of soil fertility and yields.

The dominating irrigation method in Osh Oblast is traditionally, since ancient times, the surface wild strip irrigation or, in the best way, furrow irrigation. Such irrigation has a number of advantages. It is simple and wide-available and does not demand for complex equipment. Contrarily to sprinkling irrigation, it is much cheaper and does not demand additional energy, and it is ecologically adequate as providing the best soil infiltration, no limitations regarding crop growth stages and not being affected by the wind. Under furrow irrigation the beds between furrows remain dry, which improves thermal and air behaviour of the soil, and allows higher crop yields under the same conditions.

Main shortcomings of traditional surface irrigation are high labour demand, low efficiency, and non-uniformity of field moistening. Water diversion and distribution to irrigation fields under such irrigation method are made by the irrigators manually, the account of water delivery to the field is generally not carried out, field irrigation is implemented non-uniformly, and has significant irrigation water wastes by deep infiltration and runoff. Non-uniformity of distribution and excessive water delivery to the field can result in significant soil erosion, increase of groundwater table level, soil salinity and waterlogging, and reduction of fertility. To reduce the shortcomings of furrow irrigation it is necessary to prove optimum values of irrigation technique elements: furrow discharges, furrow lengths, advance time, time of additional wetting, infiltration along the furrow length, and discharge at the tail end of furrows to find out a non-erosive process.

Environmental characteristics of irrigated areas in the Osh Oblast are marked by the large slopes (0.02-0.03). So the main task of the carried out studies was aiming at increasing irrigation efficiencies when minimizing the unproductive irrigation water wastes. This was achieved on the basis of the definition of optimal parameters for the furrow irrigation technique when applied to specific conditions, and by using irrigation scheduling models of agricultural crops, such as WINISAREG. For the last 3 years of studies the tests were conducted for 12 different options on cotton irrigation and 8 options of wheat irrigation.

To evaluate water saving technologies, the results of the study are analyzed relative to the evenness of moistening along the furrow length, the operational irrigation water losses by runoff, and erosion characteristics. The measurement of water delivered to irrigated fields was made with Cipoletti weirs and, at the tail end of furrows, by Thomson's triangular weirs. Soil humidity monitoring was carried out using TROXLER 4300 neutron probes and thermostatic-weighing methods.

To increase the water use efficiency and improvement of ecological environment, the irrigation requirements of agricultural crops needs to be to calculated operatively with ISAREG and to establish optimum elements of irrigation technique according to natural climatic and economic conditions.

The main task of implemented tests was to increase the effectiveness of water resources use, control of unproductive water losses during the irrigations, and reduction of consequences for desertification and land degradation. It was achieved based on definition of optimal technical elements of furrow irrigation, operation planning models of agricultural crops irrigation modes, control of implemented irrigations on the production plots, and extension of obtained experience giving out recommendations related to optimal elements of irrigation technique depending on slopes and soil infiltration in irrigation systems.

Site characteristics

An experimental plot of 10 ha was selected in Kara-Suu rayon of Osh Oblast within the area of private farm of K. Zakirov (position data 40^{o} 33 of North latitude and 72^{o} 49 of east longitude). The site is located to the north of Kara-Suu -2 meteorological station (Fig. 1).

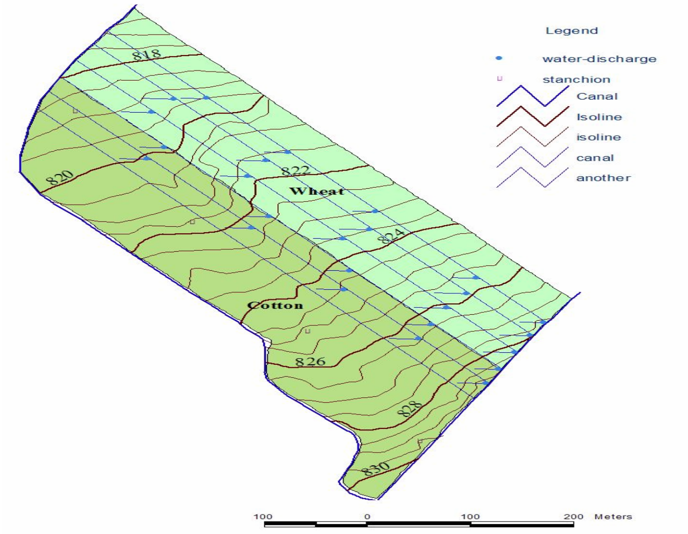

Fig. 1. The Karasuu experimental plot, Osh Oblast.

