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For the period October 2000 - September 2001

Submitted to the office of the Science Advisor
U.S. Agency for International Development

Project Title: **Surface irrigation as affected by polymer amendments and soil properties.**

Project Identification no.: CA17-008
Grant no. TA-MOU-97-CA17-008

Principal Investigator: **G.J. Levy**
Inst. of Soil, Water and Environ. Sci., ARO, The Volcani Center,
Bet Dagan, Israel

Co-Principal Investigator: **G.L. Zhuravskaya**
Scientific and Research Institute of Irrigation, Bishkek, Kyrgyzstan

Collaborators: **I. Shainberg, I. Rapp, and D. Goldstein**
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A.I.D. Grant Project Officer: David Mulenex, American Embassy, Tel Aviv, Israel

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Executive Summary

Surface irrigation is the most widely used irrigation method in the world. In Kyrgyzstan, out of 1 million hectare of irrigated land, 85% is under furrow and surface irrigation. However, surface irrigation systems are relatively inefficient and only ~60% of the applied water reaches the root zone immediately after irrigation. The overall aim of the current project is to improve the technology and managerial practices regarding the use of polyacrylamide (PAM). In Israel laboratory studies focused (i) water quality and sodicity effects on soil consolidation and hydraulic conductivity in interrupted flow, (ii) effects of soil sodicity and irrigation water quality on erosion and intake rate in continuous and surge type flow furrow irrigation, and (iii) effects of wetting rate on intake rate and rill erosion. The results showed that application of interrupted flow enhanced soil surface consolidation, thereby increasing soil bulk density and decreasing soil hydraulic conductivity. The latter was more significant with the increase in soil sodicity. Conversely, water quality had no effect on soil consolidation. Intake rate and rill erosion were affected by sodicity and water quality in both continuous and interrupted flow.

In Kyrgyzstan, a field experiment similar to the one performed in the 2nd year was carried out to study the effects of surge irrigation and PAM application on furrow erosion, infiltration rates and crop yield. The results showed that with respect to erosion control PAM was the most effective treatment. With respect to intake rate, surge irrigation was the most effective treatment. Combined application of PAM with surge irrigation was not more effective than each alone. The highest yield of sugar beet was obtained in surge irrigation treatment.

Dr. Zhuravskaya visited Israel at the beginning of 2001 for discussion of results obtained during the 3rd year of the project and planing of future experiments.

Section I

A. Research Objectives

The overall objective of this proposal is to improve the technology and managerial practices regarding the use of PAM with an emphasis on PAM interactions with soil properties and field soil factors; all in order to better control furrow erosion and improve water infiltration and tailwater quality under surface irrigation.

More specifically, the research work will focus on studying the effects of (i) polymer properties (molecular weight and charge density); (ii) soil properties (texture, mineralogy exchangeable cations (Na, K, Ca and Mg), organic matter and $CaCO_3$ content); (iii) soil factors (aggregate size, rate of wetting, aging duration); and (iv) the interactions between polymer properties, soil properties and initial field soil conditions, on erosion, sediment concentration, infiltration, tailwater quality and crop yields in surface irrigation.

During the second year of the project the following studies were conducted:

1. In Israel – (laboratory studies)

a. Effects of surge application on soil consolidation and hydraulic conductivity.
b. Soil sodicity and water quality effects on intake rate and rill erosion
c. Effect of wetting rate and interrupted flow on intake rate and rill erosion

2. In Kyrgyzstan - (field experiment)

a. The effect of surge irrigation on furrow erosion and infiltration rates.
b. The effect of PAM on furrow erosion and infiltration rate.

B. Research Accomplishments

B.1 In Israel

The first study (Effects of surge application on soil consolidation and hydraulic conductivity) has been completed; results are now being summarized in a form of a scientific paper (see appendix A). The second study (Soil sodicity and water quality effects on intake rate and rill erosion) has been finished, and data are now summarized (see appendix B for a detailed description of the study and analysis of the data). The third study (Effect of wetting rate and interrupted flow on intake rate and rill erosion)) is near completion. Data are yet to be analyzed and summarized (see appendix C for a detailed

description of the study).

B.2. In Kyrgyzstan

The field experiment that was carried out at the same field used in the first year of the project. The experimental work consisted of two stages, a preparatory stage and the main part. The preparatory stage included: (1) leveling of the area with and determining the surface slope in the direction of the irrigation, (2) determination of soil infiltration capacity, and (3) testing the irrigation with the aim of determining the flow rate of the irrigation stream. In the main stage of the experiment sugar beet was grown. The study in the main part consisted of the determination of furrow erosion, and water losses of the flow rates lengthways of a furrow, as well as crop parameters (e.g., yield, green material etc.). during 4 consecutive irrigation events. The treatments studied were continuous flow and surge flow, each with or without addition of polymer to the irrigation water during the first irrigation event. A detailed description of the experiment and the results are presented in appendix D.

C. Scientific Impact of Collaboration

Both Dr. Levy and Dr. Zhuravskaya were deeply involved in the project throughout the entire year. The two investigators communicated regularly via electronic media and fax on the scientific and administrative aspects of the project.

D. Description of Project Impact

It is too early a stage to evaluate the impact of the project.

E. Strengthening of Developing Country Institution

The project enables a large scale field study on the improvement of furrow irrigation efficiency and reduction in furrow erosion with the aid of polymers and introduction of surge irrigation technology. The need for a study of this nature has long been recognized, but lack of funding prevented its execution. A large group of both scientists and technical staff of the Scientific and Research Institute of Irrigation (SRII), Kyrgyzstan, is involved in the project, and is thus exposed to the Israeli experience and expertise in the understanding of the chemo-physical aspects of soil erosion and infiltration, and the use of polymers to alleviate the latter problems Realization of the project allowed the SRII to retain valuable equipment necessary for conducting this and similar studies.

F. Future work

In the 4th year of the project, laboratory experiments in Israel (miniflume studies) will continue to focus on the effects of soil conditions (e.g., rate of prewetting and aging), water quality and composition of exchangeable cations on intake rate and erosion, together with testing the efficacy of new PAMs on controlling erosion in furrow irrigation. In Kyrgyzstan, laboratory studies on the hydraulic conductivity of a number of soils varying in their inherent properties will be carried out. In addition the field experiment will continue in a format similar to that of the former years.

Section II

A. Managerial issue: Not applicable

B. Budget: Not applicable

C. Special Concern: Not applicable

D. Collaboration, Travel, Training and Publications:

Dr. Zhuravskaya has visited Israel in the coarse of January 2001, to discuss the results of the 2nd year field experiment and to plan the 3rd year field experiment and additional laboratory experiments to complement the studies Mr. Sharsheveek did in Israel.

The study on the impact of surge application on infiltration and erosion in furrow irrigation has been published in Soil Sci. Soc. Am. J. 65:828-834 (2001) (see appendix E).

Appendix A

Water quality and sodicity effects on soil consolidation and hydraulic conductivity in interrupted flow

Introduction

Surface irrigation is the most common irrigation practice worldwide, but its water use efficiency is low (Wolters, 1992). Interrupted irrigation, which is the intermittent application of irrigation water during the advancement stage of furrow irrigation (Stringham, 1988), has potential to reduce infiltration rate (IR) and improve efficiency of surface irrigation by increasing field water application uniformity. In spite of much research (Izuno et al, 1985; Jalali -Farahani et al, 1993; Kemper et al., 1988; Samani et al., 1985; Trout, 1991), the processes involved in interrupted flow are still not fully understood and its effects on IR are difficult to predict.

Two basic phenomena have been identified during interruption of flow: (i) moisture redistribution in the soil profile; and (ii) consolidation of soil near the rill surface. During interruption of water application, water drainage into underlying dry soil and moisture redistribution result in the development of negative pressure suction near the soil surface. This negative pressure increases forces that pull water into the soil during the next flow period (Samani et al., 1985), and should increase IR. It has also been recognized that development of negative pressure in the soil surface during flow interruptions, consolidates soil near the rill surface, increases surface bulk density, and reduces hydraulic conductivity (HC) of this surface layer. Thus, this thin layer can have a significant effect of reducing water infiltration in succeeding irrigation events (Izuno et al, 1985 Jalali Farahani et al, 1993 Samani et al., 1985).

Reported changes in HC due to consolidation vary. Samani et al. (1983) studied in the laboratory changes in HC and bulk density (BD) of 4 wetted soils subjected to a series of matric potentials. In all soils, HC decreased and BD increased

with an increase in matric potential. Magnitude of changes in HC and BD resulting from consolidation of previously wetted soil depended on matric potential and varied among soils (Samani et al. 1983).

Saleh and Hanks (1989) tested in the field surge type flow in three soils, two of which, Nibley silty clay loam and Milville silt loam, had been also studied by Samani et al. (1983). Saleh and Hanks (1989) reported of consolidation and a significant reduction in HC following 30 min of drainage in the coarse textured Millville soil, and no consolidation and a non-significant reduction in HC in the fine textured Nibley soil. An opposite phenomenon with regard to consolidation and soil texture was found by Jalali-Farahani et al. (1993). They noted that consolidation due to matric suction was nearly 5 times greater in the fine textured Greeley soil than in the sandy Poudre soil. Jalali-Farahani et al. (1993) concluded that consolidation could not be the dominating factor reducing IR in coarse textured soils subjected to wetting and draining cycles (i.e, simulation for interrupted flow). Jalali-Farahani et al. (1993) further suggested that air entrapment during rewetting of drained soils could explain observed expansion in the Poudre soil and prevention of its consolidation in the subsequent draining event. However, effect of soil expansion on soil permeability was not clear; permeability could increase due to enhancement in void space, or decrease due to entrapped air.

Soil HC, whether of the soil profile or the upper soil layer (i.e., as in crusted soil), is strongly affected by electrolyte concentration of the soil solution and sodicity of soil (Shainberg and Levy, 1992, and references cited therein). The lower the concentration of the electrolytes and the higher the exchangeable sodium percentage (ESP), the lower the HC. Clay swelling and dispersion have been identified as responsible for sodicity and salinity related decreases in HC. These mechanisms

reduce HC by narrowing and/or blocking conducting pores, and by aggregate destabilization. Soil consolidation results from water exclusion from void space followed by reorientation, rearrangement and deformation of soil particles. We hypothesize, that soil consolidation during cycles of wetting and draining under matric potential could be affected by the level of electrolytes in irrigation water and ESP of the soil. Effects of water salinity and soil sodicity could also explain some of the variation reported in the literature, with regard to effects of consolidation on BD and HC.

The objective of the current study was to investigate effects of electrolyte concentration in irrigation water and soil sodicity on BD and HC (representative parameters for soil consolidation) during cycles of wetting and draining under matric potential in arable soils.

Materials and Methods

Soils

Two arable soil types were chosen for this study: alfisol (Calcic Haploxeralf) from Nevatim, northern Negev, and two vertisols (Chromic Haploxerert) one from Hafetz-Haim and the other from Qedma, the northern part of the Pleshet Plain, Israel. Samples from loess Nevatim and vertisol Hafetz-Haim were taken from adjacent fields in each location, one from a field irrigated with fresh water (low ESP) and the other from a field irrigated with treated waste water (medium ESP). Samples from vertisol Qedma were taken from a non-irrigated field having naturally occurring high ESP. Selected physical and chemical soil properties, determined by standard analytical methods (Klute, 1986; Page et al., 1986), are presented in Table 1.

Experimental procedure

Effects of matric potential which develops during off-time in interrupted flow on BD and HC were determined in the laboratory using a procedure similar to that of Samani et al. (1983).

Air-dried soil samples, crushed to pass through a 1.0 mm sieve, were placed in 65 mm i.d. funnels fitted with a fritted disk which had a nominal maximum pore size of 40-60 μm. Prior to placing a sample in the funnel, the disk was saturated from the bottom using a peristaltic pump at a wetting rate of 14.5 mm h^{-1}. After saturation of the disk, the sample was gently packed and smoothed in the funnel. Initial average height of dry samples was 2.6 and 2.8 cm, for Nevatim loam and Hafetz-Haim and Qedma sandy clays, respectively. Saturation of the soil sample was obtained by wetting it at a rate of 30.1 mm h^{-1}. After saturation, initial saturated soil height was measured and bulk density (BD) calculated. Thereafter, the sample was leached from the top of the funnel with a constant head device. Hydraulic head was maintained at 0.45 m resulting in hydraulic gradient of 16.7, 15.0 and 13.6, for alfisol, vertisol Hafetz Haim and vertisol Qedma, respectively. Leaching lasted for 5 min during which drainage water was collected and its volume recorded. After determining saturated HC, the sample was allowed to drain till free water reached the soil surface. The soil was then further drained by applying a matric potential of -1 J kg^{-1}. This was obtained by lowering the water column connected to the bottom of the funnel so that the meniscus in the pipette was 10 cm below the surface of the sample. Drainage under matric potential was applied for 6 min. At the end of the draining process, sample height was measured and BD calculated. Thereafter, the soil sample was re-saturated again by applying water from the bottom using the same wetting rate as before, and new saturated HC of the sample was measured. These steps were

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repeated 5 times, and matric potential was increased each time by -1 J kg^{-1} till it reached -5 J kg^{-1}. Control treatment consisted of leaching the sample for 30 min at zero matric potential (i.e., no application of suction). Outflow volume and soil sample height were recorded every 5 min. for determination of BD and HC.

Four water qualities differing in salinity were studied. Electrical conductivity (EC) of the water used was 0.01 (DW), 0.95 (TW), 2.0 (SW-L) and 4.0 (SW-H) dS m^{-1}. Sodium adsorption ratio (SAR) of each of the water types was adjusted to be equal exchangeable sodium percentage (ESP) of the soil under study. Sodium chloride (NaCl) and calcium chloride dihydrate ($CaCl_2 \cdot 2H_2O$) were used to prepare the solutions.

Each treatment (i.e., control or matric potential application X water quality X soil type X soil sodicity) was duplicated. Coefficient of variation between replicates was <10%.

Results

Examples of changes in BD and HC during continuous leaching without matric potential application vs. interrupted flow together with application of matric potential are presented in Figures 1 and 2. Changes in BD and HC of vertisol Hafetz Haim with ESP 5 subjected to continuous leaching with distilled water and without matric potential application showed a slight increase in from 1.02 to 1.04 g cm^{-3}, and a moderate decrease in HC from an initial value of 4.70 mm h^{-1} to 3.20 mm h^{-1} (Fig. 1). When leaching was interrupted by matric potential, BD increased with every increase in matric potential (Fig. 2). Some swelling was noted upon re-wetting at each step, but this re-swelling did not bring the soil back to its previous height; thus BD at the end of re-saturation was higher than BD at the previous step. Furthermore,

application of matric potential caused also a sharp decrease in HC to a about one quarter of the initial HC (Fig. 2). Similar trends were noted in other soils and treatments (data not presented).

Results of initial and final BD and HC for the various treatments are presented in Tables 2 and 3, respectively. Final BD and HC data refer to data measured at the end of 30 min leaching or after applied matric potential reached –5 J kg^{-1}. Final BD was higher than initial one when matric potential was applied (Table 2). For continuous leaching with no application of matric potential differences between final and intial BD were insignificant; however, a trend was noted whereby final BD was consistently higher than initial BD (Table 2). Final HC values were always lower than initial ones (Table 3). As noted in the example of Hafetz-Haim sandy clay (Figs. 1 and 2), decrease in HC after application of matric potential was by far greater than that observed when no matric potential was used (Table 3). This observation clearly demonstrated that conditions favoring consolidation have a marked negative effect on soil permeability.

In order to evaluate specific effects of water quality and soidcity on BD and HC under conditions of application and no application of matric potential we calculated the ratio of final BD and HC to its respective initial value. These ratios were termed relative BD and relative HC, respectively. As expected, higher relative BDs were noted in all soils when matric potential was applied compared to no application of matric potential (Figs. 3 and 4). However, in alfisol, electrolyte concentration of the soil solution and ESP had no effect on relative BD, irrespective whether matric potential was applied or not (Fig. 3a&b). In vertisol, similar to alfisol, electrolyte concentration of the soil solution and sodicity did not affect relative BD when no matric potential was applied (Fig. 4a). When matric potential was applied

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relative BD within a given ESP was similar for the different electrolyte concentrations used (Fig. 4b). However, a trend was noted whereby relative BD in the vertisol with ESP 12 and 20 was higher than that in the vertisol with ESP 1.9 and 5 (Fig. 4b).

Relative HC was generally lower when matric potential was applied compared to no application of matric potential (Figs. 5 and 6). In alfisol, for each matric potential treatment, similar relative HCs were obtained irrespective of ESP and electrolyte solution, but for DW (EC=0.01 dS m^{-1})(Fig. 5a&b). When DW was used, relative HC in loess was lower than that obtained in the other solutions. Furthermore, relative HC for DW decreased with an increase in ESP (Fig. 5a&b).

When no matric potential was applied relative HC in vertisol behaved similar to that in alfisol, i.e, it was not affected by ESP or electrolyte solution but for DW that caused a significant decrease in relative HC (Fig. 6a). Conversely, when matric potential was applied, relative HC decreased with an increase in ESP. Within a given ESP, relative HC generally increased with an increase in electrolyte concentration (Fig. 6b).

References

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Samani, Z.A., W.R. Walker, and L.S. Willardson. 1985. Infiltration under interrupted flow irrigation. Trans. ASAE 28:1539-1542.

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Table 1. Some basic physical and chemical properties of the soils used.

Soil type	Classification	Location	Particle-size distribution			CEC	ESP	$CaCO_3$	OM
			Clay	Silt	Sand				
			g kg^{-1}			$cmol_c$ kg^{-1}		%	%
Alfisol	Calcic Haploxeralf	Nevatim	234	166	600	14.9	2.7	18.2	1.2
			225	165	610	16.4	6.5	18.4	1.2
Vertisol	Typic Haploxerert	Hafetz-Haim	419	131	450	33.2	1.9	11.3	4.4
			375	150	475	31.0	5.0	9.12	2.5
		Qedma	550	200	250	41.6	12.0	13.0	3.0
			600	188	212	49.4	20.0	12.7	3.0

CEC = Cation exchange capacity
ESP = Exchangeable sodium percentage
OM = organic matter

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Table 2. Effects of soil type, sodicity and water quality on soil bulk density (BD)

Soil type	ESP	Water quality	With application of matric potential				No application of matric potential			
			Initial BD		Final BD		Initial BD		Final BD	
		dS m^{-1}	g cm^{-3}	sd	g cm^{-3}	sd	g cm^{-3}	sd	g cm^{-3}	sd
Alfisol	2.7	0.01	1.19	0.004	1.29	0.005	1.19	0.012	1.23	0.013
		0.95	1.17	0.044	1.28	0.034	1.19	0.012	1.20	0.008
		2.0	1.19	0.012	1.29	0.010	1.19	0.008	1.20	0.013
	6.5	0.01	1.15	0.016	1.27	0.014	1.15	0.000	1.16	0.004
		0.95	1.09	0.010	1.19	0.012	1.11	0.004	1.13	0.004
		2.0	1.10	0.004	1.21	0.000	1.11	0.004	1.13	0.007
		4.0	1.12	0.004	1.20	0.000	1.12	0.000	1.13	0.004
Vertisol (Hafetz	1.9	0.01	1.01	0.003	1.09	0.003	1.01	0.003	1.02	0.006
-Haim)		0.95	0.96	0.008	1.05	0.006	0.98	0.008	1.00	0.009
		2.0	1.00	0.009	1.05	0.000	1.01	0.009	1.02	0.009
		4.0	0.99	0.020	1.04	0.006	1.00	0.009	1.01	0.006
	5.0	0.01	1.02	0.006	1.11	0.004	1.02	0.003	1.04	0.000
		0.95	1.00	0.003	1.10	0.014	1.01	0.003	1.02	0.003
		2.0	1.02	0.012	1.12	0.015	1.03	0.000	1.05	0.003
		4.0	1.02	0.018	1.11	0.007	1.02	0.003	1.03	0.009
Vertisol (Qedma)	12	0.95	0.91	0.005	1.02	0.003	0.91	0.005	0.93	0.005
		2.0	0.92	0.005	1.04	0.003	0.93	0.010	0.94	0.013
		4.0	0.93	0.008	1.05	0.003	0.95	0.003	0.96	0.005
	20	0.95	0.86	0.007	0.96	0.003	0.86	0.002	0.87	0.000
		2.0	0.87	0.009	0.99	0.012	0.89	0.005	0.90	0.007
		4.0	0.90	0.007	1.01	0.009	0.91	0.002	0.92	0.010

Table 3. Effects of soil type, sodicity and water quality on soil hydraulic conductivity (HC)

Soil type	ESP	Water quality	With application of matric potential				No application of matric potential			
			Initial HC		Final HC		Initial HC		Final HC	
		dS m^{-1}	g cm^{-3}	sd	g cm^{-3}	sd	g cm^{-3}	sd	g cm^{-3}	sd
Alfisol	2.7	0.01	1.90	0.035	0.50	0.035	2.59	0.102	2.02	0.092
		0.95	2.61	0.436	1.18	0.165	2.64	0.100	2.26	0.102
		2.0	2.48	0.046	1.04	0.074	2.48	0.061	2.18	0.095
	6.5	0.01	1.94	0.048	0.33	0.058	1.82	0.090	1.09	0.077
		0.95	3.72	0.382	1.69	0.306	3.87	0.480	3.04	0.157
		2.0	3.51	0.082	1.61	0.184	3.22	0.143	2.83	0.088
		4.0	3.37	0.271	1.72	0.114	3.21	0.015	2.76	0.024
Vertisol (Hafetz	1.9	0.01	7.88	0.057	3.36	0.052	9.35	0.197	7.03	0.008
-Haim)		0.95	8.43	0.249	5.56	0.541	8.81	0.098	7.85	0.154
		2.0	9.30	0.509	6.54	0.456	9.10	0.455	8.38	0.495
		4.0	9.04	0.269	7.49	0.112	9.09	0.730	8.63	0.696
	5.0	0.01	4.75	0.277	0.94	0.104	4.69	0.401	3.20	0.230
		0.95	7.70	0.200	3.94	0.292	7.93	0.674	7.02	0.699
		2.0	8.10	0.013	4.80	0.493	7.84	0.283	6.88	0.044
		4.0	7.65	0.777	4.14	0.281	8.76	0.141	7.92	0.011
Vertisol (Qedma)	12	0.95	3.97	0.210	1.33	0.105	4.41	0.419	3.01	0.053
		2.0	4.30	0.303	1.54	0.061	4.40	0.362	3.44	0.357
		4.0	4.12	0.107	1.59	0.120	3.77	0.206	2.97	0.194
	20	0.95	1.79	0.206	0.42	0.019	1.60	0.075	0.95	0.029
		2.0	2.78	0.247	0.78	0.025	2.82	0.063	1.92	0.034
		4.0	3.77	0.562	1.39	0.022	3.01	0.087	2.35	0.049

Figure legend

Figure 1: Changes in hydraulic conductivity and bulk density when no matric potential was applied in Vertisol Hafetz Haim with ESP 5.

Figure 2: Changes in hydraulic conductivity and bulk density when matric potential was applied in Vertisol Hafetz Haim with ESP 5.

Figure 3: Relative bulk density in Alfisol as a function of exchangeable sodium percentage (ESP) and water quality for (a) no matric potential application, and (b) with matric potential application. Bars indicate one standard deviation.

Figure 4: Relative bulk density in Vertisol as a function of exchangeable sodium percentage (ESP) and water quality for (a) no matric potential application, and (b) with matric potential application. Bars indicate one standard deviation.

Figure 5: Relative hydraulic conductivity in Alfisol as a function of exchangeable sodium percentage (ESP) and water quality for (a) no matric potential application, and (b) with matric potential application. Within a matric potential treatment, columns labeled by the same letter do not differ at the 0.05 level.

Figure 6: Relative hydraulic conductivity in Vertisol as a function of exchangeable sodium percentage (ESP) and water quality for (a) no matric potential application, and (b) with matric potential application. Within a matric potential treatment, columns labeled by the same letter do not differ at the 0.05 level.

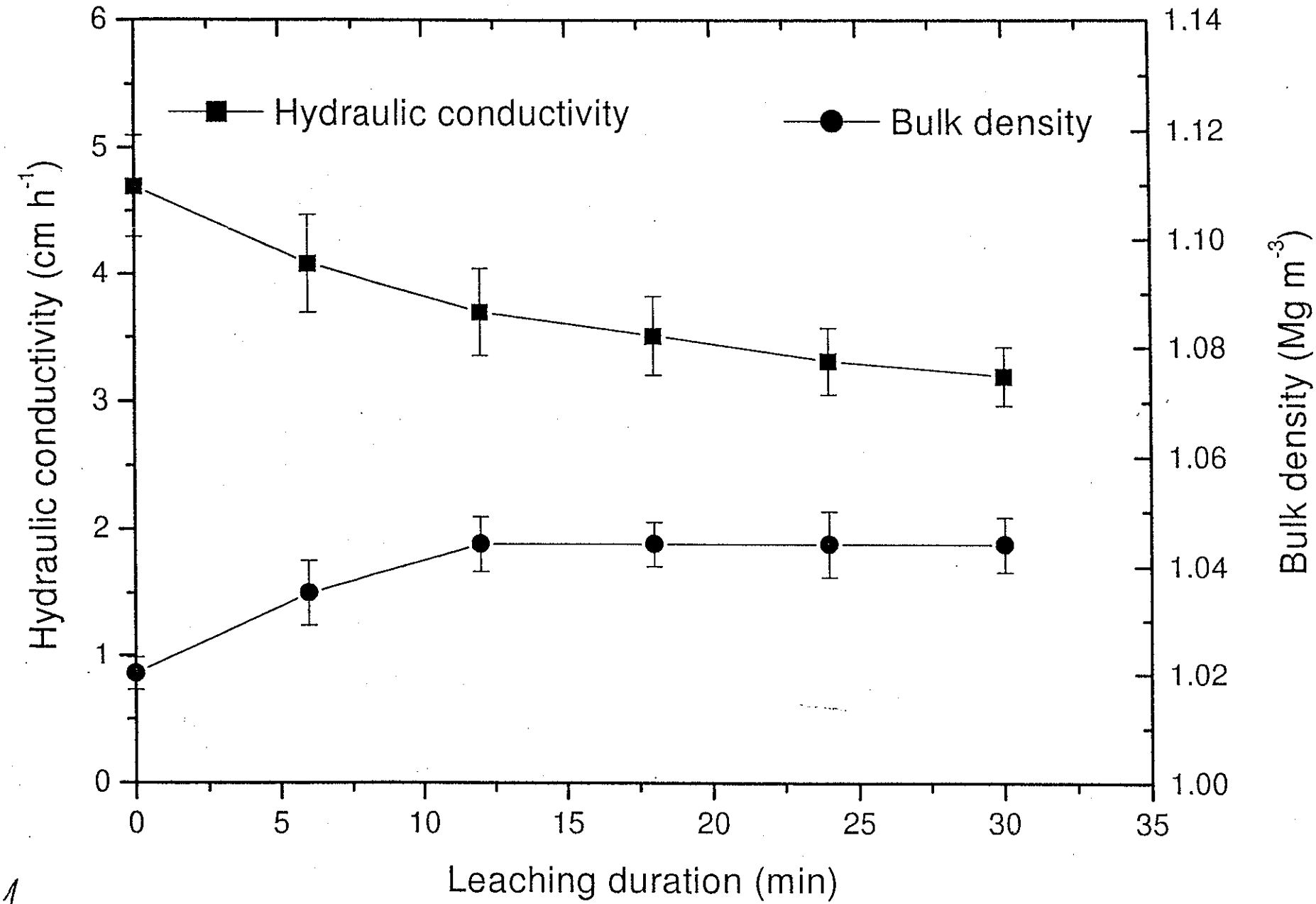
Hydraulic conductivity
Bulk density
Hydraulic conductivity (cm h-1)
Bulk density (Mg m-3)
Leaching duration (min)
0
1
2
3
4
5
6
1.00
1.02
1.04
1.06
1.08
1.10
1.12
1.14
0
5
10
15
20
25
30
35

Fig. 1

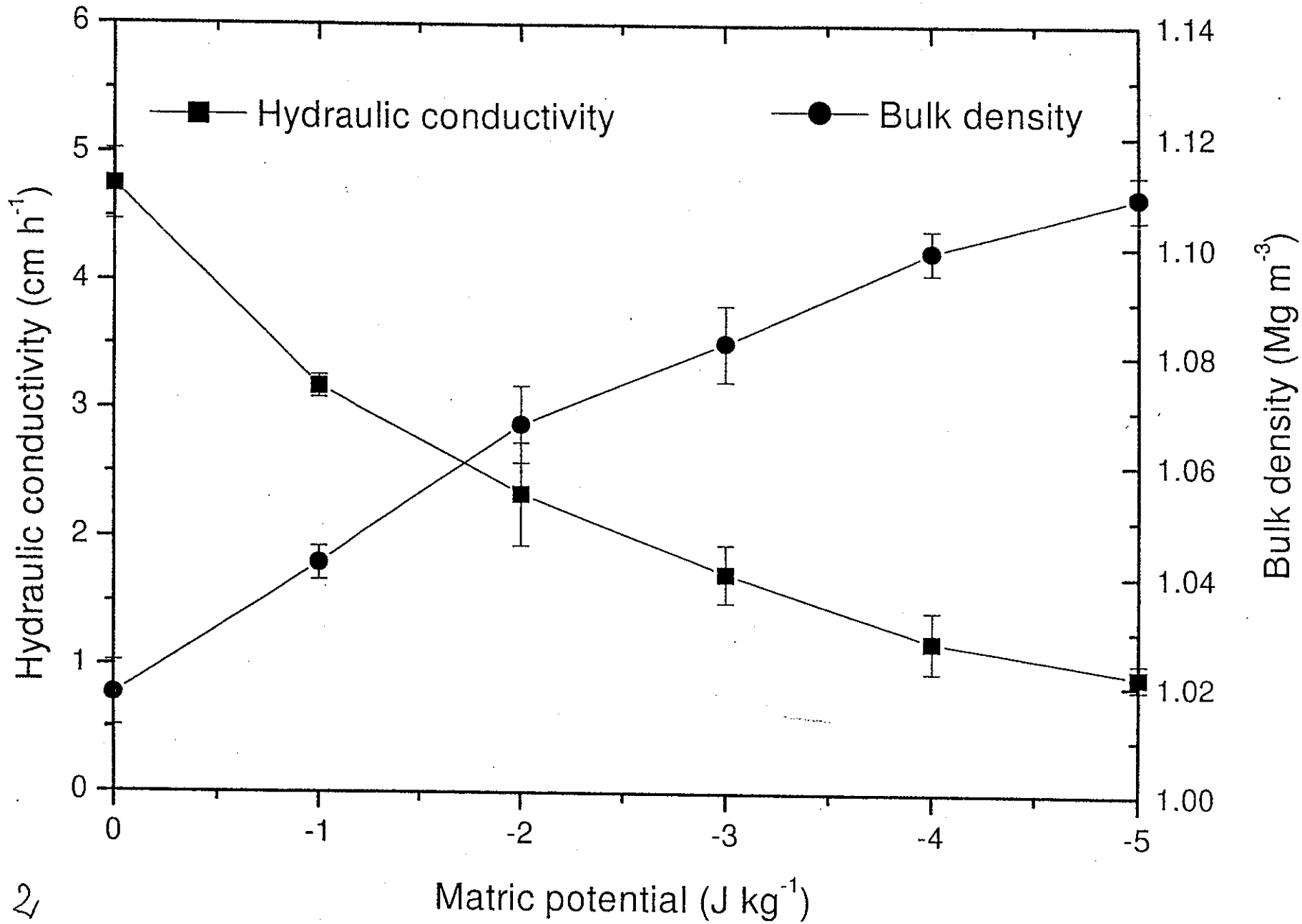
Hydraulic conductivity
Bulk density
Hydraulic conductivity (cm h-1)
Bulk density (Mg m-3)
Matric potential (J kg-1)
0
1
2
3
4
5
6
1.00
1.02
1.04
1.06
1.08
1.10
1.12
1.14
0
-1
-2
-3
-4
-5

Fig. 2

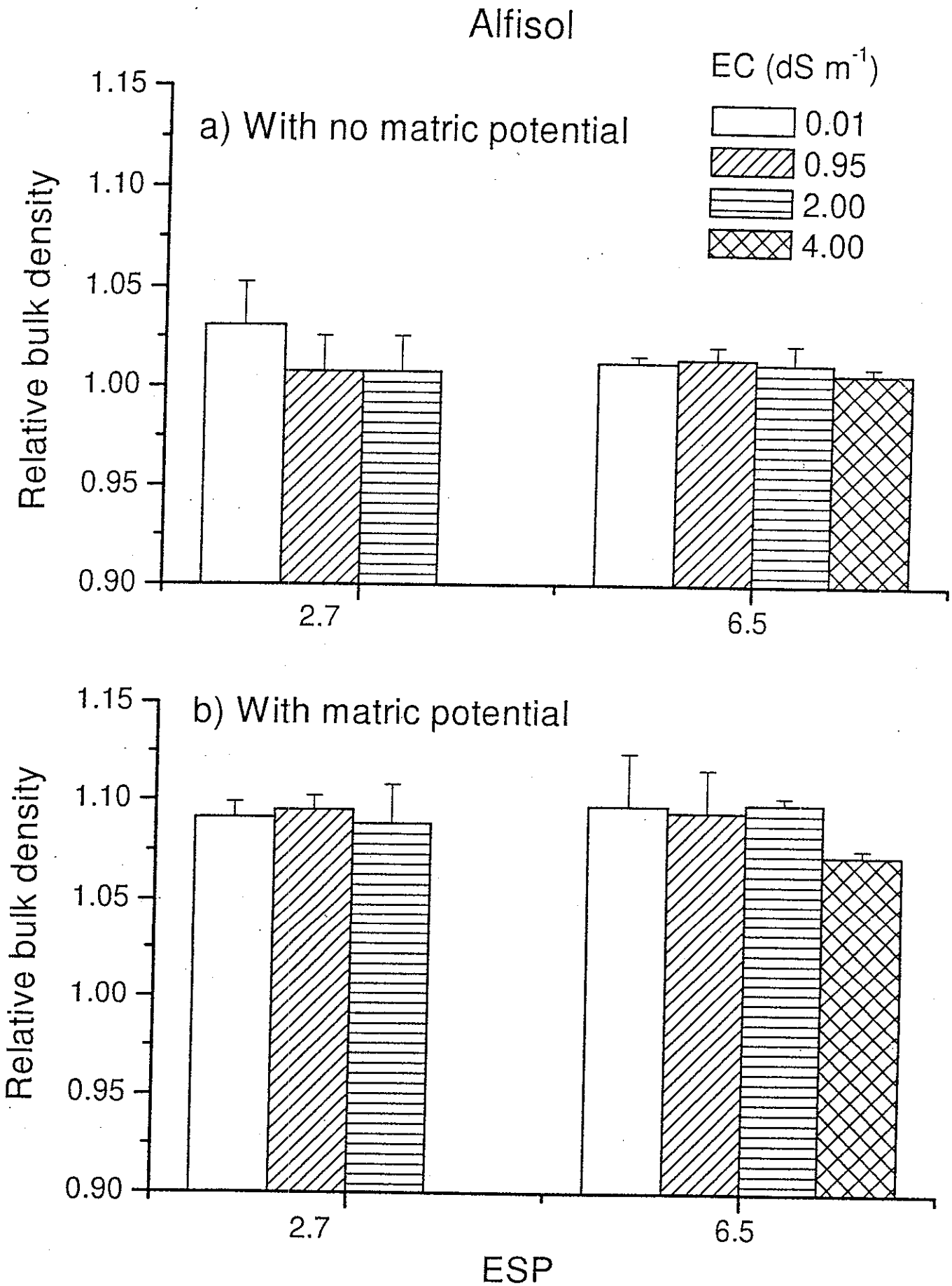
Alfisol
EC (dS m-1)
0.01
0.95
2.00
4.00
a) With no matric potential
b) With matric potential
Relative bulk density
1.15
1.10
1.05
1.00
0.95
0.90
2.7
6.5
ESP

Fig. 3

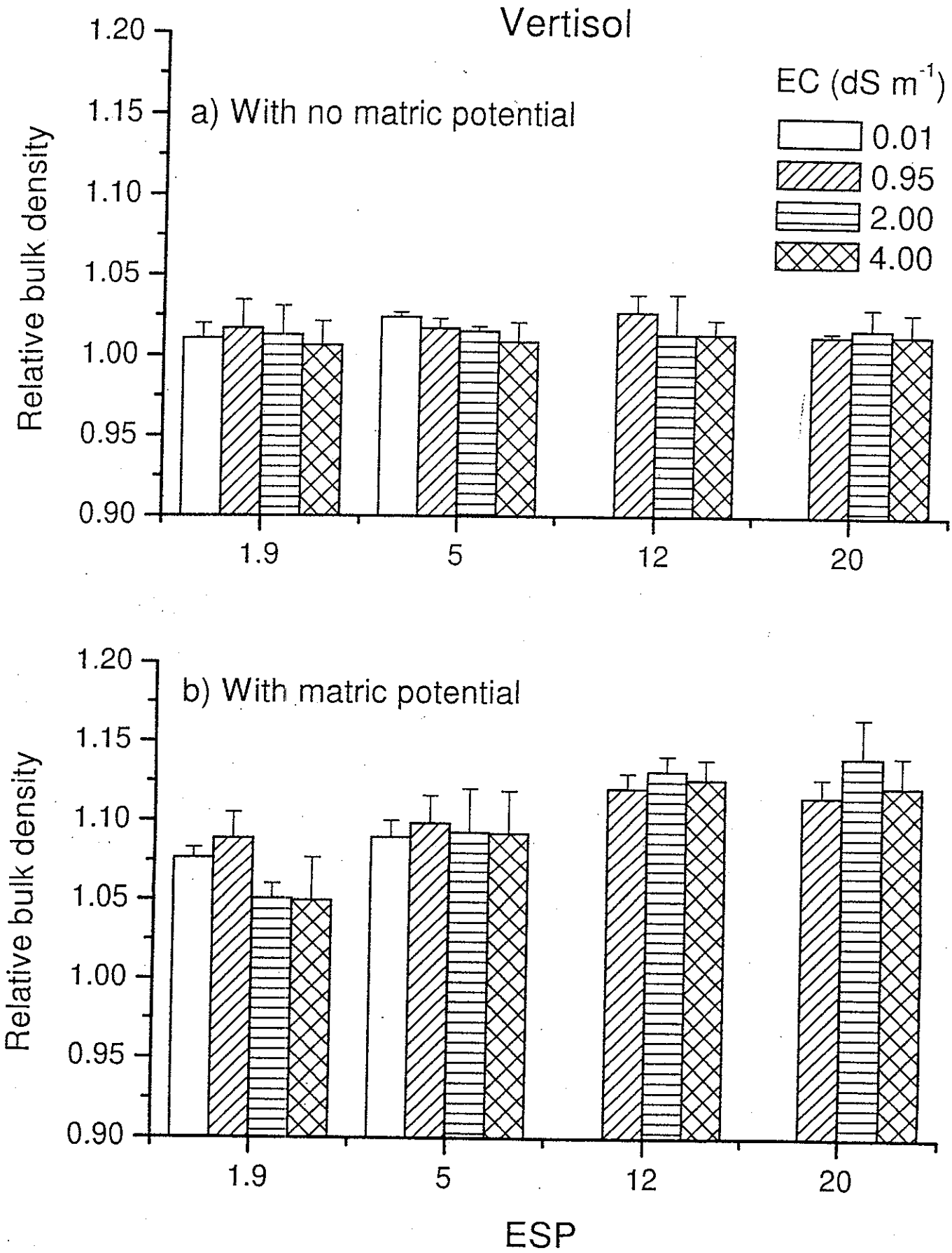
Vertisol
a) With no matric potential
EC (dS m-1)
0.01
0.95
2.00
4.00
Relative bulk density
1.20
1.15
1.10
1.05
1.00
0.95
0.90
1.9
5
12
20
b) With matric potential
Relative bulk density
1.20
1.15
1.10
1.05
1.00
0.95
0.90
1.9
5
12
20
ESP

Fig. 4

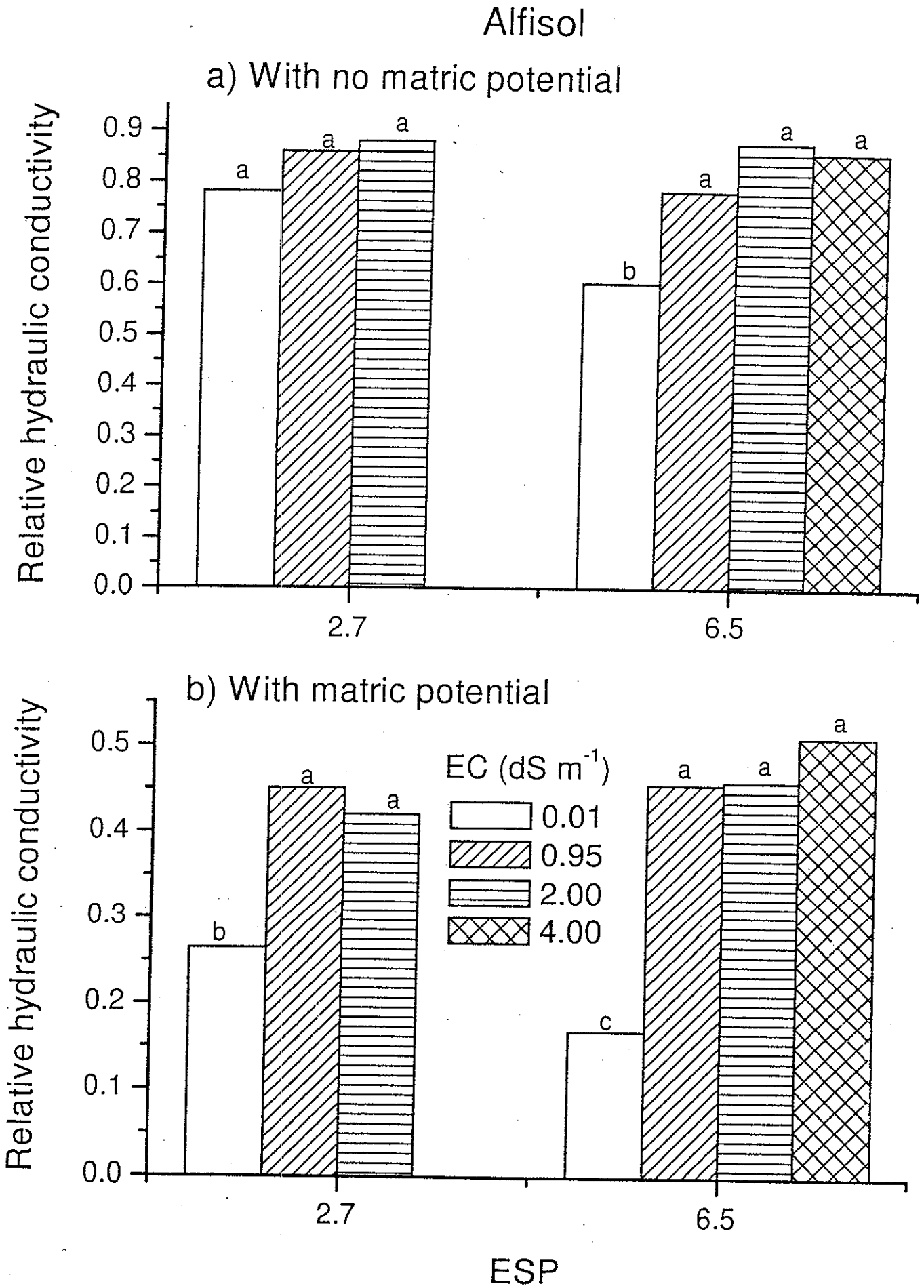
Alfisol
a) With no matric potential
Relative hydraulic conductivity
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
a
a
a
b
a
a
a
2.7
6.5
b) With matric potential
Relative hydraulic conductivity
0.5
0.4
0.3
0.2
0.1
0.0
b
a
a
c
a
a
a
EC (dS m-1)
0.01
0.95
2.00
4.00
2.7
6.5
ESP

