PN-ACS-355
119413

FINAL REPORT

For the period: June 1998 - December 2002

Submitted to the U.S. Agency for International Development; Bureau for Global Programs, Feid Support and Research; Center for Econmic Growth

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 Environmental Sci., ARO,
The Volcani Center, Bet Dagan, Israel

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

Collaborators: **I. Shainberg, I. Rapp, and D. Goldstein**
Inst. of Soil, Water and Environmental Sci., ARO,
The Volcani Center, Bet Dagan, Israel
N. Sharshekeev
Scientific and Research Institute of Irrigation, Bishkek,
Kyryzstan

A.I.D. Grant Project Officer: David Mulenex, American Embassy, Tel Aviv, Israel

Project Duration: June 1, 1998 to December 31, 2002

A

FINAL REPORT

For the period: June 1998 - December 2002

Submitted to the U.S. Agency for International Development; Bureau for Global Programs, Feid Support and Research; Center for Econmic Growth

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 Environmental Sci., ARO,
The Volcani Center, Bet Dagan, Israel

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

Collaborators: **I. Shainberg, I. Rapp, and D. Goldstein**
Inst. of Soil, Water and Environmental Sci., ARO,
The Volcani Center, Bet Dagan, Israel
N. Sharshekeev
Scientific and Research Institute of Irrigation, Bishkek,
Kyryzstan

A.I.D. Grant Project Officer: David Mulenex, American Embassy, Tel Aviv, Israel

Project Duration: June 1, 1998 to December 31, 2002

1. Table of Contents

1. Cover sheet	1
2. Table of Contents	2
3. Executive Summary	3
4. Research Objectives	4
5. Methods and Results	4
5.1. Israel	4
5.2. Kyrgyzstan	7
6. Impact, Relevance and Technology Transfer	9
7. Project Activities/Output	10
8. Project Productivity	11
9. Future Work	11
10. Literature Cited	11
Appendices	

3. 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) and surge type furrow irrigation. Intake rate (IR) and rill erosion (RE) studies under controlled laboratory conditions (using mini-flumes) allowed to study the effects of interrupted flow (simulation for surge type irrigation), PAM application and soil type. Results showed that: (i) interrupted flow led to the consolidation of the soil surface and to a decrease in IR; this decrease in IR was greater for less stable soils than for stable ones, (ii) interrupted flow resulted in decreased RE irrespective of soil type, (iii) application of PAM to the irrigation water led to a substantial reduction in RE, (iv) PAM addition reduced IR only in in a weakly structured soil, (v) irrigation with sediment-containing water decreased IR irrespective of irrigation method (continuous vs. interrupted flow). The main conclusions of our studies were that main benefits of using interrupted flow as a means for improving surface irrigation and controlling RE will be gained in weakly structured soils. Addition of polymer to the irrigation water may enhance the effects of interrupted flow in these soils. However, when the irrigation water contain sediments (i.e., tailwater), interrupted flow has no advantage over continuous flow in improving irrigation efficiency. Another laboratory experiment has shown that use of salin-sodic water also diminishes the efficiency of interrupted flow in decreasing the hydraulic conductivity of the soil surface. Field experiments were conducted in Kyrgyzstan where the effects of flow type (continuous and interrupted), inflow rate and PAM application on furrow erosion, water infiltration and yield were tested. Results showed the following general trends: (i) surge irrigation was effective in reducing furrow intake rate (IR), especially in the short (150 m) rather than the long (200 m) furrows, (ii) surge irrigation improved moisture uniformity over the entire field, (iii) PAM was effective increasing furrow intake rate and in reducing furrow erosion, and (iv) combined application of PAM with surge irrigation was not more effective than each treatment alone. With respect to yield, results were not conclusive and varied with the crop studied.

The studies preformed within the framework of this project indicated that surge type flow, PAM application and water quality have complex effects on IR and RE, which depended

on soil type. Further studies are necessary to incorporate the knowledge gained in the laboratory with that obtained in the field in order to develop guidelines for proper management of furrow irrigation that will be suitable for a large array of soil types and field conditions.

4. Research objectives:

The overall aim of the current project is to improve the technology and managerial practices regarding the use of polyacrylamide (PAM), surge type furrow irrigation and water quality; 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) irrigation type (continuous vs. surge); (ii) addition of small amounts of PAM to irrigation water; (iii) soil properties (mainly texture composition of exchangeable cations (Na, Ca and Mg); and (iv) irrigation water quality, namely level of salinity and sediment concentration.

Surface irrigation is the most widely used irrigation method in the world. In Kyrgyzstan, out of 1 million hectare of irrigated land, 85% are under furrow and surface irrigation. Farmers in Kyrgyzstan often experience poor and uneven water penetration in their land which leads to low yields and large amounts of eroded soil being removed from the field. The latter, causes a deterioration in the quality of the furrow discharge (tailwater), which frequently is reused for irrigation. Development of an irrigation management suitable for conditions in Kyrgyzstan, that will reduce furrow erosion and improve water penetration, is essential for increasing field productivity, and maintaining soil fertility and irrigation water quality. Better understanding of the combined effects of soil properties, soil amendments, and type of surface irrigation on the erosivity and permeability of soils under furrow irrigation will enable the development of irrigation management suited for individual farmers in Kyrgyzstan.

5. Methods and Results

5.1. Israel

Research activities included laboratory studies, which were summarized in four manuscripts. Three have already been published, and one is prepared for publication (see section 7). The topics of these studies were:

I. Polyacrylamide, sediments and interrupted flow effects on rill erosion and intake rate.

II. Flow interruptions effects on intake rate and rill erosion in two soils.

III. Water quality and sodicity effects on soil bulk density and conductivity in interrupted flow.

IV. Sodicity and water quality effects on intake rate and rill erosion in interrupted flow.

Abstracts of these manuscripts are presented herein. The full manuscripts are enclosed in appendices 1, 2, 3 and 4.

I. Polyacrylamide, Sediments and Interrupted Flow Effects on Rill Erosion and Intake Rate

D. Sirjacobs, I. Shainberg, I. Rapp, and G.J. Levy.

Abstract

The reduction in the intake rate (IR) during interrupted irrigation is difficult to predict. Sediments in irrigation water decrease the effect of interrupted irrigation on IR. Polyacrylamide (PAM) reduces rill erosion , but its effect on IR is controversial. The effects of water quality (tap water, tap water containing sediments, and 10 g m^{-3} PAM solution) and interrupted flow on IR and rill erosion in an Alfisol (Calcic Haploxeralf) and a Vertisol (Typic Chromoxerert), were studied using laboratory miniflumes. Rill erosion in both soils was eliminated by the PAM treatment in both continuous and interrupted flow. PAM application reduced IR in the Alfisol, and increased it in the Vertisol. In the Alfisol, interrupted flow reduced IR of PAM solution by 37% compared with only 18% for tap water. In the Vertisol, interrupted flow reduced IR only slightly and the decrease was not affected by the polymer. When the water contained sediments, cumulative infiltration was reduced by 22% for the Vertisol and 59% for the Alfisol, in comparison with tap water. These reductions were attributed to depositional seal formation. The IR of the Alfisol was more susceptible to depositional seal formation than the Vertisol. The presence of sediments in water was effective in reducing rill erosion. The effects of interrupted flow with PAM on reducing IR, were explained by partial blocking of the conducting pores leading to greater suction and compaction of the soil surface. For sediment-laden irrigation water, interrupted flow had no advantage over continuous flow in reducing IR, because of depositional seal formation associated with the sediments in the water.

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

D. Sirjacobs, I. Shainberg, I. Rapp, and G.J. Levy

Abstract

The efficiency of surface irrigation is low because of poor field uniformity, resulting from high

intake at the 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 (IR) and improves moisture uniformity over the entire field. However, IR reduction varies from one irrigation scheme to another, it depends on soil and water properties and is difficult to predict. Thus 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 silty loam loess and a clay soil were studied. Intake rate in the clay soil was higher than that in the loess. Therefore, different inflow rates were applied to the two soils, in order for the runoff flow rate to be similar. The results showed that: (i) flow interruption reduced infiltration by 19% and 6% in the loess and the clay soil, respectively, compared with continuous flow, and (ii) interrupted flow reduced cumulative soil loss by 84% in the clay soil and had only a small effect on soil loss from the loess. Consolidation of the wet soil with the unstable structure (loess) during the flow interruption was suggested as the explanation for the effects of flow interruption on intake rate. Consolidation of the soil surface and the formation of cohesive forces between soil particles, was offered to explain the large effect of interrupted flow on soil detachment in the clay soil. The results obtained with miniflumes indicated that flow interruption could reduce IR in soils with an unstable structure (loess) and reduce rill erosion in a clay soil. However, these results need to be verified in field experiments.

III. Water quality and sodicity effects on soil bulk density and conductivity in interrupted flow

G.J. Levy, N. Sharshekeev and G.L. Zhurvskaya

Abstract

Interruption of flow during furrow irrigation (e.g., use of surge technique), consolidates soil near the furrow surface, causing reorientation and rearrangement of soil particles, and leads to increased surface bulk density (BD), and reduced hydraulic conductivity (HC) of this surface layer. We hypothesized that soil consolidation could be affected by irrigation water quality and soil sodicity. We studied in the laboratory changes in the BD and HC of an alfisol (Calcic Haploxeralf) and two vertisols (Chromic Haploxerert) having different exchangeable sodium percentage (ESP) levels, that were subjected to 5 cycles of leaching and draining under matric potential of up to -5 J kg^{-1}. Four different water qualities (electrical conductivity (EC) of 0.01, 0.95, 2.0 and 4.0 dS m^{-1}) were tested. Final BD was significantly greater than the initial value

when matric potential was applied. Conversely, for continuous leaching (i.e., no application of matric potential), differences between final and initial BD were insignificant. Water quality and sodicity did not affect BD, suggesting that for a given soil exposed to a low level of matric potential, soil consolidation was not affected by water quality or ESP. Final HC values were always lower than initial ones, with the decrease in HC after application of matric potential being by far greater than that observed when continuous leaching was used. The decrease in HC relative to initial HC depended on both water quality and soil sodicity, was greater with the decrease in water EC and an increase in ESP. Adverse effects of low EC and high ESP on HC were less pronounced in matric potential application than in continuous leaching. Our results suggest that the quality of water available for irrigation and soil sodicity should be taken into account in cases where interrupted flow is considered for improving furrow irrigation efficiency via reducing soil infiltration rate.

IV. Sodicity and water quality effects on intake rate and rill erosion in interrupted flow

N. Sharshekeev, G.L. Zhuravskaya and G.J. Levy

Abstract

The efficiency of surface irrigation is low because of poor field uniformity, higher intake at upstream end and slow intake at the 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 varies from one irrigation scheme to another, it depends on soil and water properties and is difficult to predict. The effect of water quality and soil sodicity on IR and soil loss from short rills was studied in an alfisol and a vertisol using miniflumes under interrupted and continuous flow. The infiltration rate was more sensitive to the sodicity of the soil than to the electrolyte concentration. The results showed that: (i) interrupted flow reduced soil loss in the vertisol and had small effect on soil loss from the alfisol, (ii) interrupted flow reduced IR in both soils compared with that obtained in continuous flow; this reduction in IR was more effective in the alfisol than in the vertisol, and (iii) the effect of interrupted flow in reducing the IR depended on application of water quality mainly in the vertisol soil.

5.2. Kyrgyzstan

Research activities included laboratory and field studies, which were summarized in two reports. The topics of these studies were:

V. Soil sodicity, water quality and interrupted flow effects on rill erosion and intake rate (a laboratory study).

VI. Effects of polyacrylamide and surge type irrigation on intake rate, rill erosion and yield (a long term field study)

Abstracts of these reports are presented herein. The full reports are enclosed in appendices 5 and 6. For the long term field experiment due to space considerations, only the complete report for the last season is provided in appendix 6.

V. Soil sodicity, Water quality and Interrupted Flow Effects on Rill Erosion and Intake Rate in Soils from Kyrgyzstan

N. Sharshekeev and G.L. Zhuravskaya

Abstract

The effect of interaction between water flow characteristics, soil sodicity and water quality on the rill erosion and intake rate was studied in the laboratory. Specific objectives of these study were to evaluate: (i) the use interrupted flow for reducing soil erosion and intake rate, (ii) the effect of soil sodicity (exchangeable sodium percentage [ESP]) and water quality (0.01, 0.95, 2.0 and 4.0 dS m^{-1}) on the soil erosion and intake rate. Rill erosion in two ESP levels under the surge irrigation decreased soil loss for all water qualities compared with continuous flow. Decreasing soil loss was more effective in ESP 0.39%. The IR was more sensitive to the sodicity and water quality, but the surge irrigation reduced IR only slightly in ESP 5.67% and had no effect in ESP 0.39%.

VI. Effects of polyacrylamide and surge type irrigation on intake rate, rill erosion and yield (a long term field study)

G.L. Zhuravskaya and N. Sharshekeev

Abstarct

Furrow erosion, soil intake rate and crop yield were studied for 5 growing seasons (1998, 1999, 2000, 2001 and 2002) in the field. Each growing season the experiments consisted of two stages,

a preparatory stage and the main part. Preparatory stage included: (1) choosing the area for conducting of field experiments, (2) leveling of the area with the and determining the surface slope in the direction of the irrigation, (3) determination of soil permeability, (4) determination of the chemical and mechanical composition of the soil, and (5) testing the irrigation with the aim of determining the flow rate of the irrigation stream. In the main stage of the experiment crop was grown in all but the first season. The study consisted of the determination of furrow erosion and water losses to infiltration of the flow rates lengthways of 150-200 m furrows. The treatments studied were (1) continuous flow with one inflow rate [q1], (2) continuous flow with high inflow rate at the advancement stage [q1] and a lower inflow rate at the rest of the irrigation [q2], (3) surge flow with inflow rates q1 and q2, (4) continuous flow as in treatment 2 with the addition of polyacrylamide (PAM) at a concentration of 10 mg/L to the irrigation water at the advancement stage of the first irrigation, and (5) surge flow with the addition of PAM. The study consisted of determination of sediment concentration in the irrigation water and water losses to infiltration in the lengthways of the furrow for each individual irrigation, as well as crop parameters (e.g., yield, green material etc.) at the end of the growing season. Results with respect to furrow erosion and water intake rate showed the following general trends: (i) surge irrigation was effective in reducing furrow intake rate (IR), especially in the short (150 m) rather than the long (200 m) furrows, (ii) surge irrigation improved moisture uniformity over the entire field, (iii) PAM was effective increasing furrow intake rate and in reducing furrow erosion, and (iv) combined application of PAM with surge irrigation was not more effective than each treatment alone. With respect to yield, results varied over the years. In 1999, PAM application gave the best root and green yield of sugar beet, irrespective of the irrigation method (continuous vs. surge). In 2000,

the highest yield of sugar beet was obtained in surge irrigation treatment. In 2001 and 2002 the crop studied was maize and no treatment had a significant effect on yield.

6. Impact, Relevance and Technology Transfer

The principal investigator (PI) from Kyrgyzstan visited Israel every year during the project. The visits were used to summarize the past experiments and plan future ones. These visits were also used to transfer methodologies used in Israel, to the laboratory of the PI in Kyrgyzstan, for laboratory determinations of soil hydraulic conductivity, rill erosion, furrow intake rate, use of soil amendments, use of interrupted flow as well as determination of various chemical soil

properties. Participation in the project enabled the Kyrgyzian PI to purchase both standard equipment for a soil science laboratory and specific equipment pertinent for conducting research on rill erosion, and infiltration rate.

The ability of soil conditioners, namely synthetic organic polymers, to successfully control rill erosion, improve water permeability and increase yield was recognized by the Kyrgyzian investigators. It is hoped that this concept, whereby soil amendments rather than engineerically based solutions, together with the use of surge type furrow irrigation can be used to improve furrow irrigation efficiency, will influence the design of new experiments for further improvement of this commonly used irrigation method in Kyrgyzstan.

7. Project Activities/Outputs

The Israeli principal investigator visited Kyrgyzstan at the beginning of the first year of the project. The visit was dedicated for a detailed planning of the field experiments. The visit helped the Israeli investigator to better understand the problems and difficulties involved in furrow irrigation in Kyrgyzian. The visit also helped the Israeli PI to adapt the experiments in his laboratory in Israel to the needs of Kyrgyzstan.

The Kyrgzian PI visited Israel four times. The visits were used for analyses and summary of data obtained in previous studied, and design of future experiments. In Addition, another collaborator from Kyrgyzstan, N. Sharshekeev, spent a 10 month in Israel (from October 1999 to August 2000) for training in various laboratory techniques and analyses pertinent for proper execution of the project. The studies of Mr. Sharshekeev in Israel and Kyrgyzstan, will serve as part of his PhD thesis.

The out put of the project was summarized in three papers that have been published, a paper that is currently being prepared and two reports:

I. Sirjacobs, D., I. Shainberg, I. Rapp and G.J. Levy. 2000. Polyacrylamide, sediments and interrupted flow effects on rill erosion and intake rate. Soil Sci. Soc. Am. J. 64:1487-1495.

II. Sirjacobs, D., I. Shainberg, I. Rapp and G.J. Levy. 2001. Flow interruptions effects on intake rate and rill erosion in two soils. Soil Sci. Soc. Am. J. 65:828-834.

III. Levy, G.J., N. Sharshekeev and G.L. Zhuravskaya. 2002. Water quality and sodicity effects on soil bulk density and conductivity in interrupted flow. Soil Sci. 167: 692-700

IV. Sharshekeev, N., G.L. Zhuravskaya and G.J. Levy. 2003. Sodicity and water quality effects on intake rate and rill erosion in interrupted flow. (in preparation).

V. Sharshekeev, N. and G.L. Zhuravskaya (2003). The hydraulic conductivity (column studies) and rill erodibility (mini-flume experiments) of four soils from important cultivated regions (report of laboratory studies).

VI. Zhuravskaya, G.L. and N. Sharshekeev. (2003). The effect of flow rate, slope, irrigation method and soil amendments (amount and mode of application) on furrow erosion, water infiltration and crop yield (report of a long term field experiment)

8. Project productivity

The project made a contribution towards its goals and objectives. It is believed that furrow irrigation efficiency in Kyrgyzstan can be improved by applying the management developed in the project.

9. Future work

A new proposal entitled: 'Improving water use efficiency and decreasing erosion in fields irrigated with poor quality water using surge irrigation' has been submitted by the Israeli and Kyrgyzian PIs to the US-Israel CAR program. The proposal was developed based on the results obtained in the current project, and is currently under evaluation.

10. Literature cited

List of relevant literature is given at the end of each manuscript/report appearing in the Appendices.