Soil hydraulic properties were determined for several plots and are shown for a cotton field in Table 1 and for a wheat field in Fig. 2.

Table 1. Soil water retention curves for a soil in Karasuu district (pit # 2, cotton field 1).

Soil profile		Bulk density (g/cm^3)	Porosity (%)	Soil moisture (% by volume) at different pF						Total available water TAW (mm)
	Thickness (cm)			1.7	2.0	2.7	3.0	3.5	4.2	
A 0		1.35	49	20.39	17.03	15.89	14.90	12.51	6.11	109
A	33-42	1.51	43	30.31	28.15	27.16	24.89	21.43	15.89	123
A-B	42-63	1.46	45	31.62	28.48	27.17	26.20	22.41	15.68	128
B 1	63-82	1.52	43	31.46	28.40	26.14	24.53	21.39	14.86	135
Bк	82-105	1.54	42	27.56	25.20	23.97	22.33	17.32	11.66	135
Bк	105-126	1.49	44	26.08	23.48	21.73	19.71	14.23	9.96	135
B 2	126-150	1.44	46	27.92	23.58	22.18	20.67	15.47	10.03	136
B - 5	150-178	1.44	46	26.77	24.48	24.40	22.19	16.28	11.04	134
B - 6	178-200	1.42	47	26.20	22.22	23.31	19.72	13.29	9.20	130

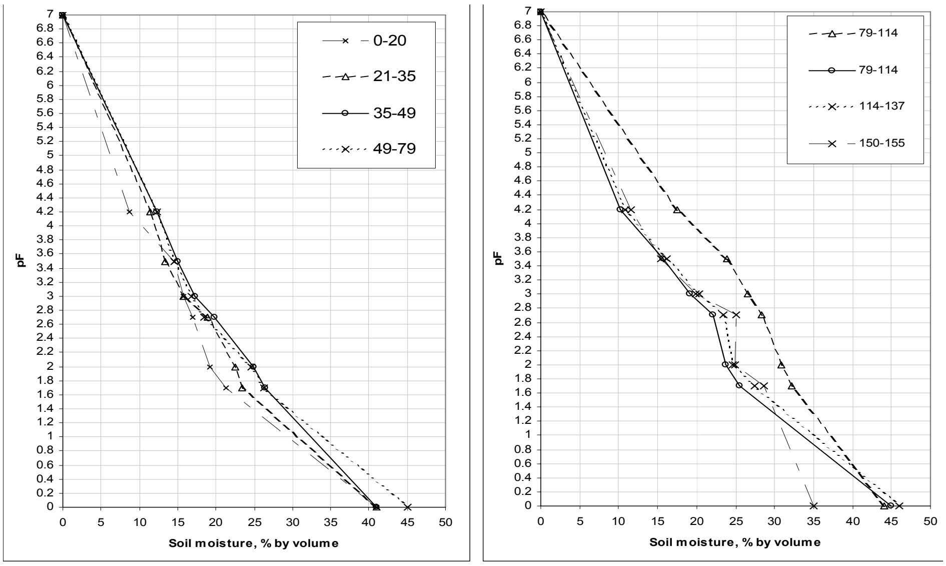

Fig. 2. Soil water retention curves for a soil in Karasuu district (pit # 1, winter wheat field).

The infiltration rates were measured in cotton fields before crop sowing with cylinder infiltrometers. Several repetitions were made each year. Testing results are shown in Fig. 3 with indication of the average and standard deviation.