Fig. 5

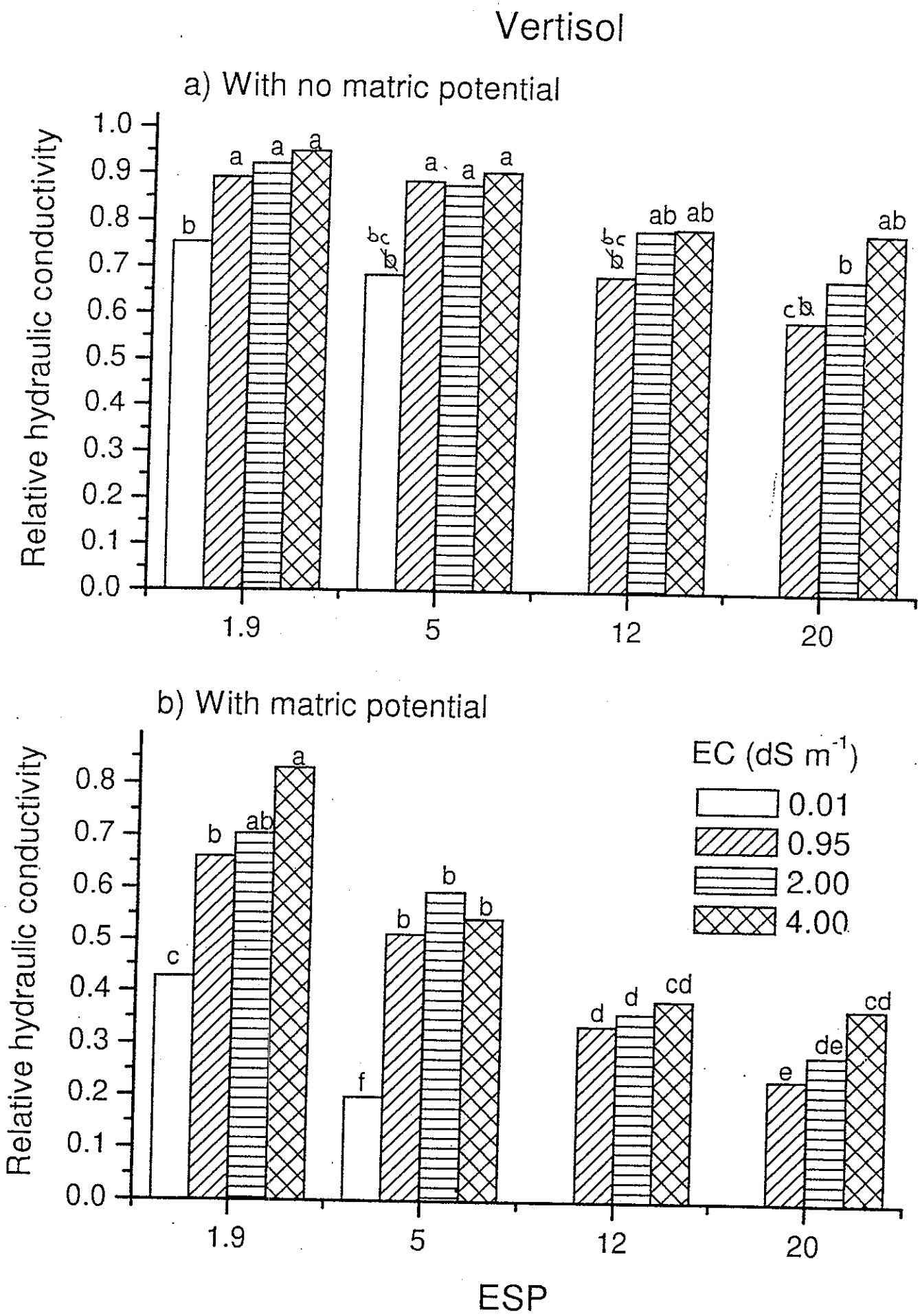
Vertisol
a) With no matric potential
Relative hydraulic conductivity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
b
a
a
a
bc
b
a
a
a
bc
b
ab
ab
cb
b
ab
1.9
5
12
20
b) With matric potential
Relative hydraulic conductivity
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
c
b
ab
a
f
b
b
b
d
d
cd
e
de
cd
EC (dS m-1)
0.01
0.95
2.00
4.00
1.9
5
12
20
ESP

Fig. 6

Appendix B

Soil sodicity and water quality effects on infiltration rate and rill erosion

ABSTRACT

The efficiency of surface irrigation is low because of low field uniformity, higher intake at upstream end and low intake at the end of the field. Surge irrigation, the intermittent supply of water to furrows, generally reduces soil intake rate and improves moisture uniformity over the entire field. However, IR varies from one irrigation scheme to another, depend on soil and water properties and difficult to predict. The effect of water quality and soil sodicity on IR and soil loss from short rills was simulated using miniflumes by interrupted and continuous flow. The infiltration rate was more sensitive to the sodicity of the soil and to the electrolyte concentration. The results showed that: (i) interrupted flow reduced soil loss in the vertisol and had had small effect on soil loss from the alfisol; and (ii) flow interruption reduced IR for all water qualities and soil sodicities of the alfisol, however, vertisol soil intake rate depended from water qualities and soil sodicities compared with contiuous flow.

MATERIALS AND METHODS

SOILS

Two arable soils of differing textures were chosen for this study: a silty loam alfisol (Calcic Haploxeralf) from Nevatim, in northern Negev, and a clay vertisol (Typic Chromoxerert) from Hafetz-Haim and Qedma, in the northern part of the Pleshet Plain, Israel. Two levels of exchangeable sodium percentage were taken from Hafetz-Haim. The ESP values of these two soil samples were 1.86% and 5%. The other two samples were taken from Qedma, having ESP levels of 12% and 20%. In the alfisol, one sample was taken from a field, irrigated with fresh water and its ESP was 2.7%. The other sample was taken from a field with treated waste water and its ESP was 6.5 Some basic physical and chemical properties of the soils are given in Table.1

Some basic physical and chemical properties of the soils used.

Soil	Classification	Particle-size distribution			CEC	ESP	$CaCO_3$	OM
		Clay	Silt	Sand				
		%	%	%	meq/100gm	%	%	%
Alfisol	Calcic	23.38	16.63	60	14.86	2.71	18.2	1.22
	Haploxeralf	22.5	16.25	61.25	16.38	6.5	18.44	1.2
Vertisol	Typic	41.88	13.13	45	33.16	1.86	11.26	4.44
	Chromoxerert	37.5	15	47.5	31.01	4.98	9.12	2.53
		55	20	25	41.57	11.82	13.01	2.96
		60	18.75	21.25	49.37	20.4	12.74	3

Rill infiltration and erosion- laboratory Miniflume study.

The experiments were carried out with a 0.5-m-long, 0.047-m-wide, and 0.12-m-deep flume; two 0.1-m-long V-shaped metallic rills were connected on both its sides. The flume was placed at a 10% slope in order to maintain high flow shear force.

Samples from the 0 - 250-mm depth were air-dried, crushed to pass through a 4-mm sieve, and slightly compacted in the flume to densities of 1.39 Mg mm^{-3} for the alfisol and 1.23 Mg mm^{-3} for the vertisol. The dry volume of the vertisol was slightly smaller than that of the alfisol. However, upon wetting and subsequent swelling, the final volume of the wet vertisol in the miniflume was similar to that of the alfisol. A V-shaped rill (44 mm wide and 22 mm deep) with a 90° angle between its sides was formed in the soil surface. Water was applied with a peristaltic pump to the upstream metallic rill, and sediments containing runoff water was collected from the downstream metallic rill in beakers. For more exact measurement of the applied water, the using water reserve was placed on an electronic balance, and the change in weight with time were recorded.

Four different levels of salinity were studied. The electrical conductivity (EC) of the water used were 0.01(DW), 0.95(TW), 2.0(SW-L) and 4.0(SW-H) dS m^{-1}. The sodium adsorption ratio (SAR) of each of the water types was adjusted to be equal to exchangeable sodium percentage (ESP) of the soils under study. Sodium chloride (NaCl) and calcium chloride dihydrate ($CaCl_2 \cdot 2H_2O$) were used to prepare these soil solutions.

Each individual experiment was divided into two stages. In the first stage either continuos (control) or interrupted flow was applied. The control treatment consisted of 4 min of flow; the interrupted flow treatment consisted of four cycles of 1

min of flow; and 10 min of interruption. Preliminary studies on the effect of off time on rill erosion and IR indicated that during <5 min, changes in IR and rill erosion were obtained but in off periods longer than 5 min the IR and rill erosion have been stabilized. In order to obtain a measurable outflow during the consecutive 4 min, the inflows applied to the vertisol and the alfisol were 320 and 240 mL m^{-1}, respectively. Total inflow, outflow, and soil loss were recorded for every minute of flow.

The second stage of the experiment started immediately at the end of the 4 min flow in the control or after completion of four cycles of interrupted flow treatment. Again in order to maintain similar flow and shear force in the rills, a continuous flow of 100 mL min^{-1} was maintained in the vertisol for 6 min and a continuous flow of 80 mL min^{-1} in the alfisol was used for 6 min too. Total inflow, outflow and soil loss, were recorded every minute for each soil.

The effect of water concentration, ESP and flow type was studied separately for the alfisol and for the vertisol. For each soil, the effects *three factors* (water concentration, ESP, flow type) on rill erosion and infiltration rate (IR) were considered. Three replicates were performed for each treatment.

For each measured IR and soil loss, a full factorial analysis of variance, based on the Standard Least Squares test (alpha=0.05), was applied. When an interaction between the three factors was found, the different levels of ESP, water concentration and flow type were compared each other. When no interaction was detected, each factor was studied individually, without distinction between the levels of the other factors

RESULTS

Effect of water quality and type of irrigation on rill erosion

Application of interrupted flow caused a significant reduction in rill erosion only in the vertisol. The high erodibility of the vertisol was ascribed to weak inter – aggrigates cohesion forces (Shainberg et al 1996). Vertisol with high clay content (Table 1) have a stable aggregated structure, with weak cohesive forces among soil particles, which in turn, made them more susceptible to transportability, compared with the aggregates of the alfisol.

The effects of interrupted flow on rill erosion rate for the alfisol and the vertisol are presented in figures 1-6 and tables 2 and 3. For both soils, most of the erosion took place during the first 4 min (stage 1 of the experiment) Fig. 18, when high flow rates exerting high shear stresses were used. No significant effect of interrupted flow on rill erosion in the alfisol was observed in this experiment, although the trends were in the same direction as those noted in the vertisol.

The effect of water quality (0.01[DW], 0.95 [TW], 2.0[SW-2] and 4 [SW-4] dS m^{-1} on rill erosion under the surge and continuous flow were studied. When the ESP was high (ESP 20 for vertisoil) increasing the electrolyte concentration from 0.01 to 0.95 dS m^{-1}, increased the erodibility, and was unchanged when electrolyte concentration increased to 2.0 and 4.0 dS m^{-1} for the surge and the continuous flow Fig. 6 . However, in the vertisol with ESP 12 the effect of the electrlyte concentration had conversely action to 2.0 dS m^{-1} for the continuous and to 0.95 dS m^{-1} for surge flow, i.e. decreased Fig. 5 . The same increase in the electrolyte concentration decreased the rill erision in the vertisol with ESP 5 for continuous flow, and not affected on the soil in the surge flow rate with the same ESP Fig. 4. The alfisol soil (ESP 6.5) rill erosion

decreased but decreasing rill erosion stopped on 0.95 dS m^{-1} and unchanged to 4.0 dS m^{-1} for the surge and the continuous flow Fig. 2. The rill erodibility in the low ESP on the both soils (ESP $\leq$ 2.7) was not affected by the electrolyte concentration for the surge and the continuous flow Figures 1 and 3.

Soil particles at the rill bed are held by interparticle cohesive forces (and gravity) against the shear stress of the flow. Low electrolyte concentration in the solution and high ESP enhance clay swelling and dispersion, leading to an easier breakdown of the soil aggregates (Agassi et. al., 1981; Kazman et al. 1983). In sodic soils the ability of the clay particles to cement adjacent soil particles (or being cemented) is diminished by the presence of exchangeable sodium on the external surfaces of quasicrystals and increasing the concentration of the soil solution reduces the tendency of the clay particles to disperse and improve the development cohesive forces. Therefore, when dispersion condition prevailed (ESP$\geq$ 5), increasing the electrolyte concentration of the eroding water decreased the erodibility of the soils. It was noted in the continuous irrigation ESP 5 and ESP 12 in the vertisol Figures 4 and 5. However, in the moderate and high ESP levels of the vertisol soil by surge irrigation where developed a negative pressure in the upper layer of the soil during the off period, increasing the electrolyte concentration of the eroding water increases the intraaggregate cohesion forces. Consequently, it increases the relative number of microaggregates and their stability while reduces interaggregate cohesion forces and increases the transportability of soil particles and the erodibility of the soil Figures 4-6. The results with low ESP soils are explained by following observations. At low ESP levels for continuous and surge irrigation, spontaneous dispersion dose not occur (Rengasamy et al, 1984) and, hence, mechanical dispersion of clay is the main

mechanism. Therefore increasing the electrolyte concentration of the eroding water had no effect on preventing rill erodibility for both flow type.

Effect of sodisity on soil loss

The effect of ESP on the soil erodibility is presented in Fig. 15. It is evident that RE increased with an increase in soil ESP for both flow type. Increasing soil ESP increased the repulsion forces between clay particles clay surface (Van Olphen, 1977) and decreased cohesion forces between clay particles. Thus leading to increase in soil particles detachment and increased soil erodibility. Also the size of soil particles decreased with increase in soil (Abu-Sharar, 1988) and the transportability of the detached microaggregates was higher.

Effect of water quality and flow type on intake rate.

The data from all experiments conducted are given in Tables 4 and 5. The effect of electrolyte concentration (0.01[DW], 0.95 [TW], 2.0[SW-2] and 4 [SW-4] dS m^{-1}) on intake rate (IR) under the surge and continuous flow were studied. When ESP of the vertisol was high (ESP 12 and ESP20) increasing the electrolyte concentration from 0.01 to 4.0 dS m^{-1} increased IR of the soils for both type of irrigation, but interrupted flow had no effect when electrolyte concentration was 0.01 dS m^{-1} Figures 11 and 12. In ESP 12 of the vertisol increasing IR stopped under 2.0 dS m^{-1} Fig. 11. Interrupted flow where ESP of the vertisol soil was low (ESP 2) increasing the electrolyte concentration to 0.95 dS m^{-1}, had tendency to increasing IR and was unchanged when electrolyte concentration increased to 4.0 dS m^{-1} The same increase in the electrolyte concentration decreased IR in the continuous flow Fig 9. In the alfisol soil with low

level of ESP the electrolyte concentration has small effect, if compare surge and continuous irrigation, interrupted flow was more effective in decreasing the intake rate than in the vertisol soil Fig. 7.

Effect of sodisity on Intake Rate

Comparing action of ESP on the intake rate we observed following data. When ESP of the vertisol and the alfisol soils were low their intake rates were high figures 13 and 14. At the moderate ESP of the alfisol (ESP 6.5) interrupted flow was more effective in reducing the IR for all water qualities, but vertisol soil (ESP5) lost effect of interrupted flow under 4.0 (SW-H) dS m^{-1} Fig. 9. The IR of the vertisol soil, in the ESP12 dramatically decreased and decreasing the IR was continued by ESP20. It explains that the IR is sensitive to soil sodisity.

SUMMARY

The effects of ESP and water quality on effect of interrupted flow on intake rate and rill erosion was studied in a silty loam alfisol and a clay vertisol, using miniflumes. In both soils, intake rate reduced when ESP was increasing by interrupted and continue flow. The increasing the electrolyte concentration of water in the vertisol with low level of ESP soil interrupted flow had deleterious affect on IR. However, interrupted flow redused IR in both soils compared with that obtained in the continuous flow. This reduction in IR was more effective in the alfisol than in the vertisol. The effect of interrupted flow in reducing the IR depended on application of water quality mainly in the vertisol soil.

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INTAKE RATE
Vertisol soil

Table 2

Time, min	SURGE IRRIGATION															
	0.01 dS/m (DW)				0.95 dS/ m (TW)				2.0 dS/m (SW-L)				4.0 dS/m (SW-H)			
	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20
1	274.82	303.25	143.29	188.67	299.98	310.66	197.38	213.51	300.39	296.49	293.70	250.60	281.68	308.05	260.65	240.26
2	87.73	110.73	16.17	28.49	97.35	116.06	32.86	26.52	104.14	104.75	51.61	32.34	99.16	121.93	51.61	37.78
3	77.20	90.45	14.71	18.07	89.11	99.93	30.85	25.78	94.92	90.34	48.87	31.74	93.50	108.68	47.53	36.35
4	71.32	82.46	13.61	13.67	84.74	94.60	28.90	23.49	89.68	86.69	47.64	29.52	88.56	98.49	45.53	33.95
5	57.03	62.20	17.00	19.23	67.32	78.37	28.96	25.89	71.38	69.28	47.46	31.33	70.86	82.81	44.66	34.33
6	34.61	40.06	4.39	2.26	39.83	46.87	14.15	8.86	42.28	40.83	22.96	11.03	42.91	41.66	23.50	14.46
7	33.19	36.87	4.75	2.86	35.98	43.10	14.15	7.43	38.23	36.71	21.95	9.91	40.88	40.19	20.68	13.55
8	32.12	36.39	5.16	2.76	37.03	42.44	13.39	6.67	38.75	36.34	21.06	10.24	39.19	39.30	22.21	12.89
9	32.48	37.69	3.56	2.42	36.82	41.58	15.00	7.73	37.26	36.17	22.29	10.08	39.82	37.23	21.72	12.97
10	28.14	32.60	0.53	2.83	32.78	37.05	7.06	2.57	33.73	31.40	19.76	2.05	36.89	42.30	17.17	7.38
TOTAL	728.64	832.70	223.19	281.27	820.94	910.65	382.68	348.43	850.76	828.99	597.31	418.84	833.46	920.65	555.26	443.92
stdv	25.40	7.02	8.35	25.79	11.69	8.88	12.65	26.57	23.73	10.28	23.23	5.69	12.72	3.85	15.77	28.02

Time, min	CONTINUE IRRIGATION															
	0.01 dS/m (DW)				0.95 dS/ m (TW)				2.0 dS/m (SW-L)				4.0 dS/m (SW-H)			
	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20
1	308.00	307.80	150.72	218.92	317.99	305.59	221.82	238.68	298.19	295.40	275.73	254.85	243.00	294.99	266.65	263.79
2	129.71	152.74	16.88	28.22	157.60	141.76	66.31	43.31	118.24	140.25	85.12	52.01	111.46	144.54	96.81	59.49
3	90.61	104.80	15.86	10.81	102.65	100.44	48.51	31.63	82.54	102.35	58.68	34.65	77.00	104.61	61.44	43.47
4	74.82	76.44	12.59	4.47	81.45	83.24	42.74	27.98	66.76	82.26	49.19	30.48	66.61	84.96	43.03	36.71
5	41.10	56.70	2.17	4.49	51.58	60.28	23.01	9.97	42.75	52.71	25.43	16.48	45.87	53.33	30.06	19.92
6	59.46	63.63	9.18	3.86	58.20	63.71	33.73	23.37	51.57	57.59	39.94	27.51	54.17	58.39	41.20	30.90
7	51.34	54.34	9.24	4.56	52.42	58.60	30.75	20.45	46.43	50.93	35.90	24.94	48.69	53.08	38.78	29.52
8	45.92	50.95	8.45	3.15	48.36	51.44	29.91	19.82	42.91	45.61	33.77	22.57	46.54	48.13	36.60	28.24
9	42.86	44.91	8.14	2.11	44.04	48.13	27.29	18.41	39.24	41.53	32.30	21.35	42.47	43.89	33.98	25.85
10	36.21	37.80	0.58	0.84	38.79	41.70	22.67	10.22	32.73	34.58	27.51	15.49	35.77	38.14	28.45	21.33
TOTAL	880.04	950.10	233.81	281.42	953.08	954.89	546.74	443.84	821.35	903.22	663.56	500.32	771.57	924.05	677.02	559.22
stdv	48.50	24.10	17.79	7.20	10.78	21.25	18.76	9.31	16.78	13.68	24.51	11.41	7.30	37.06	20.99	17.19

stdv - standard deviation among replicates

INTAKE RATE
Alfisol soil

Table3

Time, min.	SURGE IRRIGATION								CONTINUE IRRIGATION							
	0.01 dS/m (DW)		0.95 dS/ m (TW)		2.0 dS/m (SW-L)		4.0 dS/m (SW-H)		0.01 dS/m (DW)		0.95 dS/ m (TW)		2.0 dS/m (SW-L)		4.0 dS/m (SW-H)	
	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5
1	179.59	206.34	202.30	160.50	174.83	176.33	182.20	192.74	188.93	190.52	207.97	172.85	181.26	174.68	183.05	184.68
2	73.20	65.61	85.09	50.07	71.65	58.12	76.39	64.45	86.39	81.81	111.47	83.09	90.59	81.29	96.79	94.60
3	62.37	54.39	71.84	42.23	61.42	51.11	69.62	54.08	60.44	57.88	72.80	58.12	66.52	57.43	70.38	64.25
4	56.28	47.22	63.67	38.95	53.79	47.26	55.47	48.95	53.93	42.92	61.81	47.84	56.53	47.71	57.54	54.06
5	45.24	40.94	52.14	35.13	44.20	43.56	48.79	43.92	37.82	30.50	39.30	29.23	38.17	30.00	40.80	35.26
6	26.99	22.30	31.26	19.73	27.87	21.53	28.44	26.82	40.87	35.38	48.65	34.87	41.37	35.49	43.18	38.98
7	24.33	20.50	27.01	18.69	25.77	20.36	25.81	23.71	39.42	32.14	42.92	31.88	40.01	33.85	38.94	35.25
8	23.61	20.26	27.03	19.72	25.74	21.14	24.64	24.97	36.90	31.34	41.52	29.32	33.90	30.50	37.22	33.31
9	25.89	19.74	25.64	19.01	25.13	20.55	24.60	23.93	33.40	28.54	36.21	28.27	33.59	28.84	34.18	31.17
10	21.67	16.46	23.87	17.03	22.62	18.24	22.12	22.40	30.81	22.89	31.61	24.09	30.70	25.17	31.98	34.57
TOTAL	539.18	513.75	609.87	421.06	533.02	478.19	558.08	525.97	608.91	553.93	694.26	539.56	612.65	544.97	634.06	606.11
stdv	29.32	7.05	33.46	7.72	10.29	7.49	15.06	17.71	24.11	7.00	21.36	6.53	21.95	11.06	10.74	8.69

stdv - standard deviation among replicates

35

SOIL LOSS
Vertisol soil

Table 4

Time, min	SURGE IRRIGATION															
	0.01 dS/m (DW)				0.95 dS/ m (TW)				2.0 dS/m (SW-L)				4.0 dS/m (SW-H)			
	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20
1	1.71	0.98	20.55	6.97	1.02	0.84	10.94	15.30	1.35	1.60	5.72	12.52	2.08	1.02	7.51	10.82
2	5.39	6.84	2.59	5.47	6.49	7.76	4.89	4.81	6.74	10.45	18.24	7.81	3.68	10.36	13.93	7.86
3	3.93	4.65	0.41	2.12	3.02	4.19	1.20	1.06	4.67	4.99	5.49	2.51	2.42	5.88	4.51	3.22
4	2.19	3.94	0.22	1.18	2.79	2.88	0.56	0.51	3.30	2.75	2.81	1.12	1.83	3.27	2.78	2.01
5	0.10	0.06	0.01	0.08	0.15	0.05	0.05	0.05	0.13	0.08	0.11	0.10	0.12	0.05	0.27	0.21
6	0.11	0.22	0.01	0.10	0.26	0.26	0.07	0.06	0.25	0.22	0.16	0.13	0.28	0.29	0.38	0.25
7	0.14	0.35	0.01	0.12	0.25	0.46	0.08	0.06	0.28	0.24	0.15	0.13	0.26	0.36	0.35	0.25
8	0.13	0.23	0.01	0.14	0.14	0.41	0.09	0.07	0.23	0.20	0.15	0.12	0.31	0.43	0.41	0.25
9	0.06	0.18	0.01	0.13	0.14	0.49	0.09	0.06	0.19	0.25	0.48	0.13	0.25	0.54	0.37	0.25
10	0.06	0.20	0.02	0.17	0.13	0.53	0.10	0.08	0.28	0.20	0.14	0.14	0.25	0.51	0.32	0.27
TOTAL	13.81	17.65	23.83	16.49	14.38	17.86	18.09	22.06	17.42	20.98	33.45	24.70	11.49	22.71	30.83	25.38
stdv	1.17	0.76	0.78	0.51	3.93	2.12	0.2	2.07	3.44	0.86	1.9	1.92	1.88	4.27	1.79	1.28

Time, min	CONTINUE IRRIGATION															
	0.01 dS/m (DW)				0.95 dS/ m (TW)				2.0 dS/m (SW-L)				4.0 dS/m (SW-H)			
	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20	ESP 2	ESP 5	ESP12	ESP20
1	1.42	0.72	20.26	4.72	0.17	0.71	10.08	13.36	1.20	0.90	7.84	10.01	2.00	1.53	6.79	8.91
2	5.50	7.43	13.75	9.57	3.76	5.42	16.15	16.75	4.33	6.89	10.83	16.62	4.59	4.66	10.43	16.05
3	5.23	14.12	6.01	8.10	3.61	12.20	8.61	7.68	5.20	8.00	5.13	10.18	5.91	6.17	11.97	10.07
4	7.54	20.06	3.38	8.06	5.77	14.35	4.88	5.41	6.51	10.17	5.59	6.63	6.93	9.48	13.92	9.59
5	1.98	3.79	0.65	1.91	1.00	3.17	0.86	1.01	1.41	3.19	1.97	1.06	1.76	2.95	2.53	1.61
6	0.16	1.21	0.44	0.70	0.09	0.72	0.18	0.28	0.21	0.77	0.61	0.24	0.66	0.99	0.69	0.30
7	0.21	1.60	0.34	0.76	0.13	0.88	0.22	0.34	0.19	1.16	0.53	0.31	0.81	0.98	0.54	0.27
8	0.24	1.95	0.28	1.08	0.10	1.32	0.20	0.31	0.18	1.45	0.47	0.32	0.88	1.28	0.42	0.24
9	0.10	2.28	0.33	1.14	0.09	1.27	0.21	0.26	0.25	1.80	0.37	0.26	1.39	1.78	0.45	0.31
10	0.28	2.26	0.27	0.99	0.20	1.99	0.24	0.40	0.23	1.57	0.35	0.31	1.69	3.05	0.53	0.31
TOTAL	22.66	55.43	45.69	37.04	14.92	42.03	41.63	45.81	19.72	35.90	33.69	45.94	26.63	32.86	48.27	47.66
stdv	3.47	1.17	7.84	3.33	4.92	2.19	4.8	1.99	8	3.91	2.03	5.23	5.56	0.43	5.99	4.86

stdv - standard deviation among replicates

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SOIL LOSS
Alfisol soil

Table 5

Time, min	SURGE IRRIGATION								CONTINUE IRRIGATION							
	0.01 dS/m (DW)		0.95 dS/ m (TW)		2.0 dS/m (SW-L)		4.0 dS/m (SW-H)		0.01 dS/m (DW)		0.95 dS/ m (TW)		2.0 dS/m (SW-L)		4.0 dS/m (SW-H)	
	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6,5	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5	ESP 2.7	ESP 6.5
1	0.40	0.76	0.58	0.83	0.39	0.84	0.46	0.69	0.43	0.69	0.50	0.80	0.59	0.78	0.44	0.67
2	0.66	3.00	1.71	0.57	0.65	1.65	1.22	1.38	0.27	2.86	1.08	1.03	1.04	1.29	0.86	1.03
3	0.34	1.75	0.84	0.34	0.55	1.27	1.43	0.94	0.43	4.18	0.87	1.33	1.30	1.02	0.95	1.23
4	0.36	1.14	0.67	0.29	0.54	1.25	1.38	0.72	0.75	5.18	1.22	1.13	1.37	1.28	1.00	1.19
5	0.02	0.05	0.03	0.06	0.06	0.10	0.13	0.13	0.09	0.88	0.28	0.18	0.52	0.27	0.25	0.30
6	0.04	0.12	0.05	0.05	0.09	0.15	0.21	0.19	0.03	0.42	0.07	0.05	0.11	0.13	0.15	0.17
7	0.04	0.20	0.05	0.06	0.08	0.16	0.21	0.19	0.04	0.47	0.08	0.06	0.14	0.12	0.15	0.18
8	0.03	0.17	0.06	0.07	0.08	0.15	0.19	0.20	0.05	0.62	0.10	0.08	0.13	0.16	0.17	0.23
9	0.03	0.22	0.05	0.06	0.10	0.15	0.20	0.19	0.04	0.51	0.10	0.10	0.11	0.15	0.18	0.21
10	0.02	0.30	0.04	0.06	0.09	0.14	0.20	0.20	0.03	0.60	0.17	0.08	0.17	0.18	0.18	0.20
TOTAL	1.93	7.71	4.06	2.37	2.63	5.86	5.64	4.82	2.18	16.41	4.46	4.84	5.48	5.38	4.33	5.42
stdv	0.31	1.31	0.52	0.38	0.47	0.66	1.05	0.34	0.51	2.21	0.62	1.50	1.01	1.02	0.72	0.30

stdv - standard deviation among replicates

37

SOIL LOSS

Fig. 1

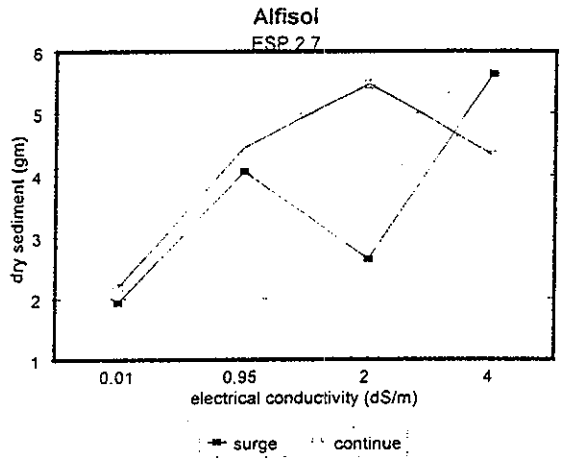


Fig.2

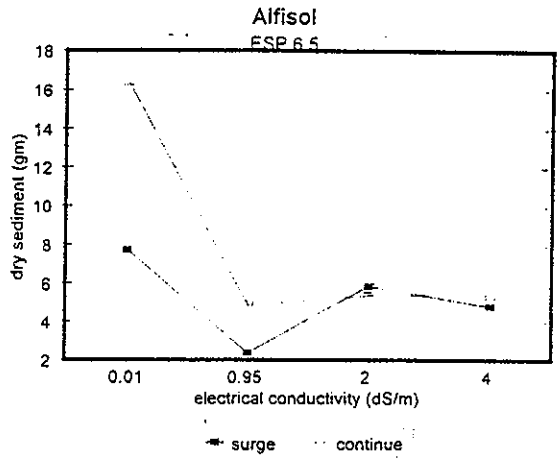


Fig. 3

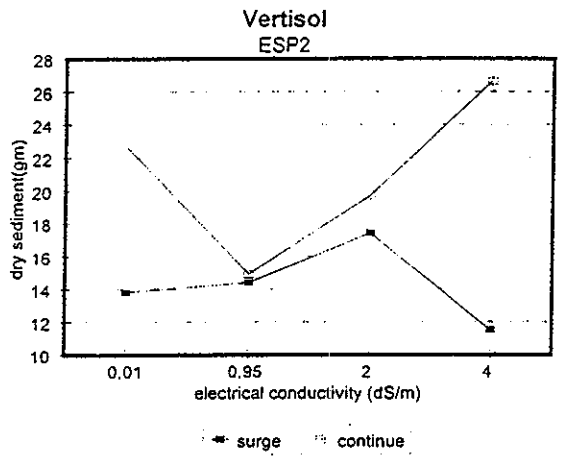


Fig.4

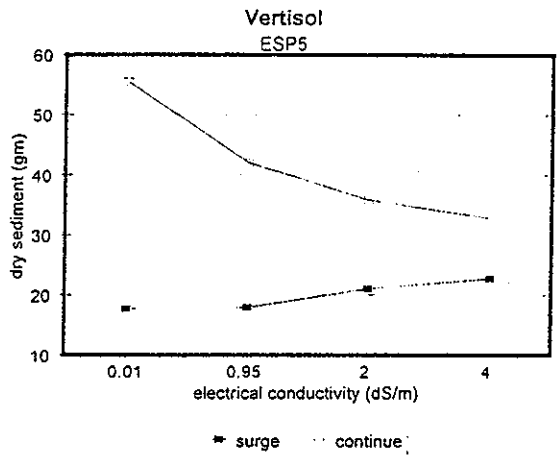


Fig.5

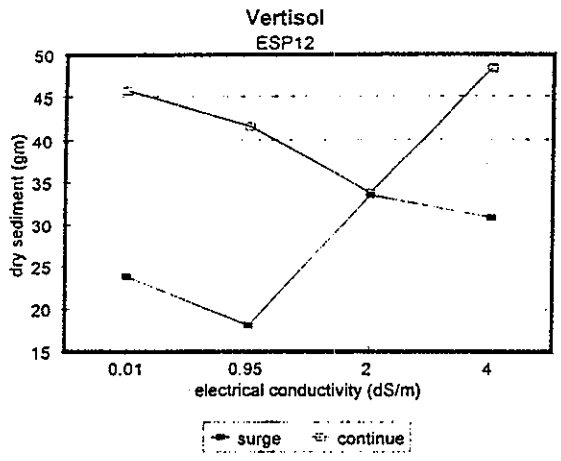
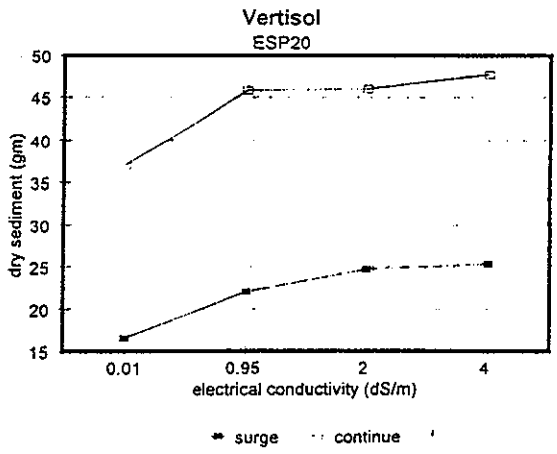


Fig.6



INTAKE RATE

Fig 7

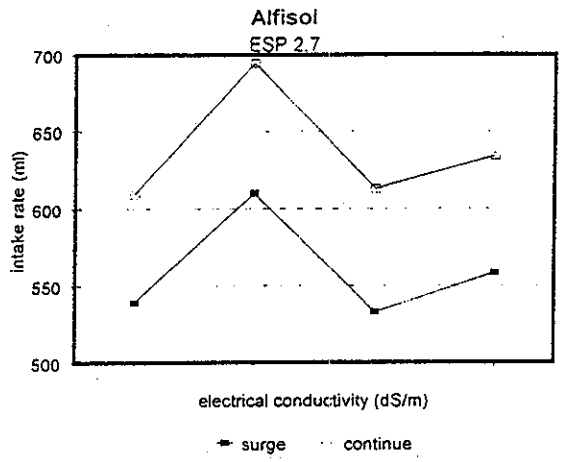


Fig 8

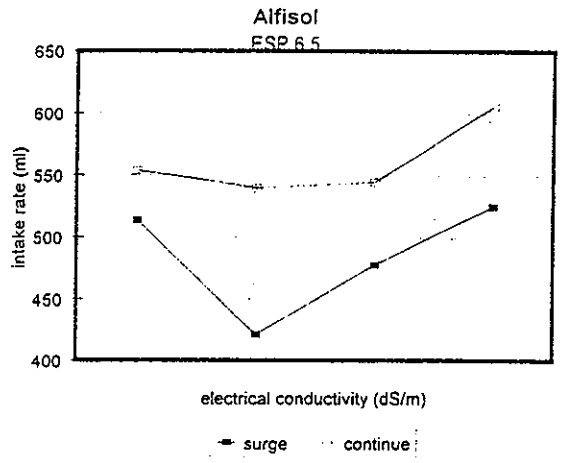


Fig 9

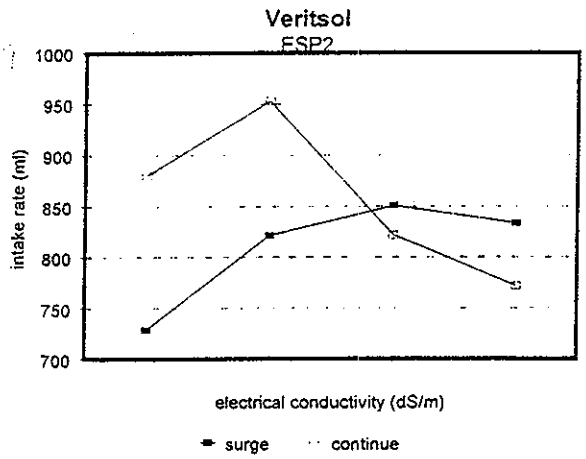


Fig 10

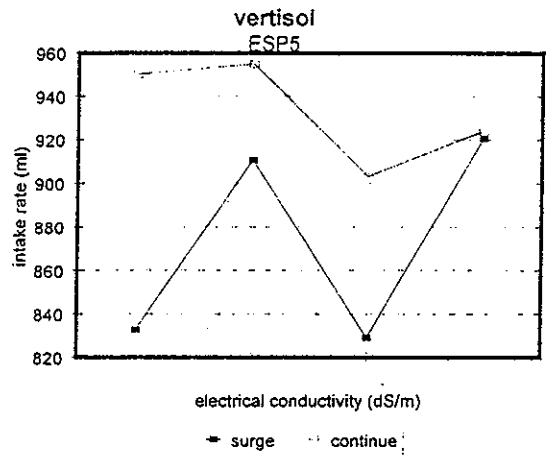


Fig 11

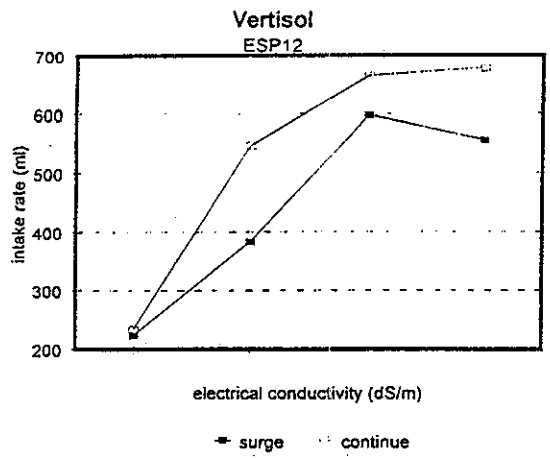
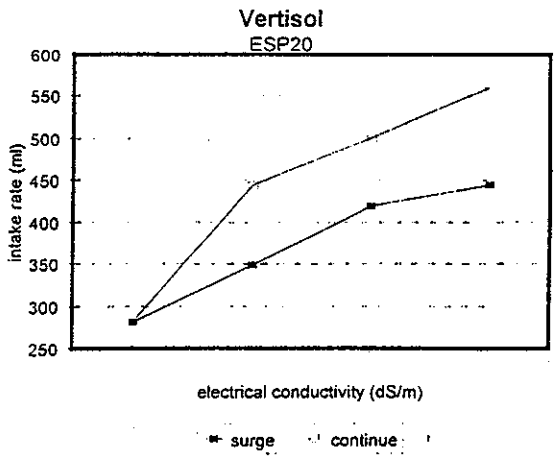