Reprinted from the *Soil Science Society of America Journal*
Volume 64, no. 4, July–Aug. 2000
677 South Segoe Rd., Madison, WI 53711 USA

APPENDIX 1

Polyacrylamide, Sediments, and Interrupted Flow Effects on Rill Erosion and Intake Rate

D. Sirjacobs, I. Shainberg, I. Rapp, and G. J. Levy*

ABSTRACT

The reduction in the intake rate (IR) during interrupted irrigation is difficult to predict. Sediments in irrigation water decrease the effect of interrupted irrigation on IR. Polyacrylamide (PAM) reduces rill erosion, but its effect on IR is controversial. The effects of water quality (tap water, tap water containing sediments, and 10 g m^{-3} PAM solution) and interrupted flow on IR and rill erosion in an Alfisol (Calcic Haploxeralf) and a Vertisol (Typic Chromoxerert) were studied using laboratory miniflumes. Rill erosion in both soils was eliminated by the PAM treatment in both continuous and interrupted flow. The PAM application reduced IR in the Alfisol and increased it in the Vertisol. In the Alfisol, interrupted flow reduced IR of the PAM solution by 37% compared with only 18% for tap water. In the Vertisol, interrupted flow reduced IR only slightly and the decrease was not affected by the polymer. When the water contained sediments, cumulative infiltration was reduced by 22% for the Vertisol and 59% for the Alfisol in comparison with tap water. These reductions were attributed to depositional seal formation. The IR of the Alfisol was more susceptible to depositional seal formation than the Vertisol. The presence of sediments in water was effective in reducing rill erosion. The effects of interrupted flow with PAM on reducing IR were explained by partial blocking of the conducting pores leading to greater suction and compaction of the soil surface. For sediment-laden irrigation water, interrupted flow had no advantage over continuous flow in reducing IR because of depositional seal formation associated with the sediments in the water.

SURFACE IRRIGATION is the most used 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 the potential to reduce IR and improve the 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 process is 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 the soil near the rill surface. During the interruption of water application, water drainage into the underlying dry soil and moisture redistribution result in the development of negative pressure suction near the soil surface. This negative pressure increases the forces that pull water into the soil during the next flow period (Samani et al., 1985), and should increase the IR. However, the development of negative pressure in the soil surface during flow interruptions consolidates the soil near the rill surface, increases surface bulk density, and reduces the 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).

An additional important mechanism controlling IR in furrow irrigation, which is not necessarily related to interrupted irrigation, is the formation of a depositional seal at the furrow perimeter. The HC of depositional seals has been reported to be two to three orders of magnitude lower than that of the underlying soil (Shainberg and Singer, 1985). Trout (1991) observed a 50% reduction in infiltration in the Portneuf (coarse-silty, mixed, superactive, mesic Durinodic Xeric Haplocalcid) silt loam during interrupted irrigation, and ascribed it to surface seal formation. The HC of the depositional seal depends on the size and mineralogy of the sediment particles, and on the electrolyte concentration of the water (Shainberg and Singer, 1985). Thus, the effect of sediment concentration on the IR varies from one irrigation scheme to another.

Soil erosion can be prevented by amending the soil with organic polymers, such as PAM, with high molecular weight and moderate negative charge density (e.g., Lentz et al., 1992; Shainberg et al., 1990; Sojka et al., 1998a, 1998b). If rill erosion is prevented, no depositional seal is formed and the rill IR increases (Lentz et al., 1992; Sojka et al., 1998b). Thus, an indirect effect of the PAM treatment is the increase in IR. However, Malik and Letey (1992) and Letey (1996) found that the addition of 10 g m^{-3} of PAM to water decreased the HC of fine porous media to 50% of that obtained when salt solutions were used. They suggested that the effective viscosity of polymer solutions in porous media was higher than would be anticipated according to standard viscosity measurements, and that the relative viscosity depended on the pore-size distribution of the soil. The effect of PAM in reducing the HC of porous media could also be explained in terms of partial blocking of conducting pores by the tails of the macromolecules that were adsorbed on soil particles. This partial blocking would probably become more pronounced in soils with narrow pores. Letey (1996) proposed that in furrow irrigation PAM treatment will reduce IR and increase the advancement rate of water in the furrows. It is possible therefore that the effect of PAM on IR in

D. Sirjacobs, I. Shainberg, I. Rapp, and G.J. Levy, Institute of Soils, Water and Environmental Sciences, Agricultural Research Organization (ARO), the Volcani Center, P.O. Box 6, Bet Dagan 50250, Israel. Contribution from the Agricultural Research Organization, the Volcani Center, P.O. Box 6, Bet Dagan 50250, Israel, no. 629/98 series. Received 24 Aug. 1999. *Corresponding author (vwguy@volcani.agri.gov.il).

Published in Soil Sci. Soc. Am. J. 64:1487–1495 (2000).

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

12

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

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

† CEC = Cation–exchange capacity.
‡ ESP = Exchangeable sodium percentage
§ EPP = Exchangeable potassium percentage.
¶ OM = Organic matter content.

furrow irrigation depends on soil properties, a topic to be clarified in this study.

The effects of interrupted irrigation in reducing IR depend on sediment concentration (Trout, 1991). As sediment concentration increases, IR decreases and the beneficial effect of interrupted irrigation for reducing the IR is reduced (Trout, 1991). It could be argued therefore, that PAM treatments will magnify interruption-induced effects on IR reduction. On the other hand, since PAM also stabilizes the structure at the soil surface (Sojka et al., 1998b), PAM may prevent the consolidation of the surface by the interrupted flow and the net effect of interrupted flow on IR in PAM treatments will be negligible. Hence it is difficult to assess the effects of PAM on the IR in interrupted flow.

Miniflumes have been used to evaluate the interaction between flow characteristics, soil properties, and water quality on rill erosion in the laboratory (Shainberg et al., 1994, 1996). The rill erodibility data obtained with the miniflumes agreed well with field data (Shainberg et al., 1994). Miniflume studies were also found to simulate well the effect of PAM on rill erosion in the field (Lentz et al., 1992; Shainberg et al., 1994). Using miniflumes, Shainberg et al. (1996) studied rill erosion in an Alfisol and a Vertisol and found that rill erosion decreased with aging of several hours and that it depended on water content in the soil. These researchers postulated that aging and water tension enhanced clay to clay contacts, increased the cohesive forces between soil particles, and led to reduction in rill erosion. We hypothesized that miniflumes may also be used to study the processes that operate in interrupted irrigation.

Interrupted flow reduced erosion in irrigated furrows (Yonts et al., 1998). In miniflumes, the same effect has been observed and was attributed to consolidation of the soil surface (Sirjacobs, 1999, unpublished data). If rill erosion and depositional seal formation are reduced, a high IR should be maintained. Interrupted flow may therefore have two opposing effects on IR; that is, it may reduce IR by consolidating the soil surface or increase IR by reducing rill erosion and seal formation. The net effect of interrupted flow on IR may be evaluated either by preventing rill erosion (e.g., by irrigation with water containing PAM) or by increasing the sediment content of the irrigation water. When rill erosion is prevented, no depositional seal is formed and the effect of interrupted flow in consolidating the rill surface and reducing IR is predominant. Conversely, sediment deposition and seal formation may be enhanced by the use of sediment-laden water (Shainberg and Singer, 1985). Applying water containing sediments will, therefore, decrease IR in both continuous and interrupted flow applications. However, the relative effects of water containing sediments on the IR in continuous and interrupted flow effect are not clear and will be studied.

The objective of our study was to investigate the effects of PAM- and sediment-containing inflow on IR and rill erosion under continuous and interrupted flow conditions in two soil types. The interaction between sediments, PAM, and soil properties on the effect of interrupted flow on IR and rill erosion were evaluated by comparing the results obtained with clear tap water with those obtained with PAM solutions and sediment-laden inflow water.

MATERIALS AND METHODS

Two arable soils of differing texture were chosen for this study: a silty loam Alfisol (Calcic Haploxeralf) from Nevatim, northern Negev, and a clay Vertisol (Typic Chromoxerert) from Hafetz-Haim, Pleshet Plains, Israel. Some basic physical and chemical properties of the soils are given in Table 1.

The experiments were carried out with a 0.5-m-long, 0.047-m-wide, 0.12-m-deep flume. Two 0.2-m-long "V"-shaped metallic rills were connected on both of its sides. The miniflumes were placed at a 10% slope in order to maintain high flow shear force, high soil detachment, and high rill erosion.

Air-dried soils, crushed to pass through a 4.0-mm sieve, were slightly compacted in the flume to densities of 1390 kg m^{-3} for the Alfisol and 1200 kg m^{-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 flume 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 the runoff containing sediments was collected from the downstream metallic rill in beakers.

Three water types were studied in the experiments: (i) 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}); (ii) tap water containing 10 g m^{-3} PAM; and (iii) tap water containing 7.5 g L^{-1} of suspended sediments. The PAM solution was prepared from a concentrated polymer solution that contained 1 g L^{-1} high molecular weight (2×10^7 Da) anionic PAM with a moderate negative charge (20% hydrolysis). Suspensions of each soil were prepared by shaking 300 g of soil with 3 L of tap water for 1 h. After shaking, the coarse particles were allowed to settle out of the suspension for 3 min. Sediment content of the suspensions was 7.5 g L^{-1} for each soil. During each miniflume run, the suspension was stirred continuously in order to ensure its homogeneity. Samples of the suspension were taken periodically during the run and the sediment content of the suspension was recorded.

Each individual experiment was divided into two stages. In the first stage either continuous (control) or interrupted flow was applied, and the three water qualities were used. The

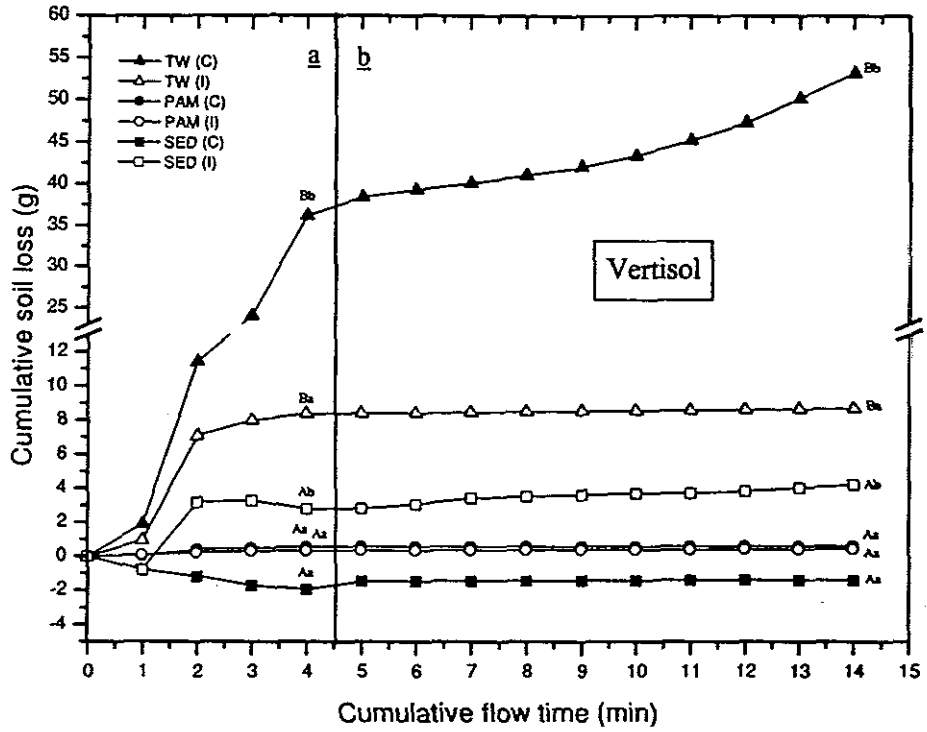


Fig. 1. Cumulative soil loss as a function of cumulative flow time for the Vertisol during (a) Stage 1 and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences between flow types for a given cumulative flow time and water type are indicated by lower-case letters ($P < 0.05$). TW is tap water, PAM is polyacrylamide-containing water, and SED is sediment-containing water. (C) and (I) denote continuous and interrupted flow, respectively.

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 interruption time on rill erosion and IR indicated that for an interruption time of <5 min, changes in interruption time affected IR and rill erosion, but choosing interruption times longer than 5 min did not affect the IR and rill erosion. Inflows applied to the Vertisol (320 mL min^{-1}) and the Alfisol (240 mL min^{-1}) were chosen in order to obtain a measurable outflow during the first minute and to obtain a similar flow rate and runoff during the consecutive 3 min. Because the IR in the Vertisol was higher than the IR in the Alfisol, it took 51 s for the clear water to wet the soil and reach the end of the rill in the Vertisol and 17 s in the Alfisol. However, during the second, third, and fourth pulses of flow, the average outflow rates in the two soils were similar (Fig. 3 and 5). 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 the four cycles of interrupted flow treatment. At this stage, only clear tap water was used and inflow rate was reduced in order to allow more precise measurements of IR, and it was applied continuously to simulate field conditions. Again, in order to maintain similar flow and shear force in the rills, a continuous 100 mL min^{-1} inflow was applied to the Vertisol and 80 mL min^{-1} was applied to the Alfisol. The second stage was terminated when the moisture content front reached a depth of ≈100 mm and the soil layer at the bottom of the miniflume remained dry (i.e., after 10 min for the Vertisol and 20 min for the Alfisol). The dry layer of soil at the bottom of the flume assured the presence of the suction needed to consolidate the soil surface. Total inflow, outflow, and soil loss were recorded every minute for both soils.

Three replicates were performed for each of the twelve combinations tested (two soils, interrupted and continuous flow, and three types of irrigation waters). The effect of water type on interrupted flow was analyzed separately for the Alfisol and for the Vertisol. For each soil, the effects of two factors (water type and flow type) on rill erosion and IR were considered. Our experiments involved three levels of water type (tap water, tap water with PAM, and tap water with sediments) and two levels of flow type (continuous and interrupted flow). For each minute and for each variable measured, a full factorial analysis of variance, based on the Standard Least Squares test ($\alpha = 0.05$), was applied. When an interaction between the two factors was found, the different levels of water type were compared within each level of flow type and vice versa. When no interaction was detected, each factor was studied individually, without distinction between the levels of the other factor.

RESULTS AND DISCUSSION

Because the effects of interrupted flow on IR depend on rill erosion and depositional seal formation (Kemper et al., 1988; Trout, 1991), the effects of water type on rill erosion in continuous and interrupted flow are discussed first.

Water Type Effects on Rill Erosion

Polyacrylamide

Rill erosion in the Vertisol exposed to a continuous flow of tap water was high (Fig. 1), and that in the Alfisol was low (Fig. 2). Application of interrupted flow caused a significant reduction in rill erosion only in the Vertisol. Most of the rill erosion in the two soils occurred during the first 4 min, when the flow rate was high

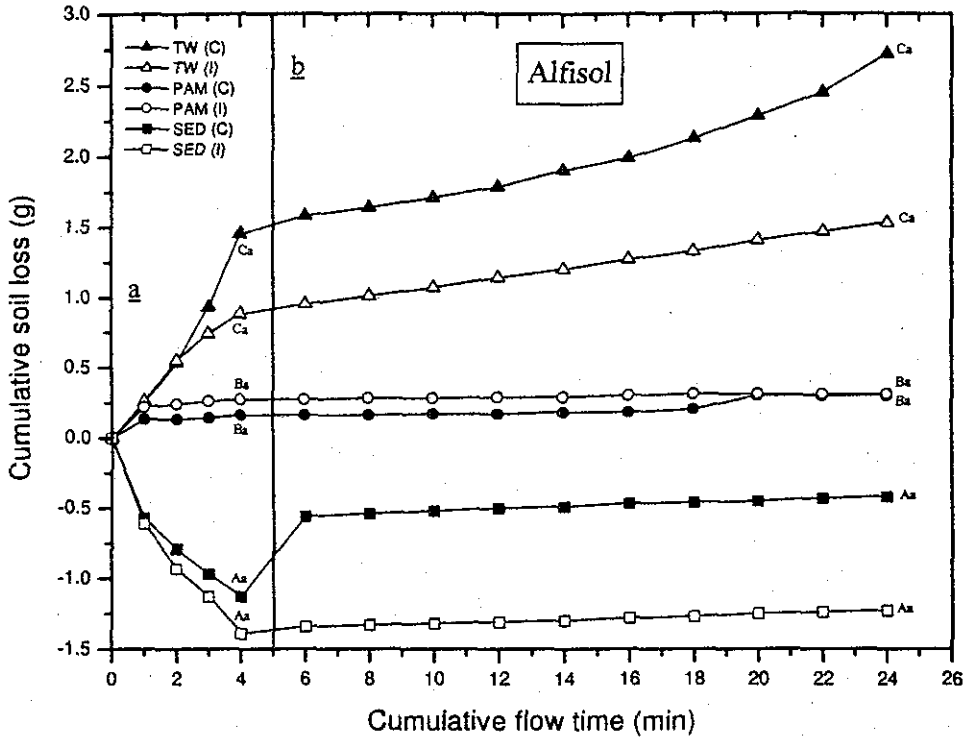


Fig. 2. Cumulative soil loss as a function of cumulative flow time for the Alfisol during (a) Stage 1, and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences between flow types for a given cumulative flow time and water type are indicated by lower-case letters ($P < 0.05$). TW is tap water, PAM is polyacrylamide-containing water, and SED is sediment-containing water. (C) and (I) denote continuous and interrupted flow, respectively.

(320 and 240 mL min^{-1} for the Vertisol and Alfisol, respectively) and the flow shear force was high. In the second stage of the experiment, when a continuous low-rate flow was used, erosion was low (Fig. 1 and 2). In the Vertisol, intraaggregate stability is greater than that in the Alfisol (Shainberg et al., 1992). However, interaggregate cohesive forces in the Vertisol are weaker than in the Alfisol (Shainberg et al., 1996), thus detachment of aggregates by the flowing water could possibly be easier in the Vertisol than in the Alfisol. At the same time, it is expected that detached particles in the Vertisol are larger than those in the Alfisol, because of the better aggregation of the Vertisol, and would thus be less available for transportation by the flowing water. Our results showed more erosion in the Vertisol, suggesting that under our experimental conditions the size of the detached particles in the Vertisol did not affect their transportability. Therefore, Vertisols, owing to their 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 detachment and subsequently to transportation than the aggregates of the Alfisol.

Polyacrylamide addition to the inflow water during the first stage of the experiment essentially eliminated rill erosion in both continuous and interrupted flow. The effect of PAM on soil loss was already evident from the first minute of inflow. Its favorable effect was especially impressive in the Vertisol, where with continuous flow, the PAM treatment reduced cumulative soil loss to 1% of the erosion obtained in tap water (Fig. 1). In the Alfisol, PAM application reduced soil loss from 2.7 g per flume to only 0.3 g per flume in continuous flow (Fig. 2). The PAM efficacy resulted from the fact that the polymer adsorbed on the external surfaces of the aggregates (Lentz et al., 1992) cemented the aggregates together and prevented their detachment.

In the PAM treatment, erosion in both soils was very low under continuous flow, and no further decrease in erosion because of interrupted flow was possible (Fig. 1 and 2). As the binding between soil particles in the presence of PAM was already strong enough to prevent erosion, further strengthening of interparticle cohesive forces by aging and compaction during flow interruptions caused no further reduction of rill erosion.