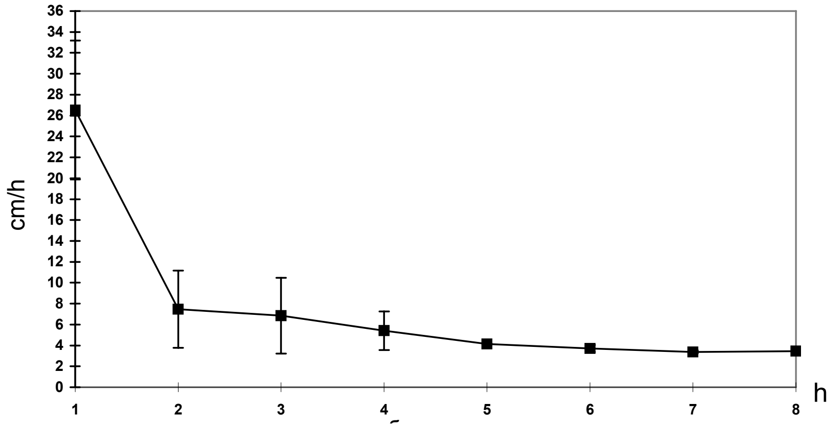

Fig. 3. Soil infiltration rate in Karasuu state farm, cotton field N°1.

Furrow irrigation experiments

To implement the field studies for determination of optimal characteristics of furrow irrigation technique and technology, 12 alternative treatments for cotton furrow irrigation were used (Table 2).

Table 2. Cotton furrow irrigation treatments.

Treatments	Furrow length (m)	Interval between furrows (m)	Gradient (m/m)	Discharge to furrow (l/s)	Irrigation method
1.1	60	0.6	0.02	0.45	Every furrow irrigation
1.2	60	0.6	0.02	0.30	
1.3	60	0.6	0.02	0.15	
1.4	60	1.2	0.02	0.45	Alternate furrows
1.5	60	1.2	0.02	0.30	
1.6	60	1.2	0.02	0.15	
1.7	120	0.6	0.02	0.45	Every furrow irrigation
1.8	120	0.6	0.02	0.30	
1.9	120	0.6	0,02	0.15	
1.10	120	1.2	0.02	0.45	Alternate furrows
1.11	120	1.2	0.02	0.30	
1.12	120	1.2	0.02	0.15	

Three Cipoletti weirs were installed to account for water intake rates and volumes. Weirs No.1 and 2 were placed on the plot canal and weir No. 3 on the discharge canal. At the end of the plot, three Thompson weirs were set in each furrow at the head, in the middle and at the tail end for alternatives. Before the irrigation starts, the irrigator prepares polyethylene films for armouring of furrow heads. Then the polyethylene film is stacked on perimeter of furrow head by pressing its ends into the ground, by hand or a shovel, on the irrigation furrow perimeter with the purpose to protect the furrow heads from washing out by irrigation water. Furrows were supplied for 13-23 hours depending on the furrow discharge. Several of treatments concern an exaggerated water application but try to reproduce what happens in practice.

Studies of advance were made every 10 m along the furrow length. Fig. 4 shows typical advance curves of the second and third irrigations.

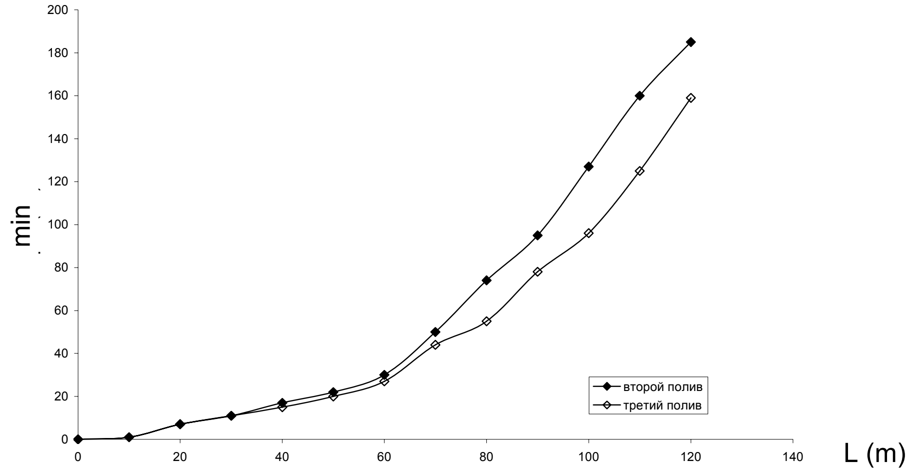

Fig. 4. Advance curves for the second and third irrigations, treatment 1.9.