Fig 12



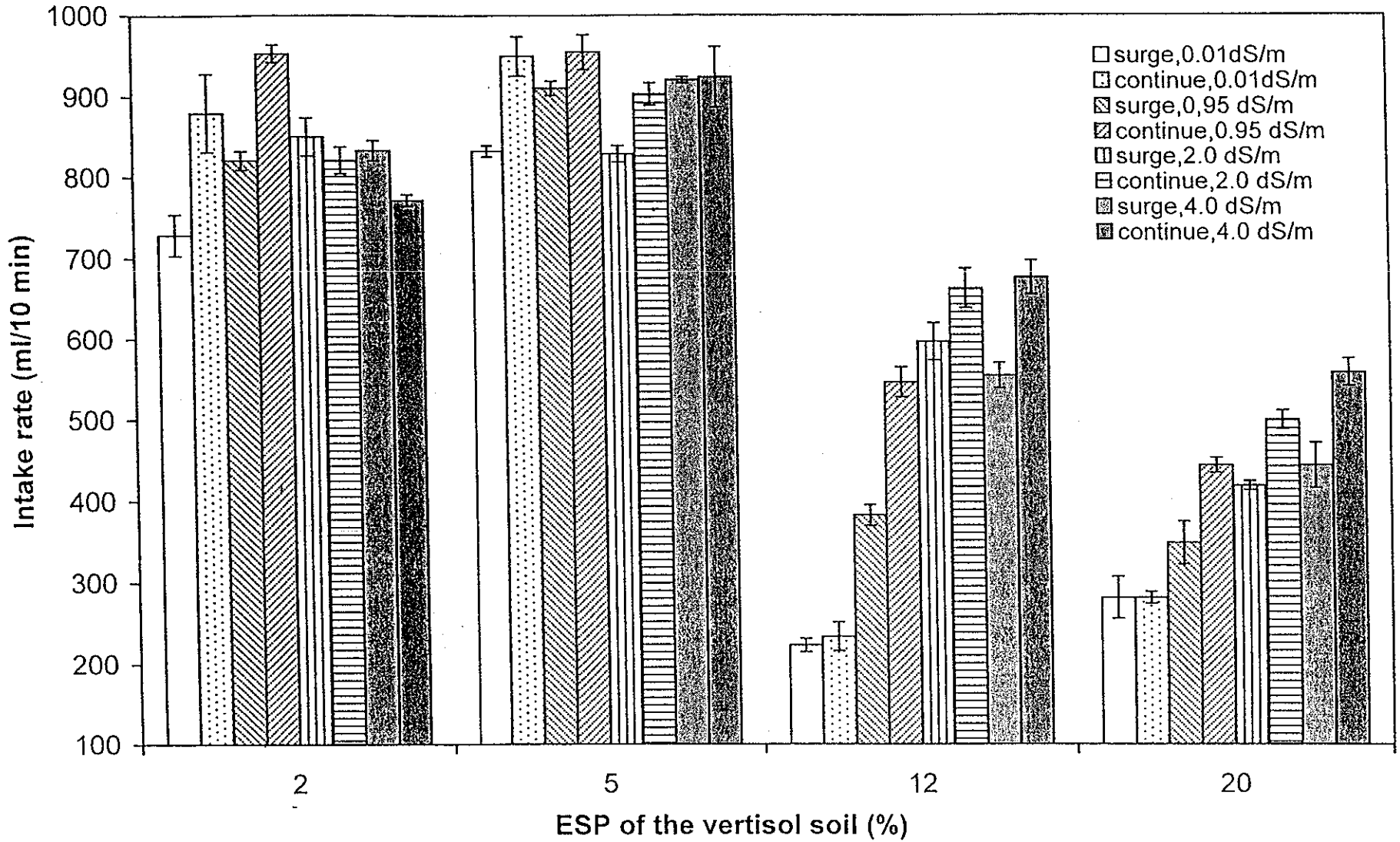

1000
900
800
700
600
500
400
300
200
100
Intake rate (ml/10 min)
2
5
12
20
ESP of the vertisol soil (%)
surge,0.01dS/m
continue,0.01dS/m
surge,0,95 dS/m
continue,0.95 dS/m
surge,2.0 dS/m
continue,2.0 dS/m
surge,4.0 dS/m
continue,4.0 dS/m

Figure 13

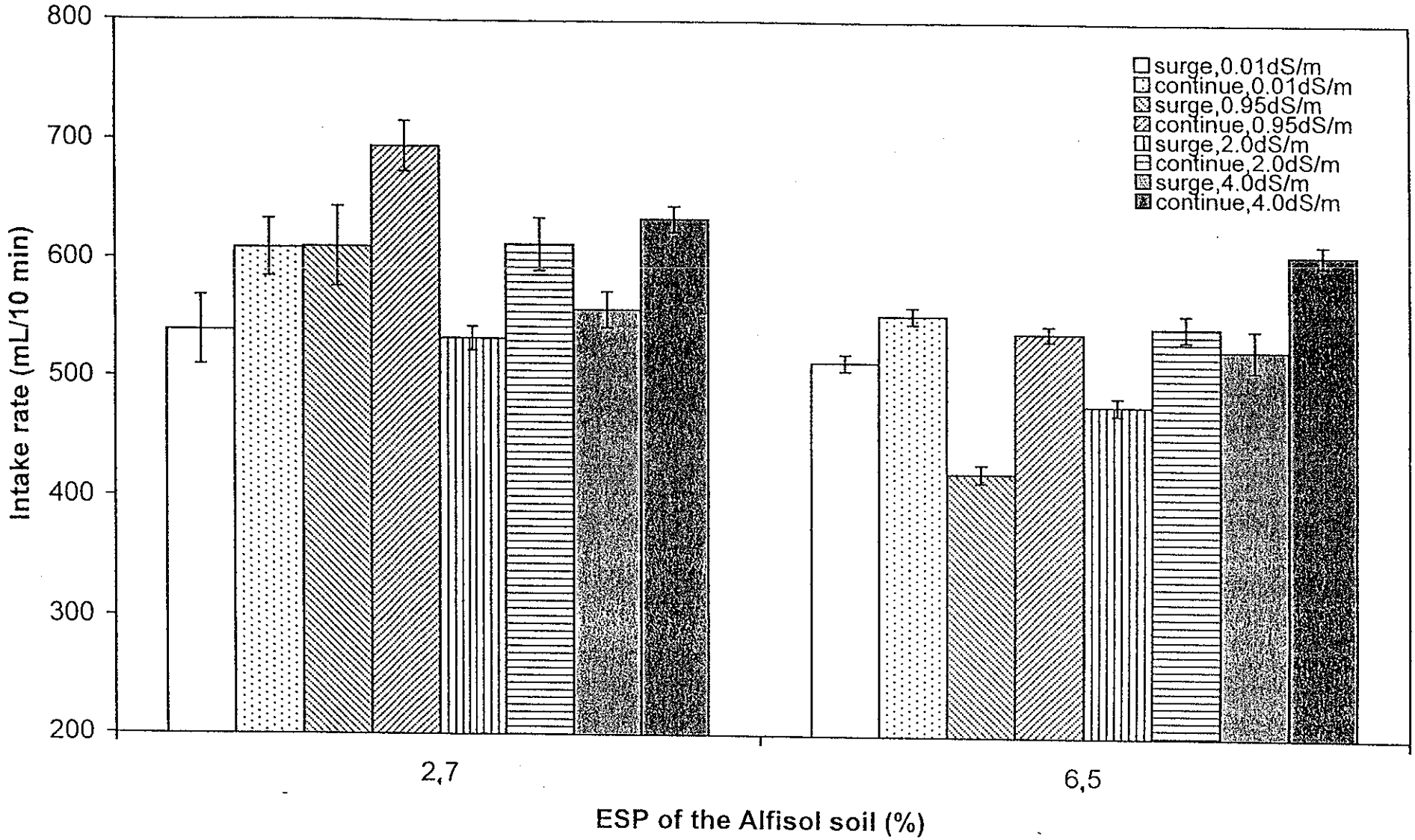

800
700
600
500
400
300
200
Intake rate (mL/10 min)
surge,0.01dS/m
continue,0.01dS/m
surge,0.95dS/m
continue,0.95dS/m
surge,2.0dS/m
continue,2.0dS/m
surge,4.0dS/m
continue,4.0dS/m
2,7
6,5
ESP of the Alfisol soil (%)

Figure 14

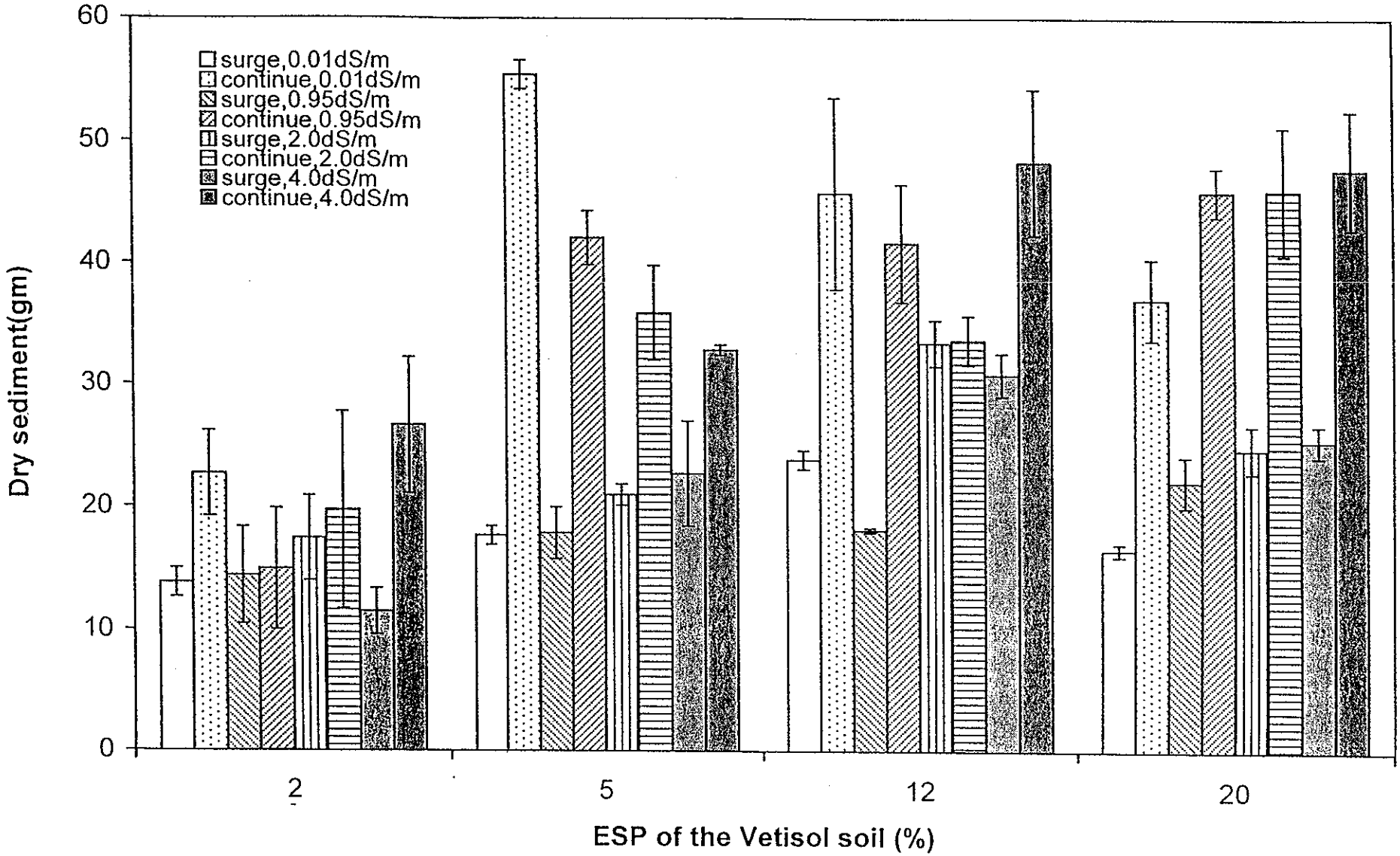

surge,0.01dS/m
continue,0.01dS/m
surge,0.95dS/m
continue,0.95dS/m
surge,2.0dS/m
continue,2.0dS/m
surge,4.0dS/m
continue,4.0dS/m
Dry sediment(gm)
0
10
20
30
40
50
60
2
5
12
20
ESP of the Vetisol soil (%)

Figure 15

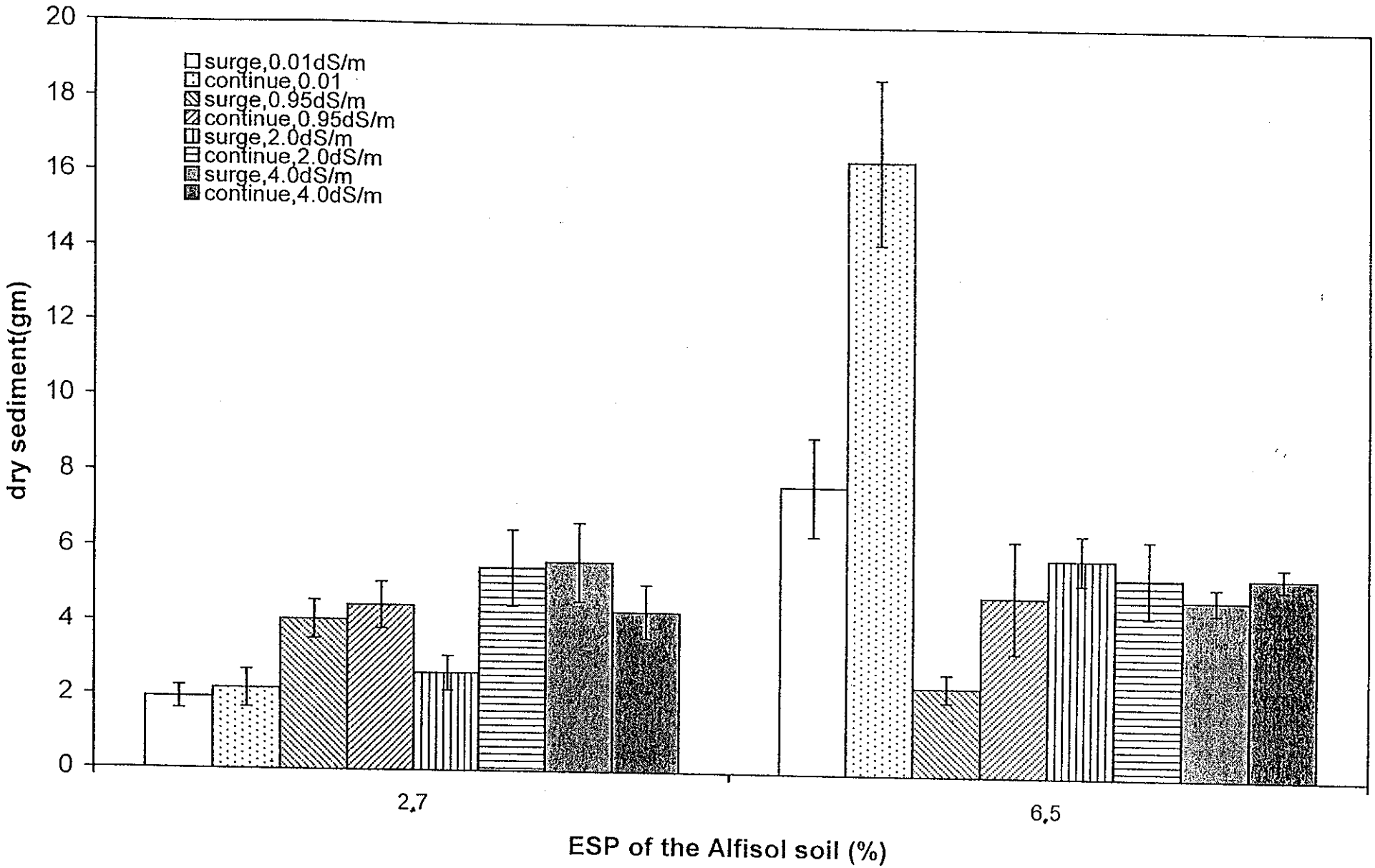

surge,0.01dS/m
continue,0.01
surge,0.95dS/m
continue,0.95dS/m
surge,2.0dS/m
continue,2.0dS/m
surge,4.0dS/m
continue,4.0dS/m
dry sediment(gm)
0
2
4
6
8
10
12
14
16
18
20
2.7
6.5
ESP of the Alfisol soil (%)

Figure 16

43

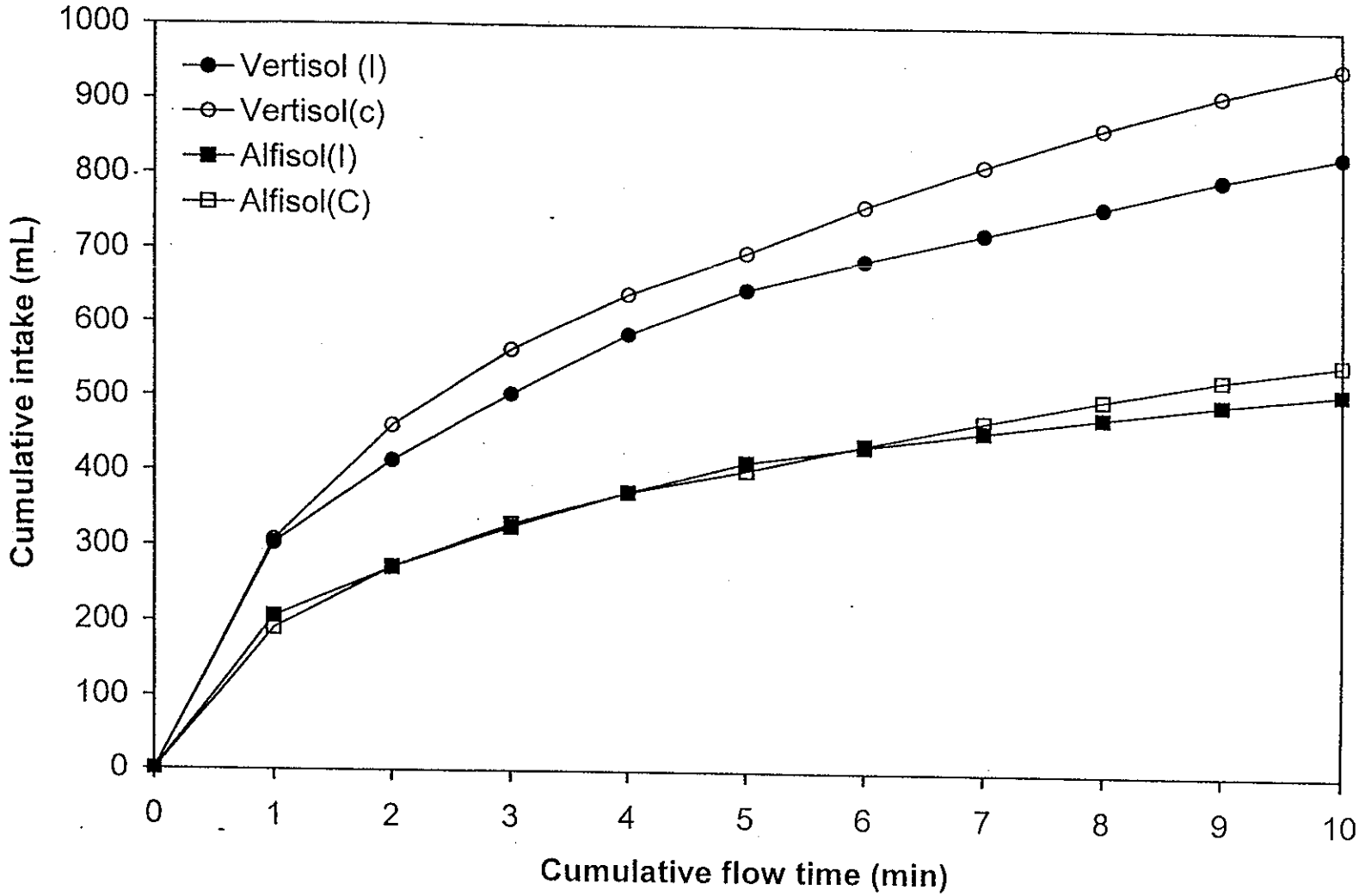

Vertisol (I)
Vertisol(c)
Alfisol(I)
Alfisol(C)
Cumulative intake (mL)
1000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
Cumulative flow time (min)

Figure 17

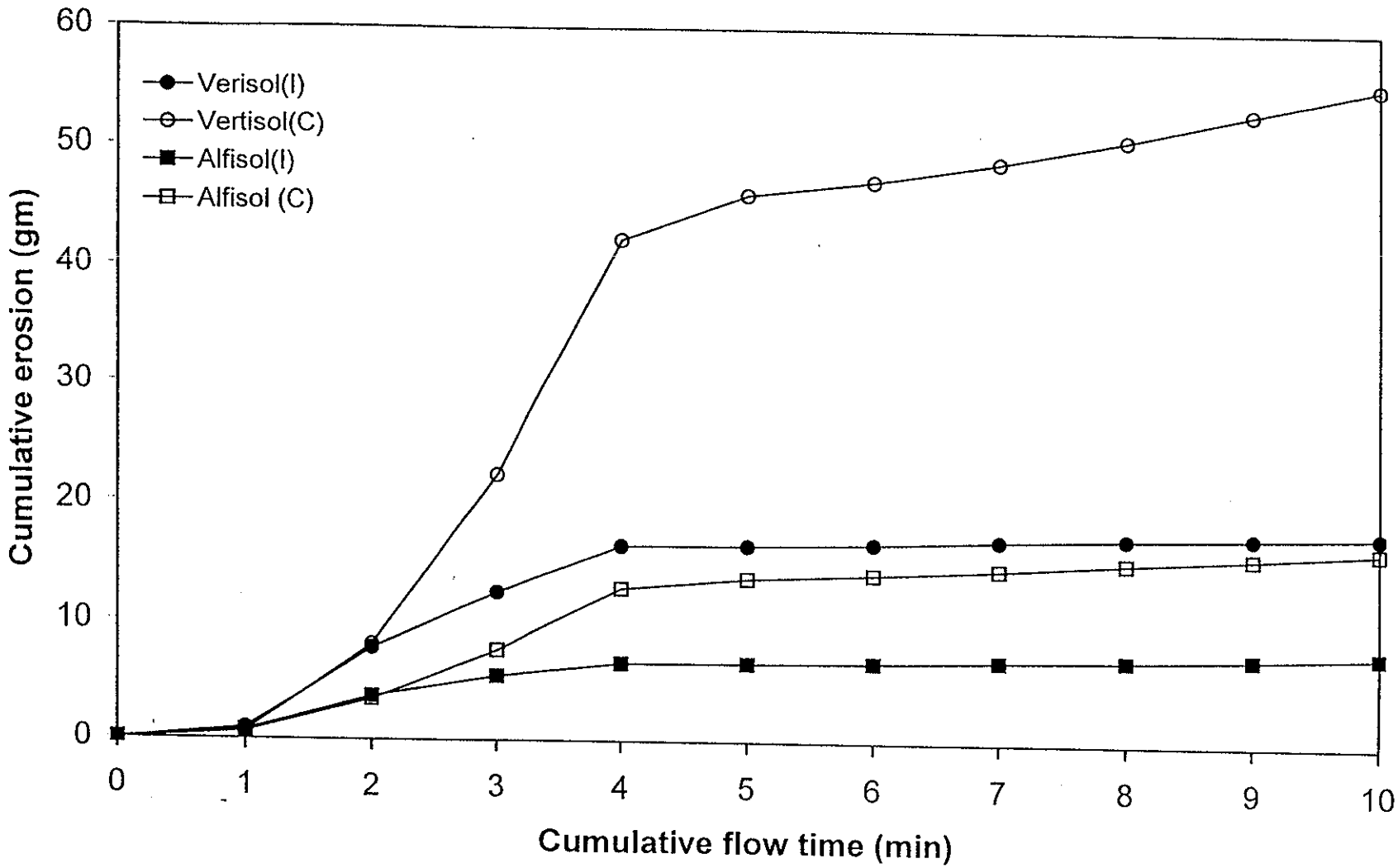

Verisol(I)
Vertisol(C)
Alfisol(I)
Alfisol (C)
Cumulative erosion (gm)
Cumulative flow time (min)
0
10
20
30
40
50
60
0
1
2
3
4
5
6
7
8
9
10

Figure 18

Appendix C

Effect of Wetting rate on Intake Rate and Rill Erosion.

Introduction

" Consolidation of the surface of soils with unstable structure during flow interruption was suggested as the explanation for the effect of flow interruption on intake rate"(see the abstract – Appendix I.) Thus , it was hypothesized that the effect of flow interruption on intake rate will be more pronounced in soils with less stable structure. Since aggregate disintegration depend on wetting rate, it is expected that the efficiency of interrupted flow increase with increase in wetting rate. This hypothesis is being studied in this report.

Materials and Methods

The same two soils (a loess and a grumusol) used in our previous study (Appendix I) were used in this study. The soils were packed in the miniflumes. A complete description of the method is given in Appendix 1.

Wetting of soils was done in two methods: I) spraying at the rates of 2.5 --- 300 mm/h and II) changing the inflow rates using the peristaltic pump at the rates of 120 -- 960 ml/min. More complete description follows:

(I) *Wetting by Spraying*

Loess

The procedure was divided into four stages. At the first stage, the soil in a flume was wetted by spraying at rates of 2.5, 10 and 60 mm /h. The sprayed amount of water was 170ml and spraying duration for the three rates were 174, 43 and 7.5 minutes. At the second stage, a continuous or interrupted flow at a rate of 120 ml/min was applied with a peristaltic pump for 3 minutes. At the third stage, a continuous flow was applied with a constant rate of 80 ml/min for 3 minutes to be followed by a constant flow of 320 ml/min for 3 minutes.

Grumusol

The procedure was divided into three stages. At the first stage, soil surface was wetted by spraying it with 230 ml within 60 , 12, 5 and 3 min. respectively. These wetting rates correspond to 10, 50 120 and 300 mm /h respectively. At the second stage, a continuous or interrupted flow was applied with a constant rate of 150 ml/min for three minutes. At the third stage, a continuous flow at 100 ml/min was applied for 6 minutes.

(II) Wetting by Inflow

Loess

The procedure was divided into four stages. At the first stage, three inflow rates 120, 240 and 360 ml/min were applied. The flow time were 100s, 60s and 50s respectively . At the second stage, a continuous or interrupted flow was applied with a constant flow rate of 120 ml/min for three minutes. At the third stage, a continuous flow rate of 80 ml/min for 3 minutes followed by a flow rate of 320 ml/min for 3 minutes was applied.

Grumusol

The procedure was divided into three stages. At the first stage, five inflow rates were applied (260, 320 , 640 , 800 and 900 ml/min) which correspond to PWRs of 630,768,1536,2000 and 2451mm / hour respectively . The flow time were 80, 70, 45, 40s and 35s respectively. At the second stage, a continuous or surge flow were applied with a constant flow rate of 150 ml/min for three minutes. At the third stages, a continuous flow of 100 ml/min was applied for 6 minutes.

Preliminary analyses of the results

The effect of wetting rates, by spraying rates or inflow rates, on the total amount of eroded sediments and the total intake rates are summarized in Table 1 and 2. The following is noted:

A. loess. Inflow rate experiments

Erosion increased with increase in wetting rates in both continuous and surge irrigation (Table 1 and Fig.1). The amount of erosion in interrupted flow was lower than that in continuous flow (Fig.1). During flow interruption consolidation of soil surface and aging decreased rill erosion . Intake rate in the continuous flow was not affected by wetting rate and intake rate in the surge flow diminished as the wetting rates increased (Table 1 and Fig.2). Efficiency of surge irrigation [intake(surge)/intake , (continuous)] increased with increase in inflow rates.

B. Loess. Spray rate experiments

The effect of spraying with different wetting rates on erosion rate was negligible. The loess was not susceptible to the increase in wetting rate from 2.5 to 60 mm/h. The loess structure is not stable even in the low PWR, because of the low clay and high silt content. In a structureless soil the effect of wetting rate is minimal.

The effect of spraying with different wetting rate on the efficiency of surge in reducing the intake rate was negligible. Surge irrigation reduced intake rate to 0.91-0.93 of that in continuous flow, but the specific effect of wetting rate was small. Again, the loess is a soil without stable aggregates even at the low wetting rates. Similar results were obtained by Mamedov et al, 2001.

C. Grumusol. Inflow rate experiments

Erosion rate in both continuous and surge flow increased with increase in inflow rate (Table 2 and Fig.3). Fast wetting weaken the cohesion force between soil particles and erosion rate increased. Erosion in surge flow was lower than that in continuous flow(Table2). Interrupted flow increases surface consolidation. The effect of wetting rate on erosion was more pronounced in the continuous flow. Interrupted flow was effective in reducing the effect of wetting rate and the erosion ratio (surge / continuous) decreased with increase in flow rate.

Intake rate was affected by inflow rates (Table2). In the continuous flow inflow rates decreased with increase in wetting rate. The increase in wetting rates disintegrates the aggregates at the soil surface and intake rate diminished. Inflow rates decreased intake rate in the surge flow experiments steeply. With increase in wetting rate, more disintegration of the aggregates at the soil surface took place and the suction at the soil surface during the flow interruption was more effective in consolidation of the soil surface. Thus, in surge flow, increase in wetting rate reduced intake rate more efficiently. As a result, the intake rate ratio (surge / continuous) decreased with increase in wetting rate.

D. Grumusol. Spray rate experiments

An increase in spraying rate increased erosion rate in both surge and continuous flow (Table 2). With increase in wetting rate, both flow shear and rill erosion increased.

Intake rates in both continuous and surge flow decreased with increase in wetting rates. The grumusol has a stable structure (due to the high clay content) and high wetting rate disintegrate the soil aggregates. The intake rate decreased with aggregate disintegration caused by the fast wetting.

Table.1 Effect of wetting rate and surge flow on erosionand intake rate (Loess)

PWR		spraying rate mm/h			inflow rate (ml/min)		
		2.5	10	60	120	240	360
erosion	surge	15.30	12.16	16.11	2.50	2.73	5.99
g/flum	continuous	6.20	7.74	10.67	24.88	33.77	38.22
	ratio	2.47	1.57	1.51	0.10	0.08	0.16
Total intake	surge	594.93	588.46	546.17	611.36	599.17	587.37
ml/flum	continuous	639.43	645.54	599.21	654.24	637.16	672.40
	ratio	0.93	0.91	0.91	0.93	0.94	0.87

Table.2 Effect of wetting rate and surge flow on erosion and intake rate (grumusol)

		spraying rate mm/h					inflow rate (ml/min)				
		10	50	120	300	300(iii)-	630	768	1536	2000	2451
erosion	surge	0.30	1.08	2.66	3.59	4.95	4.28	4.90	12.16	16.81	28.06
g/flum	cpntinuous	0.59	0.78	3.24	2.85	8.23	3.56	8.10	20.31	37.83	
	ratio	0.51	1.38	0.82	1.26	0.60	1.20	0.60	0.60	0.44	
total intake	surge	1190.02	1040.51	910.03	878.17	909.04	868.77	865.03	727.83	717.63	691.85
ml/flum	continuous	1014.72	930.15	724.61	769.29	904.86	1143.73	1026.75	1004.07	950.59	
	ratio	1.17	1.11	1.26	1.14	1.00	0.86	0.84	0.73	0.75	
total runoff	surge	125.67	248.44	347.97	393.19	379.21	593.60	583.80	734.83	791.65	
ml/flum	continuous	272.67	323.86	575.12	516.21	372.71	352.05	452.58	629.73	764.35	
	ratio	0.46	0.77	0.61	0.76	1.02	1.69	1.29	1.17	1.04	

Fig.1 Erosion as a function of Inflow rates

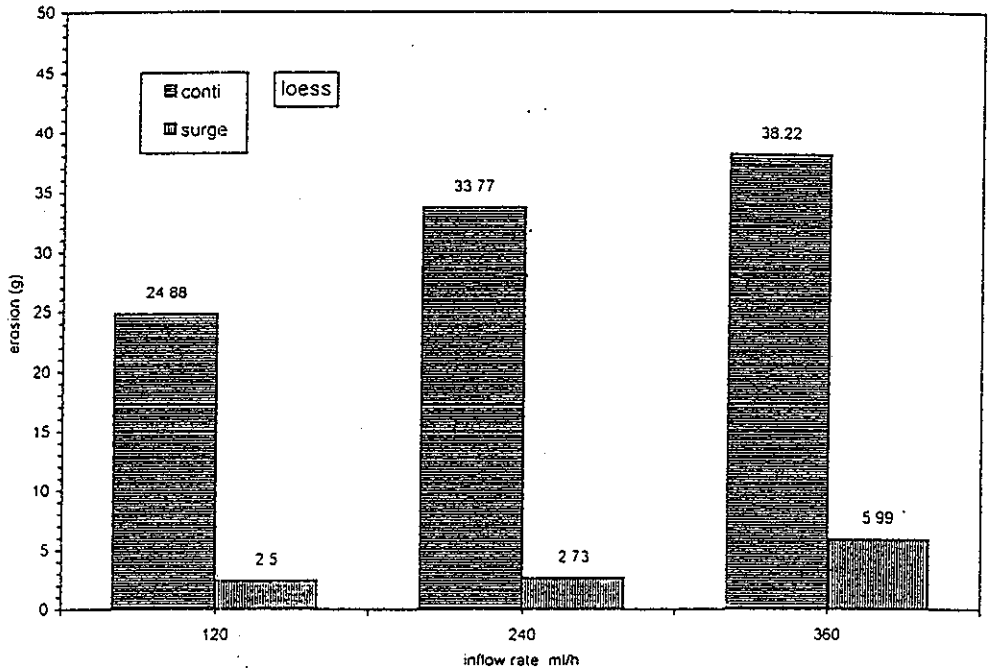


Fig.2 Total intake as a function of inflow rate

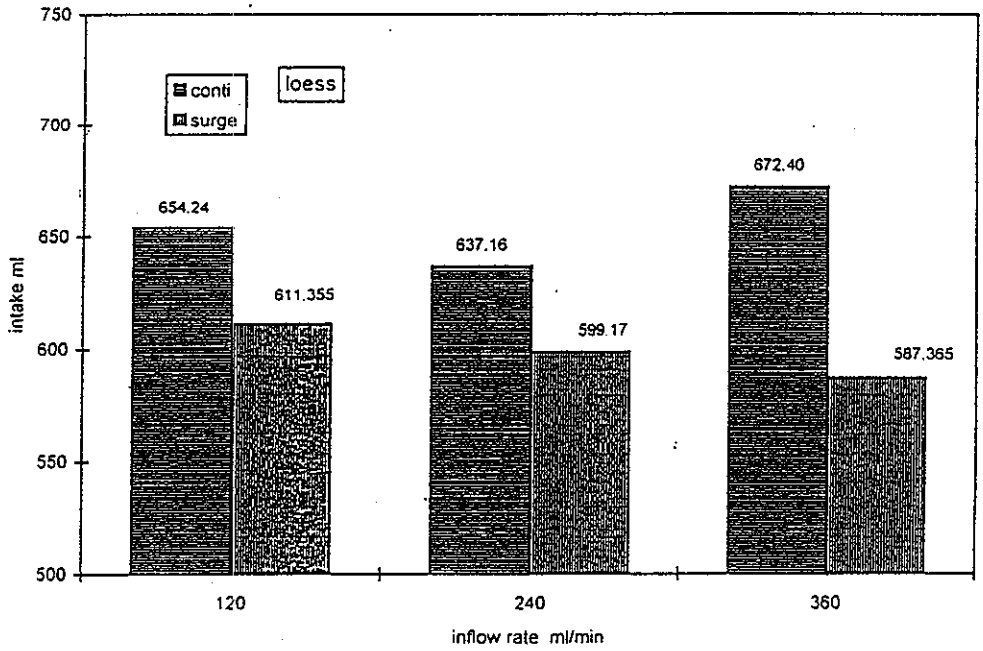


Fig.3 Erosion as a function of spraying rate

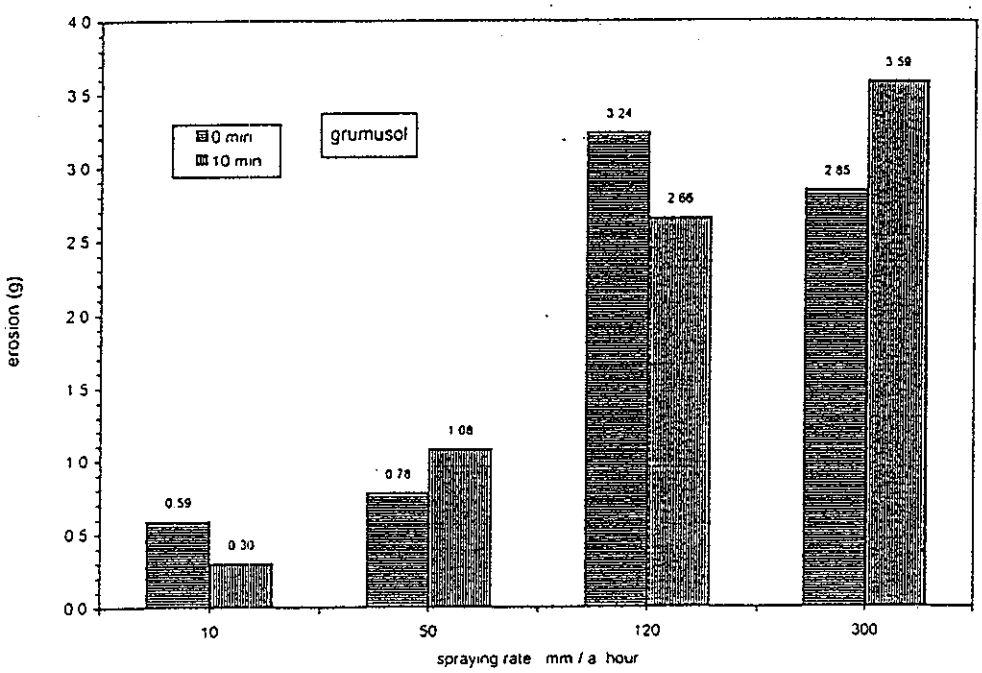


Fig.4 Erosion as a function of inflow rate

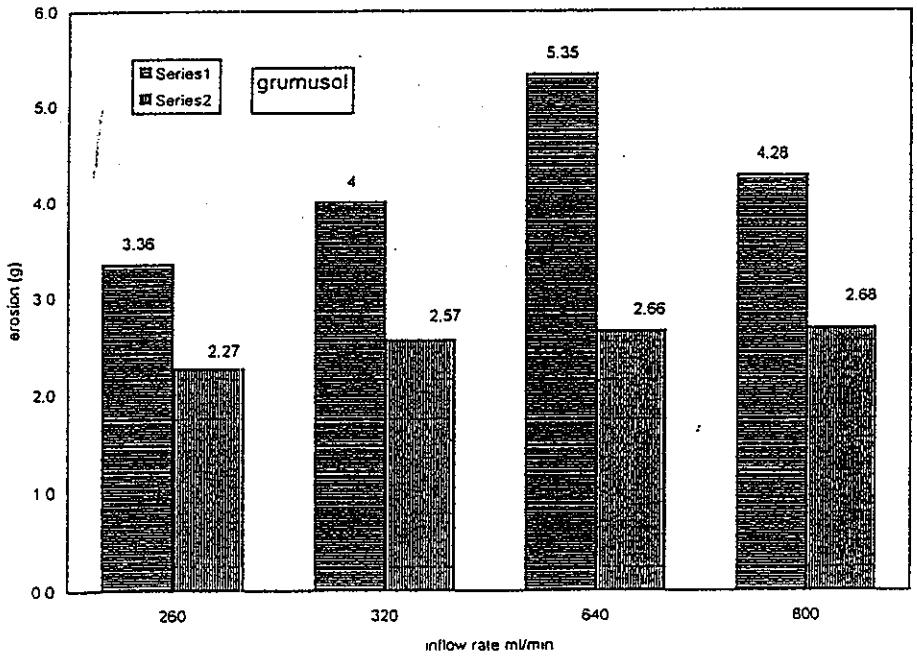


Fig.5 Intake as a function of spraying rate

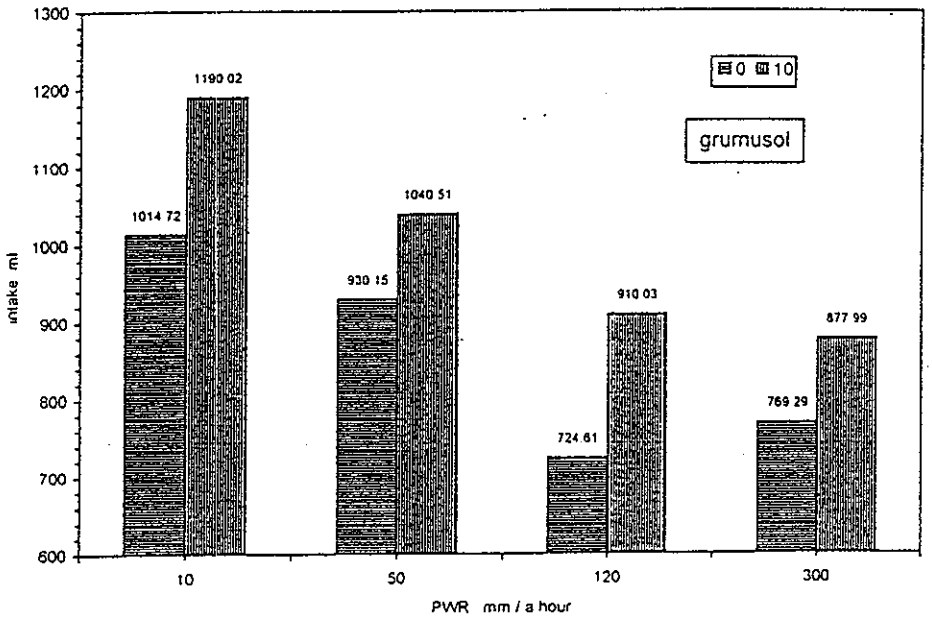
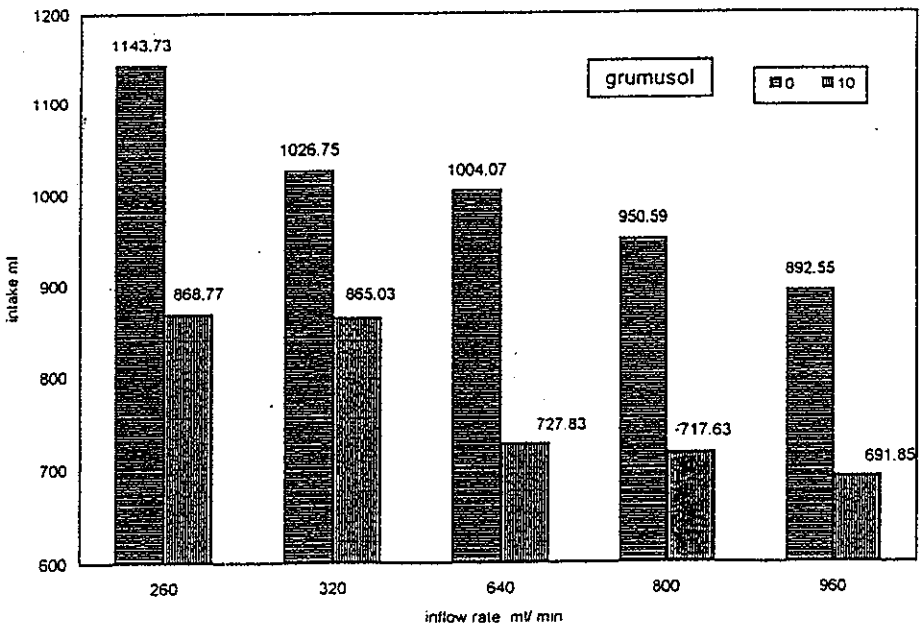


Fig.6 Intake as a function of inflow rate



USA - Israel - Kyrghyzstan

Appendix D

"Maintaining"

Director of Kyrgyz
Scientific and Research
Institute of Irrigation

_____ K. Kulov

REPORT

of the field experiments project Title:
Surface Irrigation as Affected by polymer Amendments and Soil Properties
Project Identification no : TA-MOU-97-CA17-008

Submitted by, Dr. G. L. Zhuravskaya

Bishkek - 2000

Introduction

The task which gave Principal Investigator Dr. G. J. Levy and Prof. I. Shainberg during them the visit in Kyrghyzstan in June, 1998 was basis for realization of the field experiments on Project in 2000. The extracts from them Program of the field experiments are cited bellow.