Sediments

In the Vertisol, the use of sediment-loaded water led to the formation of a visible and homogeneous seal at the rill perimeter. This depositional seal dramatically reduced rill erosion compared with inflow of tap water (Fig. 1). For continuous flow, the presence of sediments in the irrigation water was as effective as the presence of PAM in preventing rill erosion. When interrupted flow was applied, PAM was more effective than sediments in preventing rill erosion (Fig. 1). The difference in cumulative erosion between interrupted and continuous flow appeared from the second minute (Fig. 1). The higher erosion under interrupted flow was attributed to

15

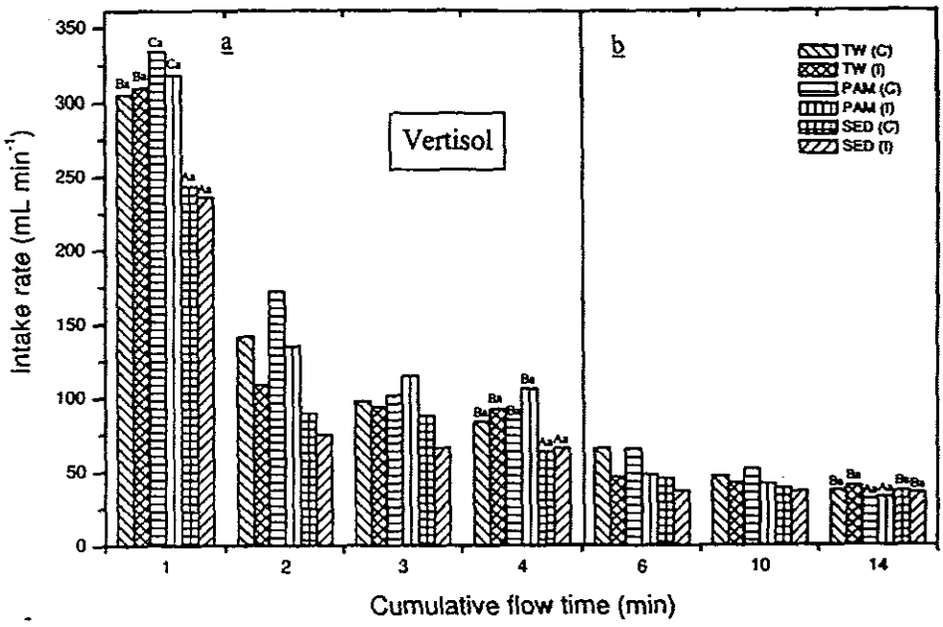


Fig. 3. Intake rate as a function of cumulative flow time for the Vertisol during (a) Stage 1 and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences between flow types for a given cumulative flow time and water type are indicated by lower-case letters ($P < 0.05$). TW is tap water, PAM is polyacrylamide-containing water, and SED is sediment-containing water. (C) and (I) denote continuous and interrupted flow, respectively.

lower intake rate in the interrupted flow (see below), which resulted in higher flow velocity and greater shear force (Kemper et al., 1988). In our study, rill erosion was high only in the second minute of inflow. Thereafter, hardly any additional difference in soil loss between the interrupted and continuous flow treatments was observed. Apparently, aging and compaction mechanisms that acted during the flow interruption created a sufficient increase in soil cohesive forces that could resist the high shear force and thus limit soil loss.

Unlike the case of the Vertisol, a net deposition of sediments was observed in the Alfisol under both interrupted and continuous flow during the 4 min of application of water containing sediments. This is represented in Fig. 2 by the negative values of cumulative soil loss, which demonstrate that ≈20% of the sediments flowing into the flume were deposited on the rill perimeter. In the second stage of the experiment when a continuous low flow rate of tap water was used for 20 min (as opposed to only 10 min in the Vertisol), a small amount of soil erosion was observed in the continuous flow treatment. Conversely, in the interrupted flow treatment, no sediments were measured in the tap water runoff and no increase in cumulative erosion was demonstrated (Fig. 2).

Deposition of sediments at the soil surface filled the pores and created a depositional seal with a smooth surface on the rill perimeter. The fine particles within the pores acted as a cementing material between soil particles, and the sealed rill surface became more resistant to erosion then the original soil surface. Similar findings were reported by Brown et al. (1988), who studied the effects of sediment-laden water on IR and furrow erosion in the field. These researchers concluded that deposition of the fine sediments on the perimeter decreased IR and thus increased soil water tension, consequently leading to an increase in the forces that hold the sediments at the perimeter, and to a decrease in erosion. The presence of sediments in the inflow water was effective in preventing net soil loss erosion in both soils. The presence of sediments in the water in continuous flow was more effective in decreasing rill erosion than interrupted flow or the addition of PAM to the inflow water. The beneficial effect of sediments in the inflow water suggest that sediments in irrigation water should not be removed prior to irrigation. This conclusion corroborates the findings of Brown et al. (1988) obtained in short furrows in the field.

Water Type Effects on Intake Rate

Polyacrylamide

In the first stage of the experiment (i.e., first 4 min) for both flow types in the Vertisol, addition of PAM to the inflow water resulted in IRs that were higher than, or similar to, those for tap water. Considering the effect of PAM on advancement time, a similar conclusion is derived. Whereas the time needed for the first pulse of tap water to reach the end of the 0.5-m rill was 51 ± 2 s, it took 57 ± 3s with the PAM solutions. Prevention of rill erosion and depositional seal formation prevented the decrease in IR during the first minute, and the advance time for the PAM solution was longer than that for tap water. Similar findings were reported by Lentz at al. (1992) and Lentz and Sojka (1994) who observed, in field experiments, that PAM reduced furrow erosion and increased furrow IR.

The effects of PAM on the cumulative intake of the

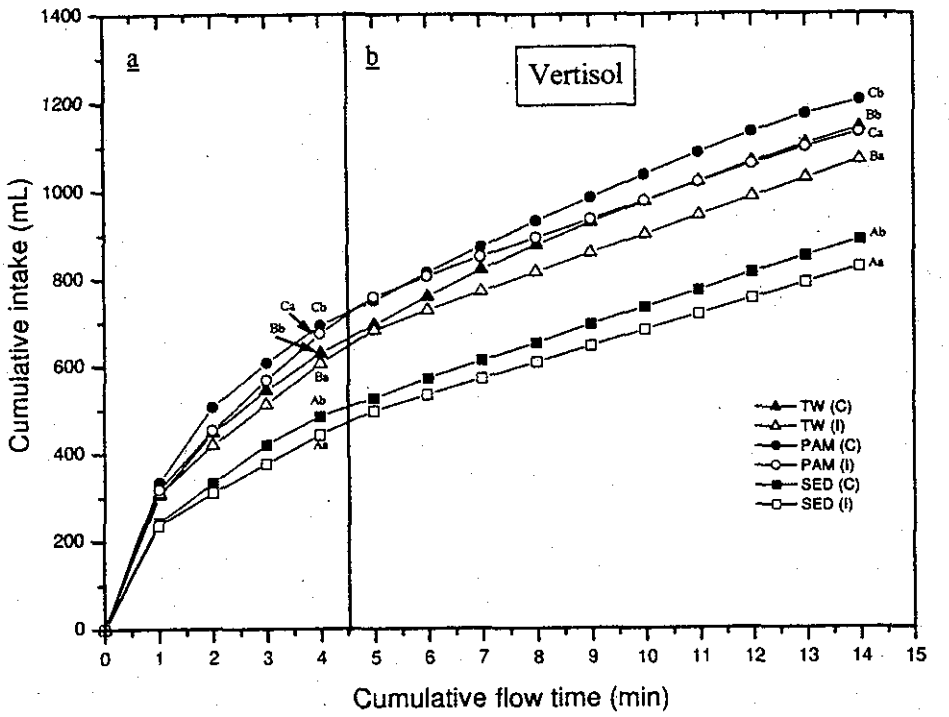


Fig. 4. Cumulative intake as a function of cumulative flow time for the Vertisol during (a) Stage 1 and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences between flow types for a given cumulative flow time and water type are indicated by lower-case letters ($P < 0.05$). TW is tap water, PAM is polyacrylamide-containing water, and SED is sediment-containing water. (C) and (I) denote continuous and interrupted flow, respectively.

Vertisol exposed to continuous and interrupted flow are presented in Fig. 3. The PAM treatment increased the cumulative intakes under both continuous and interrupted flow by 6%. This increase in IR and cumulative intake was contrary to the predictions of Letey (1996) and Malik and Letey (1992), who suggested that PAM increased the apparent viscosity of the solution within the soil pores, and therefore, that soil IR should decrease. The PAM-related IR increase observed in the Vertisol was attributed to two possible mechanisms: (i) PAM prevented rill erosion and the formation of depositional seal (Lentz et al., 1992; Sojka et al., 1998a) and (ii) PAM stabilized the soil structure and prevented deterioration of the soil surface HC (Shainberg et al., 1990). The effects of interrupted flow on IR in the PAM and the tap water treatments were similar (Fig. 3); interrupted inflow in the Vertisol decreased both cumulative intakes by 6% (Fig. 4). Interrupted flow was as effective in decreasing IR in tap water and the accompanying high erosion as it was when PAM was used and only a small amount of sediments was present in the water. The similarity in the decrease in IR for the tap water and PAM treatments is suggested to be related to the structure of the seal formed. When sediments were deposited from a solution that had an electrolyte concentration exceeding the flocculation value of the soil clay (i.e., tap water), the seal formed had an open structure (Shainberg and Singer, 1985) that was susceptible to compaction and consolidation when exposed to suction, in a way similar to that of an unsealed soil surface.

The effect of PAM on IR in the Alfisol was the opposite of that in the Vertisol. In the Alfisol, PAM decreased IR significantly, both in continuous and in interrupted flow, during the first and the second stages of the experiment (Fig. 5). The same conclusion is derived from consideration of advancement time. Advancement times in the first minute in the Alfisol were 7 ± 2 s with PAM solution and 17 ± 3 s with tap water. The high advance rate of the PAM solution in the Alfisol suggested that 10 g m^{-3} of PAM in the inflow water reduced IR. When rill erosion is low, as was the case in the Alfisol, depositional seal effect on IR is minimal, and the effect of PAM in reducing the HC (Letey, 1996) predominates. The effect of PAM on HC is further demonstrated from the consideration of the cumulative intake in the Alfisol (Fig. 6). Final cumulative intakes obtained in continuous and interrupted flows with PAM solution were lower by 37 and 51%, respectively, than those obtained with tap water for the respective flows (Fig. 6). Only little erosion and clay deposition took place in the Alfisol with either tap water or PAM solution; therefore, the effect of PAM in reducing IR was probably because of its effect on the HC of the soil (Malik and Letey, 1992; Letey, 1996). Malik and Letey (1992) suggested that the effective viscosity of polymer solutions in porous media was higher than would be anticipated according to standard viscosity measurements and that the relative viscosity depended on the pore-size distribution of the soil. The effect of PAM in reducing the HC of porous media could also be explained in terms of partial blocking of conducting pores by the tails of the macromolecules that were adsorbed

17

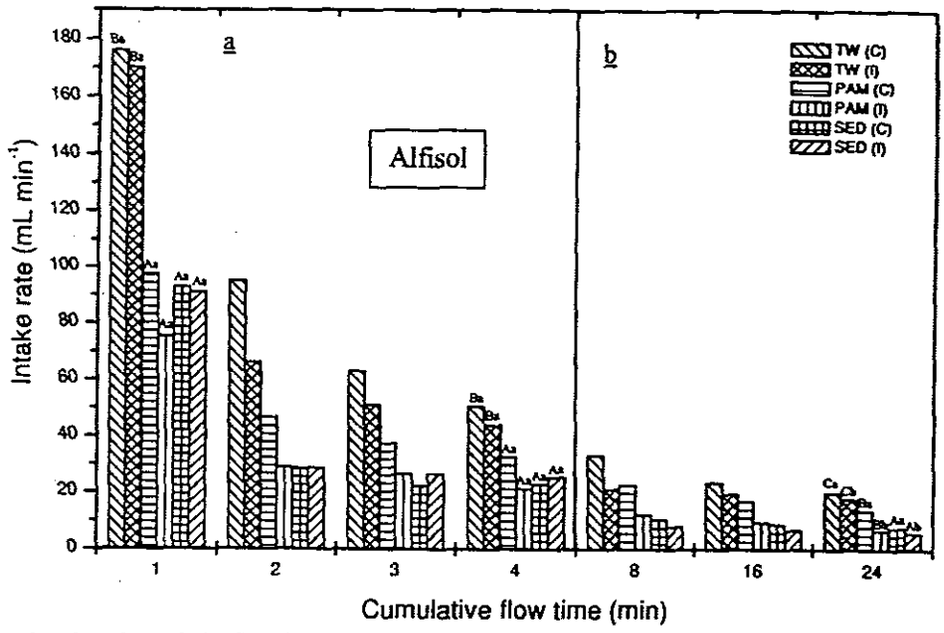


Fig. 5. Intake rate as a function of cumulative flow time for the Alfisol during (a) Stage 1 and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences between flow types for a given cumulative flow time and water type are indicated by lower-case letters ($P < 0.05$). TW is tap water, PAM is polyacrylamide-containing water, and SED is sediment-containing water. (C) and (I) denote continuous and interrupted flow, respectively.

on soil particles. This partial blocking would probably become more pronounced in soils with narrow pores. Thus, it is to be expected that in the Alfisol, with its unstable structure, low HC, and fine conducting pores, PAM would be effective in reducing IR; conversely, in the Vertisol, with its large conducting pores and high HC, the effect of PAM on IR should be small. Our data (Fig. 3–6) support this hypothesis. The PAM solutions of 10 g m^{-3} had a negligible effect on IR in the Vertisol (Fig. 3 and 4) and a marked effect on IR in the Alfisol (Fig. 5 and 6).

It is postulated that the effects of PAM on infiltration depend on two opposing mechanisms: (i) enhancement of IR by prevention of erosion and seal formation and (ii) reduction of IR because of increased apparent viscosity of the solution, or partial blocking of conducting pores by the tails of the macromolecules adsorbed on soil particles. The relative weight of each of these two opposing mechanisms, which determines the actual effect on IR, depends on soil type. Thus, PAM increased IR in the Vertisol by preventing seal formation and erosion, but decreased IR in the Alfisol by decreasing the HC, either by increasing the apparent viscosity of the soil solution or by clogging the conducting pores.

Addition of PAM to the inflow water did not alter the interrupted flow effect on IR in the Vertisol. Interrupted flow decreased the final cumulative intake by 6% in both the PAM and tap water treatments; however, in the Alfisol, interrupted flow was more effective in decreasing the IR with PAM than with tap water. In the latter case, it reduced cumulative intake by 18% compared with continuous flow, whereas in the PAM solution it reduced cumulative intake by 38% (Fig. 6). The beneficial effect of interrupted flow with PAM solutions in the Alfisol can be explained as follows: PAM decreased the HC of the soil surface by partial blocking of the conducting pores, thus also reducing air penetration into the soil surface. Consequently PAM increased the soil water tension that developed during the flow interruptions (Kemper et al., 1988) and in turn caused enhanced compaction and consolidation of the wetted perimeter, thus reducing the infiltration rate. It is hypothesized that a similar phenomenon occurs in surge irrigation and that the surge effect on irrigation efficiency is improved in PAM treatments in silty loam soils like the Alfisol.

Sediments

The effects of sediments in inflow water on IR in the Vertisol and the Alfisol are presented in Fig. 3 and 5, respectively. In both soils, IR was significantly lower from the very first minute of flow with water containing sediments than with tap water (Fig. 3 and 5). This decrease in IR led to total reductions in cumulative intake of 22% in the Vertisol (Fig. 4) and 59% in the Alfisol (Fig. 6), compared with that obtained when tap water was used. The reduction in IR was related to sediment deposition and the formation of a seal at the rill perimeter (Trout, 1991). The reduction in IR was more pronounced in the Alfisol than in the Vertisol because the Alfisol was more susceptible to seal formation (Ben-Hur et al., 1985). The Alfisol, with its poor structure, was more easily clogged with suspended clay particles than the Vertisol, with its developed structure and large water conducting pores. As a result of the low IR, this treatment also increased the advancement rates on both soils; the advancement times for irrigation with water containing sediments and with tap water were 10 and 17 s, respectively, on the Alfisol and 36 and 51 s, respec-

18

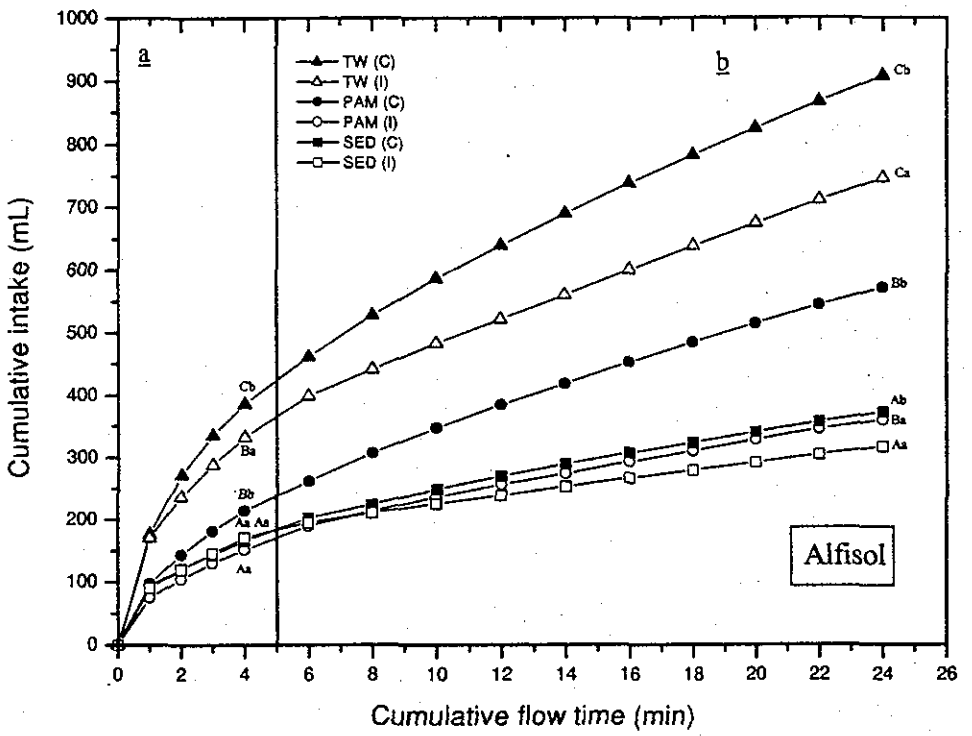


Fig. 6. Cumulative intake as a function of cumulative flow time for the Alfisol during (a) Stage 1 and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences between flow types for a given cumulative flow time and water type are indicated by lower-case letters ($P < 0.05$). TW is tap water, PAM is polyacrylamide-containing water, and SED is sediment-containing water. (C) and (I) denote continuous and interrupted flow, respectively.

tively, on the Vertisol. Sediments decreased the advancement times in the Alfisol by 41% and in the Vertisol by 29%. The effect of sediments in irrigation water in increasing the advance rate in furrow irrigation may be included in consideration of the efficiency of surface irrigation.