Table 3 is an example of results relative to the average and standard deviation (sd) for advance, recession and application times, water delivery volumes, runoff discharges and deep percolation during the cotton irrigation.

As for Table 3, the duration of irrigations varied from 800 to 1400 minutes. Irrigation duration depends on irrigation technology; in the first case, when the water is supplied for every furrow the irrigation was 800 minutes. Irrigation duration around 1400 minutes is used when the irrigation is made for alternate furrows. Runoff varied from 87% to 9% depending on inflow rates and irrigation technology.

Losses by deep percolation are small and vary depending on study option. From above tables on cotton irrigation it is obvious that to reduce unproductive water losses and to minimize erosion processes the most acceptable treatment is irrigation with alternate furrows with inflow discharge of 0.15 l/s and furrow length 120 m (treatment 1.12, Table 3). Application of short furrows to use runoff water for irrigation of downstream furrows demands high labour from the irrigator and leads to lesser land use efficiency.

Table 3. Summary of the characteristics of 2nd irrigation (17.07.2003), Field # 1, Cotton.

Treatm.	Advance time (min x 10)		Recession (min x 10)	Irrigation Duration (min)	Total inflow (m^3/ha)	Runoff (m^3/ha).	Percolation (m^3/ha)	Q av. inlet (l/s)	Q av. outlet (l/s)
	L	0,5L							
1.1.	13	3	7	800	6177	5321	856	0.46	0.41
sd	3	2	1	0	155	153	173	0	0.012
1.2.	14	4	7	800	4440	3478	962	0.33	0.27
sd	4	2	1	0	150	168	145	0	0.012
1.3.	39	13	5	800	2087	1143	944	0.16	0.09
s	9	5	1	0	75	130	56	0	0.012
1.4.	14	4	6	1400	5443	4528	916	0.47	0.39
sd	5	1	2	0	66	141	75	0	0.012
1.5.	17	5	4	1400	3772	2940	832	0.32	0.26
sd	3	1	1	0	134	140	142	0	0.012
1.6.	47	19	4	1400	1750	931	819	0.15	0.09
sd	6	4	1	0	117	62	64	0	0.006
1.7.	42	13	9	800	3089	2275	813	0.46	0.37
sd	7	2	2	0	77	21	65	0	0.006
1.8.	51	18	8	800	2289	1447	842	0.34	0.24
sd	17	9	1	0	102	145	76	0	0.020
1.9.	185	46	5	800	1000	140	860	0.15	0.06
sd	28	9	1	0	67	71	51	0	0.006
1.10.	38	10	8	1400	2697	1986	711	0.46	0.36
sd	10	2	1	0	63	56	98	0	0.006
1.11.	49	15	8	1400	1944	1190	754	0.33	0.22
sd	15	6	1	0	67	111	48	0	0.017
1.12.	165	42	4	1400	855	93	763	0.15	0.05
sd	19	5	2	0	34	49	16	0	0.010

Soil moisture was investigated for 3 furrows in all treatments. For every furrow, the soil moisture was determined with the neutron probe using two neutron pipes at the beginning and at the end of furrow. Water supplied to the furrows were measured with a Thomson's triangular weir (three weirs in every furrow as referred above). Soil moisture measurements after irrigation were made in 4-5 days by neutron and weighing methods. Soil moisture measurements up to 2 meters deep were made by only neutron method.

Dynamics of soil moistening change on the experimental plot is shown on Fig. 5. As it may be seen, soil moistening is kept near optimal concerning the accepted irrigation norms at the field. The increased moistening of bottom horizons can be explained by the existence of dense soil layers on about 2-meter depth, so leading to water accumulation during the irrigation process of adjacent plots.