Procedure

1. Effect of surge flow on furrow erosion and intake rate (IR).

1.1. Continous irrigation (Control).

a. Furrows of 200 m long. Water is applied at inflow rate of 30 L/min. Measure the time (Tc) for water to reach the end of the furrow.

b. Continue the flow at 30 L/min for additional 30 min, and take samples of water with sediments from the furrows at distances of 20, 100 and 180 m. Dry the water samples to measure sediment concentration. Repeat the measurement of sediment concentration (at the 3 locations) at 10, 20, and 30 min after the water reached the end of the furrow.

c. After measuring sediment concentration, reduce inflow to 15 L/min and continuous irrigation for 5 h. Measure inflow and outflow rates during these 5 h at 20 min intervals. Calculate the change in average IR with time and the total volume of water that infiltrated the furrows.

d. Repeat the above measurements in 5 furrows.

e. When irrigation is completed measure the water content in the profile along the furrows at 10, 100 and 180 m. Determine the uniformity of water distribution in the field.

1.2. Surge irrigation

a. Divide the time it took for continuous water flow 30 L/min to reach the end of the furrow (Tc) into 4 equal time intervals (Tc/4). Apply surge irigation of Tc/4 ON, and Tc/4 OFF with inflow rate of 30 L/min until the surges reach the end of the furrow. Record the ON time it took to wet the entire furrow.

When the water reaches the end of the furrow continue with continuous flow of 30 L/min for additional 30 min and repeat steps "b" through "e" 0in the continuous flow procedure.

2. Effect of PAM on furrow erosion and IR.

2.1. Continuous irrigation

Mix PAM, 10 g/m3, with the irrigation water and follow step "a" in 1.1., but the PAM is mixed with the irrigation water only until the entire furrow is wetted (i.e., the advancement stage is completed). Record the advancement time (Tcp). Then continue with steps "b" through "e"' in 1.1., using PAM-free irrigation water.

2.2. Surge flow with PAM application.

The same as 1.2. - surge irrigation in conventional water except that PAM in concentration of 10 g/m^3 is mixed with irrigation water during the surges (i.e., the advancement stage) using Tcp/4 time intervals for the ON and OFF periods.

The researhces were fulfiled with a whole volume.

But we could not fulfil of the Program fully due to objective causes. In the first place, a slope of locality did not make it possible to take an inflow rate of 30 L/min. We took the inflow rate of 21,6 L/min (0,36 L/s). In the second place, we considered that the infiltration capacity of out soils did not make it possible to take an inflow rate of 10,8 L/min in period after wetting. We took the inflow rate of 12,36 L/min (0,206 L/s) in period after wetting. In the third place, we did not take a repeat the above measurements in 5 furrows. We took the repeat the above measurements in 4 furrows, as wheeled tractor cuts a six furrows at the same time. The tractor cuts the first and the sixth furrows twice, so that not lose one's track only four furrows had equal a roughness and a geometrical parameters. In that case we had the four record furrows and the two protective extreme furrows.

We were studing:

1.Efect of surge irrigation on furrow erosion and infiltration raters (IR).

2.Effect of PAM on furrow erosion and IR.

3.Interaction between surge irrigation and PAM in their effects on erosion and IR.

4.Effect of surge irrigation and PAM treatment on water content in the profile along the furrows.

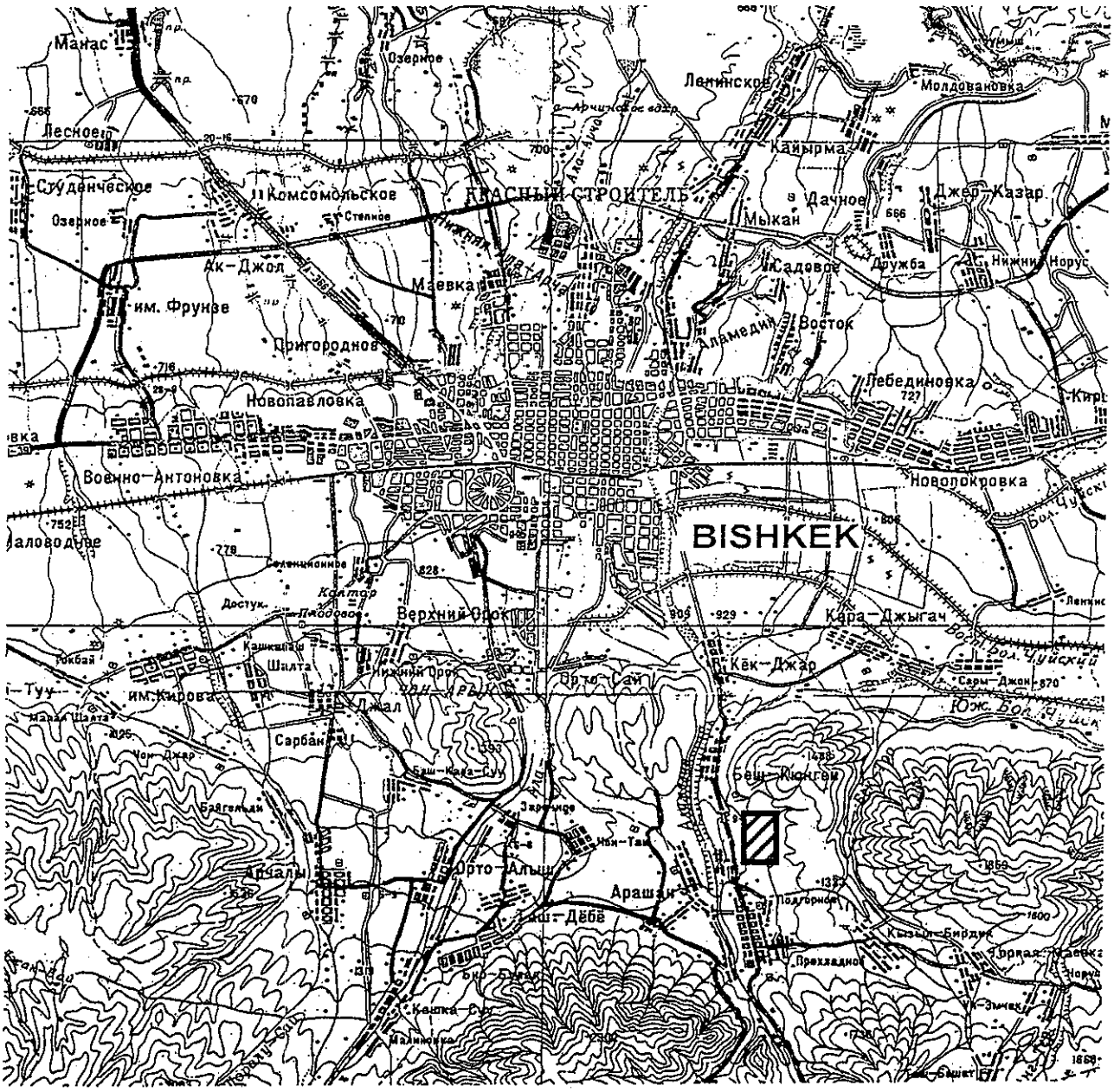
General conditionns for realization of the field experiments in 1999 and 2000.

1.The field experiments were made on the same field of peasant farm "YNTYMAK" (Fig. 1) with an identical technique, except the interruption at the water application after wetting of furrows in two variants of the surge irrigations (*surge* and *surge+PAM*). This interruption was given only in 2000 y.

2. Experimental area had thickness soils, underlying bed consists of gravel and cource gravel from a depth more 3 m. We determined a depth of soil moistening before irrigation, after first irrigation and after second irrigation at the variants of experience.

3.Experiments were conducted with an agricultural culture. We could determine an yield capacity of the sugar beet.

This is a map of location plot for field experiments



is plot for field experiments

Fig. 1

Conditions for realization of field experiments and thier distinctive features in 2000.

1. Plants of sugar beet were sowed very densely. Space between furrows was made with width 70 cm.
2. Very dry spring and summer were by cause for uneven and not simultaneous shoots of sugar beet.
3. The first two leafes on rare plants of the sugar beet appeared on May 26.
4. The first wetting irrigation of the sugar beet was made on July 7 after which in active growth have went the weeds but also appeared a new plants of the sugar beet.
5. The second wetting irrigation was made on July 17 after which a struggle with weeds began by hand.
6. The cutting of the furrows was made on July 31 for experimental irrigation. The test irrigation was made on July 31 too.
7. We conducted the first experimental irrigation of sugar beet on August 1-2.
8. Sediment concentration in irrigation water, which is gave to furrow, was not a constant value during vegetative period. It changed during one irrigation, at the variants of experiment and from irrigation to irrigation.
9. Interruption at water application was given after wetting by a jet of the entire furrow in two variants of surge irrigations (*surge irrigation* and *surge irrigation + PAM*). Irrigation was applied continuously with decreasing an inflow rate after the interruption at water application.

The field experiments were conducted from May 1, 2000 to October 14, 2000.

They are in preparatory and main works.

1. Preparatory works

The preparatory works included:

1. Leveling of e area with purpose to make more precise of surface slope in direction of irrigation.
The results of leveling are essential at choice of preliminary inflow rate.
2. Determination of some physical and chemical properties in irrigation water and irrigated soils for experimental plot.
3. Determination of soil infiltration capacity. These results are essential at choice of inflow rate in period after wetting of furrow.
4. Determination of the soil moisture content.
5. The conducting of test irrigation with the purpose to make more precise a value of the inflow rates.

1.1. **The geodetic leveling** of the area showed that surface slops of field fluctuated from 1,6 % to 4 % in direction of irrigation (Fig.2).

The mean slope was equal 2.6 %.

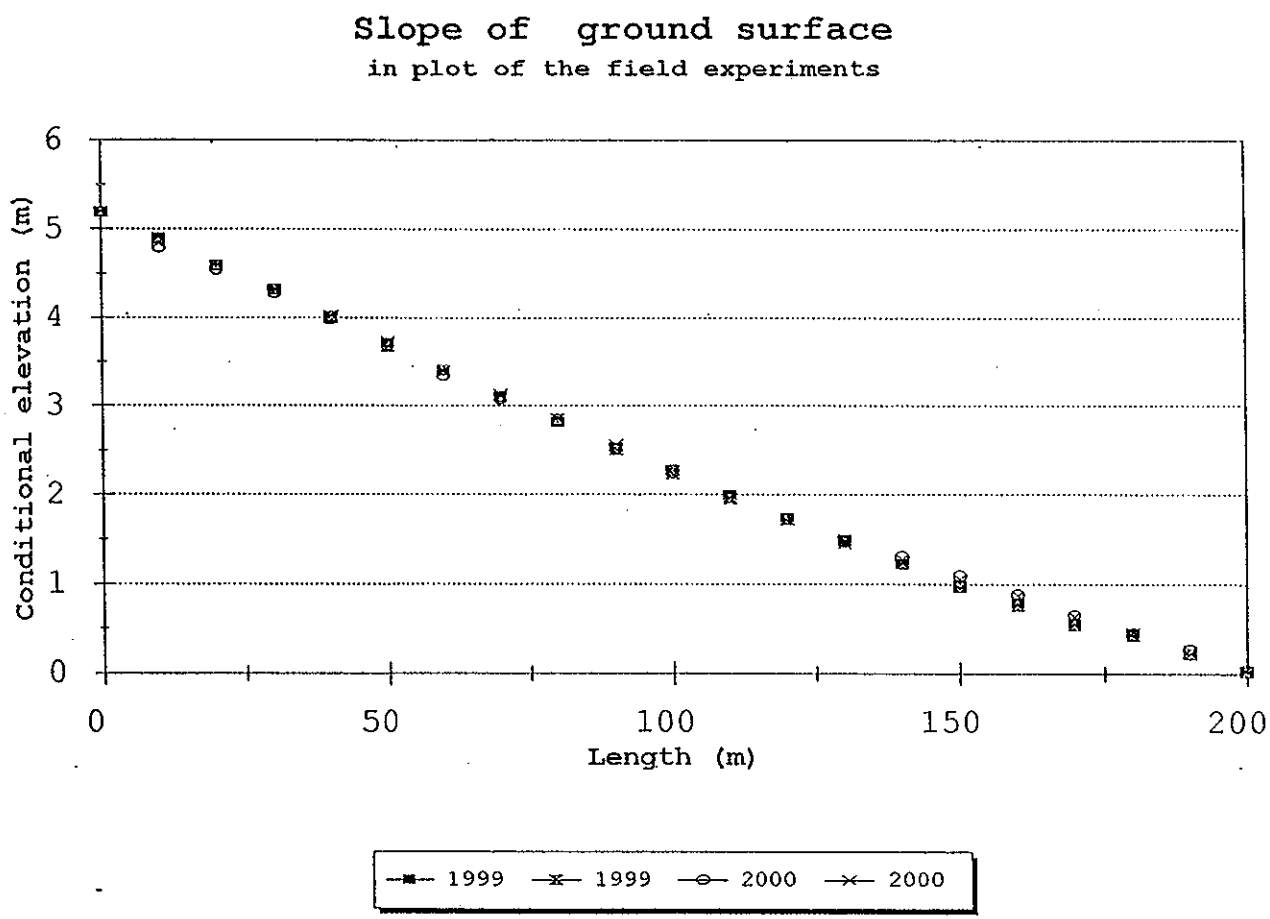

Slope of ground surface
in plot of the field experiments
Conditional elevation (m)
0
1
2
3
4
5
6
0
50
100
150
200
Length (m)
1999
1999
2000
2000

Fig.2

28

1.2. Some physical and chemical properties of irrigation water and soil of irrigated plot.

Soil of plot belongs to light-chestnut mountain-flat of type. This type of old-irrigated soils characterize by rather higt values of a close packing, an apparent density and maximum field carrying capacity. We determined maximum field carrying capacity in soil profile to depth 150 cm. The maximum field carrying capacity (this is the quantity of water what a soil can contain on the third day after copious moistening) was determined for establishment date of regular irrigation. Method was used a coated lot with water. The experiment was repeated two times. The results are presented on Table 1.

The maximum field carrying capacity change on the average from 22.44% to 23,37 for soil stratum from 0 to 150 cm. The apparent density change on the average from 1.40 g/cm^3 to 1.56 g/cm^3 and increase with depth (Mamytov A. M. is editor, 1974, a driller's log № 132) .

Table 1

VALUES OF APPARENT DENSITY AND MAXIMUM FIELD CARRYING CAPACITY IN SOIL PROFILE OF FIELD PLOT

Depth of soil stratum, cm	Apparent density, g/cm^3	Maximum field carrying capacity, % (to weight)
0-30	1.40	23.23
30-60	1.48	23.37
60-90	1.52	22.62
90-120	1.56	22.44
120-150	*1.55**	22.47
0-150	1.50	22.85

- this is took conditionally

Soil of plot were selected, were dried, were crushed and sifted through a sieve with diameter of the orifice 2 mm and were deliver to special laboratory of KSIIR for more detailed study. Soil was characterized as to their basic chemical properties and soil texture. Irrigation water were selected and were deliver also to special laboratory of KSIIR for the study. The resullts of this analyses are presented bellow (Tab.2, Tab.3). The soil of plot are not salinized. It are contained much silt. The irrigation water has a sulfate-hydrocarbonate-calcium-sodium composition and contains much of solid particles.

Table 2

CHEMICAL COMPOSITION OF A IRRIGATION WATER IN VEGETATIVE PERIOD

PH	Dry residue, g/L	SAR	Chimical composition, meq/L							Nutrition elements, meq/L			Minera-liza-tion, meq / L	Class of water
			CO_3	HCO_3	SO_4	Cl	Ca	Mg	Na	NH_4	NO_3	P_2O_5		
8.3	6,13	1.66	not	0.80	0.48	0.75	0.60	0.15	1.01	0.15	0.02	0.0005	3.79	1

Table 3

CHEMICAL COMPOSITION OF SOILS

Chimical composition of soil in stratum 0-30 cm												Organic mater, %	Meshanical composition	
PH	CEC	ESP, %	anion meq/100 g			cation meq/100 g soil			nutrition elements, mg/100g					
			HCO_3	Cl	SO_4	Ca	Mg	Na	NH_4	NO_3	P_2O_5		name	%
8.1	12.5	4.0	4.0	2.9	5.6	10.0	2.0	0.5	1.83	0.524	0.164	3.2	clay silt sand	18.1 66.2 15.7

1.3. Method for determination of soil infiltration capacity.

We make more precise of soil infiltration capacity every year. For this, the metallic circle pressed in soil, the water poured into it and measured an intensity for imbibition under pressure H=8 cm (for corresponding intervals of time). The water application and maintenance of level was accomplished by hand with help of beaker.

Two metallic circles were used at determination of the soil infiltration capacity for every variant:

1) big circle is outward, protective circle, restricting preading of water from inward circle, it is diameter 70 cm;

2) small circle is inward, register circle, diameter is 30 cm for inward circle.

Determination of infiltration capacity made for soil with double control. Distance between control circles was equal 0.7 m. At the first, we installed the big circle, then installed the small circle. Soil was pressed about outward side of circle. A ruled line was installed to every circle, it took into account level of water for maintenance of constant pressure above surface of soil. Pressure of water was equal 8 cm. The protective and the register circles poured with water simultaneously. We began to measure the added water in the register circles with this moment and during all period of observation. We measured the poured out water in inward circle and maintained on constant level of water into outward circle. The counting of time made when infiltration volumes of water composed 1000 millilitres. The soil infiltration capacity computed on formula for every interval of time:

$$Vt = dQ*60/(S*dt), \qquad (1)$$

where Vt is soil infiltration capacity, cm/h;

dQ is quantity poured out water, cm3;

60 is conversion factor from min to hour;

S is area of the register circle, 706,5 cm2;

dt is intervals of time among measurements of volume waters, min.

The value of soil infiltration capacity and the intervals of time wrote down in table and desigh in diagram form. Duration of every experiment was equal in total 480 min (approximately). The experiment was repeated two times. The results are presented on the Fig.3 for 1999 and 2000. We showed maximum and minimum values of soil infiltration capacity for 1999 (this is a top and a bottom dependences), the values of soil infiltration capacity for 2000 and the average value of soil infiltration capacity for those four dependences (it is in center of drawing). Data of drawing testify about insignificant alteration of soil infiltration capacity for irrigated land from year to year and about great alteration of soil infiltration capacity under the influence of local factors (for example, of consolidation, of soil moisture content). We did not ascertain a causes of great fluctuation for soil infiltration capacity at repetitions of experiment neither 1999 nor 2000.

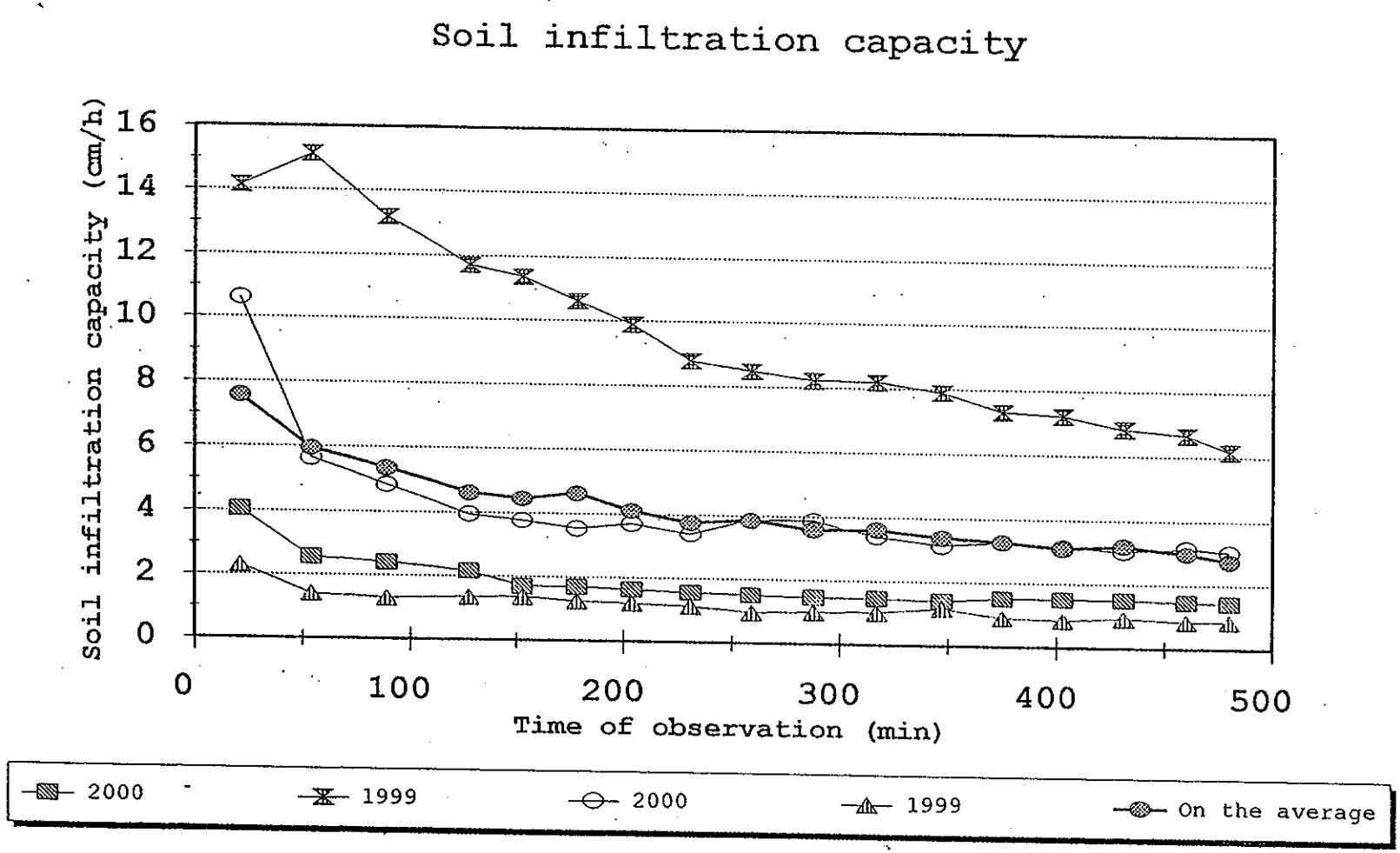

Soil infiltration capacity
Soil infiltration capacity (cm/h)
16
14
12
10
8
6
4
2
0
0
100
200
300
400
500
Time of observation (min)
2000
1999
2000
1999
On the average

Fig. 3

1.4. **Soil moisture content.** Sample collection of soil on moisture content and data processing showed that our plot had not uniform water distribution neither in profile along furrow nor along contour lines of versions on July 7 (Fig. 4). The soil moisture content falled to 28 % from maximum field carrying capacity in upper stratum 0-30 cm and approached to maximum field carrying capacity in stratum 120-150 cm from surface. The disparity at soil moisture content along a contour line composed from 262% to 101% and along vertical it composed from 347% to 139%.

Sample collection of soil on moisture content on July 31, that is to say before beginning of the first experimental irrigation, showed more uniform water distribution along a contour line after two wetting irrigation that was conducted on July 17 (Fig. 5). This gave us a foudation to suppose that we can receive the compared results on increment of soil moisture contentins with irrigation, on erosion and a water losses in furrows.

1.5. **Inflow rate**, which was planned (preliminary 30L/min), does not conform to condition of this plot.

The most authors recommend the inflow rate 0.05-0.25 L/s for conditions with surface slope 0.026 or 2.6% (Fig.6). But with this, the erosion will not take place. We must take the inflow rate more high and to finish all measuring in light time of day. We conducted a test irrigation. The test irrigation showed (Fig.7) that the rated duration of furrows wetting composed only 36 min at inflow rate q_1=36 L/min (that is very little),76 min at inflow rate q=30 L/min and 98 min at inflow rate q_1=21.6 L/min. Therefore the inflow rate had been decreased from q_1=30 L/min to q_1=21.6 L/min in period of the wetting.

We took data of soil infiltration capacity for substantiation of inflow rate in a period after (Tc+30 min). The soil infiltration capacity was taken approximately 4.2 cm/h and 3.0 cm/h (see Fig. 3) when determined inflow rate for second period:

$$q2= \frac{4.2*200000}{60*1000}=13.8 \text{ L/min} \quad \text{and} \quad q2=\frac{3.0*200000}{60*1000}=10.2 \text{ L/min},$$

where 4.2 and 3.0 are soil infiltration capacity, cm/h;
200000 is an area of water imbibition in furrow (200 m * 10 cm), cm^2;
200 m is a length of furrow;
10 cm is a perimeter of wetting in furrow;
60 is a conversion factor from hour to min;
1000 is the conversion factor from cm^3 to litre.

The inflow rate was taken q2=12.36 L/min (for some reserve) in period of after wetting.

Soil moisture content on July 7

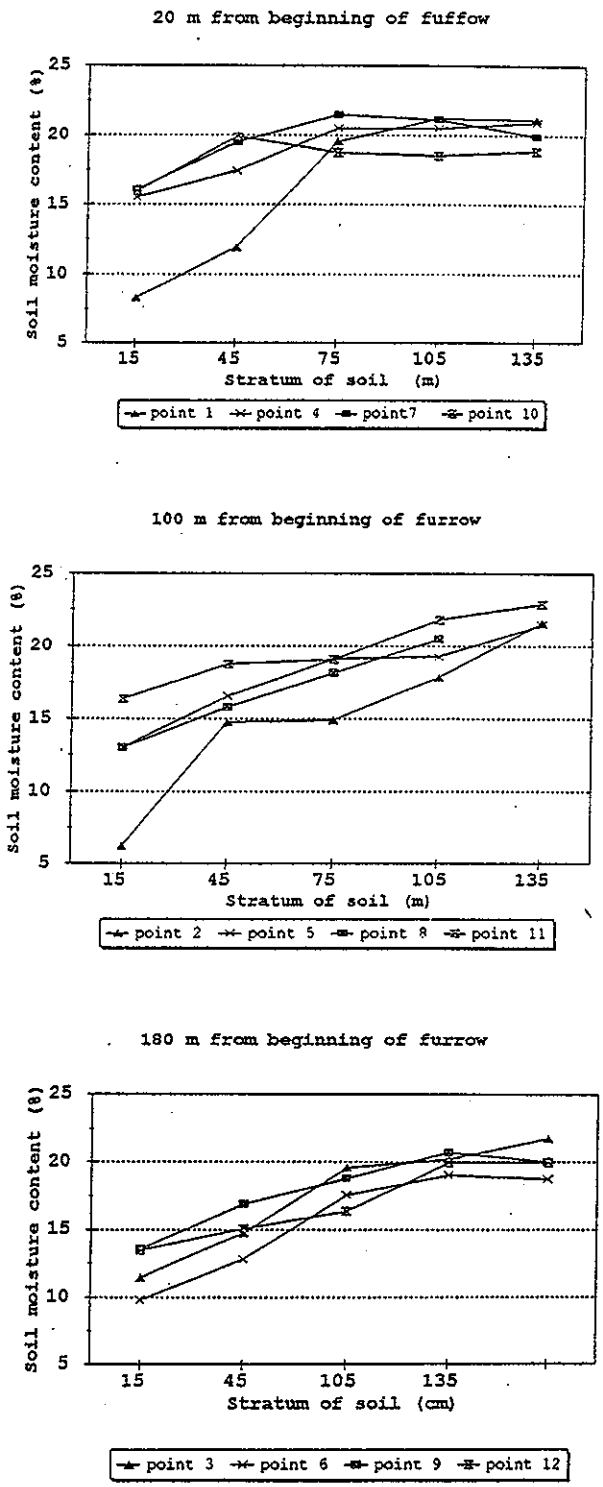
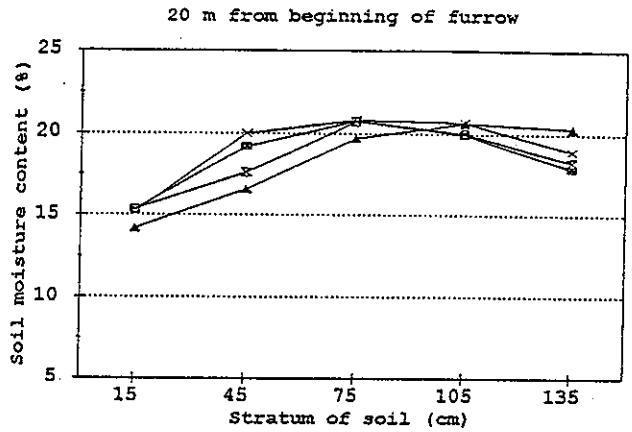
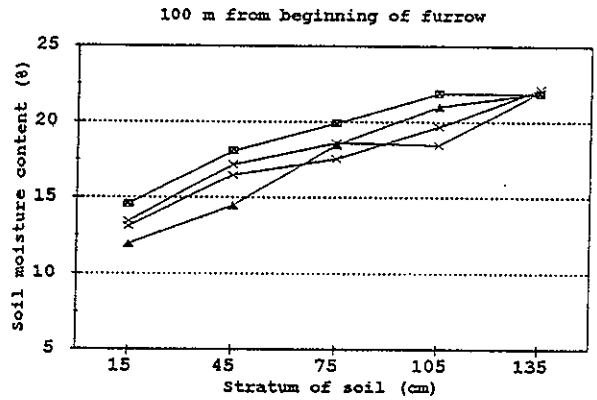


Fig.4

Soil moisture content on July 31





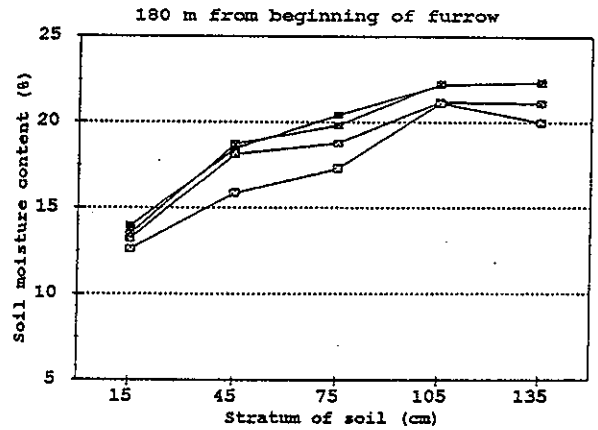


Fig.5

The recomendation q=f(i) for furrow irrigation
(from dissertation of G. L. Zhuravskaya)

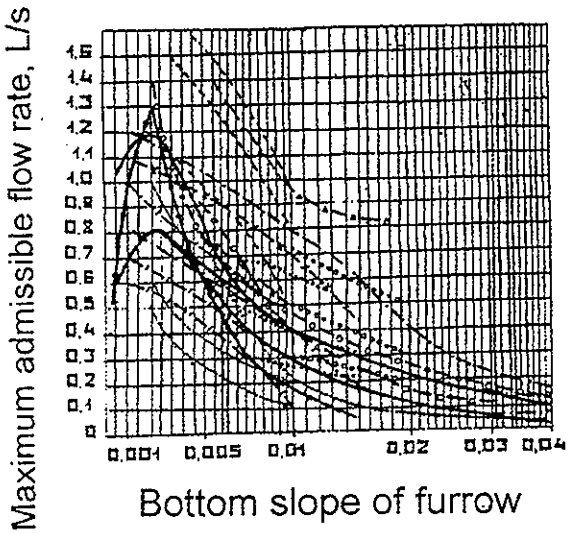


Fig. 6

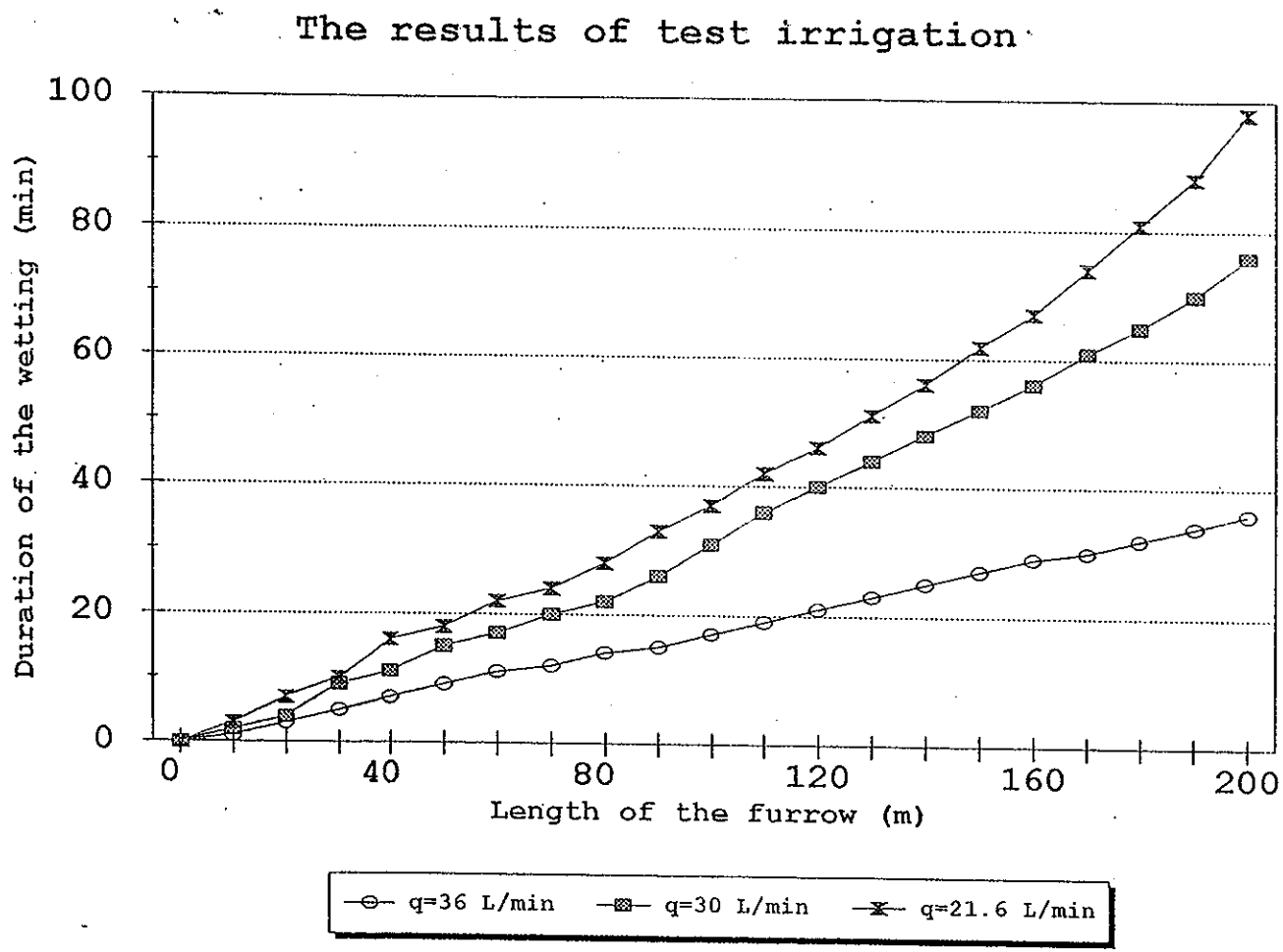

The results of test irrigation
Duration of the wetting (min)
100
80
60
40
20
0
0
40
80
120
160
200
Length of the furrow (m)
q=36 L/min
q=30 L/min
q=21.6 L/min

Fig. 7

Conclusions

1. The surface slope of this area is typical for conditions use of surface irrigation (on the average slope had composed 2,6%, an irrigation erosion in 1999 had not influenced in surface slope of experimental plot).

2. The experiments were conducted with an agricultural culture on sugar beet, in spite of a hard weather conditions.

3. The maximum field carrying capacity changes on the average from 22.44% to 23,37 for soil stratum from 0 to 150 cm. The apparent density changes on the average from 1.40 g/cm^3 to 1.57 g/cm^3 and increases with depth that is typical for a light-chestnut types of loam and old-irrigated soils of Chui valley.

4. The soils of plot is not salinized. They are contained much silt. Irrigation water has a sulfate-hydrocarbonate-calcium-sodium composition.

5. The infiltration capacity of soil had composed 2.95 cm/h on the average for 8 hour (it had changed from 4,06 cm/h to 1.83 cm/h in repetitions). This is a clay middle with infiltration coefficient 1-5 cm/h [1].

6. Inflow rate, which was planned (preliminary 30 L/min) does not conform to condition of this plot. The inflow rate was taken q1=21.6 L/min in experiment veriants for the wetting period and q2=12,36 L/min for the after wetting period.

2. Main works

They consisted in the determination:

- depth and the uniformity of the soil moistening after first irrigation and after second irrigation for receiving of information about distribution of water in soil on versions;
- water losses lengthwise of a furrow for each version of the experiments;
- furrow erosion;
- yield of a sugar beet on variants of experience.

Balance method was used for determination water losses of inflow rate lengthways of a furrow. Static head measured with help a portable water meter for those purposes (Photo 1). Employment of weir particularly is efficient for realization technology of a *surge irrigation* because orifice in diaphragm is easily re-cover with blind diaphragm in period of interruption water application.

Furrow erosion was studied by the standard method with a sample collection of a water in glasses (Photo 2). Metallic chute exploited for those purposes (Photo 3). The metallic chute have parabolic of a form and very well establishing in a transverce section of furrow.

We researched the four versions in field experiments and conducted the four experimental irrigations. The each of the four irrigation had a duration 24 hours. But the observations had duration at version:

$$T_{obs} = T_c + 30 \text{ min} + 5 \text{ h}, \qquad (2)$$

for version with surge irrigation:

$$T_c = (T_s * n + \Delta t), \qquad (3)$$

where Tc is the time for water to reach the furrow end;
$T_s = T_c/4$ (the duration of ON and OFF periods),
n is the number of ON or OFF periods,
Δt is the time for water to reach the end of the wet furrow when inflow rate is 21.6 L/min.

Some conditions and indexes of a field experiments are presented in Table 4.

Contents in the versions of field experiments are presented in Table 5.

Scheme of an arrangement for the versions in field experiment are presented in Fig.6.

During each of four irrigations was realized a dosage of a water application at furrows, were determined a sediment concentrations in irrigation water and in furrow flow, a water losses to infiltration lengthways of furrow, an yield of sugar beet. The results of field experiments are presented below on Figures 7-14 and on Annexes 1-6 in a full scope. Duration surges in period of the furrow wetting are presented in Table 6.