In the Vertisol, the use of interrupted flow caused a significant decrease in cumulative intake for both tap water and sediment-laden water (Fig. 4). However, the use of sediment-laden water did not have a greater beneficial effect (in relative terms) in decreasing cumulative intake than interrupted flow with tap water. Interrupted flow decreased the final cumulative intake in the Vertisol by 7% with water containing sediments and by 6% with tap water (Fig. 4). In the Alfisol too, the use of interrupted flow caused a significant decrease in cumulative intake for both tap water and sediment-laden water (Fig. 6). However, in the Alfisol a trend was noted whereby interrupted flow was more effective in decreasing cumulative intake with tap water (18%) compared with sediment-containing water (15%) (Fig. 6). This trend may be explained by the greater IR reduction by the formation of a depositional seal in the Alfisol than in the Vertisol (Fig. 3 and 5). When a seal with a low HC is formed, the seal controls the IR and the effects on IR of interrupted flow and the suction that develops during the off time are negligible. Similar observations were made by Trout (1991), who observed that infiltration was reduced by 50% (because of surface seal formation) when sediments were present in irrigation water and that the interrupted flow effect was less pronounced when a depositional seal of low HC was present.

SUMMARY AND CONCLUSIONS

The effects of PAM and sediment concentration in inflow water on the effect of interrupted flow on infiltration rate and rill erosion was studied in a silty loam Alfisol and a clay Vertisol, using miniflumes. In both soils, rill erosion was dramatically reduced by the PAM treatment. Polyacrylamide increased the IR in the Vertisol and decreased IR in the Alfisol. The contradictory effect of PAM on rill IR was explained by two opposing mechanisms: (i) enhancement of IR by prevention of erosion and of a depositional seal formation (Lentz et al., 1992; Trout, 1991) and (ii) reduction of IR because of increased apparent viscosity of the solution in the soil pores or by clogging of the conducting pores by the tails of adsorbed polymer molecules (Letey, 1996). The second mechanism dominates in the Alfisol with little rill erosion and no depositional seal formation. The polymer did not influence the interrupted flow effect on IR in the Vertisol. In the Alfisol, interrupted flow reduced the final cumulative intake by 37% in the PAM treatment and by 18% with tap water. The effect of interrupted flow with PAM solutions in the Alfisol was explained by the partial blocking of the conducting pores, which increased the suction and compaction of the soil surface, and so reduced the IR.

When applying sediment-containing water, deposi-

tional seal formation markedly decreased the IR of both soils. The reduction of final cumulative infiltration was more pronounced in the Alfisol (59%) than in the Vertisol (22%). The Alfisol, with its unstable structure and narrow conducting pores, was more easily clogged by sediments than the Vertisol, with its stable structure and large pores. When the inflows contained sediments, the interrupted flow effect on IR was limited. Continuous irrigation with water containing sediments increased the advancement rate and reduced rill erosion more effectively than interrupted flow or PAM treatment. This effect should be considered when water containing sediments is used in surface irrigation.

Our results indicate that the potential benefits of interrupted flow as a means of improving surface irrigation efficiency and controlling rill erosion will be gained mainly in weakly structured soils. Addition of polymer to the irrigation water may enhance interrupted flow effects in these soils. When irrigation water contain sediments, interrupted flow has no advantage over continuous flow.

ACKNOWLEDGMENTS

D. Sirjacobs is grateful to the Agricultural Research Organization, Bet Dagan, Israel, for providing him with a grant that made the realization of this work possible. This study was supported by grants TA-MOU-96-CA16-016 and TA-MOU-97-CA17-008, from the U.S.-Israel Cooperative Development Research (CDR) Program, Office of Science Advisor, U.S. Agency for International Development (AID). The support of the CDR is gratefully acknowledged.

REFERENCES

Ben-Hur, M., I. Shainberg, D. Bakker, and R. Keren. 1985. Effect of soil texture and $CaCO_3$ content on water infiltration in crusted soils as related to water salinity. Irrig. Sci. 6:281–284.

Brown, M.J., W.D. Kemper, T.J. Trout, and A.S. Humphreys. 1988. Sediment, erosion and water intake in furrows. Irrig. Sci. 9:445–55.

Izuno, F.T., T.H. Podmore, and R.H. Duke.1985. Infiltration under surge irrigation. Trans. ASAE. 28:517–521.

Jalali-Farahani, H.R, H.R. Duke, and D.F. Heermann. 1993. Physics of surge irrigation. I. Quantifying soil physical parameters. Trans. ASAE 36:37–44.

Kemper, W.D., T.J. Trout, and A.S. Humphreys. 1988. Mechanisms by which interrupted irrigation reduces rill infiltration rates in a silty loam soil. Trans. ASAE 31:821–829.

Lentz, R.D., I. Shainberg, R.E. Sojka, and D.L. Carter. 1992. Preventing irrigation rill erosion with small applications of polymers. Soil Sci. Soc. Am. J. 56:1926–1932.

Lentz, R.D., and R.E Sojka. 1994. Field results using polyacrylamide to manage furrow erosion. Soil Sci. 158:274–282.

Letey, J. 1996. Effective viscosity of PAM solutions through porous media. p. 44–96. *In* R.E. Sojka and R.D. Lentz (ed.) Proc. Conf. on managing irrigation-induced erosion and infiltration with PAM. Publ. no. 101. Univ. of Idaho, Twin Falls, ID, 6–8 May. Univ. of Idaho, Twin Falls.

Malik, M., and J. Letey. 1992. Pore size dependent apparent viscosity for organic solutes in saturated porous media. Soil Sci. Soc. Am. J. 56:1032–1035.

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

Shainberg, I., D. Goldstein, and G.J. Levy. 1996. Rill erosion dependence on soil water content, aging, and temperature. Soil Sci. Soc. Am. J. 60:916–922.

Shainberg, I., J.M. Laflen, J.M. Bradford, and L.D. Norton. 1994. Hydraulic flow and water quality characteristics in rill erosion. Soil Sci. Soc. Am. J. 58:1007–1012.

Shainberg, I., G.J. Levy, P. Rengasamy, and H. Frenkel. 1992. Aggregate stability and seal formation as affected by drops impact energy and soil amendments. Soil Sci. 154:113–119.

Shainberg, I., and M.J. Singer. 1985. Effect of electrolyte concentration on the hydraulic properties of depositional crust. Soil Sci. Soc. Am. J. 49:1260–1263.

Shainberg, I., D. Warrington, and P. Rengasamy. 1990. Effect of soil conditioner and gypsum application on rain infiltration and erosion. J. Soil. Sci. 149:301–307.

Sojka, R.E., R.D Lentz, C.W. Rose, T.J. Trout, D.L. Bjorneberg, and J.K. Aase. 1998b. PAM effect on infiltration in irrigated agriculture. Soil Water Conserv. 53:325–331.

Sojka, R.E., R.D Lentz, and D.T. Westerman. 1998a. Water and erosion management with multiple application of polyacrylamide in furrow irrigation. Soil Sci. Soc. Am. J. 62:1672–1680.

Stringham, G.E. 1988. Interrupted flow irrigation. Final report of the Western Regional Research Project W-163. Research Bull. 515. Utah Agric. Exp. Stn., Utah State Univ., Logan.

Trout, T.J. 1991. Surface seal influence on interrupted flow rill infiltration. Trans. ASAE 34:66–72.

Wolters, W. 1992. Influences on the efficiency of irrigation water use. ILRI, Publ. 51, Wageningen, the Netherlands.

Yonts, C.D., B.L. Benham, K.L. Palm, and D.L. Reichert. 1998. Influence of PAM used in combination with surge irrigation, on irrigation performance and soil erosion. ASAE paper no. 982171. ASAE, St. Joseph, MI.

ERRATUM

Timing Effects of Deep Tillage on Penetration Resistance and Wheat and Soybean Yield

W. J. Busscher, J. R. Frederick, and P. J. Bauer
Soil Sci. Soc. Am. J. 64:999–1003 (May–June 2000).

On p. 999, the division heading is incorrect. It should have read "Division S-6—Soil & Water Management & Conservation" (rather than "Division S-6—Forest & Range Soils").

20

Reprinted from the *Soil Science Society of America Journal*
Volume 65, no. 3, May–June 2001
677 South Segoe Rd., Madison, WI 53711 USA

APPENDIX 2

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

D. Sirjacobs, I. Shainberg, I. Rapp, and G. J. Levy*

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

D. Sirjacobs, I. Shainberg, I. Rapp, and G.J. Levy, Institute of Soil, Water and Environmental Sciences, Agricultural Research Organization (ARO), The Volcani Center, P.O. Box 6, Bet Dagan 50250, Israel. Contribution from the Agricultural Research Organization, The Volcani Center, P.O. Box 6, Bet Dagan 50-250, Israel. no. 625/98 series. Received 21 Sept. 1998. *Corresponding author (vwguy@volcani.agri.gov.il).

Published in Soil Sci. Soc. Am. J. 65:828–834 (2001).

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

21

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			$CaCO_3$	CEC†	ESP‡	EPP§	OM¶
		Sand	Silt	Clay					
		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.

22

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.

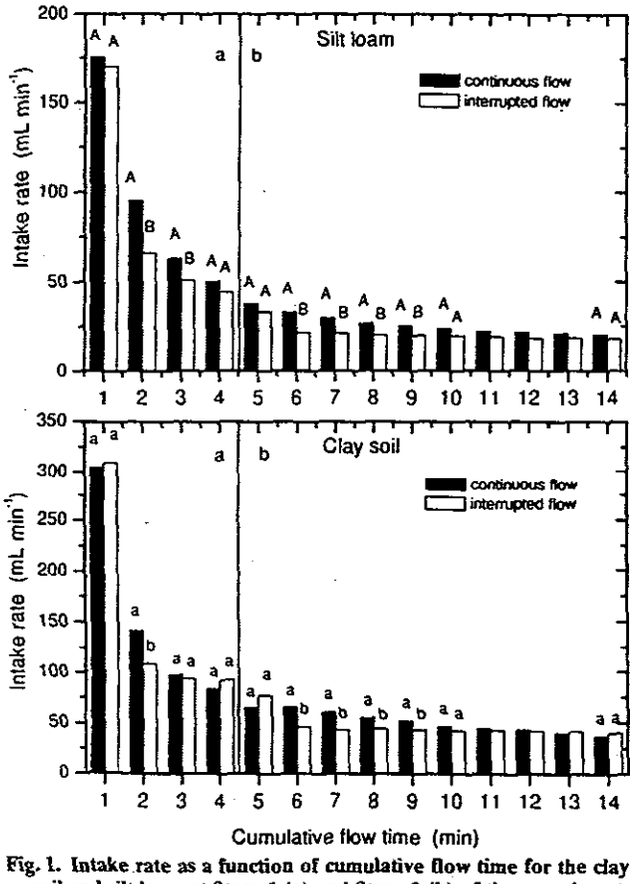


Fig. 1. Intake rate as a function of cumulative flow time for the clay soil and silt loam at Stage 1 (a) and Stage 2 (b) of the experiment. For a given cumulative flow time, and within a soil, bars labeled by the same letter (lower case for the clay soil and upper case for the silt loam) do not differ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

23

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-

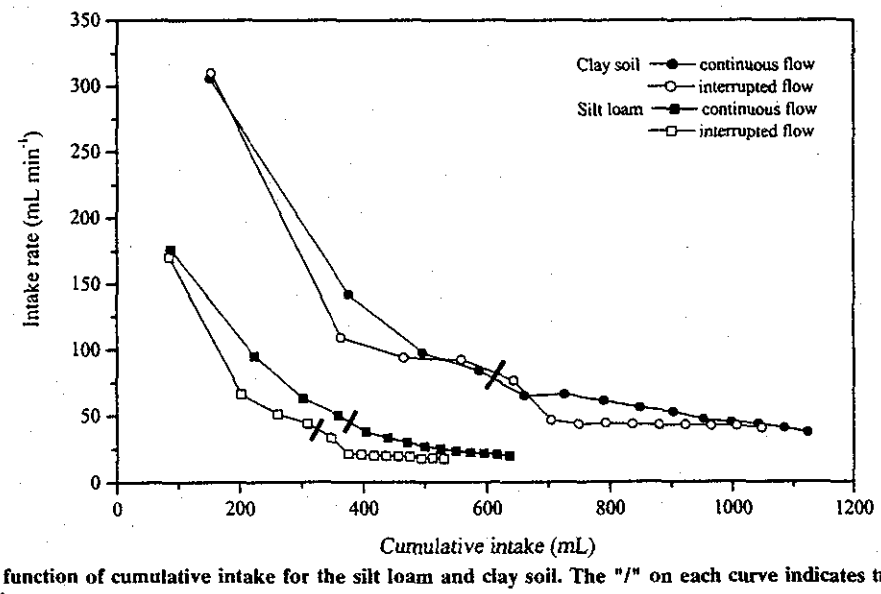


Fig. 2. Intake rate as a function of cumulative intake for the silt loam and clay soil. The "/" on each curve indicates transition from Stage 1 to Stage 2 of the experiment.

24.

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

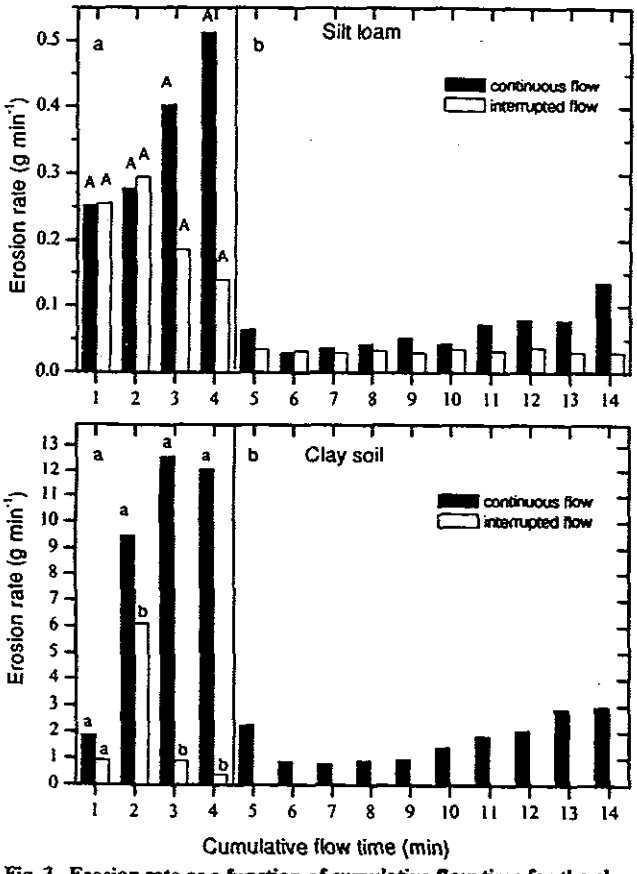


Fig. 3. Erosion rate as a function of cumulative flow time for the clay soil and silt loam at Stage 1 (a) and Stage 2 (b) of the experiment. For a given cumulative flow time, and within a soil, bars labeled by the same letter (lower case for the clay soil and upper case for the loess) do not differ significantly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

25

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.

ACKNOWLEDGMENTS

D. Sirjacobs is grateful to the Agricultural Research Organization, Bet Dagan, Israel, in providing him with a grant which made the realization of this work possible. This study was supported by grants TA-MOU-96-CA16-016 and TA-MOU-97-CA17-008 from the US-Israel Cooperative Development Research (CDR) Program, Office of Science Advisor, U.S. Agency for International Development (AID). The support of the CDR is gratefully acknowledged.

REFERENCES

Banin, A., and A. Amiel. 1970. A correlative study of the chemical and physical properties of a group of natural soils of Israel. Geoderma 3:185–198.

Ben-Hur, M., I. Shainberg, D. Bakker, and R. Keren. 1985. Effect of soil texture and $CaCO_3$ content on water infiltration in crusted soils as related to water salinity. Irrig. Sci. 6:281–294.

Izadi Bahzad, D.F. Heerman, and A. Klute. 1990. Soil water redistribution and hysteresis in surge irrigation. Trans. ASAE 33:799–806.

Izuno, F.T., T.H. Podmore, and R.H. Duke, 1985. Infiltration under surge irrigation. Trans. ASAE 28:517–521.

Jalali-Farahani, H.R., H.R. Duke, and D.F. Heermann. 1993. Physics of surge irrigation. I. Quantifying soil physical parameters. Trans. ASAE 36:37–44.

Kay, B.D., and D.A. Angers. 1999. Soil structure. p. A229–A276. *In* M.E. Sumner (ed.). Handbook of soil science. CRC Press, Boca Raton, FL.

Kemper, W.D., and E.J. Koch. 1966. Aggregate stability of soils from western U.S. and Canada. Tech. Bull. 1355. USDA-ARS. U.S. Gov. Print. Office, Washington, DC.

Kemper, W.D., and R.C. Roseneau. 1984. Soil cohesion as affected by time and water content. Soil Sci. Soc. Am. J. 48:1001–1006.

Kemper, W.D., R.C. Roseneau, and S. Nelson. 1985. Gas displacement and aggregate stability of soils. Soil Sci. Soc. Am. J. 49:25–28.

Kemper, W.D., T.J. Trout, and A.S. Humphreys. 1988. Mechanisms by which surge irrigation reduces furrow infiltration rates in a silty loam soil. Trans. ASAE 31:821–829.

Laflen, J.M., W.J. Elliot, J.R. Simanton, C.S. Holzhey, and K.D. Kohl. 1991. WEPP soil erodibility experiments for rangeland and cropland soils. J. Soil Water Conserv. 46:39–44.

Lentz, R.D., I. Shainberg, R.E. Sojka, and D.L. Carter. 1992. Preventing irrigation furrow erosion with small application of polymers. Soil Sci. Soc. Am. J. 56:1926–1932.

Mullins, C.E. 1999. Hardsetting soils. p. G65–G88. *In* M.E. Sumner (ed.) Handbook of soil science. CRC Press, Boca Raton, FL.

Rengasamy, P., R.S.B. Green, and G.W. Ford. 1984. The role of clay fraction in the particle arrangement and stability of soil aggregates—A review. Clay Res. 3:53–67.

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

Seymour, R.M. 1990. Air entrapment and consolidation as mechanisms in infiltration with surge irrigation. Ph.D thesis. Colorado State Univ., Fort Collins.

Shainberg, I., and M.J. Singer. 1985. Effect of electrolyte concentration on the hydraulic properties of depositional crusts. Soil Sci. Soc. Am. J. 49:1260–1263.

Shainberg, I., J.M. Laften, J.M. Bradford, and L.D. Norton. 1994.

26

Hydraulic flow and water quality characteristics in rill erosion. Soil Sci. Soc. Am. J. 58:1007–1012.
Shainberg, I., D. Goldstein, and G.J. Levy. 1996. Rill erosion dependence on soil water content, aging, and temperature. Soil Sci. Soc. Am. J. 60:916–922.
Stringham, G.E. 1988. Surge flow irrigation. Final report of the Western Regional Research Project W-163. Res. Bull. 515. Utah Agric. Exp. Stn., Utah State Univ., Logan.
Trout, T.J. 1991. Surface seal influence on surge flow furrow infiltration. Trans. ASAE 34:66–72.
Wolters, W. 1992. Influences on the efficiency of irrigation water use. Publ. 51. ILRI, Wageningen, the Netherlands.

APPENDIX 3

0038-075C/02/16710-692-700
Soil Science
Copyright © 2002 by Lippincott Williams & Wilkins, Inc.

October 2002
Vol. 167, No. 10
Printed in U.S.A.