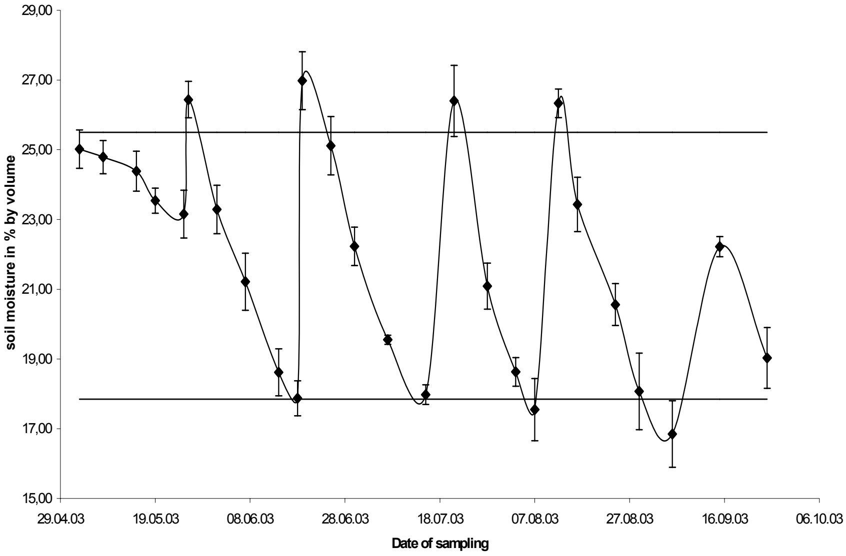

Fig. 5. Dynamics of soil moisture changes in 1.0 m soil depth in a cotton field for the vegetation period, 2003.

The erosion processes were investigated at three sections: at the beginning, middle and at the end of a furrow. For every irrigation, the furrow profiles were measured with three repetitions. Results obtained are generally not different of those on Fig. 6.

As showed (Fig. 6) the erosion process takes place along the furrow length. Such processes can occur where water discharge to furrow is >0.15 l/s. It can be explained by the largest gradient and thin soil texture. According to our observations, considerable reduction of soil erosion along the furrow length can be achieved using surge flow irrigation. To avoid erosion it is possible the application of polymers.

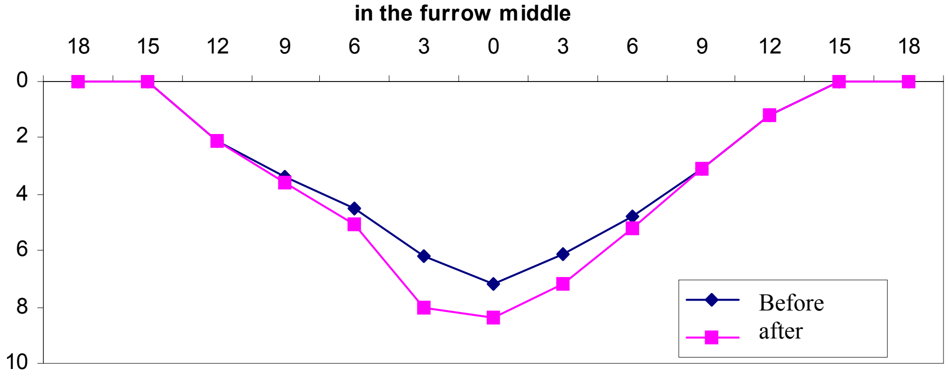

Fig. 6. Cross section profile of the furrow before and after irrigation showing erosion.

Yield results

To increase the efficiency of water use in irrigated farming it is required to minimize the non-beneficial water uses or operational losses through identifying optimum elements of furrow irrigation technique, as well increasing water conveyance and delivery efficiency. Results for the 3 years experiments with the 12 treatments described earlier are presented in Table 4.

Table 4. Cotton yields as depending on irrigation treatments.