Water meter

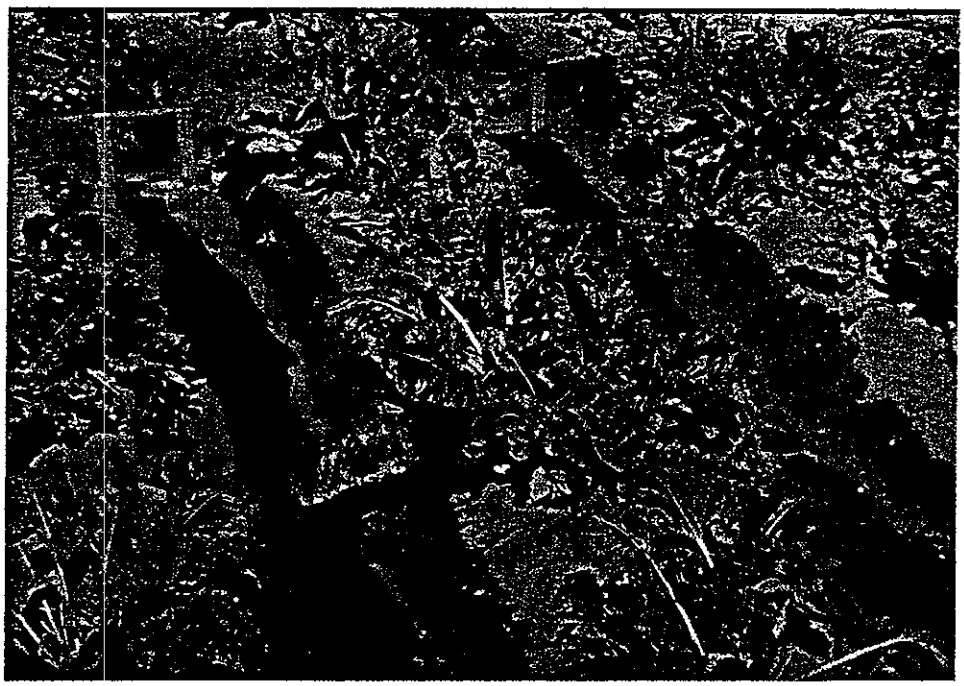


Photo 1

Sample collection of water

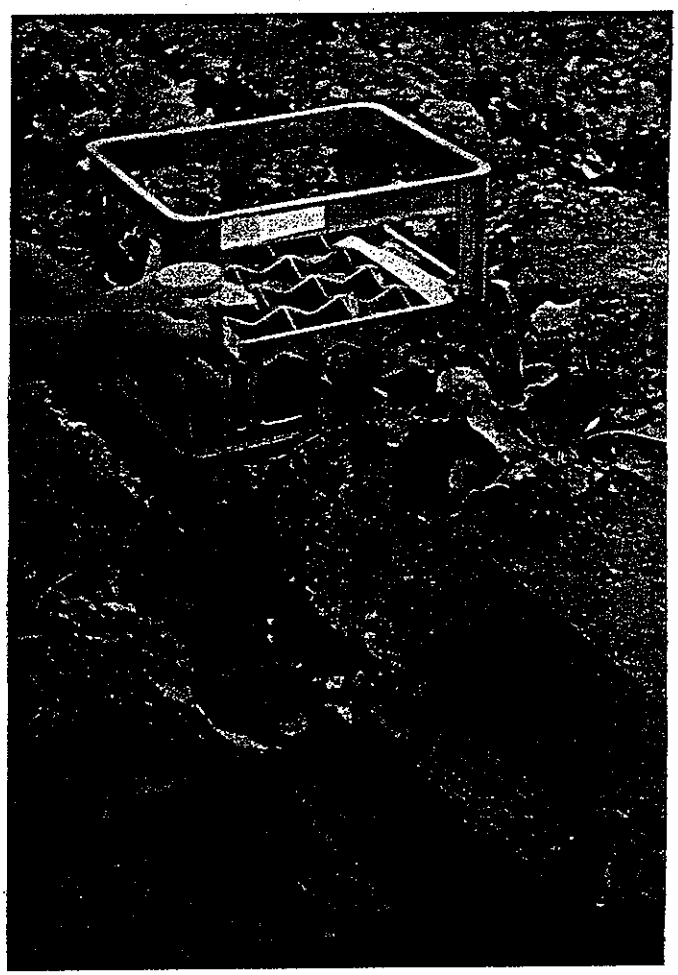


Photo 2

Metalic chute

Photo 3

Table 4

SOME CONDITIONS AND INDEXES OF THE FIELD EXPERIMENTS

Rain		Date of culti-vation	Date of soil sample collection	Irrigation			
date	norm, mm			number	version of irrigation technology	date	water application, m^3/hec
25.05	1.5	7.07	7.07		test	31.07	
29.05	0.8	31.07	31.07	1	cont.irr.	1.08	1352
30.05	2.1		7.08		cont.irr.+p	1.08	1393
31.05	5.4		17.08		surge irr.+p	2.08	1374
1.06	8.5				surge irr.	2.08	1341
14.06	3.9			2	cont.irr.	14.08	1348
16.06	0.3				cont.irr.+p	14.08	1377
20.06	0.7				surge irr.+p	15.08	1354
28.06	1.0				surge irr.	15.08	1334
29.06	1.7			3	cont.irr.	28.08	1339
30.06	2.1				cont.irr.+p	28.08	1358
02.07	1.0				surge irr.+p	29.08	1348
15.07	1.8				surge irr.	29.08	1332
17.07	2.9			4	cont.irr.	11.09	1333
18.07	0.9				cont.irr.+p	11.09	1339
24.07	0.3				surge irr.+p	12.09	1333
2.08	0.9				surge irr.	12.09	1325
3.08	2.0			5	cont.irr.	28.09	1200
09.08	1.8				cont.irr.+p	28.09	1200
17.08	3.6				surge irr.+p	28.09	1200
23.08	4.4				surge irr.	28.09	1200
19.09	0.4						
25.09	24.0						
26.09	10.1						
29.09	8.6						
30.09	13.7						
Total	104.4						

Table 5

CONTENTS IN VERSIONS OF FIELD EXPERIMENTS

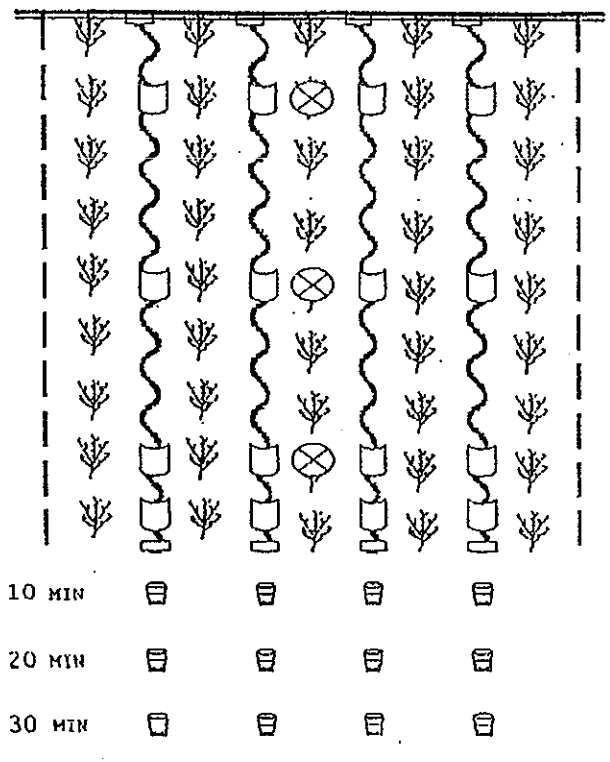
Version of irrigation technology	Contents of the version	Footnoote
Cont. irr.	Irrigation No 1. Control, continuous irrigation T1c	Furrow of 200 m long. Samples collection of water with sediments from the furrows at distances of 20, 100, 180 and 200 m. Repeat the measurement of sediment concentration at 10, 20, and 30 min after water reached the end of the furrow. Flow rate q1=21.6 L/min in period of the wetting and q2=12.36 L/min in period of the after wetting. Measure inflow and outflow rates during 5 h at 30 min intervals. Repeatition is 4 furrows
Cont.irr.+ Pam	Irrigation No 1. Continuous irrigation with PAM application (10 g/m^3). T2c	
Surge irr. +Pam	Irrigation No 1. Surge irrigation with PAM application (10 g/ m^3). Ts=T2c/4	
Surge irr.	Irrigation No 1. Surge irrigation Ts=T1c/4	
Cont. irr.	Irrigations from No 2 to No 4. Continuous irrigation. T3c	
Cont.irr.+ Pam	Irrigations from No 2 to No 4. Continuous irrigation. T4c	
Surge irr. +Pam	Irrigations from No 2 to No 4. Surge irrigation Ts=T4c/4	
Surge irr.	Irrigations from No 2 to No 4. Surge irrigation Ts=T3c/4	

Table 6

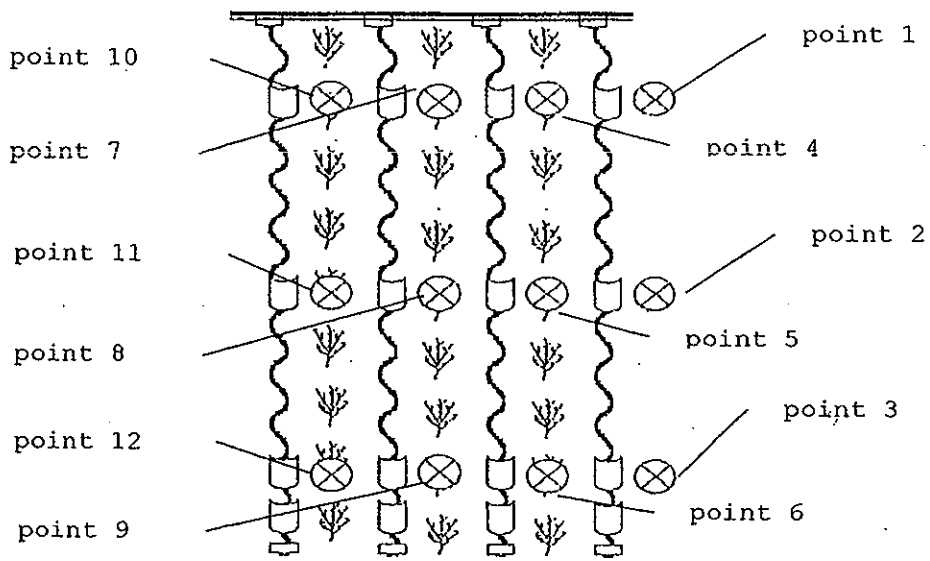
TIME FOR WATER TO REACH THE END OF THE FURROW AND THE ON (OFF) PERIOD IN THE SURGE IRRIGATION (MIN)

Version of irrigation technology	The 1st irrigation				The 2nd irrigat.		The 3rd irrigat.		The 4th irrigat.	
	Tc		Ts		Tc	Ts	Tc	Ts	Tc	Ts
	1999	2000	1999	2000						
Cont.irr.	75	93			86		73		63	
Cont.irr.+Pam	100	154			130		101		72	
Surge irr.+Pam	103	125	25	40	95	30	86	25	63	18
Surge irr.	59	75	15	25	65	20	62	18	51	16

Scheme of version



Scheme of the versions



Versions : Surge irr. Surge irr.+P Cont. irr.+P Cont. irr.

is a metalic chute for sample collection of water

is a point for sample collection of soil

is a water meter

Fig. 8

2.1. Effect of Pam on depth and uniformity of soil moistening

Depth and uniformity of soil moistening at irrigation was determined of a with method of a sample collection from different depths of soil stratum. Was used following formula at a processing of results:

$$\beta = \frac{V_1 - V_2}{V_2} * 100, \% \qquad (4)$$

where β is the soil moisture content, % to weight of absolute dry soil;

V_1 is the weight of sample before drying, g;

V_2 is the weight of sample after drying, g.

Samples was selected before first irrigation, after first irrigation and after second irrigation. The results of a data processing presented in Annex 1 and Fig. 9 and 10. The increase of soil moisture content which was determined as difference between soil moisture content after first irrigation and before first irrigation (Fig. 9) and between soil moisture content after second irrigation and after first irrigation (Fig.10) had not of uniform area distribution and depth distribution.

But we had a deep percolation for all versions of the first irrigation. On the average the increase of soil moisture content composed from 2.63 to 3.47 % in a stratum 0-150 cm (tabl. 7).

Table 7

THE INCREASE OF THE SOIL MOISTURE CONTENT FOR EXPERIMENTAL VERSION (THE FIRST IRRIGATION)

Version of irrigation technology	The increase of soil moisture content ($\Delta\beta$,%) at furrow length, m						Uniformity of water distribu-tion in soil, K
	2000			on the average			
	20	100	180	2000	1999	1999& 2000	2000
Cont. irr.	2.86	2.74	2.58	2.73	1.00	1.87	0.90
Cont.irr.+Pam	3.96	3.43	3.07	3.47	3.17	3.32	0.78
Surge irr.+Pam	3.37	3.24	3.16	3.25	2.90	3.08	0.94
Surge irr.	2.72	2.64	2.51	2.63	1.13	1.88	0.92

The average geometrical increase of soil moisture content was determined on formula:

$$\beta = (40*\Delta\beta_1+120*\Delta\beta_2+40*\Delta\beta_3)/200, \% \qquad (5)$$

where $\Delta\beta_1$, $\Delta\beta_2$, $\Delta\beta_3$ are the increase of soil moisture content at distances of furrow 20,100 and 180 m accordance;
200 is the length of furrow in experiments, m.

The Pam is mixed with irrigation water improved a phisical properties of soil (a capillarity, a pore space and other) therefore increase of soil moisture content was higher at all profile along furrows and at vertical direction.

The uniformity of water distribution in soil along the furrows composed 0.77 for version *continuous irrigation +Pam* and 0.93 for *surge irrigation* (Tabl. 7).

It was determined on formula:

$$K=\Delta\beta_3/\Delta\beta_1$$

We had the negative increase of the soil moisture content of second irrigation as regards first irrigation (see Fig.10). Moisture was redistributing on soil profile to depth.

Data for second irrigation given below.

Table 7a

THE INCREASE OF THE SOIL MOISTURE CONTENT FOR EXPERIMENTAL VERSION (THE SECOND IRRIGATION)

Version of irrigation technology	The increase of soil moisture content ($\Delta\beta$,%) at furrow length, m					
	2000			on the average		
	20	100	180	2000	1999	1999& 2000
Cont. irr.	0.29	0.30	0.29	0.30	0.71*	0.55
Cont.irr.+Pam	0.10	0.21	0.03	0.14	0.59	0.37
Surge irr.+Pam	-0.10	-0.07	-0.10	-0.08	1.39	0.66
Surge irr.	0.18	0.25	0.36	0.26	0.80*	0.53

* it's after cultivation

The increase of soil moisture content after first irrigation

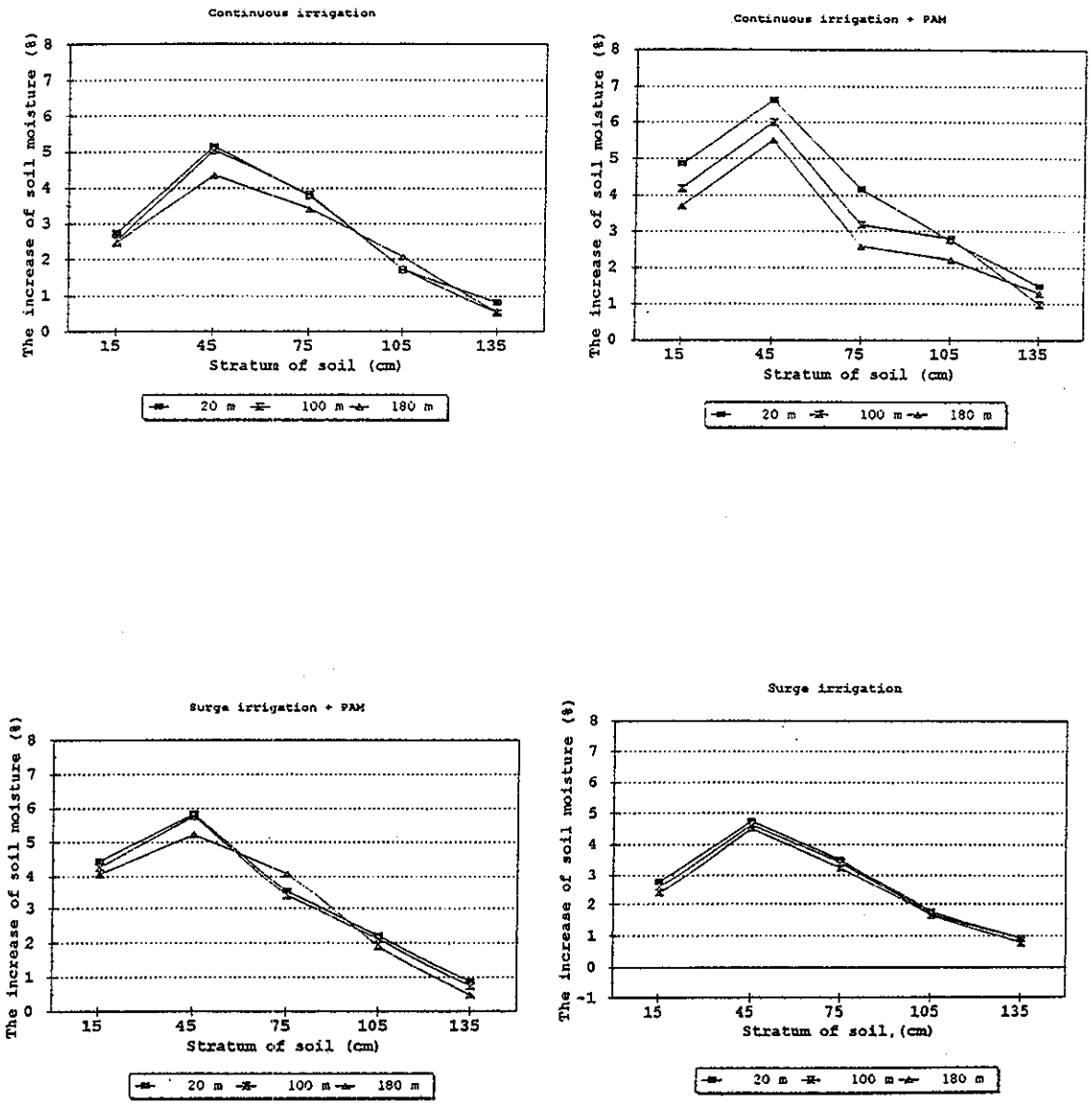


Fig.9

The increase of soil moisture content after second irrigation

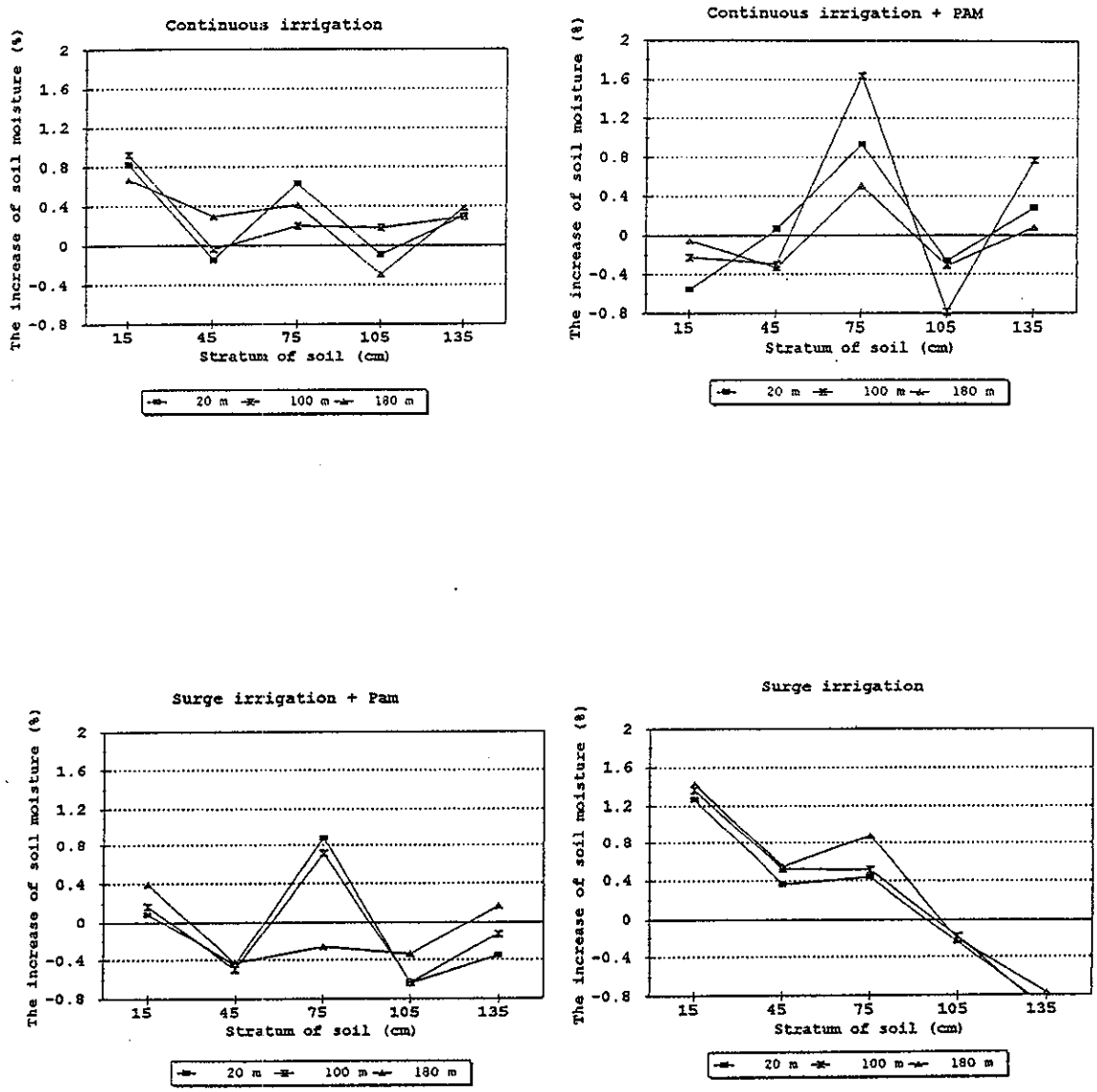


Fig.10

2.2. Effect of surge flow and Pam on water infiltration and water management

Balance method was used on determination of water losses to infiltration lengthways of a furrow. Following formulae were used:

$$W=W_{app.}-W_{o.f.}, \qquad (6)$$

where $W_{app.}$ is the volume of water application for one irrigation period, m^3/hec;

$W_{app.}= W_{app.1} + W_{app.2}$;

$W_{app.1}$ is the water application with flow rate q1=21.6 L/min in period of one irrigation;

$W_{app.1} = 21.6*(T_c+30)*N/1000$, m^3/hec;

$W_{app.2}$ is the water application with flow rate q2=12.36 L/min in period of one irrigation;

$W_{app.2} = 12.36*(1440-T_c-30)*N/1000$, m^3/hec;

N is number of furrows in the one hectare;

N=10000/(b*L);

b is the space between furrows (b=0.70 m);

L is the length of experimental furrow (L=200 m);

1440 is duration of the one irrigation, min;

$W_{o.f.}$ is the volume of the outflow on the furrow ends, m^3/hec;

$W_{o.f.}= W_{o.f.1} + W_{o.f.2}$;

$W_{o.f.1}$ is the volume of outflow in the observed period;

$W_{o.f.2}$ is the volume of outflow in period after end of observations;

$W_{o.f.1}=\omega_{o.f.1}*N/1000$, m^3/hec;

$\omega_{o.f.1}$ is the volume of outflow from one furrow in the observed period;

$\omega_{o.f.1} =\Sigma(q_{avr}*dt)$, L;

q_{avr} is the average value of out flow rate from one furrow between two measurements, L/min;

dt is interval time two between these measurements, min;

$q_{avr} =(q_i+q_{i+1})/2$, L/min;

q_i is the out flow rate from one furrow on moment of time t_i, L/min;

$q_i =f(h_i,t_i)$;

h_i is the observed value a water head with water meter on moment of time t_i, cm;

$W_{o.f.2}= q_{o.f}*(1440-T_c-30-300)*N/1000$, m^3/hec;

$q_{o.f}$ is the out flow rate from one furrow to end of observed period, L/min.

We used following formulae too:

$$q_i =0.139(h_i)^{0.5}, \text{ L/s} \quad \text{and} \quad q_i =0.096(h_i)^{0.5}, \text{ L/s}.$$

The values T_c it is necessary take from Table 6. The calculations are gave in Annex 2 of the water application for versoins of field experiments and for 4 irrigations. Data of measurement "h", of calculation values "q_i" and the volumes of

outflow from one furrow in period of observation presented in Annex 3. Calculation of total the volumes of outflow for versions of field experiments and for 4 irrigations are gave in Annex 4. The results calculation of the irrigation application efficiency presented in Table 8 and Fig. 11.

The irrigation application efficiency was rather high for all fourth irrigations (the value 0.36 of this efficiency is ordinary for conditions of Kyrgyzstan) if shall not take into consideration a water losses of flow rates lengtways of a furrow on deep percolation (more 150 cm). But we could appreciate a size those water losses for the first irrigation as we have dispose by soil descriptions in vertical profile (see Table 1 and 7).

Table 8

WATER INFILTRATION FOR PERIOD OF IRRIGATION

Index of irrigation	Version of irrigation technology	Water volume for number of irrigation, m^3/hec				
		1	2	3	4	total
Water application m^3/hec	cont. irr.	1352	1348	1339	1333	5372
	cont.irr. +Pam	1393	1377	1358	1339	5466
	surge irr.+Pam	1374	1354	1348	1333	5408
	surge irr.	1341	1334	1332	1325	5331
Outflow volume, m^3/hec	cont. irr.	683	747	787	813	3030
	cont.irr. +Pam	462	566	704	765	2497
	surge irr.+Pam	597	731	780	814	2922
	surge irr.	730	809	810	839	3188
Water infiltration, m^3/hec	cont. irr.	669	601	552	520	2342
	cont.irr. +Pam	931	811	654	574	2970
	surge irr.+Pam	777	623	568	519	2487
	surge irr.	611	525	522	486	2144
The irrigation application efficiency	cont. irr.	0.49	0.45	0.41	0.39	0.44
	cont.irr. +Pam	0.67	0.59	0.48	0.43	0.54
	surge irr.+Pam	0.57	0.46	0.42	0.39	0.46
	surge irr.	0.46	0.39	0.39	0.37	0.40

Table 8a

THE WATER INFILTRATION FOR IRRIGATION PERIOD
1999

The index of irrigation	The version	The water volumes for number of irrigat.				
		1	2	3	4	1-4
Water application, m3/hec	cont. irrig.	1400	1460	1513	1484	5857
	cont. irrig.+Pam	1406	1402	1466	1451	5726
	surge irrig.+Pam	1476	1428	1516	1497	5916
	surge irrig	1458	1454	1551	1509	5973
Outflow volume, m3/hec	cont. irrig.	831	700	854	709	3093
	cont. irrig.+Pam	290	352	717	634	1992
	surge irrig.+Pam	459	518	1086	751	2815
	surge irrig	1061	792	962	829	3645
Water infiltration, m3/hec	cont. irrig.	569	760	659	776	2764
	cont. irrig.+Pam	1116	1050	750	818	3734
	surge irrig.+Pam	1017	909	430	746	3102
	surge irrig	397	661	589	680	2328
Irrigation application efficiency	cont. irrig.	0.41	0.52	0.44	0.52	0.47
	cont. irrig.+Pam	0.79	0.75	0.51	0.56	0.65
	surge irrig.+Pam	0.69	0.64	0.28	0.50	0.52
	surge irrig	0.27	0.45	0.38	0.45	0.39

Table 8b

THE WATER INFILTRATION FOR IRRIGATION PERIOD
1999 & 2000

The index of irrigation	The version	The water volumes for number of irrigat.				
		1	2	3	4	1-4
Water application, m3/hec	cont. irrig.	1376	1404	1426	1409	5615
	cont. irrig.+Pam	1400	1390	1412	1395	5596
	surge irrig.+Pam	1425	1391	1432	1415	5663
	surge irrig	1400	1394	1442	1417	5652
Outflow volume, m3/hec	cont. irrig.	757	724	821	761	3062
	cont. irrig.+Pam	376	459	711	700	2245
	surge irrig.+Pam	528	625	933	783	2868
	surge irrig	896	801	886	834	3416
Water infiltration, m3/hec	cont. irrig.	619	681	606	648	2553
	cont. irrig.+Pam	1024	931	702	696	3351
	surge irrig.+Pam	897	767	499	633	2795
	surge irrig	504	594	556	583	2236
Irrigation application efficiency	cont. irrig.	0.45	0.48	0.42	0.46	0.45
	cont. irrig.+Pam	0.73	0.67	0.50	0.50	0.60
	surge irrig.+Pam	0.63	0.55	0.35	0.45	0.49
	surge irrig	0.36	0.43	0.39	0.41	0.40

The water content of soil you can determine on formula:

$$W\ w.c.=100*H*\gamma*\Delta\beta,\ m^3/hec, \qquad (7)$$

where H is the stratum of soil (H=1,50 m);

γ is the weight apparent density (γ=1.50 g/cm^3 on the average for soil stratum 0-150 cm);

$\Delta\beta$ is the increment of soil moisture content, % to weight of absolute dry soil.

The results of calculation are presented in Table 9 for water content on soil and water losses on deep percolation.

Table 9

WATER CONTENT OF SOIL AND WATER LOSSES IN DEEP PERCOLATION (THE FIRST IRRIGATION) 2000

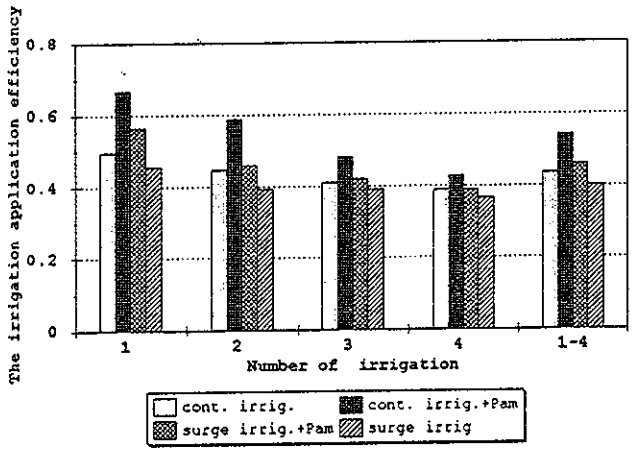
Version of irrigation technology	Water applica-tion, m^3/hec	Water infiltra-tion, m^3/hec	Water content of soil stratum 0-150 cm, m^3/hec	Water losses in deep percolation	
				m^3/hec	% to water applica-tion
Cont. irr.	1352	669	614	55	4.0
Cont. irr.+Pam	1393	931	781	150	10.8
Surge irr.+Pam	1374	777	731	46	3.3
Surge irr.	1341	611	592	19	1.4

However it is considered that the plants of sugar beet can take a water with 250-cm depth of soil stratum.

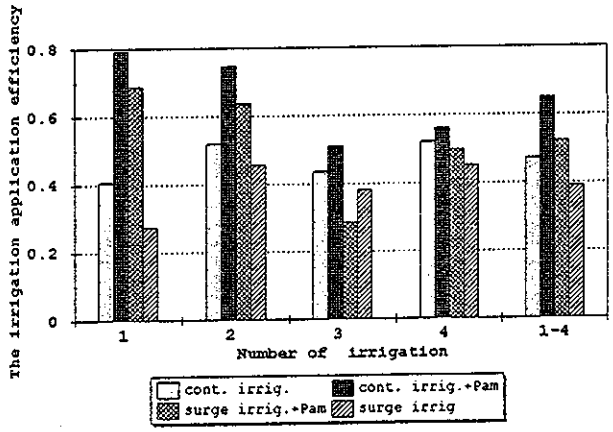
In that case, how showed our calculations, the versions *surge irrigation + Pam and continuous irrigation + Pam* was more effective on water infiltration, on water management and on the irrigation application efficiency. We have less of a water losses in the furrow end. They might be still less if we accepted a value of flow q_2 less 12.36 L/min. We took the observation data of soil infiltration capacity as a basis when calculated the value of flow q_2 (see the page 10). The observations of the soil infiltration capacity were conducted on constant level of the water h=8 cm. The fact level of the water in furrow did not exceed 1-3 cm and decreased to end of furrow. The value of inflow rate q2=10.2 L/min more correspond to reality in period of after wetting. This factor will be took by us into consideration at the experiments in 2001. The data that are presented in Table 8 and Fig. 11 are gave without consideration of the fifth irrigation data. We did not conduct the observations in period of the fifth irrigation.

Versions of irrigation technologies and the irrigation application efficiencies

2000



1999



1999&2000

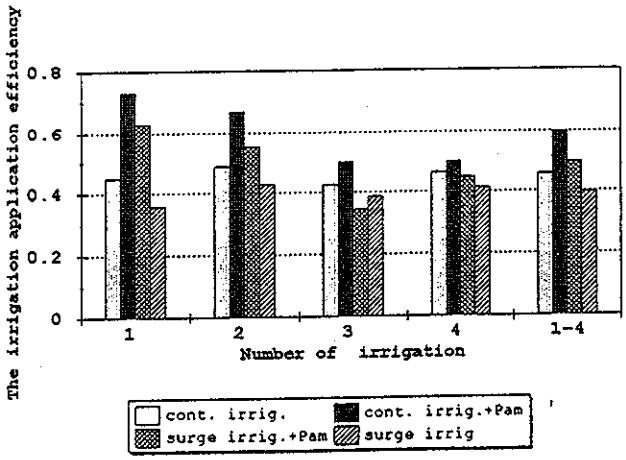


Fig. 11

Table 9a

WATER CONTENT OF SOIL AND WATER LOSSES
IN DEEP PERCOLATION (THE FIRST IRRIGATION)
1999

Version of irrigation technology	Water applica-ti on, m^3/hec	Water infiltra-tion, m^3/hec	Water content of soil stratum 0-150 cm, m^3/hec	Water losses in deep percolation	
				m^3/hec	% to water applica-tion
Cont. irr.	1400	569	225	344	24.6
Cont. irr.+Pam	1406	1116	713	403	28.6
Surge irr.+Pam	1476	1017	653	364	24.7
Surge irr.	1458	397	254	143	9.8

Table 9b

WATER CONTENT OF SOIL AND WATER LOSSES
IN DEEP PERCOLATION (THE FIRST IRRIGATION)
ON THE AVERAGE FOR 1999 & 2000

Version of irrigation technology	Water applica-ti on, m^3/hec	Water infiltra-tion, m^3/hec	Water content of soil stratum 0-150 cm, m^3/hec	Water losses in deep percolation	
				m^3/hec	% to water applica-tion
Cont. irr.	1376	619	420	199	14.5
Cont. irr.+Pam	1400	1024	747	277	19.8
Surge irr.+Pam	1425	897	692	205	14.4
Surge irr.	1400	504	423	81	5.8

85

2.3. Effect of Pam and of surge irrigation on furrow erosion

Furrow erosion, the concentration of sediments in the furrow water, were studied as a function of the following variables:

a) flow rates (21.6 L/min and 12.36 L/min);

b) slope of furrow (on the average 0.026 m/m);

c) irrigation method (*continuous irrigation* and *surge irrigation*);

d) water quality (without PAM and with PAM 10 g/m^3).

Following formulae were used:

$$\mu_{1i} = (G_S / G) * 100, \% \quad (8)$$

$$\mu_{2i} = 10*\mu_{1i}, \text{ g/L}$$

$$P_{\mu}i = Wi*\mu_{2i}/1000, \text{ kg}$$

where μ_{1i} and μ_{2i} are the sediments concentration in furrow water at the moment time t_i, % to weight of absolute dry soil;

G_S is the weight of the sample after drying, g;

G is the weight of the sample before drying, g;

W_i is the water volume at the moment time t_i that contents the sediments, L;

$P_{\mu i}$ is the weight of the sediments in this volume of water at the moment time t_i, kg.

We have for the observed period:

$$\sum P_{\mu i} = \sum (W_i * \mu_{2i}), \text{ kg} \quad (9)$$

Our field experiments showed (Fig. 12, Annex 3 and 5) that content of sediments in furrow water decreases from irrigation to irrigation in versions a *continuous irrigation* and a *surge irrigation* and increase from irrigation to irrigation in Pam's versions (Annex 3); decreases with increase of the observed time (Annex 3);increase with length of a furrow to the appointed limits, the dependence E=f(L) has a point of inflection (Fig. 12).

The surge irrigation, in comparison with the *continuous irrigation,* increases a percent of the sediment concentrations in the furrow water (Annex 3), reduces the time for furrow wetting (Table 6) and value flow for movement on field surface. The furrows were eroded bigger in versions with *surge irrigation* (Photo 4) if to compare the versions *surge irrigation* and *continuous irrigation*.

Our last observations demonstrated that *surge irrigation* influences on surface of furrow as if emery paper influences on a wood: the process of erosion continues until will be formed a smooth furrow surface or will be completed a potential possibility of flow rate at short periods of ON and OFF. However we have a advantage technology with *surge irrigation* for protect of soil from erosion at first irrigation 2000 when time intervals for the

Content of the sediment concentrations on furrow water

(on the average for 30- min observations)

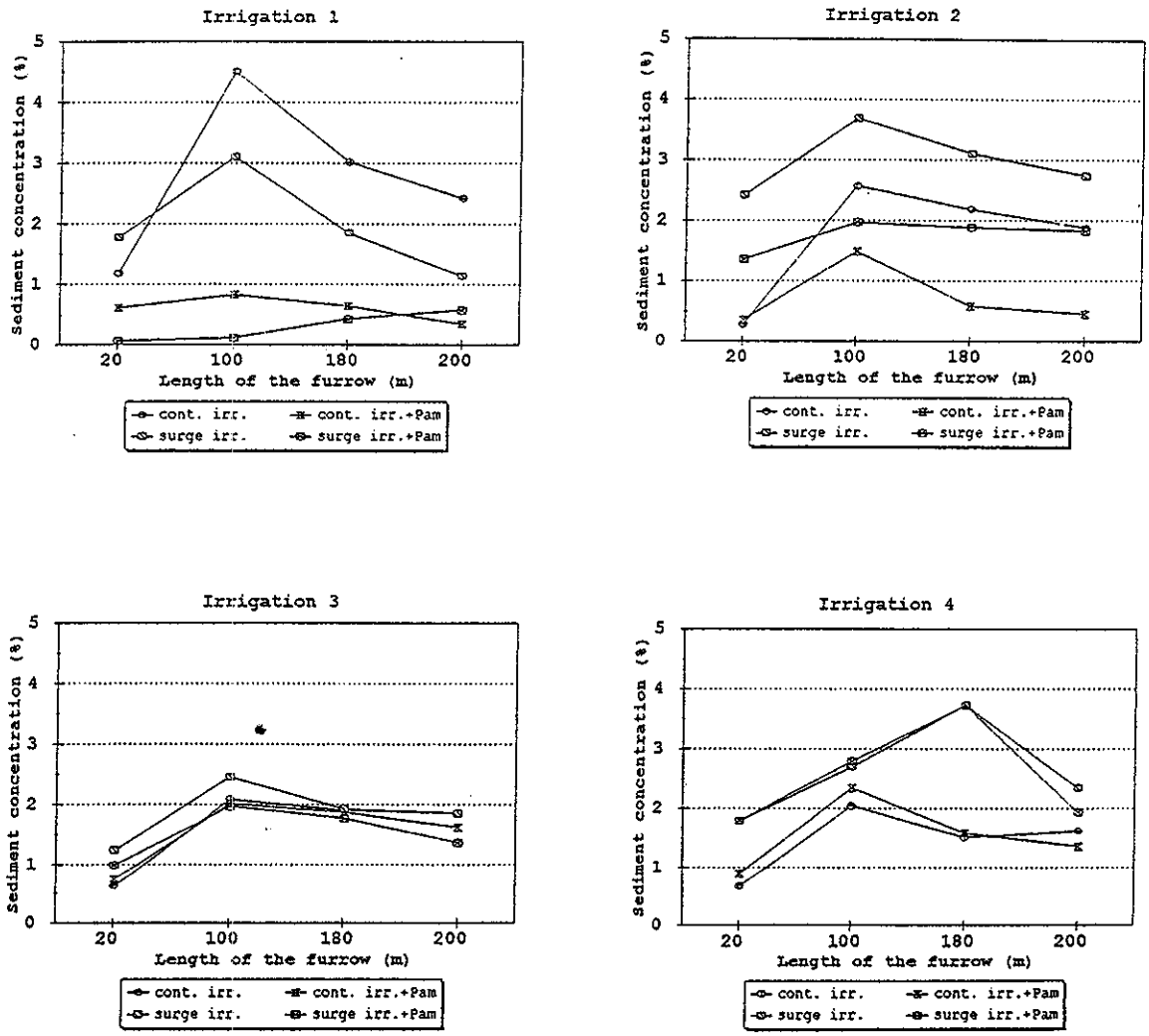


Fig. 12

ON and OFF periods composed 30 min and 40 min (Fig. 12 and Annex 5). This advantage of the irrigation technology with surge was lost at following irrigation when time intervals for the ON and OFF periods decreased (Fig 13 and 14).

We had a sedimentation in the furrow end at all versions (Annex 5). Erosion continued during all the experience. Process of erosion was stabilized to end of irrigation but the versions with *surge irrigation* maintained "leadership" after decrease of a flow rate to Q2=12.36 L/min. Effectiveness of PAM treatment decreased in 3-4 times to end our researches (Annex 3). The *surge irrigation* obviously surpassed *continuous irrigation* on intensity of erosion. But if to compare the versions *surge irrigation+Pam* and *continuous irrigation+Pam* then the superiority of the first was minimum (Annex 5). Velocity for advancement of a jet was the smaller on version with *Pam* that demonstrates a creation of a bed with permeable silting deposits on furrow surface. This drift bed with PAM addition increased an infiltration capacity of the furrows, decreased velocity for advancement of a jet and protected a furrow surface from erosion.

Balance of sediments was determined on formula:

$$\Delta P_{\mu i}=\sum P_{\mu is}-\sum P_{\mu if}$$

where $\Delta P_{\mu i}$ is the total weight of the sediments that were deposited on furrow, kg;

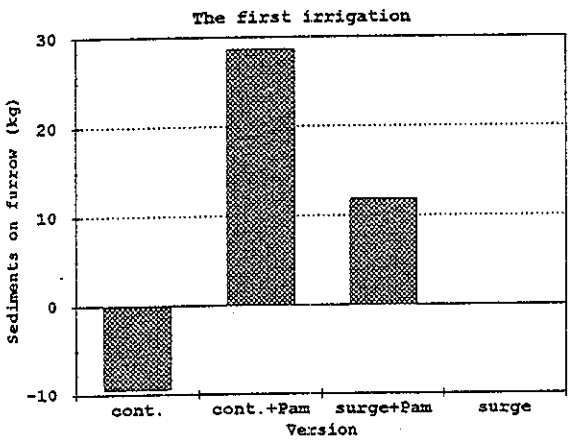
$\sum P_{\mu is}$ is the total weight of the sediments that came to furrow with irrigation water, kg;

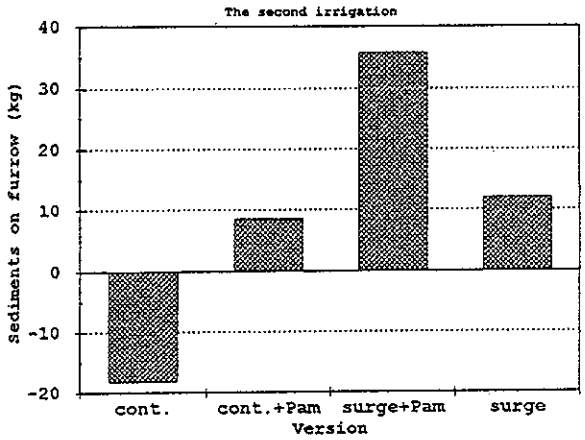
$\sum P_{\mu if}$ is the total weight of the sediments that were hollow off from furrow, kg.

Sediment concentration on irrigation water, that was gave to the furrows, had not a constant value during vegetative period. It changed during one irrigation, at the variants of experiment and from irrigation to irrigation (Fig.13 and 14). This circumstance can have an influence on the results of our experiments. In connection with this you can subject to comparison data of technology versions *continuous irrigation* and *continuous irrigation + Pam* (between oneself), *surge irrigation* and *surge irrigation* + Pam (also between oneself). We conducted every experimental irrigation during 2 days: we studied the technology versions *continuous irrigation* and *continuous irrigation* +Pam in first day and the versions with *surge irrigation* and *surge irrigation* +Pam were in second day (see Tabl. 4).

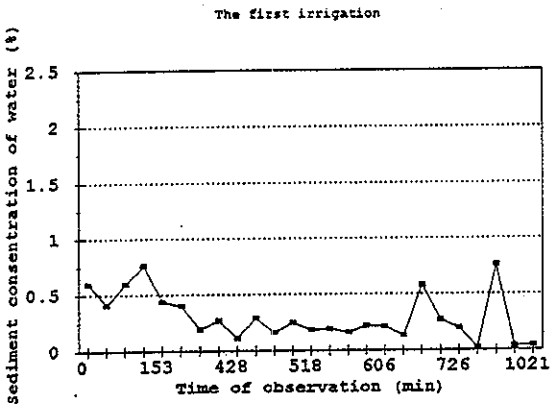
The calculations of balance sediments for one furrow tabulate Annex 5 and presented on Fig. 13 and 14. But we said earlier, you can compare an absolute data of technology versions *continuous irrigation* and *continuous irrigation + Pam* (between oneself), *surge irrigation* and *surge irrigation* + Pam (also between oneself).