WATER QUALITY AND SODICITY EFFECTS ON SOIL BULK DENSITY AND CONDUCTIVITY IN INTERRUPTED FLOW[1]

G. J. Levy[2], N. Sharshekeev[3], and G. L. Zhuravskaya[3]

Interruption of flow during furrow irrigation (e.g., use of surge technique) consolidates soil near the furrow surface, causing reorientation and rearrangement of soil particles, and leads to increased surface bulk density (BD) and reduced hydraulic conductivity (HC) of this surface layer. We hypothesized that soil consolidation could be affected by irrigation water quality and soil sodicity. We studied in the laboratory changes in the BD and HC of an alfisol (Calcic Haploxeralf) and two vertisols (Chromic Haploxerert) having different exchangeable sodium percentage (ESP) levels that were subjected to five cycles of leaching and draining under matric potential of up to -5 J kg^{-1}. Four different water qualities (electrical conductivity (EC) of 0.01, 0.95, 2.0, and 4.0 dS m^{-1}) were tested. Final BD was significantly greater than the initial value when matric potential was applied. Conversely, for continuous leaching (i.e., no application of matric potential), differences between final and initial BD were insignificant. Water quality and sodicity did not affect BD, suggesting that for a given soil exposed to a low level of matric potential, soil consolidation was not affected by water quality or ESP. Final HC values were always lower than initial ones, with the decrease in HC after application of matric potential being by far greater than that observed when continuous leaching was used. The decrease in HC relative to initial HC depended on both water quality, and soil sodicity, was greater with the decrease in water EC and an increase in ESP. Adverse effects of low EC and high ESP on HC were less pronounced in matric potential application than in continuous leaching. Our results suggest that the quality of water available for irrigation and soil sodicity should be taken into account in cases where interrupted flow is considered for improving furrow irrigation efficiency via reducing soil infiltration rate. (Soil Science 2002;167:692–700)

Key words: Interrupted flow, bulk density, hydraulic conductivity, electrical conductivity, sodicity.

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, 1990), the processes involved in interrupted flow are still not fully understood and its effects on IR are difficult to predict.

Three basic phenomena have been identified during interruption of flow: (i) water redistribution in the soil profile, (ii) air entrapment, and (iii) consolidation of soil near the furrow surface. During interruption of water application, water drainage into underlying dry soil and moisture redistribution result in the development of nega-

[1]Contribution from the Agricultural Research Organization (ARO), The Volcani Center, Bet Dagan, Israel. No. 605/2002 series.

[2]Institute of Soil, Water and Environmental Sciences, ARO, The Volcani Center, P.O. Box 6, Bet Dagan 50250, Israel. Dr. Levy is corresponding author. E-mail: vwguy@volcani.agri.gov.il

[3]Scientific and Research Institute of Irrigation, Bishkek, Kyrgyzstan.

Received April 11, 2002; accepted July 8, 2002.

DOI: 10.1097/01.ss.0000034850.98442.2c

28

tive pressure (suction) near the soil surface. This negative pressure increases capillary 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 furrow surface, increases surface bulk density, and reduces hydraulic conductivity (HC) of this surface layer. Furthermore, upon rewetting, significant trapping of air may occur in the soil surface layer (Jalali-Farahani et al., 1993). 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. (1985) studied in the laboratory changes in HC and bulk density (BD) of four 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 gradient and varied among soils (Samani et al., 1985).

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. (1985). Saleh and Hanks (1989) reported consolidation and a significant reduction in HC following 30 min of drainage in the coarse-textured Millville soil, and no consolidation and a nonsignificant 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 five 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 the increase 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 the 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 (Quirk and Schofield, 1955). These mechanisms reduce HC by narrowing and/or blocking conducting pores, and by aggregate destabilization.

Soil consolidation is the collapse of pore channels by matric forces which develop in a draining soil, followed by reorientation, rearrangement, and deformation of soil particles. Soil consolidation is commonly characterized by an increase in BD and changes (usually a decrease) in HC. 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 matric potential on HC. The objective of the current study was to investigate effects of electrolyte concentration in irrigation water and soil sodicity on soil consolidation as represented by changes in BD and HC during cycles of irrigation and draining under matric potential in arable soils.

MATERIALS AND METHODS

Soils

Two soil types were chosen for this study: alfisol (Calcic Haploxeralf) from Beer Sheva, 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 alfisol Beer Sheva and vertisol Hafetz-Haim were taken from two adjacent fields in each location where field crops were grown, 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 rain-fed cultivated 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 Procedures

Effects of matric potential that develops during off-time in interrupted flow on BD and HC were determined in the laboratory using a proce-

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	Beer Sheva	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	2.7
			375	150	475	31.0	5.0	9.12	2.1
		Qedma	550	200	250	41.6	12.0	13.0	0.96
			600	188	212	49.4	20.0	12.7	0.97

*CEC = cation exchange capacity; ESP = exchangeable sodium percentage; OM = organic matter.

dure similar to that of Samani et al. (1985). Air-dried soil samples, crushed to pass through a 1.0-mm sieve, were placed in 65-mm i.d. vertically sided funnels fitted with a fritted disk that had a nominal maximum pore size of 40 to 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 (100 g) was gently packed and smoothed in the funnel. Initial average height of dry samples was 2.6 for the alfisol and 2.8 cm for the vertisols (Hafetz-Haim and Qedma). Saturation of the soil sample was obtained by wetting it from the bottom at a rate of 30.1 mm h^{-1}. After saturation, initial saturated soil height was measured and BD calculated. Thereafter, the sample was leached from the top of the funnel with a constant head device. Hydraulic head was maintained at 4.5 J kg^{-1} resulting in hydraulic gradients 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 until 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 (attached to the drain tube) 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 by applying water from the bottom using the same water quality and wetting rate as before, and new saturated HC of the sample was measured. These steps were repeated five times, and matric potential was increased each time by −1 J kg^{-1} until it reached −5 J kg^{-1}. The 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, 0.95, 2.0, and 4.0 dS m^{-1}, representing distilled water, tap water, saline water of low salinity, and saline water of high salinity, respectively. Sodium adsorption ratio (SAR) of each of the water types was adjusted to equal the 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 × water quality × soil type × soil sodicity) was duplicated. Coefficient of variation of BD or HC data between replicates was <10%.

RESULTS AND DISCUSSION

Examples of changes in BD and HC for the control treatment (i.e., when no matric potential was applied; herein referred to as continuous leaching) vs. interrupted flow combined with application of matric potential are presented in Figs. 1 and 2. Changes in BD and HC of vertisol Hafetz Haim with ESP 5 subjected to continuous leaching with distilled water showed a slight increase in BD from 1.02 to 1.04 g cm^{-3}, and a moderate decrease in HC from an initial value of 4.70 cm h^{-1} to 3.20 cm h^{-1} (Fig. 1). When leaching was interrupted by matric potential application, 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 previ-

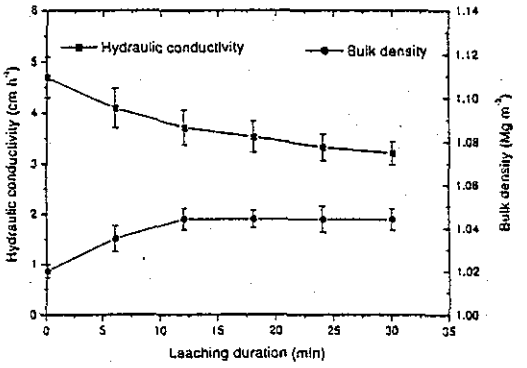


Fig. 1. Changes in hydraulic conductivity and bulk density for continuous leaching (i.e., no matric potential applied) with distilled water in vertisol Hafetz Haim with ESP 5. Bars indicate 2 SD.

ous step. Furthermore, application of matric potential caused also a sharp decrease in HC to 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 for the various treatments are presented in Table 2. Final BD data refer to data measured at the end of 30 min of continuous leaching or after applied matric potential reached -5 J kg^{-1}. Note that for alfisol with ESP 2.7 data for saline water of low salinity (EC = 2 dS m^{-1}) and of high salinity (EC = 4 dS m^{-1}) were similar and hence only those for the low salinity are presented. In addition, in vertisol Qedma, use of distilled water led to a complete blocking of the soil column due to sever swelling, and no measurement of HC could be made; hence, BD data for this treatment are not presented.

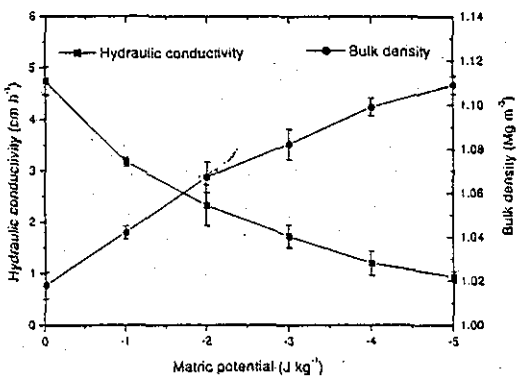


Fig. 2. Changes in hydraulic conductivity and bulk density when matric potential was applied in vertisol Hafetz Haim with ESP 5 leached with distilled water. Bars indi-

For continuous leaching, differences between final and initial BD were insignificant; however, a trend was noted whereby final BD was consistently higher than initial BD (Table 2). For continuous leaching, BD was assumed to depend on two opposing mechanisms: clay swelling and hydraulic gradient. Clay swelling leads to a decrease in BD, especially in the vertisols with high clay content (> 40%). Conversely, subjecting clay to high hydraulic gradient may cause its compression (Kemper et al., 1972) and a subsequent increase in BD. Moutier et al. (1998) reported that a hydraulic gradient of 12.7 led to a significant compression of a vertisol. In the current study, a hydraulic gradient ≥ 13.6 was maintained, suggesting that some compression of the soil column could have taken place. The fact that no significant changes were noted between initial and final BD (Table 2) indicated that the two opposing mechanisms (i.e., clay swelling and hydraulic gradient) had similar effects on BD, thus canceling each other out. It could be argued that neither mechanism operated. However, the fact that final BD was consistently higher than initial BD and evidence in the literature as to clay swelling in our particular soils (Sirjacobs et al., 2001) supported our conclusion that these two mechanisms affected BD in a similar magnitude but opposite direction.

In the matric potential application treatment, final BD was, as observed in previous studies (e.g., Samani et al., 1985), significantly higher than the initial one (Table 2). The significantly higher final BD values compared with the initial ones clearly demonstrated that application of matric potential of -5 J kg^{-1} was effective in consolidating the soil and increasing its final BD. This matric potential was similar to the matric potential developed under field conditions during 20 min of flow interruptions (Kemper et al., 1988; Trout, 1990).

In order to evaluate specific effects of water quality and sodicity on BD under conditions of continuous flow or application of matric potential, we calculated the ratio of final BD to its respective initial value, termed relative BD. As expected, higher relative BD values were noted in all soils when matric potential was applied compared with continuous leaching (Figs. 3 and 4). Similar relative BD values were obtained for the alfisol and the vertisol Hafetz Haim (different soil types but with similar ESP levels). Clay content in

31

TABLE 2

Effects of soil type, sodicity, and water quality on soil bulk density

Soil type	ESP	Water quality	Matric potential application		Continuous leaching	
			Initial BD	Final BD	Initial BD	Final BD
		dS m^{-1}	g cm^{-3}	g cm^{-3}	g cm^{-3}	g cm^{-3}
Alfisol	2.7	0.01	1.19	1.29	1.19	1.23
		0.95	1.17	1.28	1.19	1.20
		2.0	1.19	1.29	1.19	1.20
	6.5	0.01	1.15	1.27	1.15	1.16
		0.95	1.09	1.19	1.11	1.13
		2.0	1.10	1.21	1.11	1.13
		4.0	1.12	1.20	1.12	1.13
LSD (0.05)†			0.025	0.021	0.023	0.019
LSD (0.05)‡			0.049		0.031	
Vertisol	1.9	0.01	1.01	1.09	1.01	1.02
Hafetz-Haim		0.95	0.96	1.05	0.98	1.00
		2.0	1.00	1.05	1.01	1.02
		4.0	0.99	1.04	1.00	1.01
	5.0	0.01	1.02	1.11	1.02	1.04
		0.95	1.00	1.10	1.01	1.02
		2.0	1.02	1.12	1.03	1.05
		4.0	1.02	1.11	1.02	1.03
Vertisol Qedma	12	0.95	0.91	1.02	0.91	0.93
		2.0	0.92	1.04	0.93	0.94
		4.0	0.93	1.05	0.95	0.96
	20	0.95	0.86	0.96	0.86	0.87
		2.0	0.87	0.99	0.89	0.90
		4.0	0.90	1.01	0.91	0.92
LSD (0.05)			0.026	0.024	0.028	0.027
LSD (0.05)			0.041		0.029	

†Least significant difference for treatments (ESP × water quality) for a given soil type.

‡Least significant for initial and final HC for a given soil type.

the alfisol (Table 1); therefore, based on the results of Jalali-Farahani et al. (1993) for a soil with a similar texture, vertisol Hafetz Haim was expected to be more vulnerable to consolidation. However, the alfisol had a considerably higher silt-to-clay ratio and half the amount of organic matter content than the vertisol Hafetz Haim (Table 1), thus suggesting a weaker structure. Soils with weak structure were considered more susceptible to consolidation than soils with a stable structure (Mullins, 1999). The similar increase in BD in the alfisol and vertisol Hafetz Haim, and thus the similar degree of consolidation, could be explained by the opposite effects of clay content and structural stability on soil consolidation.

In the alfisol, electrolyte concentration of the leaching solution and soil ESP had no effect on relative BD, irrespective of whether matric potential was applied or not (Fig. 3). In the vertisol, similar to alfisol, electrolyte concentration of the soil solution and sodicity did not affect relative BD when continuous leaching was applied (Fig. 4a). When matric potential was applied, 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 Qedma with ESP 12 and 20 was higher than that in the vertisol Hafetz Haim with ESP 1.9 and 5 (Fig. 4b). This observation could be ascribed to the fact that the higher the soil ESP the weaker its structure; thus the greater its tendency to consolidate and yield higher BD.

Results of initial and final HC for the various treatments are presented in Table 3. Similar to BD, final HC data refer to data measured at the end of 30 min continuous leaching or after applied matric potential reached -5 J kg^{-1}. Final HC values were always lower than initial ones (Table 3). The decrease in HC in continuous flow was ascribed to clay swelling, while in the matric potential application treatment it was ascribed to soil consolidation supplemented by clay swelling. In order to qualitatively assess the effects clay swelling and consolidation on the change

32

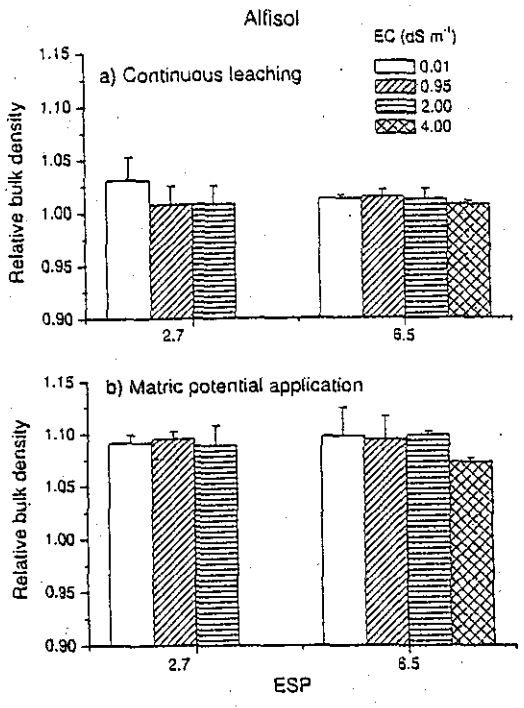


Fig. 3. Relative bulk density in alfisol as a function of exchangeable sodium percentage (ESP) and water quality for a) continuous leaching (no matric potential application), and b) matric potential application. Bars indicate 1 SD.

from initial to final HC, we expressed this change in HC (ΔHC) as a percentage of initial HC:

$$\Delta HC = 100*(\text{Initial HC} - \text{Final HC})/\text{Initial HC} \quad (1)$$

Results for continuous leaching and the matric potential application treatments are presented in Table 3. As expected, and as noted in the example of vertisol Hafetz-Haim (Figs. 1 and 2), ΔHC in the matric potential application was by far greater than that in continuous leaching (Table 3).

The data in Table 3 also indicate that ΔHC depended on water quality and sodicity level not only in continuous leaching (as expected), but also in the matric potential application treatment. Within a soil type, the level of ΔHC for matric potential application increased with an increase in soil ESP and a decrease in the EC of the applied water (Table 3). For matric potential application in a given soil type, similar BD values were noted for the different levels of water quality and sodicity (Figs. 3 and 4). It is postulated, therefore, that within a soil type, degree of consolidation was similar among the various water quality and sodicity levels. Hence, the observed differences among ΔHC values could be ascribed to effects of water quality and sodicity on clay swelling rather than on soil consolidation.

The ratio of ΔHC for matric potential application (ΔHC_M) for a given treatment to that for continuous leaching (ΔHC_C) of the same treatment showed the magnitude by which the decrease in HC for matric potential application was greater than that for continuous leaching. The higher this ratio, the greater the effect of consolidation on decreasing HC. The data presented in Figs. 5 and 6 show that, in general, the ratio of $\Delta HC_M/\Delta HC_C$ increased with an increase in the EC of the applied water and a decrease in soil ESP. Thus, under conditions where clay swelling was limited (i.e., high EC and/or low sodicity), the impact of soil consolidation on HC was greater than that for conditions favoring clay swelling. These observations could be explained as follows. At high salinity and/or low sodicity,

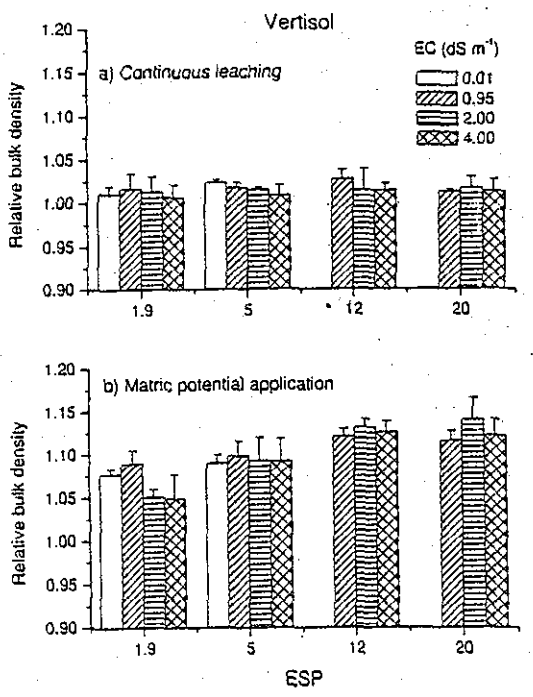


Fig. 4. Relative bulk density in vertisol as a function of exchangeable sodium percentage (ESP) and water quality for a) continuous leaching (no matric potential application), and b) matric potential application. Bars indicate one standard deviation.