Treatments	Length of furrow, m	Inflow to furrows, l/sec	Distance between furrows, m	Yield, q/ha		
				2001 г.	2002	2003
1.1	60	0.45	0.6	27.1	30.2	21.8
1.2		0.30	0.6	27.6	32.0	22.6
1.3		0.15	0.6	26.9	29.2	21.4
1.4		0.45	1.2	26.3	30.1	20.5
1.5		0.30	1.2	26.8	31.8	21.9
1.6		0.15	1.2	26.4	28.9	19.7
1.7	120	0.45	0.6	26.8	29.8	21.1
1.8		0.30	0.6	27.1	31.9	23.4
1.9		0.15	0.6	26.3	28.4	20.0
1.10		0.45	1.2	25.9	28.6	20.6
1.11		0.30	1.2	26.4	31.7	22.1
1.12		0.15	1.2	26.0	28.2	19.3
Average				27.0	29.0	20.0

In 2001, the maximum yield was 27.6 q/ha under treatment 1.2 with 60 m long furrow, 0.6 m distance between furrows, 0.30 l/sec of flow per furrow. In 2002 the same treatment provided for the highest yield, 32 q/ha, while the average yield was 29 q/ha. In 2003 the highest yield was 23.4 q/ha under treatment 1.8 with 120 m long furrow, 0.6 m distance between furrows, and 0.30 l/sec of flow per furrow. The yield 22.6 q/ha under treatment 1.2 was the second one. If based on the yield results, treatment 1.2 prevails over the others However, from an economic and technological point of view, this treatment is not the best. A 60 m long furrow is not advantageous (the number of fields increases, so the number of temporary irrigators and irrigation sections increase, labour costs also increase). Moreover, irrigating with 0.30 l/sec per furrow makes that the major part of the delivered water is discharged as runoff, and under this slope the soil is washed away and eroded.

Upon analyzing results of the field survey, both from technological as well as economic point of view, and using results of the survey run before, it can be recommended that for a slope 0.015 – 0.025, the length of furrow shall be 120-150 m, the distance between furrows be 0.6 m and the inflow rate be 0.15 l/s.

Furrow irrigation recommendations

Based on the field experiments and using the available database, it was possible to determine optimum furrow irrigation parameters, and water use and irrigation regime norms for agricultural crops under any conditions in Kara-Suu Rayon. The gross irrigation norms (depths) $M_{gross,}$ taking account percolation and runoff, shall be calculated as:

$M_{gross} = M_{net}/\eta$,

where M_{net} is net irrigation norm, m^3/ha, and η is efficiency of application, which depends on soil permeability (infiltration) and land slope. Data on efficiency are given in Table 5 following elements of irrigation technique recommended by current norms. The soil characteristics in Table 5 are defined through Table 6.

Table 5. Expected operational water losses on irrigated area under furrow irrigation.

Infiltration		Range of slopes	Operational Losses (%)				Expected application efficiency η
Soil infiltration characteristics	Index		Deep percolation	Runoff	Evaporation	Total	
Very high infiltration	A	0.05…0.02	33	13	2	50	0.50
		0.02…0.01	29	15	2	46	0.54
		0.01…0.005	26	15	1	42	0.58
		0.005…0.001	23	12	1	36	0.64
High infiltration	B	0.05…0.02	23	16	2	41	0.59
		0.02…0.01	22	16	2	40	0,60
		0.01…0.005	19	16	1	36	0.64
		0.005…0.001	16	13	1	32	0.68
Medium infiltration	C	0.05…0.02	18	18	2	38	0.62
		0.02…0.01	15	19	3	37	0.63
		0.01…0.005	13	16	2	31	0.69
		0.005…0.001	11	15	2	28	0.72
Low infiltration	D	0.05…0.02	14	24	6	44	0.56
		0.02…0.01	15	23	6	39	0.61
		0.01…0.005	17	22	5	35	0.65
		0.005…0.001	15	17	6	31	0.69

Table 6. Land classification based on soil permeability.

Class	Characteristics of the area, depending on water and physical properties of the soil	Soil Texture	Average permeability rate, (cm/h)	Average flow rate infiltrated per 100 m of furrow (l/s)
1	2	3	4	5
A	Extremely high permeability	Sandy	Over 15	> 1.5
B	Very high permeability	Loamy sand	8	0.2
C	Average permeability	Light loamy	4.5	0.1
D	Low permeability	Loamy	2.5	0.05
E	Poor permeability	Clay and clay-loamy	Less 1.5	< 0.03

In Tables 7 and 8 are given the recommended furrow lengths and inflow rates for the soil types referred in Table 6 and according the land slopes.