Balance of the sediments for one furrow





The sediment concentrations of irrigation water



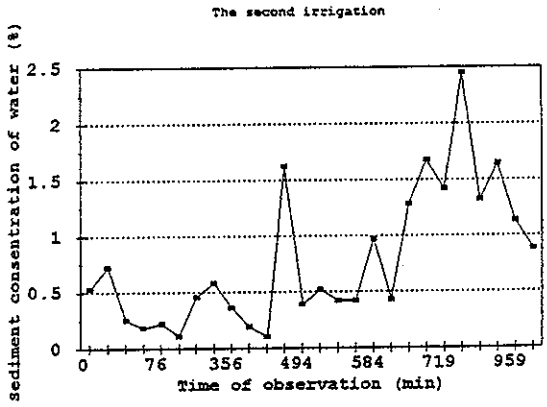
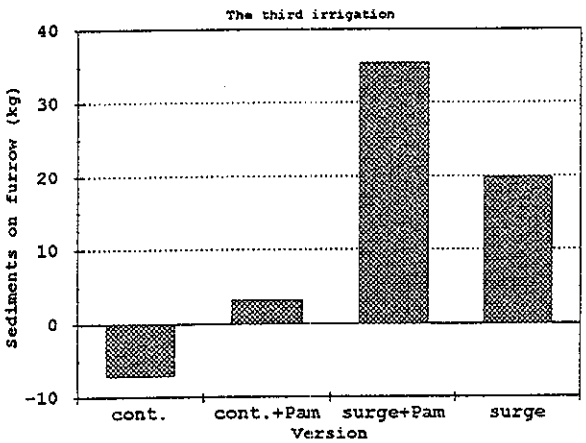
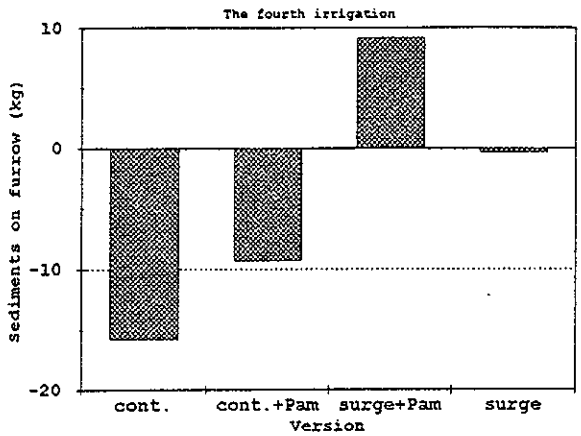


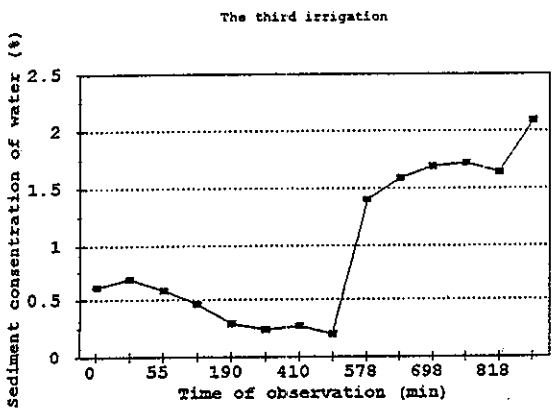
Fig. 13

Balance of the sediments for one furrow





The sediment concentrations of irrigation water



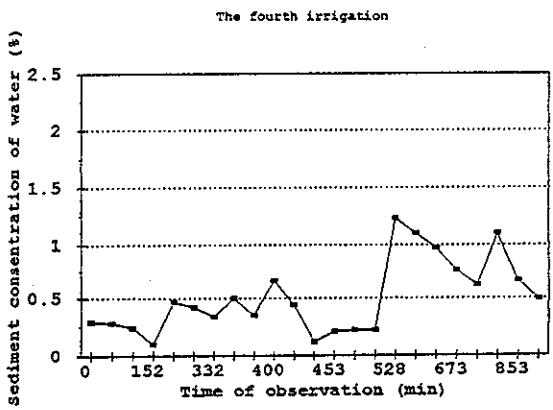


Fig. 14

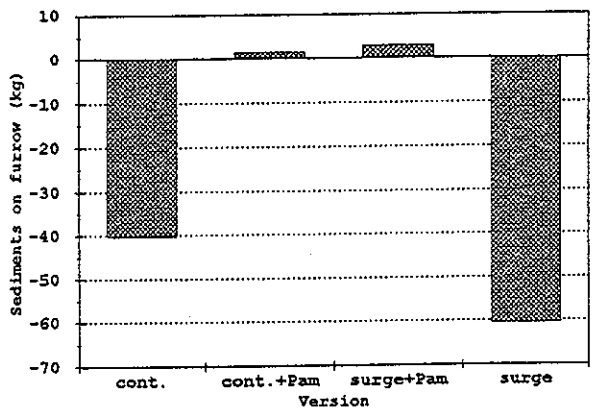
Balance of the sediments for one furrow

The irrigation 1 1999

Number of furro	Version	Duration, m: of wetting	of irrigation with q1 0.36 L/s	with q2 0.20 L/s	Sediment concen.,	Water applic., L	Weight sediments applicat kg	discharg kg	balance kg
5,6,7,8	cont.	75	105		0.05	2268	1.13		
				300	0.041	3600	1.48		
	total					5868	2.61	42.8	-40.19
1,2,3,4	cont.+Pa	100	130		0.05	2808	1.40		
				300	0.041	3708	1.52		
	total					6516	2.92	1.49	1.43
9,10,11,	surge+Pa	103	133		0.061	2872.8	1.75		
				300	0.041	3708	1.52		
	total					6580.8	3.27	0.29	2.98
13,14,15	surge	59	89		0.066	1922.4	1.27		
				300	0.048	3708	1.78		
	total					5630.4	3.05	63.6	-60.55

Balance of the sediments for one furrow

1999 (the first irrigation)



Sediment concentrations of irrigation water

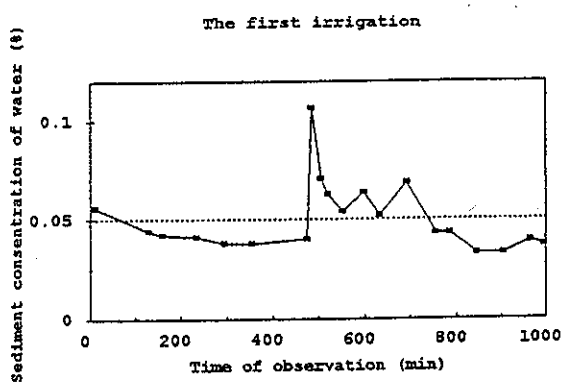


Fig. 15

2.4. **Effect of Pam and surge irrigation on yield capacity of sugar beet**

Data of a yield capacity are presented in Annex 6. Yield capacity of sugar beet was determined only for root crop and for sowing with norm 70 thousand plants at hectare.

Pam addition in irrigation water gave an increase of root crops yield capacity (we had not increase of root crops yield capacity last year: a cultivation that was conducted on version *continuous irrigation and surge irrigation* good affected yield capacity). But too the water and the soil conditions of field (low content of humus, low erosion resistance and impoverishment in connection with sowing of sugar beet over the last four years) participated in a forming of root crops yield capacity.

The calculations of the water application and the water infiltration for creation of the unit crop showed (Table 10) that the highest water expenditure on creation of a root crops took place in versions of *continuous irrigation* and *continuous irrigation+Pam*. Version *surge irrigation+Pam* had the most low the indexes of water expenditure on creation of a sugar crops. If to take only effective water application (as stated above this efficiency is aggreed as we did not take stock of loss at the deep percolation) then versions the *surge irrigation* and the *surge irrigation+Pam* were effective more. Possibly, irrigation by silty water had a relation to this.

The fifteen the biggest root crops participated on our calculations and the conclusions (Annex 6). We could do this as the sowing of sugar beet had not of an even and simultaneous shoots of sugar beet originally.

CONCLUSIONS

The researches 1999 and 2000 showed that in conditions of experiments:

1.PAM is effective anti - erosion method even if the PAM treatment of the furrows to conduct only in the first irrigation.

2. Technology of irrigation with *surge irrigation* is effective for the decrease IR.

3. Effect of technology with *surge irrigation* in PAM treatments is not as effective in the decrease IR as in conventional treatment (i.e., without PAM).

4. Technology of irrigation with *surge irrigation* in PAM treatments is effective in maintenance of high infiltration rate.

5. Irrigation by silty water is effective method for the increase of soil stratum at the irrigated areas.

6. Technology of irrigation with *surge irrigation* is effective at silty irrigation water.

7. Technology of irrigation with *continuous irrigation* is effective at turbidity-free irrigation water.

We had not of problems in conducted of field experiments, except outflow water from the above irrigated plot that came to our plot.

Table 10

WATER APPLICATION ON CREATION OF CROP

Version of irrigation technology	Water application for 4 irrigations, m^3/hec	Water infiltration for 4 irrigations, m^3/hec	Yield of the sugar beet at length of furrow				Water application on the one centner of a crop (on the average), m^3/cen	Water infiltration on the one centner of a crop (on the average), m3/cen
			20 m	100 m	180 m	on the average		
Cont. irrig.	5372	2342	323	292	297	299	17.97	7.83
Cont. irrig.+Pam	5466	2970	468	399	314	396	13.80	7.50
Surge irrig.+Pam	5408	2487	543	366	327	394	13.73	6.31
Surge irrig.	5331	2144	532	431	400	445	11.98	4.82

Sediment concentration in irrigation water, which is gave to the furrows, was not a constant value during vegetative period. It changed during one irrigation, at the variants of experiment and from irrigation to irrigation for simple reason that the outflow water from the above irrigated plot came to us. This circumstance can have influence on results of our experiments (on furrow erosion in the first place). In connection with this you can subject to comparison the data of technology versions *continuous irrigation* and *continuous irrigation + Pam* (betveen oneself), *surge irrigation* and *surge irrigation* + Pam (also betveen oneself). Possibly, the conclusions that we did for versions, are not correct in connection with this. We will try to escape this in season 2001.

References

1. V.A. Kovda. 1973. The principles of pedology. General theory of soil formation. Second book. Moscow. P. 40.

2.The Soils of Kyrgyzskaya USR (at editing A. M. Mamytov). 1974. Frunze. P. 136

Annex 1

The increase of soil moisture content and uniformity of the water distribution on soil for first irrigstion (consolidated data)

2000

Continuous irrigation

Stratum, cm	The increase of moist. content,% distance from furrow beginning 20 m	100 m	180 m	on the average	Uniformity of the water distribution
15	2.78	2.51	2.48		
45	5.13	5.04	4.36		
75	3.82	3.83	3.43		
105	1.75	1.73	2.09		
135	0.80	0.57	0.54		
	2.86	2.74	2.58	2.73	0.90

Continuous irrigation+Pam

The increase of moist. content,% distance from furrow beginning 20 m	100 m	180 m	on the average	Uniformity of the water distribution
4.83	4.21	3.68		
6.62	6.00	5.51		
4.12	3.17	2.64		
2.75	2.77	2.24		
1.49	1.01	1.29		
3.96	3.43	3.07	3.47	0.78

Surge irrigation

Stratum, cm	The increase of moist. content,% distance from furrow beginning 20 m	100 m	180 m	on the average	Uniformity of the water distribution
15	2.76	2.57	2.42		
45	4.68	4.64	4.50		
75	3.54	3.41	3.22		
105	1.74	- 1.68	1.62		
135	0.90	0.91	0.80		
	2.72	2.64	2.51	2.63	0.92

Surge irrigation+pam

The increase of moist. content,% distance from furrow beginning 20 m	100 m	180 m	on the average	Uniformity of the water distribution
4.46	4.24	4.07		
5.83	5.77	5.25		
3.51	3.37	4.11		
2.21	2.10	1.88		
0.86	0.74	0.47		
3.37	3.24	3.16	3.25	0.86

Annex 1a

The increase of soil moisture content for second irrigstion (consolidated data)

2000

Continuous irrigation

The increase of moist. content,%
distance from furrow beginning

Stratum, cm	20 m	100 m	180 m	on the average
15	0.78	0.94	0.67	
45	-0.13	-0.04	0.29	
75	0.58	0.20	0.40	
105	-0.11	0.18	-0.31	
135	0.31	0.24	0.39	
	0.29	**0.30**	**0.29**	**0.30**

Continuous irrigation+Pam

The increase of moist. content,%
distance from furrow beginning

20 m	100 m	180 m	on the average
-0.52	-0.24	-0.03	
0.07	-0.30	-0.33	
0.96	1.64	0.46	
-0.28	-0.77	-0.34	
0.28	0.74	0.08	
0.10	**0.21**	**-0.03**	**0.14**

Surge irrigation

The increase of moist. content,%
distance from furrow beginning

Stratum, cm	20 m	100 m	180 m	on the average
15	1.28	1.37	1.37	
45	0.42	0.52	0.55	
75	0.39	0.53	0.90	
105	-0.24	-0.20	-0.20	
135	-0.92	-0.97	-0.80	
	0.18	**0.25**	**0.36**	**0.26**

Surge irrigation+pam

The increase of moist. content,%
distance from furrow beginning

20 m	100 m	180 m	on the average
0.07	0.20	0.39	
-0.44	-0.51	-0.44	
0.88	0.72	-0.29	
-0.66	-0.63	-0.32	
-0.34	-0.14	0.17	
-0.10	**-0.07**	**-0.10**	**-0.08**

Annex 1b

The increase of soil moisture content for first irrigstion (consolidated data)

1999

Continuous irrigation

Stratum, cm	The increase of moist. content,% distance from furrow beginning 20 m	100 m	180 m	on the average
15	-0.95	0.49	-1.95	
45	-0.74	-0.48	1.28	
75	2.26	2.34	2.42	
105	2.01	-0.29	3.14	
135	0.88	2.62	2.69	
	0.69	**0.94**	**1.52**	**1.00**

Continuous irrigation+Pam

The increase of moist. content,% distance from furrow beginning 20 m	100 m	180 m	on the average
-0.45	0.82	3.19	
1.7	1.83	4.73	
2.52	3.31	6.06	
2.74	3.76	5.28	
2.08	5.63	5.30	
1.72	**3.07**	**4.91**	**3.17**

Surge irrigation

Stratum, cm	The increase of moist. content,% distance from furrow beginning 20 m	100 m	180 m	on the average
15	1.99	-0.7	3.5	
45	2.17	-0.73	1.65	
75	3.13	-2.25	4.76	
105	5.38	-0.75	4.25	
135	4.35	2.21	3.83	
	3.40	**-0.44**	**3.60**	**1.13**

Surge irrigation+pam

The increase of moist. content,% distance from furrow beginning 20 m	100 m	180 m	on the average
1.32	0.48	1.29	
2.02	1.91	1.03	
2.96	3.15	3.74	
2.68	4.33	4.09	
2.61	5.38	5.06	
2.32	**3.05**	**3.04**	**2.90**

The increase of soil moisture content
2000

	point1	July 31		The soil moisture content,%		point1	August7		The soil moisture content,%		point1	August17		The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
005	20.79	56.71	52.05	14.91	006	22.43	46.58	42.96	17.65	014	21.10	53.86	49.07	17.13		
012	19.99	54.71	50.65	13.24	014	21.10	57.59	52.34	16.81	001	20.31	50.72	45.99	18.42		
009	20.79	54.57	50.33	14.35	005	20.79	47.34	43.60	16.39	008	21.12	50.97	46.48	17.71		
15	**61.57**	**166**	**153**	**14.17**		**64.32**	**151.5**	**138.90**	**16.95**		**62.53**	**155.6**	**141.5**	**17.73**	**2.78**	**0.78**
015	20.51	46.64	42.78	17.33	013	21.27	60.22	53.17	22.09	003	21.33	41.87	38.16	22.04		
004	23.11	49.1	45.2	17.66	001	20.31	55.54	49.43	20.97	016	21.01	46.61	42.15	21.10		
007	21.43	50.48	46.68	15.05	008	21.12	57.92	51.25	22.15	004	23.11	58.8	52.43	21.73		
45	**65.05**	**146.2**	**134.7**	**16.61**		**62.7**	**173.7**	**153.85**	**21.74**		**65.45**	**147.3**	**132.7**	**21.61**	**5.13**	**-0.13**
010	21.02	50.45	45.6	19.73	010	21.02	49.33	43.85	24.02	012	19.99	54.89	48.12	24.07		
002	22.97	46.44	42.64	19.32	016	21.01	52.18	46.26	23.45	002	22.97	49.82	44.54	24.48		
008	21.12	52.47	47.25	19.98	004	23.11	63.26	55.72	23.12	015	20.51	58.12	50.87	23.88		
75	**65.11**	**149.4**	**135.5**	**19.71**		**65.14**	**164.8**	**145.83**	**23.53**		**63.47**	**162.8**	**143.5**	**24.11**	**3.82**	**0.58**
014	21.10	45.11	41.04	20.41	002	22.97	59.87	53.19	22.12	010	21.02	56.41	49.95	22.33		
016	21.01	56.74	50.71	20.30	003	21.33	57.66	51.01	22.41	007	21.43	53.61	47.68	22.59		
003	21.33	58.6	52.12	21.05	012	19.99	51.13	45.40	22.56	009	20.79	50.3	45.02	21.79		
105	**63.44**	**160.5**	**143.9**	**20.61**		**64.29**	**168.7**	**149.59**	**22.36**		**63.24**	**160.3**	**142.7**	**22.25**	**1.75**	**-0.11**
013	21.27	63.28	56	20.96	009	20.79	58.45	51.87	21.17	005	20.79	45.12	40.94	20.74		
001	20.31	50.22	45.3	19.69	015	20.51	58.97	52.39	20.64	013	21.27	68.16	59.81	21.67		
006	22.43	70.58	62.51	20.13	007	21.43	60.24	53.36	21.53	006	22.43	61.85	54.86	21.55		
135	**64.01**	**184.1**	**163.8**	**20.31**		**62.73**	**177.7**	**157.62**	**21.11**		**64.49**	**175.1**	**155.6**	**21.42**	**0.80**	**0.31**
												on the average		1	**2.86**	**0.29**

Continuation of Annex 1

	point2 July 31			The soil moisture content,%		point2 August7			The soil moisture content,%		point2 August17			The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
15	029	22.58	57.96	54.06	12.39	030	21.74	58.22	53.71	14.12	029	22.58	51.14	47.19	16.05		
	018	21.28	62.19	57.85	11.87	019	19.83	52.17	48.20	14.01	026	22.36	45.3	42.21	15.57		
	032	21.89	72.79	67.46	11.70	020	21.24	59.94	54.83	15.23	039	22.25	44.08	41.34	14.35		
		65.75	**192.9**	**179.4**	**11.94**		**62.81**	**170.3**	**156.73**	**14.45**		**67.19**	**140.5**	**130.7**	**15.39**	**2.51**	**0.94**
45	026	22.36	45.34	42.36	14.90	021	21.48	64.18	57.16	19.66	024	23.04	60.07	54.26	18.61		
	036	22.48	41.58	39.14	14.65	018	21.28	62.78	55.92	19.82	037	21.55	56.11	50.22	20.54		
	019	19.83	43.42	40.52	14.02	017	20.26	59.34	53.06	19.16	023	22.73	49.03	44.75	19.44		
		64.67	**130.3**	**122**	**14.51**		**63.02**	**186.3**	**166.14**	**19.55**		**67.32**	**165.2**	**149.2**	**19.51**	**5.04**	**-0.04**
75	030	21.74	69.18	61.63	18.93	026	22.36	67.45	59.18	22.47	019	19.83	36.61	33.39	23.75		
	037	21.55	64.12	57.64	17.96	038	22.17	69.84	61.17	22.24	021	21.48	47.74	42.97	22.20		
	024	23.04	67.54	60.6	18.48	039	22.25	61.39	54.28	22.19	020	21.24	47.78	42.99	22.02		
		66.33	**200.8**	**179.9**	**18.47**		**66.78**	**198.7**	**174.63**	**22.30**		**62.55**	**132.1**	**119.4**	**22.50**	**3.83**	**0.20**
105	039	22.25	71.29	62.61	21.51	023	22.73	62.16	55.01	22.15	018	21.28	46.67	41.91	23.07		
	021	21.48	60.49	53.74	20.92	032	21.89	60.85	53.48	23.32	032	21.89	49.34	44.33	22.33		
	023	22.73	65.53	58.25	20.50	037	21.55	57.52	50.86	22.73	036	22.48	58.95	52.07	23.25		
		66.46	**197.3**	**174.6**	**21.00**		**66.17**	**180.5**	**159.35**	**22.73**		**65.65**	**155**	**138.3**	**22.91**	**1.73**	**0.18**
135	017	20.26	61.05	53.46	22.86	029	22.58	63.44	55.91	22.61	030	21.74	67.69	59.06	23.12		
	020	21.24	65.93	58.06	21.37	036	22.48	54.83	48.81	22.85	038	22.17	51.92	46.35	23.04		
	038	22.17	63.94	56.53	21.57	024	23.04	68.27	60.12	21.97	017	20.26	52.37	46.61	21.86		
		63.67	**190.9**	**168.1**	**21.91**		**68.1**	**186.5**	**164.84**	**22.48**		**64.17**	**172**	**152**	**22.72**	**0.57**	**0.24**
													on the average		2	**2.74**	**0.30**

Continuation of Annex 1

		point3 July 31			The soil moisture content,%		point3 August7			The soil moisture content,%		point3 August17			The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
15	090	21.83	51.97	48.32	13.78	047	22.80	47.64	44.04	16.94	102	21.61	59.31	53.76	17.26		
	087	20.57	48.53	45.03	14.31	044	20.96	45.78	42.30	16.32	111	22.45	59.99	54.72	16.33		
	093	20.42	60.46	55.59	13.85	042	21.66	49.2	45.39	16.04	100	23.04	55.8	50.85	17.80		
		62.82	**161**	**148.9**	**13.96**		**65.42**	**142.6**	**131.73**	**16.43**		**67.1**	**175.1**	**159.3**	**17.10**	**2.48**	**0.67**
45	092	21.05	54.89	49.45	19.15	055	23.11	59.12	52.32	23.28	109	21.32	59.48	52.37	22.90		
	082	22.68	69.46	62.33	17.98	046	23.27	55.38	49.36	23.06	103	22.35	48.77	43.76	23.40		
	086	22.67	76.66	68.24	18.48	043	22.72	58.18	51.75	22.16	107	22.84	50.65	45.42	23.16		
		66.4	**201**	**180**	**18.47**		**69.1**	**172.7**	**153.43**	**22.83**		**66.51**	**158.9**	**141.6**	**23.12**	**4.36**	**0.29**
75	085	21.16	73.24	64.35	20.58	049	20.60	60.25	52.58	23.99	098	21.38	67.18	58.04	24.93		
	078	22.20	66.8	59.35	20.05	051	22.15	59.13	51.91	24.27	101	22.75	63.35	55.61	23.55		
	073	22.48	73.37	64.71	20.51	040	20.48	57.79	50.76	23.23	099	22.54	57.54	50.74	24.11		
		65.84	**213.4**	**188.4**	**20.40**		**63.23**	**177.2**	**155.24**	**23.83**		**66.67**	**188.1**	**164.4**	**24.23**	**3.43**	**0.40**
105	094	21.49	64.9	56.92	22.52	045	21.58	54.46	48.01	24.41	097	21.90	57.65	50.7	24.13		
	091	20.88	64.01	56.22	22.04	048	22.68	51.28	45.59	24.86	110	23.04	61.96	54.32	24.42		
	081	22.56	62.04	54.91	22.04	054	22.55	53.24	47.37	23.63	108	23.42	60.32	53.32	23.41		
		64.93	**191**	**168.1**	**22.21**		**66.81**	**159**	**140.97**	**24.30**		**68.36**	**179.9**	**158.3**	**23.99**	**2.09**	**-0.31**
135	084	22.43	55.06	49.11	22.30	052	22.60	60.83	53.62	23.24	106	22.79	47.36	42.53	24.47		
	095	21.34	63.5	55.74	22.56	041	22.50	62.31	54.93	22.74	105	22.73	64.8	56.91	23.08		
	075	21.91	64.63	56.84	22.30	053	21.66	59.56	52.52	22.82	096	21.18	64.11	56.11	22.90		
		65.68	**183.2**	**161.7**	**22.39**		**66.76**	**182.7**	**161.07**	**22.93**		**66.7**	**176.3**	**155.6**	**23.32**	**0.54**	**0.39**
													on the average		3	2.58	0.29
													on the average		1-3	2.73	0.30

	point July 31				The soil moisture content,%	point August7				The soil moisture content,%	point4 August17				The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
15	044	20.96	52.83	48.58	15.39	058	22.54	44.36	40.67	20.36	070	22.55	44.71	41.11	19.40		
	047	22.80	55.1	51.02	14.46	070	22.55	49.11	44.61	20.38	071	22.82	44.11	40.67	19.27		
	052	22.60	50.77	46.92	15.83	062	22.69	45.08	41.45	19.32	061	21.60	51.27	46.38	19.73		
		66.36	**158.7**	**146.5**	**15.19**		**67.78**	**138.6**	**126.74**	**20.02**		**66.97**	**140.1**	**128.2**	**19.50**	**4.83**	**-0.52**
45	045	21.58	62.5	55.59	20.32	066	22.39	52.13	45.86	26.71	072	20.98	48.01	42.41	26.13		
	046	23.27	53.32	48.36	19.77	072	20.98	54.29	47.20	27.04	056	22.80	51.97	45.69	27.44		
	051	22.15	64.12	57.18	19.81	056	22.80	55.73	48.92	26.05	064	22.85	62.02	53.82	26.48		
		67	**179.9**	**161.1**	**19.98**		**66.17**	**162.2**	**141.99**	**26.60**		**66.63**	**162**	**141.9**	**26.67**	**6.62**	**0.07**
75	042	21.66	53.54	48.09	20.62	069	22.72	54.33	48.09	24.59	062	22.69	59.52	52.11	25.19		
	055	23.11	62.06	55.41	20.59	063	21.51	57.36	50.09	25.42	060	21.09	49.63	43.75	25.95		
	049	20.60	53.77	47.97	21.19	060	21.09	52.81	46.52	24.73	067	22.99	53.99	47.47	26.63		
		65.37	**169.4**	**151.5**	**20.79**		**65.32**	**164.5**	**144.71**	**24.91**		**66.77**	**163.1**	**143.3**	**25.88**	**4.12**	**0.96**
105	048	22.68	60.62	54.06	20.91	071	22.82	58.43	51.56	23.89	058	22.54	58.56	51.75	23.31		
	053	21.66	50.87	45.89	20.55	067	22.99	59.18	52.39	23.11	065	21.85	53.86	47.91	22.83		
	041	22.50	54.92	49.43	20.39	061	21.60	58.97	51.95	23.14	066	22.39	55.33	49.14	23.14		
		66.84	**166.4**	**149.4**	**20.63**		**67.41**	**176.6**	**155.90**	**23.38**		**66.78**	**167.8**	**148.8**	**23.10**	**2.75**	**-0.28**
135	043	22.72	53.77	48.74	19.33	065	21.85	61.34	54.61	20.56	063	21.51	56.64	50.59	20.80		
	054	22.55	47.19	43.33	18.58	059	21.92	60.07	53.71	20.00	059	21.92	65.66	58.08	20.96		
	040	20.48	41.29	37.99	18.85	064	22.85	59.99	53.60	20.77	069	22.62	60.86	54.39	20.37		
		65.75	**142.3**	**130.1**	**18.96**		**66.62**	**181.4**	**161.92**	**20.44**		**66.05**	**183.2**	**163.1**	**20.72**	**1.49**	**0.28**
													on the average		4	**3.96**	**0.10**

Continuation of Annex 1

		point5 July 31			The soil moisture content,%		point5 August7			The soil moisture content,%		point5 August17			The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
	060	22.39	51.52	47.77	14.78	075	21.91	58.79	53.39	17.16	085	21.16	37.43	34.97	17.81		
	066	21.09	53.83	49.91	13.60	091	20.88	56.12	50.74	18.03	081	22.56	44.37	41.07	17.83		
	070	22.55	60.3	56.15	12.35	078	22.20	59.45	53.82	17.82	073	22.48	48.47	44.72	16.86		
45		**66.03**	**165.7**	**153.8**	**13.46**		**64.99**	**174.4**	**157.94**	**17.67**		**66.2**	**130.3**	**120.8**	**17.43**	**4.21**	**-0.24**
	059	21.92	58.65	53.39	16.71	085	21.16	62.38	54.71	22.87	084	22.43	62.8	55.34	22.67		
	061	21.60	63.6	57.48	17.06	094	21.49	61	53.57	23.15	094	21.49	66.36	57.95	23.07		
	069	22.72	60.67	54.97	17.67	092	21.05	59.22	51.97	23.43	092	21.05	66.12	57.75	22.81		
75		**66.24**	**182.9**	**165.8**	**17.15**		**63.7**	**182.6**	**160.25**	**23.15**		**64.97**	**195.3**	**171**	**22.85**	**6.00**	**-0.30**
	071	22.82	64.08	57.56	18.77	073	22.48	64.63	57.03	22.01	095	21.34	47.84	42.81	23.43		
	064	22.85	73.04	65.12	18.74	090	21.83	63.18	55.81	21.68	075	21.91	43.99	39.79	23.49		
	065	21.85	60.28	54.37	18.17	086	22.67	65.44	57.85	21.56	087	20.57	38.62	35.22	23.21		
105		**67.52**	**197.4**	**177.1**	**18.58**		**66.98**	**193.3**	**170.69**	**21.75**		**63.82**	**130.5**	**117.8**	**23.39**	**3.17**	**1.64**
	067	22.99	57.37	51.99	18.55	084	22.43	57.45	51.40	20.89	090	21.83	46.94	42.63	20.72		
	056	22.80	55.72	50.6	18.42	087	20.57	64.74	56.94	21.43	086	22.67	46.18	42.25	20.07		
	063	21.51	66.58	59.59	18.36	093	20.42	62.56	55.17	21.28	078	22.20	43.43	39.82	20.49		
135		**67.3**	**179.7**	**162.2**	**18.43**		**63.42**	**184.8**	**163.51**	**21.20**		**66.7**	**136.6**	**124.7**	**20.43**	**2.77**	**-0.77**
	058	22.54	72.25	63.26	22.08	082	22.68	66.65	58.53	22.66	091	20.88	44.91	40.31	23.67		
	072	20.98	58.69	51.94	21.80	095	21.34	67.23	58.72	22.78	082	22.68	38.6	35.56	23.60		
	062	22.69	64.49	56.97	21.94	081	22.56	62.59	54.99	23.44	093	20.42	48.69	43.26	23.77		
		66.21	**195.4**	**172.2**	**21.95**		**66.58**	**196.5**	**172.23**	**22.96**		**63.98**	**132.2**	**119.1**	**23.70**	**1.01**	**0.74**
													on the average		5	**3.43**	**0.21**

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Continuation of Annex 1

		point6 July 31			The soil moisture content,%		point6 August7			The soil moisture content,%		point6 August17			The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
15	098	21.38	48.67	45.48	13.24	097	21.90	44.76	41.40	17.22	043	22.72	63.10	57.05	17.62		
	107	22.84	63.98	59.01	13.74	102	21.61	42.45	39.51	16.45	040	20.48	51.6	47.24	16.29		
	099	22.54	67.47	62.38	12.78	110	23.04	48.59	44.86	17.09	053	21.66	56	51.12	16.56		
		66.76	**180.1**	**166.9**	**13.24**		**66.55**	**135.8**	**125.77**	**16.92**		**64.86**	**170.7**	**155.4**	**16.89**	**3.68**	**-0.03**
45	103	22.35	56.79	51.48	18.23	107	22.84	52.12	46.58	23.35	049	20.60	72.92	63.06	23.22		
	111	22.45	65.5	58.96	17.91	100	23.04	54.66	48.49	24.23	055	23.11	62.15	54.74	23.43		
	106	22.79	65.67	59.01	18.39	098	21.38	52.48	46.57	23.47	042	21.66	66.93	58.33	23.45		
		67.59	**188**	**169.5**	**18.17**		**67.26**	**159.3**	**141.64**	**23.68**		**65.37**	**202**	**176.1**	**23.36**	**5.51**	**-0.33**
75	102	21.61	47.36	43.31	18.66	109	21.32	59.37	52.82	20.80	054	22.55	60.34	53.65	21.51		
	110	23.04	60	54.15	18.80	105	22.73	58.24	51.92	21.67	048	22.68	54.72	48.79	22.71		
	101	22.75	66.89	59.9	18.82	099	22.54	51.4	46.24	21.78	045	21.58	45.12	40.98	21.34		
		67.4	**174.3**	**157.4**	**18.78**		**66.59**	**169**	**150.97**	**21.42**		**66.81**	**160.2**	**143.4**	**21.88**	**2.64**	**0.46**
105	108	23.42	55.8	50.05	21.59	108	23.42	48.23	43.49	23.62	047	22.80	55.41	49.41	22.55		
	109	21.32	51.2	46.01	21.02	103	22.35	53.79	47.85	23.29	041	22.50	58.14	51.57	22.60		
	105	22.73	68.37	60.45	21.00	106	22.79	61.49	54.17	23.34	052	22.60	65.76	57.44	23.88		
		67.47	**175.4**	**156.5**	**21.18**		**68.56**	**163.5**	**145.51**	**23.42**		**67.9**	**179.3**	**158.4**	**23.08**	**2.24**	**-0.34**
135	097	21.90	54.44	48.93	20.38	101	22.75	56.31	50.24	22.09	051	22.15	50.41	45.16	22.82		
	100	23.04	64.08	56.86	21.35	111	22.45	57.06	50.60	22.97	046	23.27	67.19	59.26	22.03		
	096	21.18	65.55	57.72	21.43	096	21.18	54.43	48.40	22.14	044	20.96	47.4	42.48	22.86		
		66.12	**184.1**	**163.5**	**21.11**		**66.38**	**167.8**	**149.24**	**22.40**		**66.38**	**165**	**146.9**	**22.48**	**1.29**	**0.08**
													on the average 6			**3.07**	**-0.03**
													on the average 4-6			**3.47**	**0.14**

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Continuation of Annex 1

		point7 July 31			The soil moisture content,%		point7 August7			The soil moisture content,%		point7 August17			The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
15	115	22.86	62.33	56.94	15.82	126	21.99	50.23	45.53	19.97	121	22.71	74.6	66.11	19.56		
	119	22.24	54.03	49.73	15.64	121	22.71	54.76	49.42	20.01	119	22.24	59.86	53.45	20.54		
	124	22.28	57.1	52.66	14.61	113	22.64	54.47	49.28	19.49	124	22.28	46.37	42.42	19.61		
		67.38	**173.5**	**159.3**	**15.37**		**67.34**	**159.5**	**144.22**	**19.82**		**67.23**	**180.8**	**162**	**19.89**	**4.46**	**0.07**
45	112	22.91	53.54	48.52	19.60	115	22.86	56.77	49.99	25.01	115	22.86	41.09	37.51	24.44		
	126	21.99	46.14	42.26	19.14	118	22.18	59.01	51.53	25.49	122	21.66	54.29	47.72	25.21		
	114	21.89	51.26	46.61	18.81	119	22.24	57.21	50.31	24.57	113	22.64	48.77	43.73	23.90		
		66.79	**150.9**	**137.4**	**19.19**		**67.28**	**173**	**151.83**	**25.02**		**67.16**	**144.2**	**129**	**24.58**	**5.83**	**-0.44**
75	118	22.18	52.67	47.46	20.61	120	22.49	58.45	51.48	24.04	118	22.18	58.34	51.04	25.29		
	122	21.66	54.16	48.48	21.18	112	22.91	57.39	50.55	24.73	123	21.53	51.91	45.84	24.97		
	113	22.64	54.23	48.88	20.39	114	21.89	57.24	50.41	23.95	117	22.95	61.56	53.82	25.07		
		66.48	**161.1**	**144.8**	**20.73**		**67.29**	**173.1**	**152.44**	**24.24**		**66.66**	**171.8**	**150.7**	**25.12**	**3.51**	**0.88**
105	117	22.95	50.91	46.13	20.62	117	22.95	62.09	54.98	22.18	125	22.13	46.18	42.01	20.98		
	127	21.91	58.71	52.62	19.83	122	21.66	60.38	53.23	22.65	126	21.99	54.68	48.83	21.80		
	123	21.53	68.05	60.41	19.65	124	22.28	64.47	56.96	21.67	120	22.49	61.46	54.54	21.59		
		66.39	**177.7**	**159.2**	**19.95**		**66.89**	**186.9**	**165.17**	**22.17**		**66.61**	**162.3**	**145.4**	**21.51**	**2.21**	**-0.66**
135	121	22.71	57.17	51.81	18.42	123	21.53	60.32	54.34	18.22	127	21.91	52.05	47.36	18.43		
	125	22.13	49.88	45.72	17.63	127	21.91	62.91	56.39	18.91	112	22.91	42.92	39.83	18.26		
	120	22.49	48.48	44.61	17.50	125	22.13	64.7	57.86	19.14	114	21.89	49.92	45.54	18.52		
		67.33	**155.5**	**142.1**	**17.90**		**65.57**	**187.9**	**168.59**	**18.76**		**66.71**	**144.9**	**132.7**	**18.42**	**0.86**	**-0.34**
													on the average		7	3.37	-0.10

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Continuation of Annex 1

		point8	July 31				point8	August7		The soil moisture content,%		point8	August17		The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
15	138	21.79	64.66	59.06	15.03	128	22.82	49.33	45.09	19.03	136	23.24	63.62	57	19.61		
	139	21.40	55.97	51.7	14.09	129	22.81	48.15	44.06	19.26	135	22.43	64.77	58.12	18.63		
	136	23.24	59.47	54.89	14.47	134	22.62	44.65	41.27	18.11	130	22.76	58.64	52.97	18.77		
		66.43	**180.1**	**165.7**	**14.56**		**68.25**	**142.1**	**130.42**	**18.80**		**68.43**	**187**	**168.1**	**19.00**	**4.24**	**0.20**
45	135	22.43	50.53	46.17	18.37	133	20.80	51.17	45.30	23.94	140	22.91	52.88	47.31	22.83		
	137	22.91	63.49	57.13	18.59	139	21.40	54.28	47.98	23.72	142	22.87	60.77	53.56	23.49		
	133	20.80	67.97	60.97	17.43	140	22.91	50.77	45.41	23.83	128	22.82	51.61	46.11	23.62		
		66.14	**182**	**164.3**	**18.06**		**65.11**	**156.2**	**138.69**	**23.83**		**68.6**	**165.3**	**147**	**23.32**	**5.77**	**-0.51**
75	142	22.87	59.85	53.7	19.95	138	21.79	61.31	53.77	23.58	129	22.81	69.52	60.41	24.23		
	131	21.05	59.1	52.82	19.77	131	21.05	59.46	52.22	23.22	131	21.05	49.63	43.81	25.57		
	132	22.73	65.95	58.75	19.99	136	23.24	64.35	56.65	23.03	133	20.80	62.66	54.92	22.68		
		66.65	**184.9**	**165.3**	**19.90**		**66.08**	**185.1**	**162.65**	**23.28**		**64.66**	**181.8**	**159.1**	**23.99**	**3.37**	**0.72**
105	134	22.62	65.25	57.31	22.89	137	22.91	64.33	56.37	23.78	141	22.60	55.53	49.16	23.98		
	141	22.60	66.03	58.21	21.96	141	22.60	62.32	54.59	24.18	134	22.62	51.94	46.31	23.77		
	128	22.82	66.27	58.79	20.80	132	22.73	60.02	52.81	23.95	139	21.40	59.2	52.27	22.45		
		68.04	**197.6**	**174.3**	**21.87**		**68.24**	**186.7**	**163.77**	**23.97**		**66.62**	**166.7**	**147.7**	**23.34**	**2.10**	**-0.63**
135	130	22.76	51.64	46.58	21.24	135	22.43	63.49	55.86	22.83	132	22.73	57.92	51.58	21.98		
	140	22.91	57.67	51.34	22.27	142	22.87	60.37	53.40	22.81	137	22.91	44.97	40.89	22.69		
	129	22.81	53.68	48.13	21.92	130	22.76	66.13	58.28	22.09	138	21.79	55.9	49.58	22.74		
		68.48	**163**	**146.1**	**21.84**		**68.06**	**190**	**167.55**	**22.58**		**67.43**	**158.8**	**142.1**	**22.43**	**0.74**	**-0.14**
													on the average		8	**3.24**	**-0.07**

Continuation of Annex 1

	point9 July 31				The soil moisture content,%	point9 August7				The soil moisture content,%	point9 August17				The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
15	153	22.17	60.36	55.78	13.63	146	22.06	46.32	42.75	17.24	146	22.06	68.11	61.11	17.93		
	152	21.73	71.56	65.53	13.77	153	22.17	47.74	43.94	17.43	159	20.64	56.02	50.58	18.17		
	146	22.06	59.53	55.21	13.03	157	22.44	44.95	41.51	18.04	147	22.72	53.84	49.14	17.79		
		65.96	**191.5**	**176.5**	**13.50**		**66.67**	**139**	**128.21**	**17:57**		**65.42**	**178**	**160.8**	**17.96**	**4.07**	**0.39**
45	157	22.44	54.63	49.61	18.48	152	21.73	49.23	43.90	24.06	149	22.47	53.28	47.47	23.24		
	154	22.49	62.15	55.83	18.96	143	22.25	48.41	43.35	24.01	155	22.75	55.76	49.45	23.63		
	159	20.64	60.83	54.48	18.76	147	22.72	48.77	43.74	23.93	145	21.39	58.96	51.75	23.75		
		65.57	**177.6**	**159.9**	**18.75**		**66.7**	**146.4**	**130.98**	**24.00**		**66.61**	**168**	**148.7**	**23.56**	**5.25**	**-0.44**
75	156	21.16	67.27	59.46	20.39	154	22.49	58.32	51.35	24.17	152	21.73	53.04	47.04	23.71		
	144	21.80	73.67	65.26	19.35	155	22.75	56.55	49.94	24.30	153	22.17	55.97	49.57	23.36		
	147	22.72	56.12	50.63	19.67	159	20.64	58.29	51.19	23.25	157	22.44	59.41	52.31	23.77		
		65.68	**197.1**	**175.4**	**19.80**		**65.88**	**173.2**	**152.48**	**23.91**		**66.34**	**168.4**	**148.9**	**23.61**	**4.11**	**-0.29**
105	158	22.84	62.14	55.03	22.09	149	22.47	57.56	50.70	24.28	154	22.49	67.69	59.08	23.53		
	149	22.47	55.91	49.79	22.40	156	21.16	62.23	54.17	24.41	156	21.16	63.51	55.37	23.79		
	155	22.75	61.66	54.53	22.44	158	22.84	60.51	53.25	23.86	158	22.84	66.51	57.98	24.27		
		68.06	**179.7**	**159.4**	**22.30**		**66.47**	**180.3**	**158.13**	**24.18**		**66.49**	**197.7**	**172.4**	**23.86**	**1.88**	**-0.32**
135	151	22.90	59.08	52.63	21.70	144	21.80	55.55	49.34	22.54	143	22.25	62.66	54.92	23.69		
	145	21.39	61.19	53.78	22.88	151	22.90	57.02	50.66	22.91	144	21.80	54.19	48.13	23.02		
	143	22.25	70.09	61.34	22.38	145	21.39	54.96	48.69	22.98	151	22.90	58.11	51.73	22.13		
		66.54	**190.4**	**167.8**	**22.34**		**66.09**	**167.5**	**148.69**	**22.81**		**66.95**	**175**	**154.8**	**22.98**	**0.47**	**0.17**
													on the average 9			**3.16**	**-0.10**
													on the average 7-9			**3.25**	**-0.08**