33

TABLE 3

Effects of soil type, sodicity, and water quality on soil hydraulic conductivity

Soil type	ESP	Water quality	Matric potential application			Continuous leaching		
			Initial HC	Final HC	ΔHC	Initial HC	Final HC	ΔHC
		dS m⁻¹	cm h⁻¹	cm h⁻¹	%	cm h⁻¹	cm h⁻¹	%
Alfisol	2.7	0.01	1.90	0.50	73.7	2.59	2.02	22.0
		0.95	2.61	1.18	54.8	2.64	2.26	14.4
		2.0	2.48	1.04	58.1	2.48	2.18	12.1
	6.5	0.01	1.94	0.33	83.0	1.82	1.09	40.1
		0.95	3.72	1.69	54.6	3.87	3.04	21.4
		2.0	3.51	1.61	54.1	3.22	2.83	12.1
		4.0	3.37	1.72	49.0	3.21	2.76	14.0
LSD (0.05)†			0.581	0.380		0.477	0.227	
LSD (0.05)‡			0.509			0.499		
Vertisol	1.9	0.01	7.88	3.36	57.4	9.35	7.03	24.8
Hafetz-Haim		0.95	8.43	5.56	34.1	8.81	7.85	10.9
		2.0	9.30	6.54	29.7	9.10	8.38	7.9
		4.0	9.04	7.49	17.1	9.09	8.63	5.1
	5.0	0.01	4.75	0.94	80.3	4.69	3.20	31.8
		0.95	7.70	3.94	48.8	7.93	7.02	11.5
		2.0	8.10	4.80	40.7	7.84	6.88	12.2
		4.0	7.65	4.14	45.9	8.76	7.92	9.6
Vertisol Qedma	12	0.95	3.97	1.33	66.5	4.41	3.01	31.7
		2.0	4.30	1.54	64.2	4.40	3.44	21.8
		4.0	4.12	1.59	61.5	3.77	2.97	21.3
	20	0.95	1.79	0.42	76.5	1.60	0.95	40.6
		2.0	2.78	0.78	71.9	2.82	1.92	31.9
		4.0	3.77	1.39	63.1	3.01	2.35	21.9
LSD (0.05)			0.730	0.561		0.785	0.697	
LSD (0.05)			1.290			1.473		

†Least significant difference for treatments (ESP × water quality) for a given soil type.

‡Least significant difference for initial and final HC for a given soil type.

ΔHC in continuous leaching was in most cases < 25% (Table 3), suggesting that swelling was limited, leading to a small reduction in the size of the water conducting pores. In matric potential application, degree of swelling was not expected to change from that noted for continuous flow, thus swelling remained limited. However, because of soil consolidation, average pore size decreased, and the effects of swelling on further narrowing water conducting pores and reducing HC was now greater; consequently, the ratio of $\Delta HC_M/\Delta HC_C$ was high (Figs. 5 and 6). Conversely, at low salinity and/or high sodicity, ΔHC in continuous leaching was already high (Table 3), indicating distinct swelling. The contribution of consolidation to further reduction of pore size was thus of lesser importance, leading to a lower $\Delta HC_M/\Delta HC_C$ ratio compared with that obtained for conditions of high salinity and/or low sodicity (Figs. 5 and 6).

Our observations show that soil consolidation resulted in a significant decrease in HC. These ob-

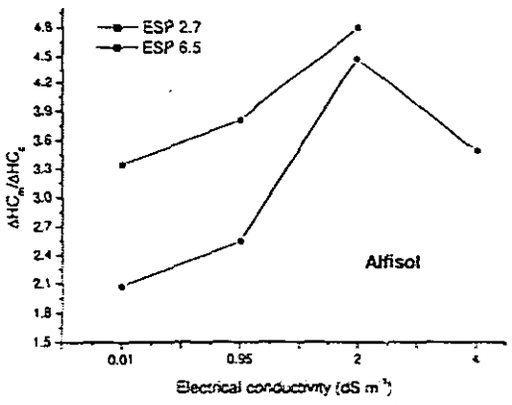


Fig. 5. The ratio of decrease in hydraulic conductivity for matric potential application to the decrease in hydraulic conductivity for continuous leaching ($\Delta HC_M/\Delta HC_C$) in alfisol as a function of the electrical conductivity of the water used.

34

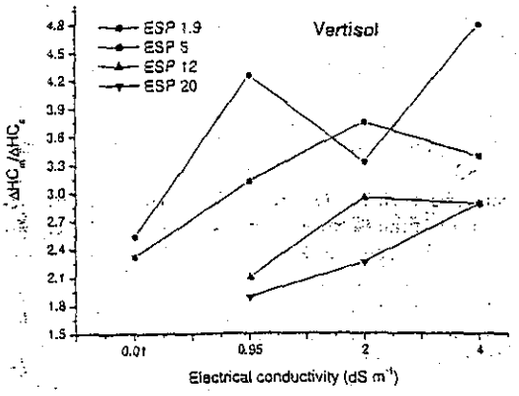


Fig. 6. The ratio of decrease in hydraulic conductivity for matric potential application to the decrease in hydraulic conductivity for continuous leaching ($\Delta HC_M/\Delta HC_C$) in vertisol as a function of the electrical conductivity of the water used.

servations agreed with the results reported by Samani et al. (1985) and Jalali-Farahani et al. (1993) for medium- and fine-textured soils. Conversely, our observation did not agree with those of Saleh and Hanks (1989), who did not observe an effect of consolidation on HC in a fine-textured soil. In addition, we also noted that the magnitude of the decrease in HC depended on water quality and soil sodicity via their effect on clay swelling. A lesser decrease in HC was noted under conditions favoring clay swelling (i.e., low EC and/or high sodicity).

SUMMARY AND CONCLUSIONS

We studied the effects of water quality and sodicity on BD and HC in continuous leaching and matric potential application (simulating conditions leading to soil consolidation in interrupted flow). For continuous leaching, differences between final and intial BD were insignificant. Conversely, final BD was significantly higher than the initial one when matric potential was applied, indicating that the soil columns consolidated upon subjecting it to matric potential. Water quality and sodicity did not affect BD and hence soil consolidation. Final HC values were always lower than initial ones, with the decrease in HC after application of matric potential being by far greater than that observed when continuous leaching was used. This observation emphasized the significant negative impact of soil consolidation on HC. Unlike BD, the decrease in final HC relative to initial HC depended on both water quality and soil sodicity, tending to increase with the decrease in water EC and an increase in ESP. Comparison of the decrease in HC for matric potential application for a given treatment to the decrease in HC for continuous leaching showed that conditions favoring clay swelling (i.e., low EC and high ESP) resulted in a smaller relative decrease in HC than conditions where clay swelling was limited (high EC and low ESP).

In surface irrigation, use of interrupted flow (e.g., surge technique) during the advancement stage of furrow irrigation has the potential to reduce infiltration rate and improve irrigation efficiency. The reduction in infiltration rate is ascribed to soil consolidation at the soil surface during flow interruptions. Our results suggest that the quality of water available for irrigation and soil sodicity should be taken into account in cases where interrupted flow is considered for improving furrow irrigation efficiency via reducing soil infiltration rate.

ACKNOWLEDGMENT

This study was supported by grant TA-MOU-97-CA17-008 from the U.S.-Israel Cooperative Development Research (CDR) Program, Office of Science Advisor, U.S. Agency for International Development (AID). The support of the CDR is gratefully acknowledged.

REFERENCES

Izuno, F. T., T. H. Podmore, and R. H. Duke. 1985. Infiltration under surge irrigation. Trans. ASAE 28: 517–521.

Jalali-Farahani, H. R., H. R. Duke, and D. F. Heermann. 1993. Physics of surge irrigation. I. Quantifying soil physical parameters. Trans. ASAE 36: 37–44.

Kemper, W. D., I. Shainberg, and J. P. Quirk. 1972. Swelling pressures, electric potentials and ion concentrations: Their role in hydraulic and osmotic flow through clays. Soil Sci. Soc. Am. J. 36:229–236.

Kemper, W. D., T. J. Trout, A. S. Humphreys, and M. S. Bullock. 1988. Mechanisms by which surge irrigation reduces furrow I infiltration rates in a silty loam soil. Trans. ASAE 31:821–829.

Klute, A. (ed.). 1986. Methods of Soil Analysis, Part 1, 2nd Ed. Physical and Mineralogical Methods. Agron. Monogr. No. 9. ASA and SSSA, Madison, WI.

Moutier, M., I. Shainberg, and G. J. Levy. 1998. Effects of hydraulic pressure gradient, aging and water quality on the permeability of a vertisol. Soil Sci. Soc. Am. J. 62:1488–1496.

Mullins, C. E. 1999. Hardsetting soils. In M. E. Sumner (ed.). Handbook of Soil Science. CRC Press, Boca Raton, FL, pp. G65–G88.

35

Page, A. L., R. H. Miller, and D. R. Keeney (eds.). 1986. Methods of Soil Analysis, Part 2, 2nd Ed. Chemical and Microbiological Properties. Agronn Monogr. No. 9. ASA and SSSA, Madison, WI.

Quirk, J. P., and R. K. Schofield. 1955. The effect of electrolyte concentration on soil permeability. J. Soil Sci. 6:163–178.

Saleh, A., and R. J. Hanks. 1989. Field evaluation of soil hydraulic property changes caused by surge water application. Soil Sci. Soc. Am. J. 53:1526–1530.

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

Shainberg, I., and G. J. Levy. 1992. Physiochemical effects of salts upon infiltration and water movement in soils. *In* R. J. Wagenet, P. Baveye, and B. A. Stewart (eds.). Interacting Processes in Soil Science. Advances in Soil Science, Lewis Publishers, pp. 37–94.

Sirjacobs, D., I. Shainberg, I. Rapp, and G. J. Levy. 2001. Flow interruption effects on intake rate and rill erosion in two soils. Soil Sci. Soc. Am. J. 65:828–834.

Stringham, G. E. 1988. Surge flow irrigation. Final report of the Western Regional Research Project W-163. Research Bulletin 515. Utah Agricultural Experiment Station, Utah State Univ., Logan.

Trout, T. J. 1990. Surface seal influence on surge flow furrow infiltration. Trans. ASAE 34:66–72.

Wolters, W. 1992. Influences on the efficiency of irrigation water use. ILRI, Publ. 51, Wageningen, 150 pp.

Appendix 4: Sodicity and water quality effects on intake rate and rill erosion in interrupted flow

N. Sharshekeev, G.L. Zhuravskaya and G.J. Levy

ABSTRACT

The efficiency of surface irrigation is low because of poor field uniformity, higher intake at upstream end and slow intake at the 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 varies from one irrigation scheme to another, it depends on soil and water properties and is difficult to predict. The effect of water quality and soil sodicity on IR and soil loss from short rills was studied in an alfisol and a vertisol using miniflumes under interrupted and continuous flow. The infiltration rate was more sensitive to the sodicity of the soil than to the electrolyte concentration. The results showed that: (i) interrupted flow reduced soil loss in the vertisol and had small effect on soil loss from the alfisol, (ii) interrupted flow reduced IR in both soils compared with that obtained in continuous flow; this reduction in IR was more effective in the alfisol than in the vertisol, and (iii) the effect of interrupted flow in reducing the IR depended on application of water quality mainly in the vertisol soil.

Introduction

Interrupted irrigation (also termed surge irrigation), the intermittent application of surface irrigation water (Stringham, 1988), has been proposed as a potential alternative to overcome low water use efficiency, ~45% (Wolters, 1992), commonly found in traditional surface irrigation. Surge irrigation may increase uniformity (and thus efficiency) of surface irrigation application by: (i) increasing the advance rate, which decreases cross-field differences in infiltration opportunity time; and (ii) decreasing intake rate (IR) at the upstream end of the furrows to compensate for longer infiltration opportunity times at these locations (Kemper et al., 1988). Numerous studies were devoted to surge irrigation (e.g., Izuno et al., 1985; Samani et al., 1985; Kemper et al., 1988; Trout, 1991), yet the processes involved in interrupted irrigation are still not fully understood and its effects on IR are thus difficult to predict. For instance, a recent laboratory study has shown that effects of interrupted flow on decreasing IR depended on soil type, the decrease in IR was greater for a silt loam than a sandy clay (Sirjacobs et al., 2001). Conversely, interrupted flow reduced rill erosion in both soils to a similar degree.

Three basic phenomena have been identified during interruption of flow: (i) water redistribution in the soil profile, (ii) air entrapment, and (iii) consolidation of soil near the furrow 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 capillary 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 furrow surface, increases surface bulk density, and reduces the hydraulic conductivity and the IR of this surface layer. Furthermore, upon rewetting, significant trapping of air may occur in the soil surface layer (Jalali Farahani,et al., 1993). 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).

An additional important mechanism which may affect IR during flow interruption is furrow erosion and subsequent depositional seal formation. Furrow erosion, and particle transportation, deposition and rearrangement may significantly reduce water IR by decreasing the permeability of the surface layer (depositional seal formation). Trout (1991) observed a 50% reduction of infiltration during interrupted irrigation because of depositional seal formation in the Portneuf silt loam soil. Shainberg and Singer (1985) observed that depositional seals reduced the rate of water penetration by 1-2 orders of magnitude.

The response of soils to saline and sodic conditions has been summarized in numerous reviews (e.g. Shainberg and Letey, 1984; Sumner and Naidu 1998; Levy 1999). These reviews demonstrated that soil properties (e.g., soil texture, clay mineralogy, pH, sesquioxide content, lime, and CO_2 concentration) affect the response of soils to saline-sodic conditions. Soils with high clay content, high portion of 2:1 clay minerals, high pH, and low sesquioxides content were found to be susceptible to these conditions. The significant effects of soil sodicity and the electrolyte concentration in the irrigation water on water movement in the soil (e.g., Shainberg and Letey, 1984), and soil erosion (Levy et al., 1994) have been attributed to their effects on clay swelling and dispersion and aggregate destabilization. Water flow decreases and soil erosion increases under conditions favoring clay dispersivity and aggregates instability, i.e., low concentration of electrolytes and/or high levels of exchangeable sodium percentage (ESP).

Recently, some studies tested the effects of dispersive conditions on some of the processes that occur during flow interruption. Shainberg and Singer (1985) showed that depositional seals made of flocculated particles had much faster permeability than seals made of dispersed clay and silt particles. Even for a soil with ESP <1, differences in seal structure and permeability were noted when solutions of different salinities were used (Shainberg and Singer, 1985). In addition, Trout (1991) observed that with the decrease in IR due to an increase in sediment concentration, the beneficial effect of interrupted irrigation on reducing IR decreases. Combining the observations of Shainberg and Singer (1985) and those of Trout (1991) suggested that conditions favoring formation of a depositional seal of low permeability, i.e. dispersive conditions, may limit the efficiency of interrupted flow in reducing IR. Levy et al., (2002) who compared the effects of sodicity and water quality on the hydraulic conductivity (HC) under consolided and non-consolidated conditions noted similar effects to sodicity and salinity. They observed that for a consolidated soil, as occurs during interrupted flow, the decrease in hydraulic conductivity following consolidation was less pronounced under conditions favoring clay swelling and dispersion than under a flocculated soil system.

The results of the aforementioned studies on the individual processes that take place during interrupted flow indicated that soidc and saline conditions have an adverse on the efficiency of interrupted flow in reducing IR. We proposed to test whether these observations hold true under interrupted flow conditions. Our specific objective was to evaluate in a systematic way the effects of soil sodicity and water quality on IR and rill erosion under conditions of interrupted flow in two soil types using 4 sodicity and 4 water salinity levels.

MATERIALS AND METHODS

Soils

Two soil types were chosen for this study: an alfisol (Calcic Haploxeralf) from Beer Sheva, 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 alfisol Beer Sheva and vertisol Hafetz-Haim were taken from two adjacent fields in each location where field crops were grown, 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 rain-fed cultivated field having naturally occurring high ESP. Selected physical and chemical properties of the soils studied, determined by standard analytical methods (Klute, 1986; Page et al., 1986), are presented in Table 1.

Experimental procedure

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 of its sides. The flume was placed at a 10% slope in order to maintain high flow shear force , high soil detachment and high rill erosion.

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 m^{-3} for the alfisol and 1.23 Mg m^{-3} for the vertisols. The dry volume of the vertisols was slightly smaller than that of the alfisol. However, upon wetting and subsequent swelling, the final volume of the wet vertisols 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 sediment containing runoff water was collected from the downstream metallic rill in beakers. For accurate measurement of the applied water, the water reservoir was placed on an electronic balance, and the change in weight with time was recorded and used for calculation of inflow rate.

Four different salinity levels were studied. Electrical conductivity (EC) of the water used was 0.01(DW), 0.95(TW), 2.0(SW-L) or 4.0(SW-H) dS m^{-1}. The sodium adsorption ratio (SAR) of each of the water types was adjusted to be equal to the 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 these solutions.

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. Studies by Sirjacob et al. (2000, 2001) who used a similar experimental set up showed that off time of 10 min was sufficient for changes in rill erosion and IR, caused by flow interruption, to be completed. In order to obtain a measurable outflow during the consecutive 4 min, the inflow applied to the vertisol and the alfisol was 320 and 240 mL min^{-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, 6 min of continuous flow of 100 mL min^{-1} was maintained in the vertisol and a continuous flow of 80 mL min^{-1} in the alfisol. Total inflow, outflow and soil loss, were recorded every minute for each soil.

Three replicates were performed for each treatment tested. Effects of treatments, soil sodicity, water quality and flow type (continuous and interrupted), were analyzed separately for the Alfisol and the Vertisol.

RESULTS

Effect of water quality and type of irrigation on rill erosion

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. 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 – aggregates cohesion forces (Shainberg et al 1996). Vertisol with high clay content (Table 1) has 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. 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.

Water quality (0.01[DW], 0.95 [TW], 2.0[SW-2] and 4 [SW-4] dS m^{-1}) had inconsistent effects on rill erosion under surge and continuous flow. 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; upon further increases in electrolyte concentration to 2.0 and 4.0 dS m^{-1} erodibility remained unchanged for the surge and the continuous flow (Fig. 6). Conversely, in the vertisol with ESP 12 the effect of the

electrolyte concentration was opposite, i.e., rill erosion decreased in continuous flow when the electrolyte concentration in the water used was increased (Fig. 12). In a different instance, the same increase in the electrolyte concentration decreased the rill erosion in the vertisol with ESP 5 for continuous flow, and not affected soil erosion in the surge flow with the same ESP (Fig. 4). In the alfisol soil (ESP 6.5) rill erosion decreased, but decreasing rill erosion stopped at 0.95 dS m^{-1} and then remained unchanged up to EC of 4.0 dS m^{-1} for the surge and the continuous flow (Fig. 2).

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 of cohesive forces. Therefore, when dispersive conditions prevailed (ESP$\geq$ 5), increasing the electrolyte concentration of the eroding water decreased the erodibility of the soils. It was noted in continuous irrigation for ESP 5 and ESP 12 in the vertisol (Figs. 4 and 5). However, in the moderate and high ESP levels of the vertisol use of surge irrigation led to the development of a negative pressure in the upper layer of the soil during the off period, thus ,increasing the electrolyte concentration of the eroding water increases the intra-aggregate cohesion forces. Consequently, it increases the relative number and stability of microaggregates, while reducing interaggregate cohesion forces and increasing the transportability of soil particles and the erodibility of the soil (Figs. 4-6). The results with low ESP soils are explained by the 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 rill erosion 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 ESP (Abu-Sharar, 1988) and the transportability of the detached microaggregates was higher.