Table 7. Basic parameters for furrow systems under continuous flow.

Characteristics based on soil water-physical properties	Parameters		Furrow slope					
			0.05-0.03	0.03-0.015	0.015-0.007	0.007-0.003	0.003-0.001	0 to 0.001
1	2		3	4	5	6	7	8
Extremely high	Length	L, m	50	80	110	180	200	150
permeability	Inflow rate	q, l/s	0.22	0.35	0.50	0.80	0.90	0.70
Very high	Length	L, m	80	110	140	220	250	200
permeability	Inflow rate	q, l/s	0.18	0.24	0.30	0.48	0.55	0.45
Average	Length	L, m	110	135	160	260	300	250
permeability	Inflow rate	q, l/s	0.13	0.15	0.18	0.30	0.35	0.30
Low permeability	Length	L, m	135	160	185	300	350	300
	Inflow rate	q, l/s	0.08	0.09	0.11	0.18	0.20	0.18
Poor permeability	Length	L, m	150	180	210	350	400	350
	Inflow rate	q, l/s	0.05	0.06	0.08	0.12	0.15	0.12

Table 8. Basic parameters for furrow systems when double inflow rates are applied.

Characteristics based on soil water-physical properties	Parameters		Furrow slope					
			0.05-0.03	0.03-0.015	0.015-0.007	0.007-0.003	0.003-0.001	Plain to 0.001
1	2		3	4	5	6	7	8
Extremely high	Length	L, m	50	80	110	200	250	200
permeability	Inflow rates	q, l/s	0.30	0.48	0.03	1.20	2.00	1.00
			0.80	0.92	0.42	1.00	1.00	0.80
Very high	Length	L, m	80	110	160	260	300	250
permeability	Inflow rate	q, l/s	0.22	0.35	0.48	0.90	1.30	1.10
			0.15	0.25	0.34	0.55	0.65	0.50
Average	Length	L, m	90	140	190	320	350	300
permeability	Inflow rate	q, l/s	0.14	0.21	0.30	0.48	0.70	0.60
			0.09	0.14	0.19	0.32	0.35	0.30
Low permeability	Length	L, m	120	170	220	350	400	350
	Inflow rate	q, l/s	0.10	0.16	0.20	0.33	0.40	0.42
			0.06	0.10	0.12	0.22	025	0.20
Poor permeability	Length	L, m	150	200	250	400	450	400
	Inflow rate	q, l/s	0.07	0.09	0.12	0.18	0.28	0.24
			0.05	0.06	0.08	0.12	0.14	0.12

Based on the analysis of field research relative to furrow irrigated cotton and taking into consideration technological, economic and ecological point of views and the given slope of area, it is concluded that furrow lengths should be kept within the limits 120-150 m, the distance between irrigated furrows-shall be 1.2 m, i.e. alternate furrow irrigation should be adopted, and furrow discharge should range 0.15-0.2 l/s.

Bibliography

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 2001. *Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements.* FAO Irrig. Drain. Pap. 56, Russian Translation, SIC-ICWC, Tashkent.

Iziumov, 1986. Reference Book on Technique and Means of Irrigation of Agricultural crops, Kiev.

Mamytov, A.M., 1974. Soils of the Kyrgyz SSR, Frunze, 419 pp. (in Russian).

Reports of INCO-Copernicus Project, Bishkek, 2001-2004.

1966, Reference Book on Climate in the USSR, Kyrgyz SSR, Issue 32, Part 2, Hydrometizdat, Leningrad.

1969, Reference Book on Climate in the USSR, Kyrgyz SSR, Issue 32, Part 4, Hydrometizdat, Leningrad.

1975, Agroclimatic Resources of Osh Oblast, Kyrgyz SSR, Hydrometizdat, Leningrad.

1998, Methods of Calculation of Consumptive Water Use and Irrigation Norms for Agricultural Crops in the Kyrgyz Republic, Report on Research Work, Kyrgyz Scientific Research Institute of Irrigation.