Continuation of Annex 1

		point1(July 31			The soil moisture content,%		point1(August7			The soil moisture content,%		point10 August17			The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
15	166	21.9	50.13	46.23	16.03	160	21.5	47.44	43.40	18.45	167	21.98	39.68	36.89	18.71		
	164	22.06	41.94	39.43	14.45	167	21.98	49.72	45.48	18.04	175	22.74	49.8	45.41	19.36		
	169	22.35	36.27	34.42	15.33	175	22.74	43.14	40.05	17.87	168	21.13	46.91	42.63	19.91		
		66.31	**128.3**	**120.1**	**15.36**		**66.22**	**140.3**	**128.93**	**18.12**		**65.85**	**136.4**	**124.9**	**19.40**	**2.76**	**1.28**
45	167	21.98	52.87	48.08	18.35	174	22.44	41.50	38.12	21.58	171	21.66	64.58	56.54	23.05		
	174	22.44	49.75	45.8	16.91	161	23.16	43.26	39.57	22.46	166	21.9	55.96	49.61	22.92		
	173	22.58	52.42	47.97	17.53	164	22.06	46.31	41.79	22.88	172	22.01	56.7	50.41	22.15		
		67	**155**	**141.9**	**17.62**		**67.66**	**131.1**	**119.49**	**22.31**		**65.57**	**177.2**	**156.6**	**22.73**	**4.68**	**0.42**
75	163	23.15	42.14	38.93	20.34	170	21.92	43.55	39.23	24.95	169	22.35	60.33	52.85	24.52		
	168	21.13	66.23	58.45	20.85	165	22.87	49.83	44.55	24.37	173	22.58	59.33	52.13	24.37		
	161	23.16	55.74	50.15	20.71	173	22.58	48.68	43.73	23.42	161	23.16	65.41	56.97	24.96		
		67.44	**164.1**	**147.5**	**20.70**		**67.37**	**142.1**	**127.51**	**24.25**		**68.09**	**185.1**	**162**	**24.63**	**3.54**	**0.39**
105	171	21.66	63.54	56.48	20.28	169	22.35	58.80	52.25	21.92	164	22.06	63.85	56.49	21.38		
	175	22.74	70.93	63.18	19.16	171	21.66	56.42	50.25	21.58	165	22.87	62	54.91	22.13		
	160	21.5	62.58	55.51	20.79	168	21.13	51.14	45.77	21.78	174	22.44	52.09	46.96	20.92		
		65.9	**197.1**	**175.2**	**20.02**		**65.14**	**166.4**	**148.27**	**21.76**		**67.37**	**177.9**	**158.4**	**21.52**	**1.74**	**-0.24**
135	165	22.87	74.04	66.32	17.77	172	22.01	60.04	53.91	19.20	170	21.92	59.91	53.97	18.53		
	172	22.01	68.63	61.17	19.05	166	21.9	59.47	53.38	19.33	160	21.5	61.81	55.75	17.69		
	170	21.92	57.14	51.75	18.07	163	23.15	61.05	54.99	19.04	163	23.15	65.77	59.09	18.59		
		66.8	**199.8**	**179.2**	**18.29**		**67.06**	**180.6**	**162.29**	**19.19**		**66.57**	**187.5**	**168.8**	**18.27**	**0.90**	**-0.92**
													on the average		10	**2.72**	**0.18**

Continuation of Annex 1

		point11 July 31			The soil moisture content,%		point11 August7			The soil moisture content,%		point11 August17			The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
15	185	22.6	37.13	35.44	13.16	182	22.09	57.43	52.60	15.83	185	22.6	53.8	49.34	16.68		
	182	22.09	40.39	38.18	13.74	187	22.7	56.27	51.77	15.48	183	22.27	42.88	39.74	17.97		
	183	22.27	49.18	46.15	12.69	180	21.94	51.13	47.15	15.77	187	22.7	61.79	56.14	16.90		
		66.96	**126.7**	**119.8**	**13.12**		**66.73**	**164.8**	**151.52**	**15.69**		**67.57**	**158.5**	**145.2**	**17.06**	**2.57**	**1.37**
45	177	21.83	41.98	39.14	16.41	176	22.39	56.85	50.88	20.97	182	22.09	48.94	44.08	22.10		
	180	21.94	43.17	40.18	16.39	177	21.83	57.43	51.29	20.83	181	22.58	55.63	49.84	21.24		
	184	22.79	41.46	38.8	16.61	188	22.89	57.52	51.39	21.51	184	22.79	58.75	52.36	21.61		
		66.56	**126.6**	**118.1**	**16.47**		**67.11**	**171.8**	**153.56**	**21.10**		**67.46**	**163.3**	**146.3**	**21.62**	**4.64**	**0.52**
75	181	22.58	51.7	47.29	17.85	181	22.58	58.49	52.31	20.78	188	22.89	49.99	45.12	21.91		
	178	22.85	71.18	64.09	17.19	190	22.84	57.38	51.35	21.13	177	21.83	45.49	41.23	21.96		
	188	22.89	60.4	54.75	17.73	184	22.79	59.31	52.99	20.91	193	22.99	56.42	50.67	20.77		
		68.32	**183.3**	**166.1**	**17.53**		**68.21**	**175.2**	**156.66**	**20.94**		**67.71**	**151.9**	**137**	**21.47**	**3.41**	**0.53**
105	187	22.7	48.73	44.47	19.57	183	22.27	60.44	53.67	21.56	179	23.24	47.51	43.33	20.81		
	179	23.24	62.45	55.87	20.17	178	22.85	62.18	55.45	20.63	178	22.85	62.89	55.85	21.33		
	189	22.02	54.42	49.21	19.16	179	23.24	59.83	53.27	21.86	190	22.84	53.56	48.19	21.18		
		67.96	**165.6**	**149.6**	**19.67**		**68.36**	**182.5**	**162.39**	**21.35**		**68.93**	**164**	**147.4**	**21.15**	**1.68**	**-0.20**
135	193	22.99	44.28	40.5	21.59	193	22.99	63.39	55.72	23.44	189	22.02	48.73	43.82	22.52		
	190	22.84	50.64	45.58	22.25	189	22.02	60.15	53.01	23.03	176	22.39	53.92	48.32	21.60		
	176	22.39	48.46	43.66	22.57	185	22.6	62.84	55.38	22.77	180	21.94	52.96	47.31	22.27		
		68.22	**143.4**	**129.7**	**22.17**		**67.61**	**186.4**	**164.11**	**23.08**		**66.35**	**155.6**	**139.5**	**22.11**	**0.91**	**-0.97**
													on the	average	11	**2.64**	**0.25**

Continuation of Annex 1

		point12 July 31			The soil moisture content,%		point12 August7			The soil moisture content,%		point12 August17			The soil moisture content,%	The increase of moisture cont.% irrig.1	irrig.2
15	211	22.12	42.53	40.24	12.64	194	22.26	41.33	38.78	15.41	202	21.84	65.91	59.75	16.25		
	209	23.19	40.45	38.47	12.96	205	20.28	44.67	41.45	15.23	207	21.11	52.47	48.07	16.32		
	203	22.15	38.39	36.62	12.23	199	22.28	48.51	45.20	14.46	199	22.28	57.32	52.31	16.68		
		67.46	**121.4**	**115.3**	**12.62**		**64.82**	**134.5**	**125.43**	**15.03**		**65.23**	**175.7**	**160.1**	**16.41**	**2.42**	**1.37**
45	205	20.28	52.24	48.05	15.09	208	21.83	46.19	42.15	19.88	203	22.15	65.21	57.74	20.99		
	196	21.24	51.89	47.61	16.23	202	21.84	48.45	43.87	20.81	197	22.55	74.46	65.53	20.78		
	207	21.11	39.24	36.65	16.67	195	21.05	46.74	42.38	20.44	210	22.95	55.49	49.82	21.10		
		62.63	**143.4**	**132.3**	**15.87**		**64.72**	**141.4**	**128.40**	**20.38**		**67.65**	**195.2**	**173.1**	**20.93**	**4.50**	**0.55**
75	201	22.86	59.2	53.81	17.42	197	22.55	49.23	44.75	20.16	204	22.65	68.93	60.81	21.28		
	210	22.95	60.92	55.32	17.30	210	22.95	50.03	45.45	20.35	201	22.86	71.39	62.68	21.87		
	194	22.26	52.37	47.94	17.25	207	21.11	49.28	44.36	21.14	209	23.19	59.73	53.36	21.11		
		68.07	**172.5**	**157.1**	**17.33**		**66.61**	**148.5**	**134.57**	**20.55**		**68.7**	**200.1**	**176.9**	**21.45**	**3.22**	**0.90**
105	202	21.84	54.92	49.2	20.91	203	22.15	53.49	47.59	23.18	205	20.28	61.68	54.05	22.59		
	197	22.55	59.21	52.91	20.75	196	21.24	51.27	45.74	22.56	211	22.12	51.45	45.99	22.87		
	208	21.83	57.3	50.99	21.64	204	22.65	56.00	49.89	22.42	196	21.24	53.08	47.32	22.09		
		66.22	**171.4**	**153.1**	**21.10**		**66.04**	**160.8**	**143.23**	**22.72**		**63.64**	**166.2**	**147.4**	**22.52**	**1.62**	**-0.20**
135	199	22.26	55.3	49.88	19.62	209	23.19	51.04	46.21	21.00	208	21.83	53.1	47.89	19.99		
	204	22.65	54.83	49.54	19.67	201	22.86	55.89	50.20	20.82	194	22.26	66.72	59.18	20.42		
	195	21.05	50.21	45.21	20.70	211	22.12	58.48	52.30	20.48	195	21.05	65.09	57.91	19.48		
		65.96	**160.3**	**144.6**	**19.97**		**68.17**	**165.4**	**148.70**	**20.77**		**65.14**	**184.9**	**165**	**19.96**	**0.80**	**-0.80**
													on the average		12	**2.51**	**0.36**
													on the average		10-12	**2.63**	**0.26**

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Annex 2

Calculations of a water application

2000

The first irrigation

Version of the irrigation technology	Duration of furrow wetting, min	Duration of irrigat., hour	Duration of irrigat (min) with flow rate		The water application (m3/hect) with flow rate		
			q1=21.6 L/min	q2=12.36 L/min	q1=21.6 L/min	q2=12.36 L/min	Total
Cont. irr.	93	24	123	1317	190	1163	1352
Cont. irr.+Pam	154	24	184	1256	284	1109	1393
Surge irr+Pam	125	24	155	1285	239	1134	1374
Surge irr	75	24	105	1335	162	1179	1341

The second irrigation

Cont. irr.	86	24	116	1324	179	1169	1348
Cont. irr.+Pam	130	24	160	1280	247	1130	1377
Surge irr+Pam	95	24	125	1315	193	1161	1354
Surge irr	65	24	95	1345	147	1187	1334

The third rrigation

Cont. irr.	73	24	103	1337	159	1180	1339
Cont. irr.+Pam	101	24	131	1309	202	1156	1358
Surge irr+Pam	86	24	116	1324	179	1169	1348
Surge irr	62	24	92	1348	142	1190	1332

The fourth irrigation

Cont. irr.	63	24	93	1347	143	1189	1333
Cont. irr.+Pam	72	24	102	1338	157	1181	1339
Surge irr+Pam	63	24	93	1347	143	1189	1333
Surge irr	51	24	81	1359	125	1200	1325

Total

Cont. irr.	315	96	435	5325	671	4701	5372
Cont. irr.+Pam	457	96	577	5183	890	4576	5466
Surge irr+Pam	369	96	489	5271	754	4654	5408
Surge irr	253	96	373	5387	575	4756	5331

The outflow volume, the sediments

1999

Irrigation 1

Cont. irr.

Furrows 5,6,7,8		Out flow rate		Outflow	The sediments		
T, min	dti,min	qi L/s	q av L/s	volume,L W o. f.	m2, g/l	m av, g/L	Pmi, kg
10		0.174			34.4		
	10		0.179	107.10		32.400	3.47
20		0.183			30.4		
	10		0.190	114.00		29.000	3.31
30		0.197			27.6		
	30		0.178	320.40		24.750	7.93
60		0.159			21.9		
	30		0.135	243.00		19.350	4.70
90		0.111			16.8		
	30		0.101	180.90		16.300	2.95
120		0.090			15.8		
	30		0.100	179.10		15.450	2.77
150		0.109			15.1		
	60		0.115	414.00		14.050	5.82
210		0.121			13		
	60		0.124	446.40		13.100	5.85
270		0.127			13.2		
	60		0.128	459.00		13.100	6.01
330		0.128			13		
				2463.90			**42.80**

Cont. irr.+Pam

Furrows 1,2,3,4		Out flow rate		Outflow	The sediments		
T, min	dti,min	qi L/s	q av L/s	volume,L W o. f.	m2, g/l	m av, g/L	Pmi, kg
10		0.111			0.27		
	10		0.112	67.20		0.240	0.02
20		0.113			0.21		
	10		0.114	68.40		0.205	0.01
30		0.115			0.2		
	30		0.083	148.50		0.245	0.04
60		0.050			0.29		
	30		0.043	76.50		0.310	0.02
90		0.035			0.33		
	30		0.032	56.70		0.450	0.03
120		0.028			0.57		
	30		0.031	54.90		1.235	0.07
150		0.033			1.9		
	60		0.031	111.60		2.550	0.28
210		0.029			3.2		
	60		0.036	127.80		3.100	0.40
270		0.042			3		
	60		0.058	207.00		3.000	0.62
330		0.073			3		
				918.60			**1.49**

Irrigation 1

Surge irr.+Pam

Furrows	9,10, 11, 12	Out flow rate		Outflow	The sediments		
T, min	dti,min	qi L/s	q av L/s	volume, L W o. f.	m2, g/l	m av, g/L	Pmi, kg
10		0.125			0.22		
	10		0.130	78.00		0.210	0.02
20		0.135			0.2		
	10		0.139	83.40		0.195	0.02
30		0.143			0.19		
	30		0.127	227.70		0.210	0.05
60		0.11			0.23		
	30		0.104	187.20		0.215	0.04
90		0.098			0.2		
	30		0.071	126.90		0.185	0.02
120		0.043			0.17		
	30		0.048	86.40		0.190	0.02
150		0.053			0.21		
	60		0.057	205.20		0.205	0.04
210		0.061			0.2		
	60		0.061	219.60		0.200	0.04
270		0.061			0.2		
	60		0.065	232.20		0.205	0.05
330		0.068			0.21		
				1446.6			**0.29**

Surge irr.

Furrows	13,14, 15,16	Out flow rate		Outflow	The sediments		
T, min	dti,min	qi L/s	q av L/s	volume, L W o. f.	m2, g/l	m av, g/L	Pmi, kg
10		0.232			34.5		
	10		0.234	140.10		32.000	4.48
20		0.235			29.5		
	10		0.237	141.90		28.300	4.02
30		0.238			27.1		
	30		0.204	367.20		24.400	8.96
60		0.17			21.7		
	30		0.158	284.40		21.650	6.16
90		0.146			21.6		
	30		0.151	270.90		21.250	5.76
120		0.155			20.9		
	30		0.151	270.90		20.150	5.46
150		0.146			19.4		
	60		0.148	531.00		18.550	9.85
210		0.149			17.7		
	60		0.151	541.80		17.500	9.48
270		0.152			17.3		
	60		0.152	547.20		17.250	9.44
330		0.152			17.2		
				3095.4			**63.60**

Annex 3

The outflow volume, the sediments

2000

Irrigation 1

Cont. irr.

Furrows 1,2,3,4		Out flow rate		Outflow		The sediments	
		qi	q av	volume, L	m2, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.		g/L	
10		0.147			25.2		
	10		0.152	91.20		24.650	2.25
20		0.157			24.1		
	10		0.159	95.40		23.650	2.26
30		0.161			23.2		
	30		0.140	252.00		21.400	5.39
60		0.119			19.6		
	30		0.115	207.00		18.050	3.74
90		0.111			16.5		
	30		0.109	196.20		15.650	3.07
120		0.107			14.8		
	30		0.110	197.10		14.650	2.89
150		0.112			14.5		
	60		0.115	414.00		13.700	5.67
210		0.118			12.9		
	60		0.118	424.80		11.800	5.01
270		0.118			10.7		
	60		0.119	428.40		10.450	4.48
330		0.120			10.2		
				2306.10			**34.75**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2	0.136	3	0.166	3	0.166	1.4	0.114	1.6	0.121
2.5	0.152	2.5	0.152	2.5	0.152	1.8	0.129	1.1	0.101
2.6	0.155	2.5	0.152	3	0.166	1.4	0.114	1.3	0.109
	0.147		**0.157**		**0.161**		**0.119**		**0.111**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
1.1	0.101	1.2	0.105	1.5	0.118	1.2	0.105	1.2	0.105
1.3	0.109	1.5	0.118	1.5	0.118	1.6	0.121	1.7	0.125
1.3	0.109	1.4	0.114	1.5	0.118	1.8	0.129	1.8	0.129
	0.107		**0.112**		**0.118**		**0.118**		**0.120**

Continuation of Annex 3

Irrigation 1

Cont. irr.+Pam

Furrows 5,6,7,8		Out flow rate		Outflow		The sediments	
		qi	q av	volume, L	m2, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.		g/L	
10		0.109			3.2		
	10		0.113	67.50		3.300	0.22
20		0.116			3.4		
	10		0.121	72.30		3.600	0.26
30		0.125			3.8		
	30		0.106	189.90		2.750	0.52
60		0.086			1.7		
	30		0.081	145.80		1.750	0.26
90		0.076			1.8		
	30		0.077	138.60		1.800	0.25
120		0.078			1.8		
	30		0.079	141.30		1.800	0.25
150		0.079			1.8		
	60		0.081	291.60		1.650	0.48
210		0.083			1.5		
	60		0.083	298.80		1.250	0.37
270		0.083			1		
	60		0.084	300.60		1.050	0.32
330		0.084			1.1		
				1646.40			**2.93**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2	0.136	1.2	0.105	1.5	0.118	0.7	0.080	0.5	0.068
1.5	0.118	2.5	0.152	2.7	0.158	1	0.096	0.6	0.074
0.9	0.091	1	0.096	1.3	0.109	0.7	0.080	0.8	0.086
0.9	0.091	1.3	0.109	1.4	0.114	0.8	0.086	0.6	0.074
	0.109		**0.116**		**0.125**		**0.086**		**0.076**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
0.5	0.068	0.5	0.068	0.7	0.080	0.8	0.086	0.8	0.086
0.4	0.061	1	0.096	1	0.096	0.9	0.091	1	0.096
0.9	0.091	0.9	0.091	0.7	0.080	0.6	0.074	0.7	0.080
0.9	0.091	0.4	0.061	0.6	0.074	0.7	0.080	0.6	0.074
	0.078		**0.079**		**0.083**		**0.083**		**0.084**

Continuation of Annex 3

Irrigation 1

Surge irr.+Pam

Furrows	9,10, 11, 12	Out flow rate qi	q av	Outflow volume, L	The sediments m2, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.		g/L	
10		0.116			7.1		
	10		0.121	72.30		6.400	0.46
20		0.125			5.7		
	10		0.132	79.20		5.150	0.41
30		0.139			4.6		
	30		0.124	223.20		3.400	0.76
60		0.109			2.2		
	30		0.107	192.60		2.100	0.40
90		0.105			2		
	30		0.105	189.00		1.950	0.37
120		0.105			1.9		
	30		0.105	189.00		1.750	0.33
150		0.105			1.6		
	60		0.105	376.20		1.550	0.58
210		0.104			1.5		
	60		0.106	381.60		1.100	0.42
270		0.108			0.7		
	60		0.107	385.20		0.850	0.33
330		0.106			1		
				2088.3			**4.06**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.8	0.129	2	0.136	1.8	0.129	1	0.139	1	0.139
1.1	0.101	1.3	0.109	1.6	0.121	0.9	0.091	0.7	0.080
1.5	0.118	1.8	0.129	3	0.166	1	0.096	1	0.096
	0.116		**0.125**		**0.139**		**0.109**		**0.105**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
1	0.139	1	0.139	1.1	0.146	0.9	0.132	0.9	0.132
1	0.096	0.7	0.080	0.9	0.091	1	0.096	0.9	0.091
0.7	0.080	1	0.096	0.6	0.074	1	0.096	1	0.096
	0.105		**0.105**		**0.104**		**0.108**		**0.106**

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Continuation of annex 3

Irrigation 1

Surge irr.

Furrows	13,14, 15,16	Out flow rate qi	q av	Outflow volume, L	The sediments m2, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.		g/L	
10		0.157			12.4		
	10		0.159	95.40		11.800	1.13
20		0.161			11.2		
	10		0.163	97.50		10.900	1.06
30		0.164			10.6		
	30		0.143	257.40		9.350	2.41
60		0.122			8.1		
	30		0.121	216.90		7.350	1.59
90		0.119			6.6		
	30		0.114	204.30		6.050	1.24
120		0.108			5.5		
	30		0.109	196.20		5.200	1.02
150		0.110			4.9		
	60		0.116	415.80		4.350	1.81
210		0.121			3.8		
	60		0.125	450.00		3.500	1.58
270		0.129			3.2		
	60		0.127	457.20		3.150	1.44
330		0.125			3.1		
				2390.7			**13.27**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2.7	0.158	2.8	0.161	2.5	0.152	1	0.139	1	0.139
3.2	0.172	3.4	0.177	5	0.215	1.2	0.152	1.1	0.146
2.5	0.152	2.8	0.161	2	0.136	1	0.096	0.9	0.091
2.3	0.146	2.3	0.146	2.5	0.152	1.1	0.101	1.1	0.101
	0.157		**0.161**		**0.164**		**0.122**		**0.119**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
0.8	0.124	0.9	0.132	1	0.139	1.1	0.146	1.1	0.146
0.8	0.124	0.9	0.132	1	0.139	1.3	0.158	1.3	0.158
0.8	0.086	0.9	0.091	1.3	0.109	1.3	0.109	1.1	0.101
1	0.096	0.8	0.086	1	0.096	1.1	0.101	1	0.096
	0.108		**0.110**		**0.121**		**0.129**		**0.125**

Continuation of Annex 3

The outflow volume, the sediments

2000

Irrigation 2

Cont. irr.

Furrows 1,2,3,4		Out flow rate		Outflow	The sediments		
T, min	dti,min	qi L/s	q av L/s	volume, L W o. f.	m, g/l	m av, g/L	Pmi, kg
10		0.161			20.8		
	10		0.165	98.70		19.450	1.92
20		0.168			18.1		
	10		0.173	103.80		17.800	1.85
30		0.178			17.5		
	30		0.155	278.10		13.850	3.85
60		0.131			10.2		
	30		0.129	232.20		9.850	2.29
90		0.127			9.5		
	30		0.125	225.00		8.500	1.91
120		0.123			7.5		
	30		0.122	218.70		8.350	1.83
150		0.120			9.2		
	60		0.125	450.00		10.650	4.79
210		0.130			12.1		
	60		0.130	466.20		11.200	5.22
270		0.129			10.3		
	60		0.129	462.60		9.700	4.49
330		0.128			9.1		
				2535.3			**28.15**

T, min	10		20		30		60		90	
h	q	h	q	h	q	h	q	h	q	h	q
2.5	0.152	2.9	0.163	3.8	0.187	2.1	0.139	2.1	0.139
3	0.166	3	0.166	3.9	0.190	2.3	0.146	2.2	0.142
3	0.166	3.5	0.180	3.8	0.187	2.1	0.139	2	0.136
2.8	0.161	2.9	0.163	2.4	0.149	1.1	0.101	0.9	0.091
	0.161		**0.168**		**0.178**		**0.131**		**0.127**

120		150		210		270		330	
h	q	h	q	h	q	h	q	h	q
1.8	0.129	1.7	0.125	1.9	0.132	1.9	0.132	1.9	0.132
2.1	0.139	2	0.136	2.4	0.149	2.4	0.149	2.3	0.146
1.8	0.129	1.6	0.121	1.8	0.129	1.9	0.132	1.9	0.132
1	0.096	1	0.096	1.3	0.109	1.1	0.101	1.1	0.101
	0.123		**0.120**		**0.130**		**0.129**		**0.128**

Continuation of Annex3

Irrigation 2

Cont.irr.+Pam

Furrows 5,6,7,8		Out flow rate		Outflow		The sediments		
		qi	q av	volume, L	m, g/l	m av,	Pmi, kg	
T, min	dti,min	L/s	L/s	W o. f.		g/L		
10		0.131			4			
	10		0.137	81.90		4.400	0.36	
20		0.142			4.8			
	10		0.148	88.80		4.800	0.43	
30		0.154			4.8			
	30		0.125	225.00		4.100	0.92	
60		0.096			3.4			
	30		0.094	169.20		3.250	0.55	
90		0.092			3.1			
	30		0.093	167.40		3.200	0.54	
120		0.094			3.3			
	30		0.096	172.80		3.200	0.55	
150		0.098			3.1			
	60		0.099	354.60		2.900	1.03	
210		0.099			2.7			
	60		0.101	361.80		2.750	0.99	
270		0.102			2.8			
	60		0.102	365.40		2.550	0.93	
330		0.101			2.3			
				1986.90			**6.30**	

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.4	0.114	1.5	0.118	1.7	0.125	1.1	0.101	1.1	0.101
1.8	0.129	2.3	0.146	2.5	0.152	0.8	0.086	0.8	0.086
2.4	0.149	3	0.166	3.8	0.187	1.1	0.101	1	0.096
1.9	0.132	2.1	0.139	2.5	0.152	1	0.096	0.8	0.086
	0.131		**0.142**		**0.154**		**0.096**		**0.092**
T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
1.1	0.101	1.2	0.105	1.2	0.105	1.2	0.105	1.2	0.105
1.2	0.105	1.2	0.105	1.3	0.109	1.2	0.105	1.1	0.101
1.1	0.101	1.1	0.101	1	0.096	1.2	0.105	1.2	0.105
0.5	0.068	0.7	0.080	0.8	0.086	0.9	0.091	0.9	0.091
	0.094		**0.098**		**0.099**		**0.102**		**0.101**

Continuation of Annex3

Irrigation 2

Surge irr.+Pam

Furrows	9,10, 11,12	Out flow rate qi	q av	Outflow volume, L	m, g/l	The sediments m av, g/L	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.			
10		0.142			17.3		
	10		0.146	87.30		17.650	1.54
20		0.149			18		
	10		0.155	92.70		18.700	1.73
30		0.160			19.4		
	30		0.137	246.60		16.100	3.97
60		0.114			12.8		
	30		0.116	207.90		12.300	2.56
90		0.117			11.8		
	30		0.119	213.30		10.450	2.23
120		0.120			9.1		
	30		0.123	220.50		9.350	2.06
150		0.125			9.6		
	60		0.127	455.40		9.150	4.17
210		0.128			8.7		
	60		0.128	460.80		8.600	3.96
270		0.128			8.5		
	60		0.128	459.00		8.350	3.83
330		0.127			8.2		
				2443.5			**26.05**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2	0.136	2.2	0.142	3	0.166	1.5	0.118	1.1	0.101
2	0.136	2.8	0.161	2.8	0.161	1.3	0.109	2	0.136
3.5	0.180	3.4	0.177	3.5	0.180	1.6	0.121	1.4	0.114
1.5	0.118	1.5	0.118	1.9	0.132	1.3	0.109	1.5	0.118
	0.142		**0.149**		**0.160**		**0.114**		**0.117**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
0.9	0.091	1	0.096	1.1	0.101	1.1	0.101	1.1	0.101
1.9	0.132	1.7	0.125	1.7	0.125	1.7	0.125	1.7	0.125
2.1	0.139	2.8	0.161	3	0.166	2.8	0.161	2.7	0.158
1.5	0.118	1.5	0.118	1.6	0.121	1.7	0.125	1.7	0.125
	0.120		**0.125**		**0.128**		**0.128**		**0.127**

Continuation of Annex 3

Irrigation 2

Surge irr.

Furrows	13,14, 15,16	Out flow rate		Outflow		The sediments	
T, min	dti,min	qi L/s	q av L/s	volume, L W o. f.	m, g/l	m av, g/L	Pmi, kg
10		0.195			28.3		
	10		0.196	117.60		27.700	3.26
20		0.197			27.1		
	10		0.201	120.30		26.800	3.22
30		0.204			26.5		
	30		0.171	306.90		21.700	6.66
60		0.137			16.9		
	30		0.134	240.30		16.750	4.03
90		0.130			16.6		
	30		0.131	235.80		16.100	3.62
120		0.132			15.6		
	30		0.125	225.00		15.400	3.37
150		0.118			15.2		
	60		0.124	446.40		15.450	6.95
210		0.130			15.7		
	60		0.133	478.80		15.600	7.27
270		0.136			15.5		
	60		0.138	496.80		15.750	7.29
330		0.140			16		
				2667.9			**45.67**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.5	0.170	2.5	0.220	2	0.197	0.5	0.098	0.6	0.108
3.5	0.260	3	0.241	3.5	0.260	2	0.197	1.8	0.186
3.2	0.172	2.4	0.149	3	0.166	1.6	0.121	1.2	0.105
3.5	0.180	3.5	0.180	4	0.192	1.9	0.132	1.6	0.121
	0.195		**0.197**		**0.204**		**0.137**		**0.130**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
1.2	0.152	1	0.139	1	0.139	1.3	0.158	1.5	0.170
1.3	0.158	1.1	0.146	1.4	0.164	1.6	0.176	1.6	0.176
1.1	0.101	0.8	0.086	1.1	0.101	1.1	0.101	1.2	0.105
1.5	0.118	1.1	0.101	1.5	0.118	1.3	0.109	1.3	0.109
	0.132		**0.118**		**0.130**		**0.136**		**0.140**

Continuation of Annex 3

The outflow volume, the sediments
2000

Irrigation 3

Cont. irr.

Furrows 1,2,3,4

T, min	dti,min	Out flow rate qi L/s	q av L/s	Outflow volume,L W o. f.	m, g/l	The sediments m av, g/L	Pmi, kg
10		0.187			18.1		
20	10		0.190	114.0		18.200	2.07
		0.193			18.3		
30	10		0.196	117.3		18.850	2.21
		0.198			19.4		
60	30		0.168	301.5		17.350	5.23
		0.137			15.3		
90	30		0.133	238.5		14.150	3.37
		0.128			13		
120	30		0.128	230.4		12.150	2.80
		0.128			11.3		
150	30		0.129	232.2		10.650	2.47
		0.130			10		
210	60		0.135	484.2		9.550	4.62
		0.139			9.1		
270	60		0.136	487.8		9.000	4.39
		0.132			8.9		
330	60		0.133	478.8		8.800	4.21
		0.134			8.7		
				2684.7			**31.39**

T, min	10		20		30		60		90
h	q		q	h	q	h	q	h	q
1.5	0.170	1.5	0.170	1.5	0.170	0.7	0.116	0.7	0.116
2.2	0.206	2.3	0.211	3	0.241	1.2	0.152	1	0.139
2.1	0.201	2.2	0.206	3	0.241	1.1	0.146	0.9	0.132
1.5	0.170	1.8	0.186	1	0.139	0.9	0.132	0.8	0.124
	0.187		**0.193**		**0.198**		**0.137**		**0.128**

T, min	120		150		210		270		
h	q	h	q	h	q	h	q	h	q
0.8	0.124	0.7	0.116	0.8	0.124	0.8	0.124	0.8	0.124
1	0.139	1.1	0.146	1.1	0.146	1	0.139	1	0.139
0.9	0.132	0.9	0.132	1	0.139	0.8	0.124	0.9	0.132
0.7	0.116	0.8	0.124	1.1	0.146	1	0.139	1	0.139
	0.128		**0.130**		**0.139**		**0.132**		**0.134**

Continuation of Annex 3

Irrigation 3

Cont. irr.+Pam

Furrows 5,6,7,8		Out flow rate		Outflow	The sediments		
		qi	q av	volume, L	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.		g/L	
10		0.161			14.2		
	10		0.163	97.8		14.650	1.43
20		0.165			15.1		
	10		0.168	100.8		17.250	1.74
30		0.171			19.4		
	30		0.144	258.3		17.050	4.40
60		0.116			14.7		
	30		0.118	211.5		11.950	2.53
90		0.119			9.2		
	30		0.120	215.1		8.850	1.90
120		0.120			8.5		
	30		0.120	216.0		8.450	1.83
150		0.120			8.4		
	60		0.121	435.6		8.050	3.51
210		0.122			7.7		
	60		0.122	439.2		7.500	3.29
270		0.122			7.3		
	60		0.123	441.0		7.100	3.13
330		0.123			6.9		
				2415.3			**23.76**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.2	0.152	1.5	0.170	1.5	0.170	0.7	0.116	0.7	0.116
1.8	0.186	2	0.197	1.9	0.192	1	0.139	1	0.139
1.4	0.164	1.5	0.170	1.7	0.181	0.9	0.132	0.9	0.132
1	0.139	0.8	0.124	1	0.139	0.3	0.076	0.4	0.088
	0.161		**0.165**		**0.171**		**0.116**		**0.119**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
0.7	0.116	0.7	0.116	0.8	0.124	0.8	0.124	1	0.139
1	0.139	1	0.139	1	0.139	1	0.139	1	0.139
0.7	0.116	0.6	0.108	0.6	0.108	0.6	0.108	0.6	0.108
0.6	0.108	0.7	0.116	0.7	0.116	0.7	0.116	0.6	0.108
	0.120		**0.120**		**0.122**		**0.122**		**0.123**

Continuation of Annex 3

Irrigation 3

Surge irr.+Pam

Furrows	9,10, 11,12	Out flow rate qi	q av	Outflow volume, L	The sediments m, g/l	m av, g/L	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.			
10		0.170			14.5		
	10		0.173	103.8		14.050	1.46
20		0.176			13.6		
	10		0.180	107.7		13.300	1.43
30		0.183			13		
	30		0.155	278.1		12.450	3.46
60		0.126			11.9		
	30		0.125	225.0		11.800	2.66
90		0.124			11.7		
	30		0.128	229.5		11.650	2.67
120		0.131			11.6		
	30		0.130	234.0		11.600	2.71
150		0.129			11.6		
	60		0.132	475.2		11.450	5.44
210		0.135			11.3		
	60		0.136	487.8		11.300	5.51
270		0.136			11.3		
	60		0.136	487.8		11.100	5.41
330		0.135			10.9		
				2628.9			**30.76**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.3	0.158	1.3	0.158	1.3	0.158	0.6	0.108	0.6	0.108
1.5	0.170	1.6	0.176	1.5	0.170	0.8	0.124	0.8	0.124
1.5	0.170	1.7	0.181	2.1	0.201	1	0.139	1	0.139
1.7	0.181	1.8	0.186	2.1	0.201	0.9	0.132	0.8	0.124
	0.170		**0.176**		**0.183**		**0.126**		**0.124**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
0.7	0.116	0.7	0.116	0.8	0.124	0.7	0.116	0.9	0.132
0.9	0.132	0.9	0.132	0.9	0.132	1	0.139	1	0.139
1.1	0.146	1.2	0.152	1.2	0.152	1.4	0.164	1.1	0.146
0.9	0.132	0.7	0.116	0.9	0.132	0.8	0.124	0.8	0.124
	0.131		**0.129**		**0.135**		**0.136**		**0.135**

Continuation of Annex 3

Irrigation 3

Surge irr.

Furrows	13,14, 15,16	Out flow rate		Outflow		The sediments	
T, min	dti,min	qi L/s	q av L/s	volume, L W o. f.	m, g/l	m av, g/L	Pmi, kg
10		0.204			18.7		
	10		0.206	123.3		20.500	2.53
20		0.207			22.3		
	10		0.209	125.4		22.700	2.85
30		0.211			23.1		
	30		0.172	308.7		19.950	6.16
60		0.132			16.8		
	30		0.129	232.2		16.200	3.76
90		0.126			15.6		
	30		0.129	232.2		15.750	3.66
120		0.132			15.9		
	30		0.133	239.4		15.600	3.73
150		0.134			15.3		
	60		0.133	478.8		15.800	7.57
210		0.132			16.3		
	60		0.136	487.8		16.300	7.95
270		0.139			16.3		
	60		0.137	493.2		15.900	7.84
330		0.135			15.5		
				2721.0			**46.04**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2.4	0.215	2.5	0.220	2.5	0.220	0.9	0.132	0.9	0.132
2	0.197	2	0.197	2	0.197	0.8	0.124	0.7	0.116
2.2	0.206	2.4	0.215	2.5	0.220	1	0.139	0.9	0.132
2	0.197	2	0.197	2.2	0.206	0.9	0.132	0.8	0.124
	0.204		**0.207**		**0.211**		**0.132**		**0.126**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
1	0.139	0.9	0.132	0.9	0.132	1	0.139	0.9	0.132
0.9	0.132	0.9	0.132	0.9	0.132	1	0.139	1.0	0.139
0.9	0.132	0.9	0.132	0.8	0.124	0.9	0.132	0.8	0.124
0.8	0.124	1	0.139	1	0.139	1.1	0.146	1.1	0.146
	0.132		**0.134**		**0.132**		**0.139**		**0.135**

Continuation of Annex 3

The outflow volume, the sediments
2000

Irrigation 4

Cont. irr.

Furrows 1,2,3,4		Out flow rate		Outflow		The sediments	
		qi	q av	volume, L	m, g/L	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.		g/L	
10		0.207			16.7		
	10		0.209	125.1		16.450	2.06
20		0.210			16.2		
	10		0.212	127.2		16.000	2.04
30		0.214			15.8		
	30		0.187	335.7		14.100	4.73
60		0.159			12.4		
	30		0.151	271.8		12.250	3.33
90		0.143			12.1		
	30		0.140	252.0		12.000	3.02
120		0.137			11.9		
	30		0.136	244.8		11.750	2.88
150		0.135			11.6		
	60		0.137	493.2		11.150	5.50
210		0.139			10.7		
	60		0.137	493.2		10.600	5.23
270		0.135			10.5		
	60		0.136	489.6		10.600	5.19
330		0.137			10.7		
				2832.60			**33.97**

T, min	10		20		30		60		90
h	q		q	h	q	h	q	h	q
1.5	0.170	1.6	0.176	1.5	0.170	0.9	0.132	0.8	0.124
2.5	0.220	2.6	0.224	2.7	0.228	1.5	0.170	1.2	0.152
3	0.241	3.1	0.245	3	0.241	1.8	0.186	1.4	0.164
2	0.197	2	0.197	2.4	0.215	1.1	0.146	0.9	0.132
	0.207		**0.210**		**0.214**		**0.159**		**0.143**

T, min	120		150		210		270		
h	q	h	q	h	q	h	q	h	q
0.9	0.132	0.9	0.132	1	0.139	1	0.139	1.1	0.146
1.1	0.146	1.1	0.146	1.1	0.146	1	0.139	1	0.139
1	0.139	1	0.139	1.1	0.146	1	0.139	1	0.139
0.9	0.132	0.8	0.124	0.8	0.124	0.8	0.124	0.8	0.124
	0.137		**0.135**		**0.139**		**0.135**		**0.137**

Continuation of Annex 3

Irrigation 4

Cont. irr.+Pam

Furrows 5,6,7,8		Out flow rate		The outflow	The sediments		
		qi	q av	volume, L	m, g/L	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.		g/L	
10		0.172			13.1		
	10		0.173	103.5		13.350	1.38
20		0.173			13.6		
	10		0.175	104.7		13.950	1.46
30		0.176			14.3		
	30		0.150	270.0		13.050	3.52
60		0.124			11.8		
	30		0.121	217.8		10.550	2.30
90		0.118			9.3		
	30		0.121	217.8		9.950	2.17
120		0.124			10.6		
	30		0.126	226.8		9.950	2.26
150		0.128			9.3		
	60		0.129	464.4		10.100	4.69
210		0.130			10.9		
	60		0.130	468.0		11.000	5.15
270		0.130			11.1		
	60		0.131	471.6		10.500	4.95
330		0.132			9.9		
				2544.6			**27.88**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.2	0.152	1.2	0.152	1.8	0.186	0.9	0.132	0.8	0.124
2.1	0.201	2	0.197	1.7	0.181	0.9	0.132	0.8	0.124
2	0.197	1.9	0.192	1.4	0.164	0.8	0.124	0.7	0.116
1	0.139	1.2	0.152	1.5	0.170	0.6	0.108	0.6	0.108
	0.172		**0.173**		**0.176**		**0.124**		**0.118**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
0.8	0.124	0.9	0.132	0.9	0.132	0.9	0.132	0.9	0.132
0.9	0.132	1	0.139	1	0.139	0.8	0.124	0.8	0.124
0.8	0.124	0.8	0.124	0.8	0.124	0.8	0.124	0.9	0.132
0.7	0.116	0.7	0.116	0.8	0.124	1	0.139	1	0.139
	0.124		**0.128**		**0.130**		**0.130**		**0.132**

Continuation of Annex 3

Irrigation 4

Surge irr.+Pam

Furrows	9,10, 11,12	Out flow rate qi	q av	Outflow volume, L	m, g/L	The sediments m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.		g/L	
10		0.176			21.4		
	10		0.178	106.8		20.200	2.16
20		0.180			19		
	10		0.183	109.8		18.350	2.01
30		0.186			17.7		
	30		0.158	283.5		14.650	4.15
60		0.129			11.6		
	30		0.128	229.5		11.450	2.63
90		0.126			11.3		
	30		0.128	230.4		11.150	2.57
120		0.130			11		
	30		0.133	238.5		10.750	2.56
150		0.135			10.5		
	60		0.134	482.4		10.050	4.85
210		0.133			9.6		
	60		0.135	486.0		9.700	4.71
270		0.137			9.8		
	60		0.139	498.6		9.700	4.84
330		0.140			9.6		
				2665.50			**30.48**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.8	0.186	1.8	0.186	2.2	0.206	1.1	0.146	1	0.139
1.7	0.181	1.7	0.181	1.8	0.186	1	0.139	0.9	0.132
1.4	0.164	1.4	0.181	1.5	0.170	0.8	0.124	0.8	0.124
1.5	0.170	1.5	0.170	1.7	0.181	0.6	0.108	0.6	0.108
	0.176		**0.180**		**0.186**		**0.129**		**0.126**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
1	0.139	1	0.139	1	0.139	1	0.139	1.1	0.146
1	0.139	1.1	0.146	1.1	0.146	1.1	0.146	1.2	0.152
0.8	0.124	0.8	0.124	0.7	0.116	0.8	0.124	0.9	0.132
0.7	0.116	0.9	0.132	0.9	0.132	1	0.139	0.9	0.132
	0.130		**0.135**		**0.133**		**0.137**		**0.140**

Continuation of Annex 3

Irrigation 4

Surge irr.