Effect of water quality and flow type on intake rate

The effects 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 20) increasing the electrolyte concentration from 0.01 to 4.0 dS m^{-1} increased IR of the soils for both type of irrigations, but interrupted flow had no effect on IR when electrolyte concentration was 0.01 dS m^{-1} (Figs. 11 and 12). In ESP 12 of the vertisol increasing IR stopped under 2.0 dS m^{-1} (Fig. 11). For interrupted flow in the vertisol soil with low ESP, increasing the electrolyte concentration to 0.95 dS m^{-1}, had tendency to increase IR, which then remained 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 with low level of ESP the electrolyte concentration had small effects on IR. Upon comparing surge and continuous irrigation, interrupted flow was more effective in decreasing the intake rate in the alfisol than in the vertisol soil (Fig. 7).

Effect of sodisity on Intake Rate

Comparing effects of ESP on the intake rate we observed the following. When ESP of the vertisol and the alfisol soils was low their intake rates were high (Figs. 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 (ESP 5) lost effect of interrupted flow under 4.0 (SW-H) dS m^{-1} (Fig. 9). The IR of the vertisol with ESP 12 dramatically decreased and decreasing the IR was continued by ESP 20. It is proposed that the IR is sensitive to soil sodisity.

SUMMARY

The effect of water quality and soil sodicity on IR and soil loss from short rills was studied in a silty loam alfisol and a clay vertisol, using miniflumes and applying interrupted and continuous flow. The intake rate was more sensitive to the sodicity of the soil and to the electrolyte concentration than rill erosion. The results showed that: (i) interrupted flow reduced soil loss in the vertisol and only had small effects on soil loss from the alfisol, (ii) interrupted flow reduced IR in both soils compared with that obtained in continuous flow; this reduction in IR was more effective in the alfisol than in the vertisol, and (iii) the effect of interrupted flow in reducing the IR depended on application of water quality mainly in the vertisol soil.

References

Agassi, M., J. Morin and I. Shainberg.1985. Effect of raindrop impact energy and water salinity on infiltration rate of sodic soils. Soil Sci. Soc. Am. J. 49: 186-190

Kemper, W.D., R.C. Roseneau, and S. Nelson.1985. Gas displacement and agregate stability of soils. Soil Sci. Soc. Am. J 49:25-28

Kemper, W.D., and R.C. Roseneau. 1984. Soil cohesion as affected by time and water content. Soil Sci. Soc. Am. J. 49:25-28

Kemper, W.D., T.J. Trout, and A.S. Humphreys. 1988. Mechanisms by which surge irrigation reduces furrow infiltration rates in a silty loam soil. TRANS ASAE 31;821-829

D. Sirjacobs, I. Shainberg, I. Rapp, and G. J. Levy. 2000. Polyacrylamide, Sediments, and Interrupted Flow Effects on Rill Erosion and Intake Rate. Soil Sci. Soc. Am. J. 64:1487-1495

Shainberg, I., and M.J. Singer. 1985. Effect of electrolyte concentration on hydraulic properties of depositional crust. Soil Sci. Soc. Am.J. 49: 1260-1263.

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

43

SOIL LOSS

Fig. 1

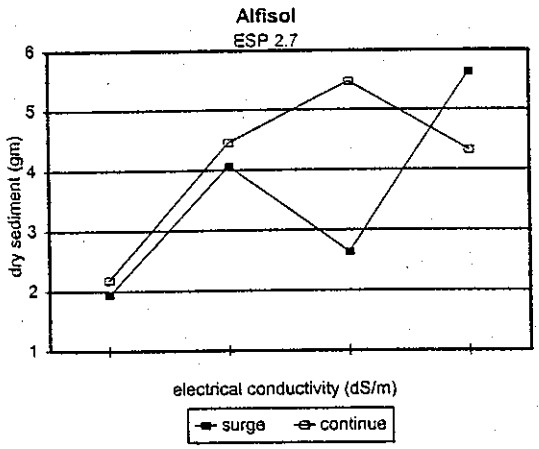


Fig.2

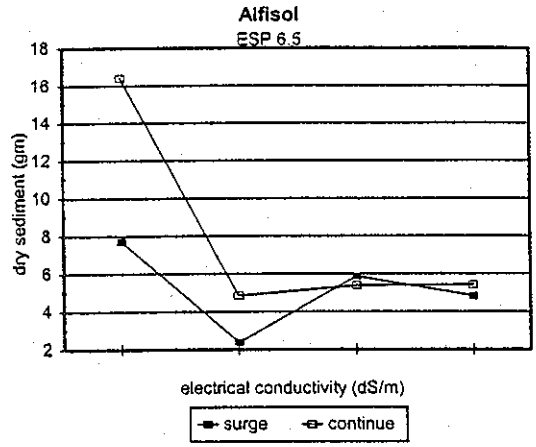


Fig. 3

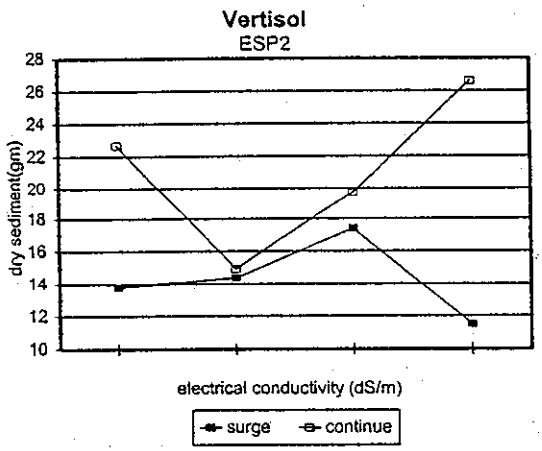


Fig.4

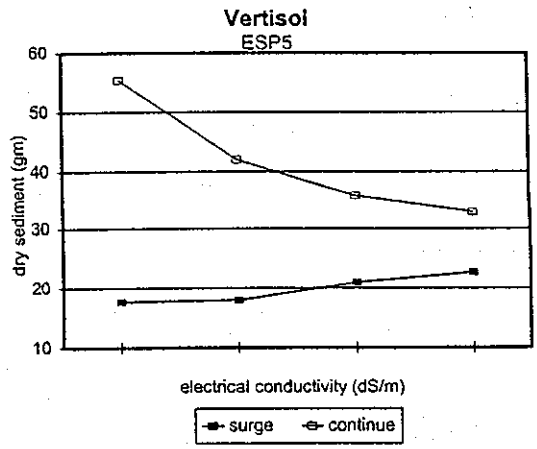


Fig.5

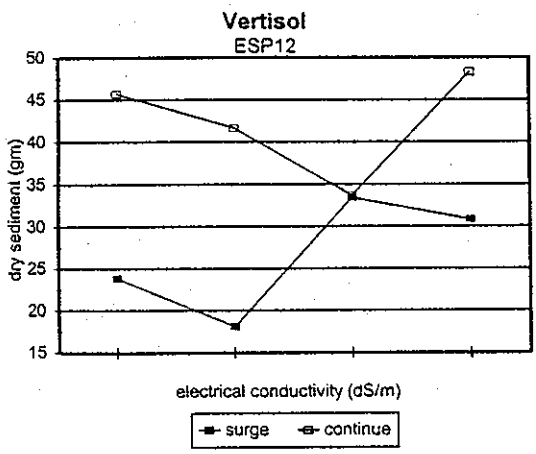
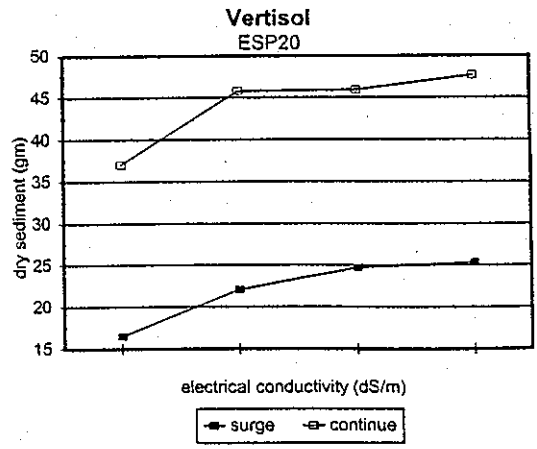


Fig.6



44

INTAKE RATE

Fig 7

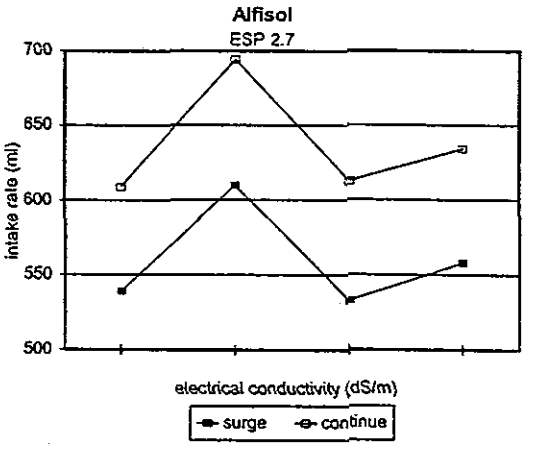


Fig 8

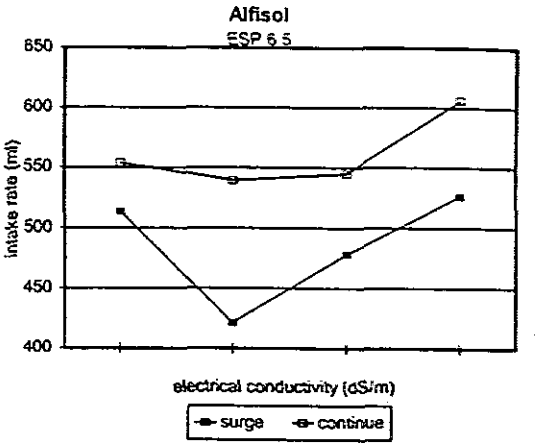


Fig 9

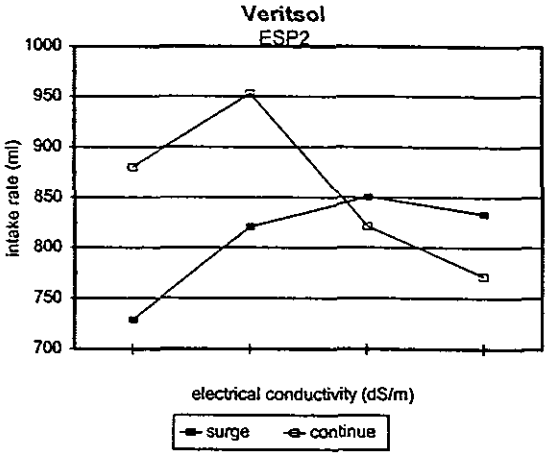


Fig 10

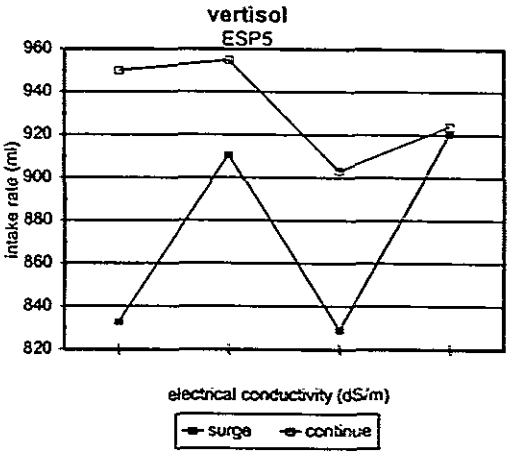


Fig 11

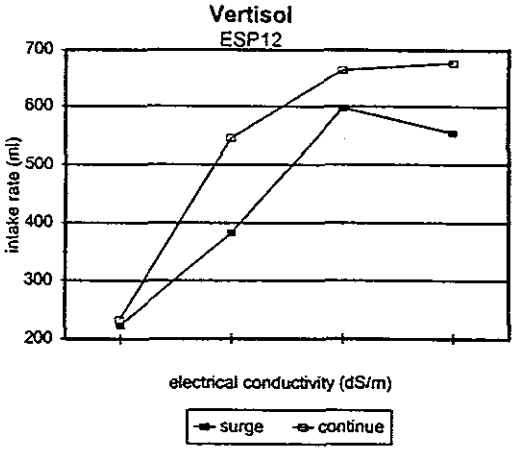
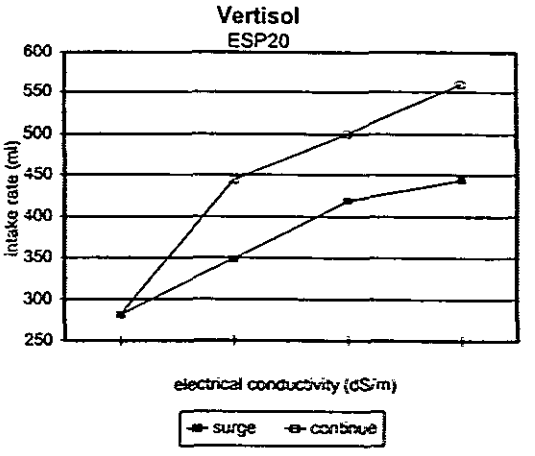


Fig 12



45

Appendix 5: Soil sodicity, Water guality and Interrupted Flow Effects on Rill Erosion and Intake Rate in Soils from Kyrgyzstan

N. Sharshekeev and G.L. Zhuravskaya

ABCTRACT

The effect of interaction between water flow characteristics, soil sodicity and water quality on the rill erosion and intake rate was studied in the laboratory. Specific objectives of these study were to evaluate: (i) the use interrupted flow for reducing soil erosion and intake rate, (ii) the effect of soil sodicity (exchangeable sodium percentage [ESP]) and water quality (0.01, 0.95, 2.0 and 4.0 dS m^{-1}) on the soil erosion and intake rate. Rill erosion in two ESP levels under the surge irrigation decreased soil loss for all water qualities compared with continuous flow. Decreasing soil loss was more effective in ESP 0.39%. The IR was more sensitive to the sodicity and water quality, but the surge irrigation reduced IR only slightly in ESP 5.67% and had no effect in ESP 0.39%.

INDRODUCTION

Surfase irrigation is the most used 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 IR and improve the efficiency of surface irrigation by increasing field water application uniformity.

Several studies have been conducted to determine the processes acting during the interruption of flow (Izuno et.al, 1985; Jalali-Farahani et al, 1993; Kemper et al., 1988; Samani et al., 1985; Trout, 1991) and basic phenomena have been identified: (i) moisture redistribution in the soil profile; and (ii) consolidation of the soil near the soil surface. During the interruption application, water drainage into the underlying dry soil and moisture redistribution result in the development of negative pressure suction near soil surface. This negative pressure increases forses that pull water into the soil during the next flow period (Samani et al., 1985), and should increase the IR. However, the development of negative pressure in the soil surface during flow interruptions, consolidates the soil near the rill surface, increases surface bulk density, and reduces the 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 Jalili-Farahani et al. 1993 Samani et al., 1985).

An additional important mechanism controlling IR in furrow irrigation, which is necessarily related to interrupted irrigation, is the formation of depositional seal at the furrow perimeter. The HC of depositional seals has been reported to be two-to-three orders magnitude lower than that of the underlying soil (Shainberg and Singer, 1985). Trout (1991) observed a 50% reduction in infiltration in the Portneuf silt loam during interrupted irrigation, and ascribed it to surface seal formation. The hydraulic conductivity of the depositional seal depends on the size and mineralogy of the sediment particles and on the electrolyte concentration of the water (Shainberg and Singer 1985). Thus, the effect of electrolyte concentration on the IR varies from one irrigation scheme to another. The permeability of the soil also depends on the exchangeable sodium percentage (ESP) of the soil, tending to decrease with increasing ESP and decreasing salt concentration (Agassi, Shainberg, and Morin, 1985; Quirk and Schofield, 1955; McNeal et al., 1968).

Miniflumes have been used to evaluate the interaction between flow characteristics, soil properties and water quality on rill erosion in the laboratory (Shainberg et al, 1994; Shainberg et al, 1996). The rill erodibility data obtained with the miniflumes agreed well with field data (Shainberg et al, 1994). Using miniflumes Shainberg et al (1996) studied rill erosion in an alfisol and a vertisol, and found that rill erosion decreased with aging of several hours and that it dependent on water content in the soil. These researches postulated that aging and water tension enhanced clay to clay contacts, increased the cohesive forces between soil particles and led to reduction in rill erosion. It was hypothesized (Sirjabobs et al., 1999), that the miniflumes would also be used to study the processes that operate in interrupted irrigation.

Soil sodicity and water quality may also influence the sediment transport capacity of the furrow stream. Water quality affected flocculation, which determined the size and density of detached soil material (Arora and Coleman, 1979; Goldberg and Glaubig, 1987). Gerard (1965) found that increasing Na saturation of the exchange complex of a fine sandy loam from 1.2 to 13.5% increased the tensile strength of the soil by 50%. Dowby and Larson (1971) and Warkentin and Yong (1962) showed that shear strength of Na montmorillonite was greater greater than comparable Ca-saturated cores.

Sirjacobs et al (1999) found that significant reduce rill erosion by consolidating the soil surface. When depositional seal is formed and effect of interrupted flow in consolidating the rill surface and reducing IR is predominant.

The objective of the present study was to investigate the effect of water quality and ESP on IR and rill erosion, in continuous and interrupted flow.

MATERIALS AND METHODS

SOILS

A soil Serozem-meadow from northern part and Kastanosem from southern part of Chuy valley Kyrgyz Republic were chosen for this study. The levels of exchangeable sodium percentage of the kastanosems soil was 0.39%. The ESP values of the serosem soil sample was 5.67%. Some basic physical and chemical properties of the soils are given in Table.1

Table 1

Some basic physical and chemical properties of the soils used.

Soil	Particle-size distribution			CEC	ESP	OM
	Clay	Silt	Sand			
	%	%	%	meq/100gm	%	%
Kastanosem	23.1	61.2	15.7	16.18	0.39	3.2
Serosem	25	37.9	36.6	11.41	5.67	0.88

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 1.31 Mg mm^{-3}. 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 Mario bottle 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 Mario bottle with water solution reserve was placed on an electronic balance, and the change in weight with time were recorded.

Four different levels of water salinity were studied. The electrical conductivity (EC) of the waters was used 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 ($CaCl_2$) were used to prepare these water 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 1 min of flow; and 10 min of off time. 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 320 mL m^{-1}. 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 for 6 min 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. Three replicates were performed for each treatment.

RESULTS

Effect of water quality and type of irrigation on rill erosion

The effect of interrupted flow on rill erosion rate for serozem-medow and kastanosems soils are presented in figures 1 and 2 and tables 2-5. For both soils, most of the erosion process took place during the first 4 min (stage 1 of the experiment), when high flow rates exerting high shear stresses were used. No significant effect of interrupted flow on rill erosion in the ESP 5.67% was observed in this experiment, although the trends were in the same direction as those noted in the ESP 0.39%.