Furrows	13,14 15,16	Out flow rate qi	q av	Outflow volume, L		The sediments m, g/L	m av, g/L	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				
10		0.209				22.3		
	10		0.211	126.3			23.550	2.97
20		0.212				24.8		
	10		0.213	127.8			24.000	3.07
30		0.214				23.2		
	30		0.184	331.2			19.350	6.41
60		0.154				15.5		
	30		0.152	273.6			14.650	4.01
90		0.150				13.8		
	30		0.148	266.4			11.500	3.06
120		0.146				9.2		
	30		0.143	256.5			10.500	2.69
150		0.139				11.8		
	60		0.135	484.2			12.250	5.93
210		0.130				12.7		
	60		0.135	484.2			12.450	6.03
270		0.139				12.2		
	60		0.141	505.8			11.000	5.56
330		0.142				9.8		
				2856.0				**39.74**

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2.2	0.206	2.3	0.211	2.5	0.220	1.3	0.158	1.1	0.146
2.4	0.215	2.4	0.215	2.4	0.215	1.1	0.146	1.1	0.146
2.5	0.220	2.5	0.220	2.5	0.220	1.4	0.164	1.4	0.164
2	0.197	2.1	0.201	2.1	0.201	1.1	0.146	1.1	0.146
	0.209		**0.212**		**0.214**		**0.154**		**0.150**

T, min	120		150		210		270		330
	q	h	q	h	q	h	q	h	q
1	0.139	1	0.139	1	0.139	1.1	0.146	1.1	0.146
1.1	0.146	1	0.139	0.8	0.124	1	0.139	1.1	0.146
1.3	0.158	1.1	0.146	0.8	0.124	1.1	0.146	1.1	0.146
1	0.139	0.9	0.132	0.9	0.132	0.8	0.124	0.9	0.132
	0.146		**0.139**		**0.130**		**0.139**		**0.142**

The calculation of a total outflow volume

2000

Version of the irrigat.technolo	Fact outflow volume from one furrow (L for a observed period (it is 5.5 hours) at number of irrigation				
	1	2	3	4	total
Cont. irr.	2306	2535	2685	2833	10359
Cont. irr.+Pam	1646	1987	2415	2545	8593
Surge irr+Pam	2088	2444	2629	2666	9827
Surge irr	2391	2668	2721	2856	10636

Version of the irrigat.technolo	Fact outflow volume from one furrow (m3/hec) for a observed period at number of irrigation				
	1	2	3	4	total
Cont. irr.	165	181	192	202	740
Cont. irr.+Pam	118	142	173	182	614
Surge irr+Pam	149	175	188	190	702
Surge irr	171	191	194	204	760

Version of the irrigat.technolo	Steady outflow rate from one furrow (L/ to end of a observed period at number of irrigation				
	1	2	3	4	on the ave
Cont. irr.	0.119	0.129	0.134	0.136	0.130
Cont. irr.+Pam	0.084	0.101	0.123	0.131	0.110
Surge irr+Pam	0.106	0.128	0.135	0.139	0.127
Surge irr	0.126	0.138	0.137	0.14	0.135

Version of the irrigat.technolo	Duration of irrigation after end of observation (min) at number of irrigatio				
	1	2	3	4	on the ave
Cont. irr.	1017	1024	1037	1047	1031
Cont. irr.+Pam	956	980	1009	1038	996
Surge irr+Pam	985	1015	1024	1047	1018
Surge irr	1035	1045	1048	1059	1047

Version of the irrigat.technolo	Outflow volume after end observation(m3/he at number of irrigation				
	1	2	3	4	total
Cont. irr.	519	566	596	610	2291
Cont. irr.+Pam	344	424	532	583	1883
Surge irr+Pam	447	557	592	624	2220
Surge irr	559	618	615	635	2428

Version of the irrigat.technolo	Total of outflow volume (m3/hec) at number of irrigation				
	1	2	3	4	total
Cont. irr.	683	747	787	813	3031
Cont. irr.+Pam	462	566	704	765	2497
Surge irr+Pam	597	731	780	814	2922
Surge irr	730	809	810	839	3187

Annex 5

Balance of sediments for one furrow

2000

Irrigation 1

Number of furr.	Version	Duration, min wetting	of observation with q1= 21.6L/min	with q2= 12.36L/min	Sedimen. concen., %	Weight of sediments, kg applic.	disch.	balance
1,2,3,4	cont.irr.	93	123		0.592	15.73		
				300	0.259	9.60		
	total					**25.33**	**34.75**	**-9.42**
5,6,7,8	cont.irr. +Pam	154	184		0.581	23.09		
				300	0.229	8.49		
	total					**31.58**	**2.93**	**28.65**
9,10, 11,12	surge irr. +Pam	125	155		0.239	8.00		
				300	0.214	7.94		
	total					**15.94**	**4.06**	**11.88**
13,14, 15,16	surge irr.	75	105		0.239	5.42		
				300	0.211	7.82		
	total					**13.24**	**13.27**	**-0.03**

Irrigation 2

Number of furr.	Version	Duration, min wetting	of observation with q1= 21.6L/min	with q2= 12.36L/min	Sedimen. concen., %	Weight of sediments, kg applic.	disch.	balance
1,2,3,4	cont.irr.	86	116		0.185	4.64		
				300	0.145	5.38		
	total					**10.01**	**28.15**	**-18.14**
5,6,7,8	cont.irr. +Pam	130	160		0.274	9.47		
				300	0.145	5.38		
	total					**14.85**	**6.3**	**8.55**
9,10, 11,12	surge irr. +Pam	95	125		0.611	16.50		
				300	1.221	45.27		
	total					**61.77**	**26.05**	**35.72**
13,14, 15,16	surge irr.	65	95		0.588	12.07		
				300	1.232	45.68		
	total					**57.75**	**45.67**	**12.08**

Continuation Annex 5

Irrigation 3

Number of furr.	Version	Duration, min wetting	of observation with q1= 21.6L/min	with q2= 12.36L/min	Sedimen. concen., %	Weight of sediments, kg applic.	disch.	balance
1,2,3,4	cont.irr.	73	103		0.604	13.44		
				300	0.294	10.90		
	total					**24.34**	**31.39**	**-7.05**
5,6,7,8	cont.irr. +Pam	101	131		0.587	16.61		
				300	0.28	10.38		
	total					**26.99**	**23.76**	**3.23**
9,10, 11,12	surge irr. +Pam	86	116		0.296	7.42		
				300	1.649	58.85		
	total					**66.26**	**30.76**	**35.50**
13,14, 15,16	surge irr.	62	92		0.237	4.71		
				300	1.587	61.14		
	total					**65.85**	**46.04**	**19.81**

Irrigation 4

Number of furr.	Version	Duration, min wetting	of observation with q1= 21.6L/min	with q2= 12.36L/min	Sedimen. concen., %	Weight of sediments, kg applic.	disch.	balance
1,2,3,4	cont.irr.	63	93		0.271	5.44		
				300	0.344	12.76		
	total					**18.20**	**33.97**	**-15.77**
5,6,7,8	cont.irr. +Pam	72	102		0.275	6.06		
				300	0.337	12.50		
	total					**18.55**	**27.88**	**-9.33**
9,10, 11,12	surge irr. +Pam	63	93		0.544	10.93		
				300	0.774	28.70		
	total					**39.63**	**30.48**	**9.15**
13,14, 15,16	surge irr.	51	81		0.415	7.26		
				300	0.867	32.15		
	total					**39.41**	**39.74**	**-0.33**

Irrigations 1-4

Number of furr.	Version	Duration, min wetting	of observation with q1= 21.6L/min	with q2= 12.36L/min	Sedimen. concen., %	Weight of sediments, kg applic.	disch.	balance
1,2,3,4	cont.irr.	315	435		0.418	39.25		
				1200	0.261	38.64		
	total					**77.88**	**128.26**	**-50.38**
5,6,7,8	cont.irr. +Pam	457	577		0.443	55.23		
				1200	0.248	36.75		
	total					**91.98**	**60.87**	**31.11**
9,10, 11,12	surge irr. +Pam	369	489		0.406	42.84		
				1200	0.965	143.05		
	total					**185.90**	**91.35**	**94.55**
13,14, 15,16	surge irr.	253	373		0.366	29.46		
				1200	0.974	144.50		
	total					**173.96**	**144.72**	**29.24**

Crops of sugar beet

Number of root crops	Crops of sugar beet (g) for version											
	continuous irrigation			continuous irrigation+PAM			surge irrigation+Pam			surge irrigation		
	distance from furrow beginning, m											
	20	100	180	20	100	180	20	100	180	20	100	180
1	747	626	692	1125	787	900	1267	1206	856	1176	730	1026
2	647	661	563	959	706	707	1054	699	668	1125	711	954
3	545	542	479	946	675	594	874	654	567	944	703	810
4	539	465	447	741	674	533	842	603	531	894	699	740
5	510	431	447	721	641	475	841	510	523	823	689	585
6	498	418	446	689	591	477	821	494	437	814	668	583
7	429	387	424	672	566	464	783	454	435	745	645	544
8	416	395	421	667	558	422	777	451	421	728	636	503
9	396	358	397	582	525	340	708	431	398	695	633	438
10	387	342	374	572	522	338	697	420	391	671	584	431
11	387	347	351	527	524	316	663	415	380	587	550	424
12	376	330	343	519	508	300	648	408	370	585	546	397
13	358	326	339	475	456	295	559	362	365	555	509	394
14	345	313	332	433	422	282	557	375	336	528	478	381
15	343	311	316	398	401	285	550	358	330	527	456	364
16	328	288	306	381	389	261	516	286	326	492	388	293
17	319	255	283	322	363	258	424	235	326	472	383	284
18	304	198	280	322	292	203	417	239	320	395	320	282
19	297	182	274	313	270	163	341	199	279	374	307	241
20	272	180	246	291	253	156	294	159	252	367	284	236
Total 1-20, g	8443	7355	7760	11655	10123	7769	13633	8958	8511	13497	10919	9910
Mean, g	422	368	388	583	506	388	682	448	426	675	546	496
Total 1-15, g	6923	6252	6371	10026	8556	6728	11641	7840	7008	11397	9237	8574
Mean, g	462	417	425	668	570	449	776	523	467	760	616	572
Total 1-15 cen/hec	323	292	297	468	399	314	543	366	327	532	431	400
Mean, cen/hec			299			396			394			445

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Appendix E

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Flow Interruption Effects on Intake Rate and Rill Erosion in Two Soils

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ABSTRACT

Efficiency of surface irrigation is often low because of poor infiltration uniformity, resulting from relatively long periods of infiltration at the upstream end and short periods of infiltration at the downstream end of the field. Surge irrigation, the intermittent supply of water to furrows, generally reduces soil intake rate (IR) and improves moisture uniformity over the entire field. However, IR reduction varies from one irrigation scheme to another, depends on soil and water properties, and is difficult to predict. A laboratory study using miniflumes was designed to investigate the effect of interrupted flow on IR and soil loss from short rills. Two soils differing in their textures, a silt loam (Calcic Haploxeralf) derived from loess and a clay soil (Typic Haploxerert), were studied. Intake rate in the clay soil was greater than that in the silt loam. Therefore, different inflow rates were applied to the two soils to achieve similar runoff flow rates from the two soils. Cumulative infiltration decreased from 646 mL in continuous flow to 539 mL in interrupted flow for the silt loam and from 1142 to 1068 mL in the clay soil. Interrupted flow also reduced cumulative soil loss by 84% in the clay soil but had only a small effect on soil loss from the silt loam. However, when flow rate was increased from 80 to 320 mL min^{-1}, interrupted flow reduced soil loss in the silt loam as much as in the clay soil. Consolidation of the soil surface and formation of cohesive forces between soil particles of the silt loam with unstable structure during flow interruption was suggested as the explanation for the effect of flow interruption on intake rate and soil detachment. These results need to be verified in field experiments.

SURFACE IRRIGATION is the most used irrigation practice worldwide. However, water application efficiency of surface irrigation is low, typically ≈45% (Wolters, 1992). Surge irrigation is the intermittent application of surface irrigation water (Stringham, 1988). It has the potential to increase infiltration uniformity of surface irrigation application by (i) increasing the advance rate, which decreases cross-field differences in infiltration opportunity time, and (ii) decreasing the IR at the upstream end of the furrows to compensate for the longer infiltration opportunity times at these locations (Kemper et al., 1988).

The infiltration decrease caused by surge flow is highly variable, is not fully understood, and is difficult to predict (Izuno et al., 1985; Kemper et al., 1988; Trout, 1991; Samani et al., 1985). Many studies have been conducted to determine the mechanisms taking place during the intermittent off period of surge flow irrigation. Several basic phenomena have been recognized:

1. Moisture Redistribution in the Soil Profile. During the interruption of water application, moisture redistribution is caused by the unbalanced capillary and gravitational forces acting on the water that has infiltrated. The redistribution process results in development of negative capillary pressure below the soil surface and a greater hydraulic gradient that increases water infiltration during the succeeding water application in surge flow irrigation (Samani et al., 1985). However, Izadi et al. (1990) demonstrated that this effect is short lived and that the net effect over a practical period of off time is negligible.

2. Consolidation of the Soil near the Furrow Perimeter. Development of negative pressure at the soil surface during flow interruptions leads to consolidation of the soil near the furrow perimeter. Kemper et al. (1988) measured negative pressures of up to 500 cm H_2O in a Portneuf soil (20% clay and 40% silt). The consolidated soil surface has a greater bulk density, lower porosity, and a lower HC; thus, even a thin consolidated layer can have a significant effect on reducing infiltration (Samani et al., 1985).

3. Surface Seal Formation. Furrow erosion, and particle transport, and subsequent deposition and rearrangement also significantly reduce infiltration by decreasing the permeability of the surface layer (seal formation). During surface irrigation, soil aggregates are weakened or partially broken by wetting (Kemper and Koch, 1966). Fast wetting disintegrates large aggregates into small aggregates, which then can be detached from the soil bed by the shear force of water and can be easily rolled along the bed of a furrow by moving water until deposition (Kemper et al., 1988). Trout (1991) observed a 50% reduction of infiltration because of surface seal formation on the Portneuf silt loam soil. Shainberg and Singer (1985) observed that depositional crusts (formed when turbid water infiltrates into soil) reduced the rate of water penetration by one to two orders of magnitude, and the magnitude of this decrease depended on soil properties and water quality.

In addition, other mechanisms related mainly to bed load have been proposed to explain the effects of surge irrigation on furrow IR: (i) filling of cracks that develop during flow interruption with bed load during the following surge (Kemper et al., 1988); (ii) greater sediment detachment and movement caused by more rapid advance of the surge stream front (Kemper et al., 1985; Trout, 1991); (iii) forced deposition (and consolidation) of suspended sediment on the furrow perimeter when the water supply is interrupted (Kemper et al., 1985); and (iv) air entrapment (Seymour, 1990) and its expansion upon rewetting (Jalali-Farahani et al., 1993).

Miniflumes have been used to evaluate the interactive effects of flow characteristics, soil properties and water quality on rill erosion in the laboratory (Shainberg et

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Abbreviations: HC, hydraulic conductivity; IR, intake rate.

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al., 1994, 1996). Rill erodibility data obtained with miniflumes agreed well with field data (Shainberg et al., 1994). Miniflume studies were also found to simulate well the effect of polyacrylamide (PAM) on furrow erosion in the field (Lentz et al., 1992; Shainberg et al., 1994). Miniflumes were used by Shainberg et al. (1996) to study rill erosion in a loess and a clay soil; it was found that (i) rill erosion decreased with aging of several hours, (ii) the decease in erosion was more pronounced in the clay soil, and (iii) erosion depended on water content in the soil. These researchers postulated that aging and water tension enhanced clay to clay contacts and increased cohesive forces between soil particles, thus leading to the observed reduction in erosion. Application of these mechanisms to surge irrigation suggests that the water tension that builds up during the off period of the surge may cause an enhanced reduction in erosion.

It is hypothesized that interrupted flow will affect both soil IR and rill erosion, and that it can be evaluated from laboratory miniflume studies. Thus, the objectives of our study were (i) to study the effects of continuous and interrupted flow on the IR and on rill erosion in a silt loam and a clay soil and (ii) to improve the understanding of the mechanisms that cause interrupted flow to reduce rill erosion and IR in the two soils. It was assumed that the erodibilities of the two different soils could be compared, provided similar runoff rates are maintained.

MATERIALS AND METHODS

Two calcareous soils were chosen for this study: a silty loam (Calcic Haploxeralf) from Nevatim, northern Negev, and a clay soil (Typic Chromoxerert) from Hafetz-Haim, the Pleshet plains, Israel. Samples of the cultivated layer (0–250 mm) of each soil type were brought to the laboratory, air-dried, and crushed to pass through a 4-mm sieve. Selected physical and chemical properties of the soils are given in Table 1. Smectite was the dominant clay type in the soils (≈60%), with kaolinite, illite, and calcite also present (Banin and Amiel, 1970). The fact that the clay content and cation-exchange capacity in the clay soil were twice that in the silt loam indicated that the clay mineralogy in the two soils was similar.

The experiments were carried out with a 0.5-m-long, 0.047-m-wide, and 0.12-m-deep flume; two 0.1-m-long V-shaped metallic rills were connected on both ends of each flume. The flume was placed at a 10% slope in order to maintain high flow shear force, high soil detachment, and high rill erosion. Water used in the experiments was laboratory tap water (electrical conductivity = 0.95 dS m^{-1}; Na adsorption ratio = 2.5 $(mmol_c\ L^{-1})^{0.5}$; Ca + Mg = 5 $mmol_c\ L^{-1}$; Na = 4 $mmol_c\ L^{-1}$; Cl = 6.2 $mmol_c\ L^{-1}$).

Air-dried soil was slightly compacted in the flumes to field densities of 1390 kg m^{-3} for the silt loam and of 1280 kg m^{-3} for the clay soil. When dry, the volume of the clay soil was intentionally kept smaller than that of the silt loam. However, upon wetting and subsequent swelling, the final volume of the wet clay soil in the flume was similar to that of the silt loam, and the wet bulk density of the silt loam and clay soil was 1390 and 1200 kg m^{-3}, respectively. A V-shaped rill (44 mm wide and 22 mm deep) with a 90° angle between its sides was formed in the soil surface. Water was applied with a peristaltic pump to the upstream metallic rill, and runoff water containing sediment was collected in beakers from the downstream metallic rill. Runoff volume was measured by weighing the beakers and sediment content in the outflow was determined by drying. Inflow and outflow rates were continuously recorded and average IR for each minute of flow time was calculated from the difference. Similarly rill erosion as a function of flow time was calculated.

Each individual experiment was divided into two stages. In the first stage either continuous (control) or interrupted flow was applied. The control treatment consisted of 4 min of flow; the interrupted flow treatment consisted of four cycles of 1 min of flow and 10 min of interruption. Preliminary studies on the effect of off time on rill erosion and IR in the miniflumes indicated that most of the changes in IR and erosion were obtained in off periods of <5 min. Thus it was assumed that an off time of 10 min would be sufficient for the changes in rill erosion and IR caused by flow interruption to be completed. In order to obtain a measurable outflow during the first minute and to obtain similar runoff during the consecutive 3 min, the inflows applied to the clay soil and the silt loam were 320 and 240 mL min^{-1}, respectively. Because the IR in the clay soil was higher than that in the silt loam, it took 57 s for the first surge to reach the end of the rill in the clay soil, and only 17 s in the silt loam. However, during the second, third, and fourth surges, the outflow rates were similar in both soils because of the higher IR in the clay soil. Thus, the shear stress of flowing water on the rill perimeter and stream transport capacity were similar for both soils.

The second stage of the experiment started immediately at the end of the 4-min flow in the control or after completion of the four cycles of interrupted flow in the interrupted flow treatment. At this stage, the inflow was reduced to allow more precise measurements of IR and was applied continuously to simulate field conditions. A continuous inflow of 100 mL min^{-1} for 10 min was applied to the clay soil, and a continuous inflow of 80 mL min^{-1} for 10 min was applied to the silt loam. Total inflow, outflow, and soil loss were recorded every minute for both soils. The second stage was terminated when the moisture front reached a depth of ≈100 mm, and the soil layer at the bottom of the miniflume remained dry. The length of the

Table 1. Physical and chemical properties of the soils used.

Soil	Classification	Particle-size distribution: Sand	Silt	Clay	$CaCO_3$	CEC†	ESP‡	EPP§	OM¶
		g kg^{-1}			g kg^{-1}	$cmol_c\ kg^{-1}$	%		g kg^{-1}
Silt loam	Calcic Haploxeralf	413	362	225	180	17.7	2.1	9.1	21
Clay soil	Typic Chromoxerert	438	156	406	107	34.2	2.3	2.9	34

† Cation-exchange capacity.
‡ Exchangeable Na percentage.
§ Exchangeable K percentage.
¶ Organic matter content.

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second stage was estimated from preliminary experiments done on the same miniflumes packed with the same soils. The dry layer of soil at the bottom of the flume assured the presence of the suction needed to consolidate the soil surface. The suction was maintained at the bottom of the soil in the flume to simulated the moisture profile prevailing under field conditions.

Three replicates were performed for each of the soils and the two flow patterns. Each replicate consisted of a miniflume packed with a fresh dry soil sample. For each soil, the Honestly Significant Difference test (Tukey–Kramer, $\alpha = 0.05$) was used to compare the means of the IR and rill erosion between the two flow patterns studied. Differences in the IR and rill erosion between the two soils could not be statistically analyzed because inflow rates differed between the soils. However, because the outflow in the two soils were similar, the flow shear force and the stream transport capacity at the down stream end of the rill were similar and rill erodibility of the two soils could be compared and discussed.

RESULTS AND DISCUSSION

Effects of Flow Type on Infiltration Rate in the Two Soils

The effects of interrupted flow on IR (obtained from the difference between the inflow and the outflow rate) in the silt loam and the clay soil are presented in Fig. 1. Intake rate in the clay soil was significantly greater than that in the silt loam. The high IR in the clay soil (both the initial and the steady state values) was ascribed to its aggregated structure and stable aggregates. Aggregate stability of soils from semiarid regions generally increases with increasing clay content, since the clay acts as a cementing material, enhancing the formation and stabilization of aggregates (Kemper and Koch, 1966). Stable aggregates lead to stable interaggregate macropores, which are responsible for the high IR (Rengasamy et al., 1984; Kay and Angers, 1999). Conversely, in the silt loam the low IR values (Fig. 1) were ascribed to its medium clay and high silt content (Table 1), which resulted in a markedly less aggregated structure than that of the clay soil (Kemper and Koch, 1966; Rengasamy et al., 1984). Thus, difference in texture between the two soils was considered as the main reason for the large difference in IR between the two soils.

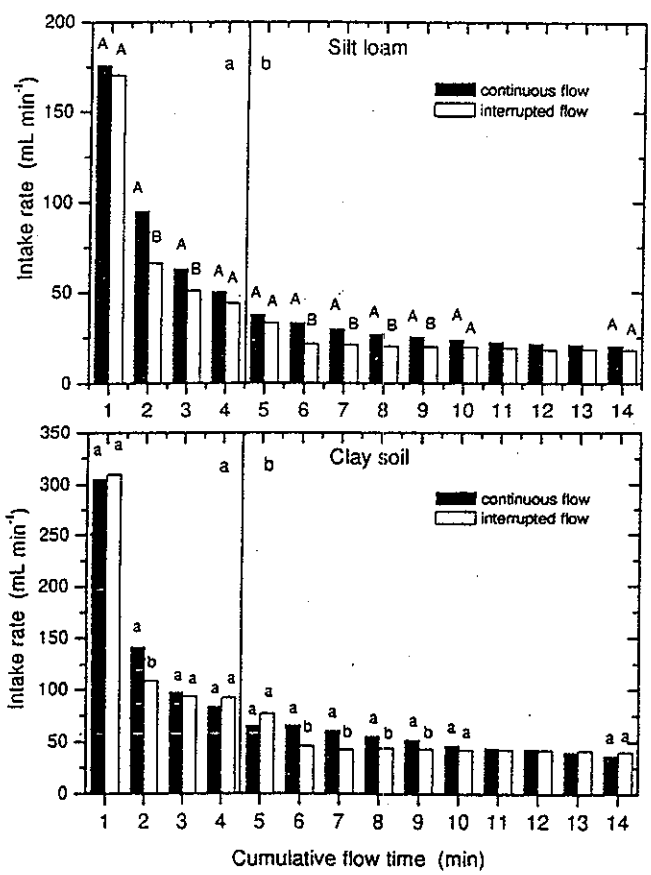

Fig. 1. Intake rate as a function of cumulative flow time for the clay soil and silt loam at Stage 1 (a) and Stage 2 (b) of the experiment. For a given cumulative flow time, and within a soil, bars labeled by the same letter (lower case for the clay soil and upper case for the silt loam) do not differ significantly at the 0.05 level.

The IR decreased with increasing cumulative flow time (Fig. 1). With increasing depth of water penetration in the soil profile, the hydraulic gradient, which provided the main driving force for water movement into the soil, decreased and IR also decreased. Reduction of IR between the first and the second minute in the continuous flow was more pronounced in the clay soil than in the silt loam (Fig. 1). This was probably due to (i) more water penetrating into the clay soil during the first minute, leading to a lower hydraulic gradient and lower infiltration rate of water, and (ii) more clay swelling and aggregate breakdown occurring in the clay soil, which resulted in a decrease in the size of the interaggregate macropores (Rengasamy et al., 1984; Kay and Angers, 1999).

In the interrupted flow treatment, the first flow interruption (i.e., off period) was effective in reducing the IR with the effect being similar (in relative terms) in both soils (Fig. 1, second minute). The second off period was effective only in the silt loam in reducing the IR compared with that of continuous flow. The effect of interrupted flow disappeared in the fourth and fifth minute measurements (Fig. 1). With the introduction of continuous low-rate inflow in the second stage of the experiment, the effect of interrupted flow in reducing IR became evident again (Fig. 1). Four cycles of interrupted flow reduced the final cumulative intake of the silt loam by 19% and that of the clay soil by 6% (Fig. 1). The effect of interrupted flow on intake rate was significant in both soils, but its effect was more pronounced in the silt loam.

During the period of flow interruption, compaction and consolidation of the soil surface caused by the soil water tension most likely occurred, and the hydraulic conductivity of the soil surface is thus reduced (Kemper et al., 1988; Samani et al., 1985). More surface consolidation and a decrease in infiltration is expected in soils with weak structure such as the silt loam (Mullins, 1999). This conclusion was verified by a complementary experiment similar to the one described by Samani et al. (1985). In those experiments disturbed dry soil samples (100 g) of the silt loam or the clay soil were placed inside a funnel with a fritted disc (40–60 μm pores) in the bottom. The internal diameter of the funnel was 65

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mm and the thickness of the soil samples was ≈22 mm. The funnel was connected to a plastic tube filled with water. The soil sample was saturated from the bottom by raising the plastic tube. After saturation, the saturated hydraulic conductivity of the soil sample was measured by applying water to the top of the soil sample in the funnel and collecting the outflow from the end of plastic tube. After measuring the saturated hydraulic conductivity, the same soil was drained to a tension of 20 cm by lowering the plastic tube. At the end of the draining process, the soil sample was saturated again by raising the plastic tube and new saturated hydraulic conductivity of the soil samples was measured. Finally, a tension of 50 cm water was applied, the soil sample was saturated, and saturated hydraulic conductivity following 50-cm tension was measured. Under no tension the hydraulic conductivities of the silt loam and clay soil were 11.8 and 55.6 mm h^{-1}, respectively. When a tension of 20 cm H_2O was applied, the hydraulic conductivities of the silt loam and the clay soils dropped to 0.69 and 0.94 of the reference values. When the silt loam and clay soils were exposed to 50 cm suction, the hydraulic conductivity dropped to 0.5 and 0.73 of the values at no tension, respectively. The silt loam hydraulic conductivity was more susceptible to the effect of water tension than the clay soil.

The low IR (Fig. 1) and low hydraulic conductivity of the silt loam suggests that its fraction of water-conducting pores was small and a higher soil water tension could develop before air penetrated the soil surface (Kemper et al., 1988). Thus, the more pronounced effects of interrupted flow in the silt loam, compared with the clay soil, is explained by both a greater consolidation of the soil surface and a greater tension that can develop during the off period.

Aggregate disintegration by fast wetting may have also contributed to the beneficial effect of interrupted flow in the silt loam. Rapid advance of the stream front increases aggregate disintegration and seal formation. Conversely, when soils are wetted slowly, entrapment and subsequent explosion of entrapped air is limited, and soil structure is maintained (Kemper et al., 1985, 1988). Fast prewetting predominated in the silt loam, where the 0.5-m-long furrow was wetted in 17 s, compared with 51 s for the clay soil.

Opposing Effects of Interrupted Flow

Applying flow in surges should have two opposing effects on IR: (i) water tension that is developed during the off period consolidates the soil surface and reduces the IR; and (ii) reduced intake leads to an increase in the hydraulic gradient in the soil profile, which in turn increases the IR (Izadi et al., 1990; Izuno et al., 1985). In our study the effects of interrupted flow on reducing the IR decreased with flow time (Fig. 1). Similar observations were made by Izuno et al. (1985), who concluded from field data that the infiltration decrease with surge irrigation occurred in the first cycle only. No further reduction in infiltration rate was observed in subsequent surges of a given irrigation (Izuno et al., 1985). The disappearance of the effect of flow interruption on IR with flow time is explained by the fact that less water infiltrated during subsequent interrupted flow. This is demonstrated in Fig. 2, where IR is presented as a function of cumulative intake for both continuous and interrupted flow. Comparing IRs of continuous and interrupted flow for both soils at identical cumulative intakes (e.g., during the second minute of water application; Fig. 2) revealed that the intake rate in the interrupted flow treatment was smaller than in the continuous flow treatment. Conversely, in the third minute of water application, less water penetrated the soil in the interrupted flow treatment, and the effect of interrupted flow on intake rate became less pronounced in both soils (Fig. 2). The suction that developed in the interrupted flow treatment (due to the smaller cumulative intake) was high enough to cause an increase in the IR. Conse-

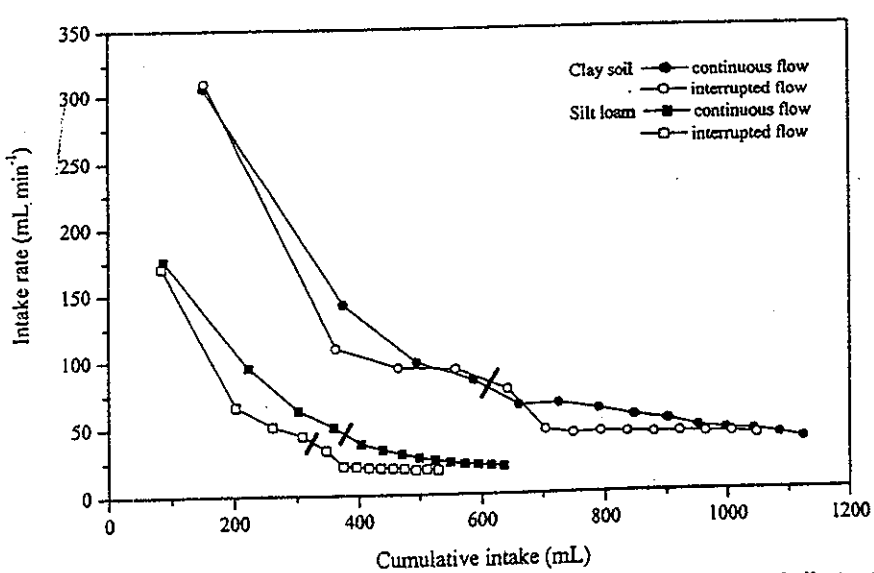

Fig. 2. Intake rate as a function of cumulative intake for the silt loam and clay soil. The "/" on each curve indicates transition from Stage 1 to Stage 2 of the experiment.

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quently, the IR in the interrupted flow treatment increased to a level similar to that in the continuous flow treatment.

The favorable effect of interrupted flow in reducing the IR reappeared for both soils when flow rate was reduced (Fig. 2). During the continuous low flow (80 and 100 mL min^{-1} for the silt loam and the clay soil, respectively), flow was limited to the bottom of the rills as predicted by the Manning equation (e.g., Shainberg et al., 1994). This part of the rill perimeter was more affected by particle deposition and soil consolidation caused by the interrupted flow, and had a lower HC than the upper part of the wetted perimeter. Thus, concentrating the flow in the bottom of the rill, where the effect of interrupted flow is more pronounced, caused the reappearance of the interrupted flow effect (Fig. 2).

Effects of Soil and Flow Type on the Erosion Process

Effects of continuous and interrupted flow on rill erosion rate for the silt loam and the clay soil are presented in Fig. 3. For both soils, most of the erosion took place during the first 4 min (Stage 1 of the experiment), when high flow rates (240 and 320 mL min^{-1} for the silt loam and clay soils, respectively) exerting high shear stresses (Shainberg et al., 1994) were used. In the control

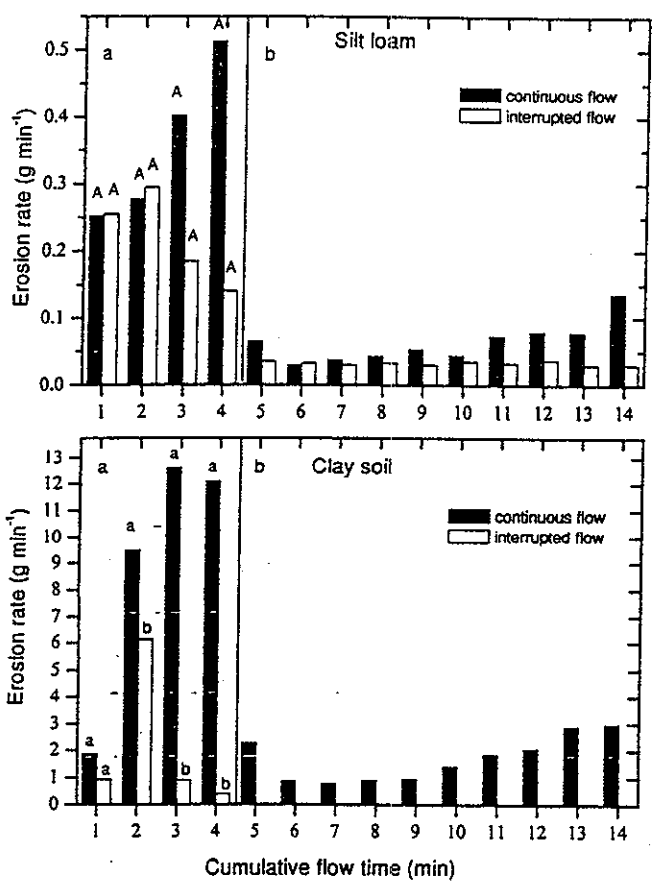

Fig. 3. Erosion rate as a function of cumulative flow time for the clay soil and silt loam at Stage 1 (a) and Stage 2 (b) of the experiment. For a given cumulative flow time, and within a soil, bars labeled by the same letter (lower case for the clay soil and upper case for the loess) do not differ significantly at the 0.05 level.

treatment (i.e., continuous flow), rill erosion in the clay soil was one to two orders of magnitude greater than that in the silt loam (Fig. 3).

The rill erosion in the two soils can be compared, despite the difference in inflow rate (240 and 320 mL min^{-1}), because runoff flows in the two soils were similar. The IRs in the clay soil exposed to continuous flow during the second, third, and fourth minute of Stage 1 were 145, 105, and 90 mL min^{-1} (Fig. 1), which resulted in respective runoff flow of 175, 215, and 230 mL min^{-1}. Similarly, for the silt loam the IRs were 90, 65, and 55 mL min^{-1} for the second, third, and fourth minute of the first stage (Fig. 1), and the corresponding runoff flows were 150, 175, and 185 mL min^{-1}. Runoff in the clay soil were only slightly higher than runoff from the silt loam, and a comparison between the rill erodibilities of the two soils was possible. The fact that under these conditions inflow rate and shear stress at the upper end of the flume were higher in the clay soil than in the silt loam cannot explain the observed differences in rill erosion between the two soils. Shainberg et al. (1996) used similar inflow rates and observed greater rill erosion in the clay soil than in the silt loam.

The differences in runoff between the two soils could not explain in full the differences in rill erodibility of the two soils (Fig. 3). Thus, the higher erodibility of the clay soil was ascribed to the weak cohesive forces that existed between the aggregates (Shainberg et al, 1996). Aggregate stability increases with increase in clay content (Kemper and Koch, 1966). Soils with high clay content, such as the one used in our study (Table 1), have stable aggregates and high interaggregate macroporosity (Rengasamy et al., 1984; Kay and Angers, 1999) leading to greater distance and fewer contacts between adjacent aggregates. The larger distance between aggregates contributes to weak cohesive forces among the aggregates, which in turn makes the aggregates more susceptible to detachment from the soil surface. This may explain the higher erodibility of the clay soil compared with the silt loam. Our results seem not to agree with many observations suggesting that clay soils are less erodible than silt loams (e.g., Laflen et al., 1991; Ben-Hur et al., 1985). Studying the effect of clay content on crusting, runoff, and erosion in soils exposed to simulated rain, Ben-Hur et al. (1985) found that soils with 20% clay were susceptible to crusting and that soils with higher clay content had more stable aggregates and less runoff and erosion. The low erosion in clay soils was because of low runoff. When soil erosion from two soils with similar runoff is compared, as in the conditions of this study, erosion from the clay soil may exceed erosion from the silt loam.

The first flow interruption of 10 min significantly reduced the erosion rate of the clay soil compared with that obtained in continuous flow (second minute, Fig. 3). This decrease in erodibility of the clay soil during the first flow interruption became even more pronounced during the subsequent surge cycles (Minutes 3–5, Fig. 3). Four flow interruptions, each of 10 min, had a lasting effect on the rill erosion of the clay soil during the following 10 min of continuous flow (Fig. 3). In the

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clay soil interrupted flow reduced cumulative erosion by 84% (Fig. 3).

Rill erosion in the silt loam exposed to inflow of 240 and 80 mL min^{-1} was too small for accurate measurement, and for evaluation of the effects of interrupted flow on erosion (Fig. 3). Thus, a complementary experiment was performed. Following the continuous and interrupted flow in Stages 1 and 2, the miniflumes with the silt loam were exposed to an additional 3 min of continuous inflow of 320 mL min^{-1}. Amount of erosion obtained in these last 3 min in the silt loam decreased from 42.6 g in the continuous flow to 7.6 g in the interrupted flow treatment. Evidently, the silt loam was less erodible than the clay soil, but when the silt loam was exposed to high flow rate, interrupted flow reduced rill erosion to 18% of the erosion in continuous flow. Interrupted flow in the silt loam was as effective in reducing rill erosion as in the clay soil.

The observed effects of interrupted flow on rill erosion can be attributed to two mechanisms that are active during flow interruption. First, the suction developed at the soil surface during the off period pulled the soil particles closer together and increased the cohesive forces between the surface particles and reduced erosion rate (Kemper and Roseneau, 1984; Shainberg et al., 1996). Second, aging (four periods of 10 min) increased the cohesive forces between soil particles (Kemper and Roseneau, 1984). These authors postulated that slightly soluble components diffusing to and cementing points of contact between particles were responsible for the bonding mechanism of the cohesive forces. Realizing, that net attractive forces acted between clay edges and clay surfaces, and also between clay surfaces with high charge densities, Shainberg et al. (1996) suggested that under conditions of high water content supplemented by an adequate aging period, clay to clay contacts occur, and clay cementing was responsible for the development of a cohesive structure that resisted rill erosion.

Interrupted flow reduced cumulative erosion in the two soils to <20% of the erosion in continuous flow. These results suggested that surge irrigation can be considered as an effective management tool for the control of furrow erosion problems in surface irrigation.

SUMMARY AND CONCLUSIONS

Effects of interrupted flow on rill erosion and IR of a silt loam and a clay soil were studied. Interrupted flow reduced the IR in both soils compared with that obtained with continuous flow. This reduction in IR was more effective in the silt loam because of its unstable structure than in the stable structured clay soil. The effect of interrupted flow in reducing the IR decreased with increase in the number of flow cycles and depended on soil type. Interrupted flow consolidated the soil surface and reduced the depth of water that infiltrated. Eventually, the higher hydraulic gradient created by the interrupted flow (due to the reduced depth of infiltrating water) compensated for the consolidation of the soil surface, and the favorable effect of interrupted flow on decreasing IR vanished.

Rill erosion in the clay soil was higher than rill erosion in the silt loam. However, interrupted flow reduced rill erosion in both soils and to a similar degree. Flow interruption reduced rill erosion to 16 and 18% of the rill erosion in continuous flow for the clay soil and silt loam, respectively.

Our results show that, unlike many studies have shown for interrill erosion, rill erosion is higher in clay soil than in silt loam. However, the results also suggest that interruption of flow might be considered as an effective management tool in surface irrigation to enhance infiltration uniformity and for the control of furrow erosion in the two soil types.

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