The effect of water quality (0.01[DW], 0.95[TW], 2.0[SW-2] and 4.0[SW-4] dS m^{-1}) on rill erosion by the surge and continuous flow were studied. When ESP was 5.67% increasing the electrolyte concentration from 0.01 to 0.95 dS m^{-1}, unchanged the erosion process for continuous and interrupted flow, and was slightly increased by continuous flow when electrolyte concentration increased to 2.0 and 4.0 dS m^{-1} Fig (1 and 5). However, in the interrupted flow with the same ESP effect of electrolyte concentration had conversely action on the same range Fig 5. The increase of the electrolyte concentration in the ESP 0.39%, increased the rill erosion for interrupted flow, and not affect on the soil in the continuous flow.

The results with low ESP soils are explained by following observations. At low ESP levels for continuous and interrupted flow, spontaneous dispersion dos not occur (Rengassamy 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 erosion process for both flow type of irrigation

Effect of sodicity on rill erosion

The effect of ESP on the soil erodibility is presented in Fig. 5. It is evident that rill erosion decreased with an increase in soil ESP for both type of flow. Our results are explained by following observations. Gerard (1965) found that increasing Na saturation of the exchange complex of a fine sandy loam from 1.2 to 13.5% increased the tensile strength of the soil by 50%. Dowdy and Larson (1971) and Warkentin Yong (1962) showed that shear strength of Na-montmorolonite was greater than comparable Ca-saturated cores. Soil structure research by Kemper and Koch (1966) and many others have shown that aggregate stability is directly related to soil clay content and increasing clay content increases the strength by which soil particles are bonded into aggregates. Soil strength and aggregate stability increase with better mineral to mineral contact, facilitating fusion-type mineral bonding in low organic matter soils (Kemper et al., 1987). Increases in soil ESP in the range between 0 and 10% apparently increases clay dispersion and improves the contacts between clay particles, sufficient to increase the soil tensile strength. It was noted in the continuous and surge irrigation at the ESP5.67%.

Effect of water quality and flow type on intake rate

The data from all experiments are given in tables 6-9. The effect of electrolyte concentration (0.01[DW], 0.95[TW], 2.0[SW-2] and 4.0[SW-4] dS m^{-1} on intake rate under the interrupted and continuous flow were studied. When ESP of the soils was 0.39% increasing electrolyte concentration from 0.01 to 2.0 dS m^{-1} increased IR of the soil for continuous flow and was unchanged when water concentration was 4.0 dS m^{-1} Fig. Interrupted flow had the same tends but it stopped an increase of IR in range from 0.95 to 2.0 dS m^{-1} (Fig.4 and 6) continued increase to 4.0 dS m^{-1}. The electrolyte concentration had small conversely action in ESP 5.67% for continuous and interrupted flow. Type of irrigation for both ESP had small effect in decreasing IR. It is evident that IR was not pronounced dependence of the electrolyte concentration and flow type.

Effect of sodicity on Intake rate

Comparing action of ESP on the intake rate we observed following data When ESP of the soil was 0.39% its IR for all water qualities and flow type except for DW was high if compare with ESP 5.67% (fig. 6). When distilled water is applied to a soil, even with levels of exchangeable sodium, chemical dispersion of the soil clay also occurs, the dispersed clay particles are washed into the soil with the infiltrating water, and the pores immediately beneath the surface become clogged. It explains why IR by distilled water was independent of the ESP of the soil. The effect of interaction between the electrolyte concentration and the ESP is also seen when salinity waters are used (Fig. 6). A concentration of 0.95 dS m^{-1} is enough to decrease the chemical dispersion in soil with ESP 0.39% for all water type of irrigation. For ESP 5.67% responded to the electrolyte concentration of the applied water, as expected, however, soil with ESP 0.39% was more responsive to the electrolyte concentration of the applied water than soil with ESP 5.67%. The presence of electrolytes in the solution prevented the chemical dispersion of the soil aggregates, and IR was maintaining at high values.

SUMMARY

The effects of ESP, water quality and interrupted flow on intake rate and rill erosion in serozem-meadow and kastanosem soils were studied, using miniflumes.IR

reduced when ESP was increasing by interrupted and continue flow. The increasing the electrolyte concentration of water had small effect on the intake rate and soil erosion. Type of irrigation for both ESP had small effect in decreasing IR. However, interrupted flow reduced rill erosion for both ESP compared with continuous. This reduction was more effective in the 0.39%ESP than in the ESP 5.67%.

References

Agassi, M., J. Morin and I. Shainberg.1985. Effect of raindrop impact energy and water salinity on infiltration rate of sodic soils. Soil Sci. Soc. Am. J. 49: 186-190

Kemper, W.D., R.C. Roseneau, and S. Nelson.1985. Gas displacement and agregate stability of soils. Soil Sci. Soc. Am. J 49:25-28

Kemper, W.D., and R.C. Roseneau. 1984. Soil cohesion as affected by time and water content. Soil Sci. Soc. Am. J. 49:25-28

Kemper, W.D., T.J. Trout, and A.S. Humphreys. 1988. Mechanisms by which surge irrigation reduces furrow infiltration rates in a silty loam soil. TRANS ASAE 31;821-829

D. Sirjacobs, I. Shainberg, I. Rapp, and G. J. Levy. 2000. Polyacrylamide, Sediments, and Interrupted Flow Effects on Rill Erosion and Intake Rate. Soil Sci. Soc. Am. J. 64:1487-1495

Shainberg, I., and M.J. Singer. 1985. Effect of electrolyte concentration on hydraulic properties of depositional crust. Soil Sci. Soc. Am.J. 49: 1260-1263.

Shainberg, I., D. Goldstein, and G. J. Levy. 1996. Rill erosion dependence on soil water content, aging and temperature. Soil Sci. Soc. Am. J. 60:916-922

Soil loss

Kastanosem soil

Table 2

Time, min	SURGE IRRIGATION							
	0,01 dS/m		0,95 dS/m		2,00 dS/m		4,00 dS/m	
	ESP 0,39	STDV	ESP 0,39	STDV	ESP 0,39	STDV	ESP 0,39	STDV
1	4,83	1,12	3,68	0,69	3,09	0,49	4,70	1,21
2	2,05	0,73	2,03	0,54	2,46	0,82	2,55	0,31
3	0,89	0,39	1,08	0,55	1,25	0,67	1,60	0,13
4	0,60	0,31	0,82	0,49	0,81	0,51	1,57	0,59
5	0,03	0,02	0,08	0,03	0,10	0,06	0,09	0,01
6	0,03	0,03	0,11	0,06	0,10	0,04	0,15	0,03
7	0,05	0,05	0;10	0,06	0,12	0,05	0,14	0,03
8	0,08	0,07	0,06	0,03	0,10	0,02	0,28	0,06
9	0,08	0,06	0,07	0,05	0,79	1,08	0,23	0,10
10	0,07	0,03	0,06	0,03	0,13	0,09	0,42	0,13
Total	8,70	2,44	8,09	1,64	8,94	1,76	11,73	2,61

Table3

Time, min	CONTINUE IRRIGATION							
	0,01 dS/m		0,95 dS/m		2,00 dS/m		4,00 dS/m	
	ESP 0,39	STDV	ESP 0,39	STDV	ESP 0,39	STDV	ESP 0,39	STDV
1	4,70	0,53	4,52	0,76	4,23	0,22	2,98	0,34
2	3,19	1,72	4,70	0,97	3,08	0,74	4,77	0,81
3	3,19	1,07	4,99	1,29	3,81	0,94	5,01	0,87
4	2,57	0,50	4,42	0,32	4,06	1,51	6,02	0,65
5	0,12	0,09	0,37	0,10	0,45	0,42	1,18	0,91
6	0,07	0,06	0,17	0,01	0,31	0,31	0,20	0,05
7	0,10	0,10	0,25	0,09	0,21	0,08	0,15	0,07
8	0,14	0,10	0,15	0,05	0,30	0,30	0,21	0,11
9	0,14	0,13	0,37	0,20	0,48	0,40	0,27	0,16
10	0,12	0,10	0,41	0,28	0,50	0,37	0,19	0,09
Total	14,34	2,70	20,36	2,63	17,42	4,37	20,97	1,44

Soil loss

Serosem-meadow soil

Table4

Time, min	SURGE IRRIGATION							
	0,01 dS/m		0,95 dS/m		2,00 dS/m		4,00 dS/m	
	ESP 5.67	STDV	ESP 5.67	STDV	ESP 5.67	STDV	ESP5.67	STDV
1	2,86	0,75	2,80	0,74	2,31	0,69	2,46	0,20
2	0,36	0,24	0,18	0,09	0,33	0,23	0,15	0,06
3	0,13	0,08	0,09	0,03	0,09	0,03	0,11	0,03
4	0,10	0,05	0,07	0,03	0,05	0,05	0,09	0,03
5	0,01	0,01	0,01	0,01	0,01	0,01	0,03	0,03
6	0,01	0,01	0,02	0,01	0,00	0,01	0,02	0,03
7	0,01	0,00	0,02	0,02	0,02	0,02	0,03	0,03
8	0,01	0,01	0,02	0,01	0,02	0,01	0,03	0,02
9	0,01	0,01	0,01	0,01	0,02	0,01	0,03	0,03
10	0,01	0,01	0,02	0,01	0,01	0,01	0,02	0,02
Total	3,50	0,36	3,24	0,76	2,85	0,34	2,97	0,45

Table5

Time, min	CONTINUE IRRIGATION							
	0,01 dS/m		0,95 dS/m		2,00 dS/m		4,00 dS/m	
	ESP 5.67	STDV	ESP 5.67	STDV	ESP 5.67	STDV	ESP 5.67	STDV
1	2,22	0,19	2,34	0,30	2,69	0,50	2,60	0,05
2	0,24	0,18	0,37	0,10	0,43	0,05	0,27	0,10
3	0,09	0,03	0,19	0,09	0,26	0,09	0,34	0,05
4	0,18	0,16	0,21	0,08	0,20	0,10	0,32	0,04
5	0,03	0,02	0,06	0,02	0,09	0,09	0,11	0,02
6	0,01	0,01	0,02	0,01	0,03	0,01	0,09	0,03
7	0,00	0,01	0,02	0,01	0,03	0,01	0,09	0,03
8	0,00	0,01	0,01	0,01	0,03	0,01	0,09	0,03
9	0,00	0,00	0,01	0,02	0,02	0,02	0,08	0,01
10	0,00	0,01	0,02	0,01	0,05	0,02	0,29	0,27
Total	2,78	0,34	3,25	0,13	3,82	0,46	4,27	0,36

Intake rate

Kastanozem soil

Table 6

Time, min	SURGE IRRIGATION							
	0,01 dS/m		0,95 dS/m		2,00 dS/m		4,00 dS/m	
	ESP 0,39	STDV	ESP 0,39	STDV	ESP 0,39	STDV	ESP 0,39	STDV
1	125,26	12,26	162,20	17,73	203,46	8,12	179,52	23,12
2	34,32	3,11	47,61	2,82	53,79	2,53	52,31	4,51
3	26,08	4,47	39,65	4,87	46,93	1,76	48,34	1,75
4	22,87	1,06	39,53	2,55	47,81	2,09	42,78	1,43
5	21,06	3,00	32,71	3,43	37,33	0,70	42,54	1,40
6	6,08	1,52	16,89	1,56	16,35	3,61	16,68	1,29
7	8,32	2,09	16,79	4,86	15,22	2,73	19,04	1,87
8	6,69	2,90	13,76	1,52	16,83	3,24	16,79	3,97
9	5,23	1,66	12,22	2,67	15,88	1,73	18,58	2,29
10	4,52	1,16	10,81	1,21	7,60	3,53	11,97	0,03
Total	260,45	25,09	392,17	35,06	461,20	7,14	448,55	17,10

Table 7

Time, min	CONTINUE IRRIGATION							
	0,01 dS/m		0,95 dS/m		2,00 dS/m		4,00 dS/m	
	ESP 0,39	STDV	ESP 0,39	STDV	ESP 0,39	STDV	ESP 0,39	STDV
1	135,30	22,52	165,12	4,66	163,43	23,62	219,66	27,61
2	37,89	2,70	60,50	1,44	55,64	2,98	62,60	3,86
3	30,42	5,75	34,15	1,38	36,33	9,50	47,63	3,75
4	14,07	4,73	30,19	2,14	32,81	9,82	38,17	8,40
5	16,50	12,15	24,57	6,18	26,87	7,24	29,91	6,29
6	26,07	11,13	27,73	2,26	27,31	3,99	33,59	3,14
7	12,17	2,28	25,37	1,91	24,52	2,76	30,57	0,60
8	16,33	3,25	24,45	1,63	22,59	2,16	29,93	1,53
9	13,02	1,67	23,33	1,75	23,85	0,87	29,45	2,72
10	8,79	2,54	18,83	3,89	15,73	1,18	21,87	1,41
Total	310,58	18,15	434,24	18,09	429,08	43,73	543,38	35,30

Intake rate

Serosem-meadow soil

Table 8

Time, min	SURGE IRRIGATION							
	0,01 dS/m		0,95 dS/m		2,00 dS/m		4,00 dS/m	
	ESP 5.67	STDV	ESP5.67	STDV	ESP5.67	STDV	ESP 5.67	STDV
1	127,80	20,49	103,90	10,51	129,11	36,91	87,89	15,93
2	37,94	3,22	39,11	5,02	59,11	31,13	31,21	5,59
3	36,54	3,21	41,74	16,06	34,40	13,01	22,44	3,53
4	35,21	3,77	26,54	12,23	35,61	11,48	23,04	3,28
5	30,01	4,39	29,33	1,81	29,04	3,33	21,80	5,93
6	13,09	1,29	16,76	1,94	12,53	3,75	9,85	4,73
7	13,69	0,78	16,54	3,36	12,46	3,34	9,31	4,14
8	14,36	1,73	16,86	0,63	11,70	5,06	11,15	5,01
9	13,07	0,46	14,14	2,79	11,26	5,46	8,41	1,66
10	10,09	6,37	9,93	1,13	11,34	5,73	9,22	2,98
Total	331,81	27,07	314,86	32,31	346,56	46,89	234,32	27,27

Table 9

Time, min	CONTINUE IRRIGATION							
	0,01 dS/m		0,95 dS/m		2,00 dS/m		4,00 dS/m	
	ESP 5.67	STDV	ESP 5.67	STDV	ESP 5.67	STDV	ESP 5.67	STDV
1	118,69	17,21	96,08	3,96	126,99	9,38	74,72	8,31
2	40,52	5,62	36,88	5,44	31,44	4,66	30,18	1,35
3	25,56	8,99	24,19	1,95	24,54	5,16	24,65	3,46
4	23,27	9,24	25,42	2,70	19,99	6,34	23,11	4,75
5	11,68	2,52	8,72	3,48	11,99	3,63	19,20	5,87
6	15,50	1,97	16,26	0,73	15,14	2,16	15,38	4,88
7	15,31	0,37	14,09	2,12	13,48	3,75	15,45	0,87
8	14,12	1,55	14,67	2,55	12,02	0,87	12,60	0,93
9	13,62	0,85	12,62	1,02	12,38	3,46	13,94	2,64
10	8,39	0,69	6,23	1,44	5,12	2,90	10,21	1,47
Total	286,66	12,68	255,17	13,27	273,10	17,14	239,43	7,21

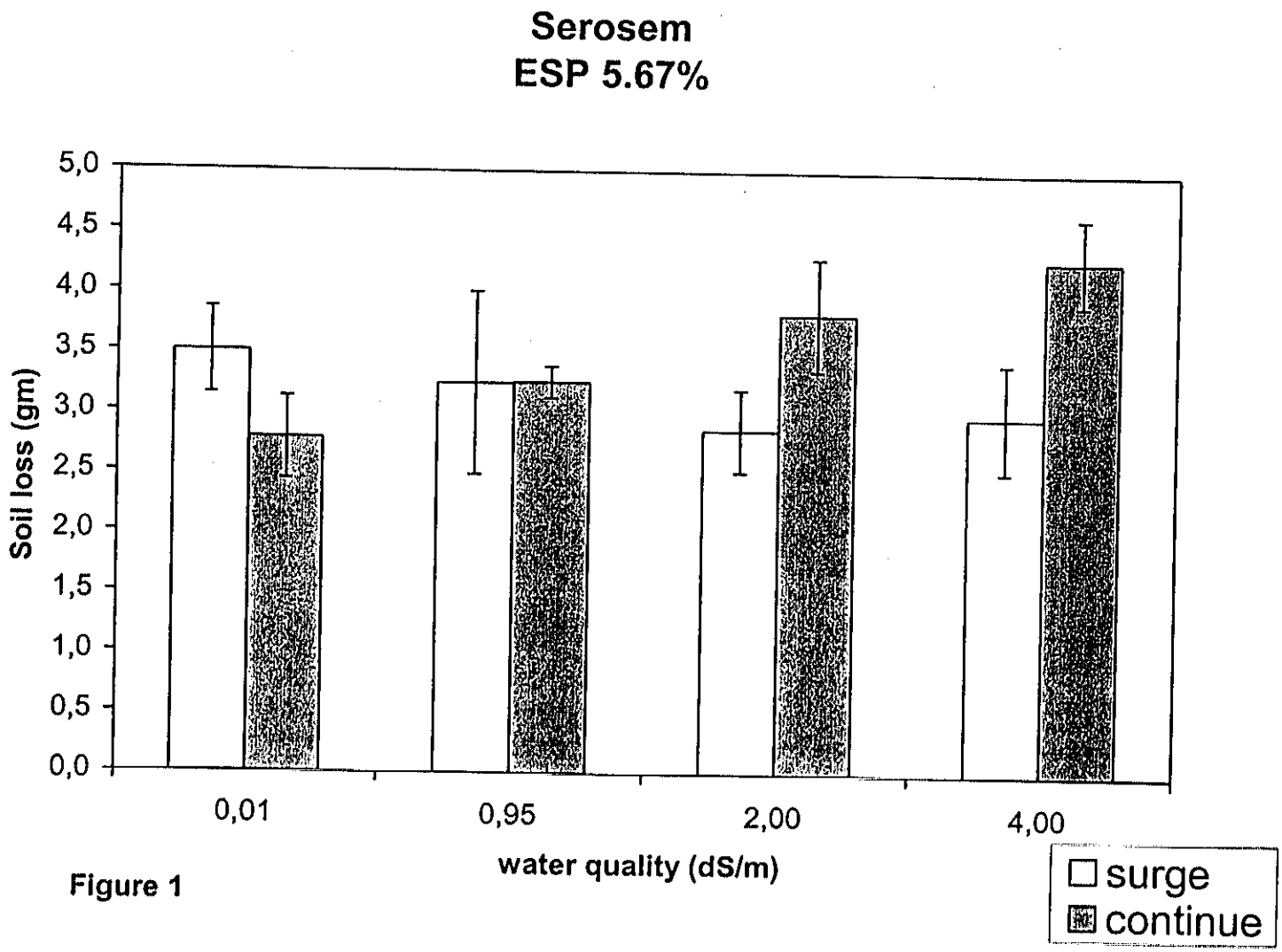

Serosem
ESP 5.67%
Soil loss (gm)
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,01
0,95
2,00
4,00
water quality (dS/m)
surge
continue

Figure 1

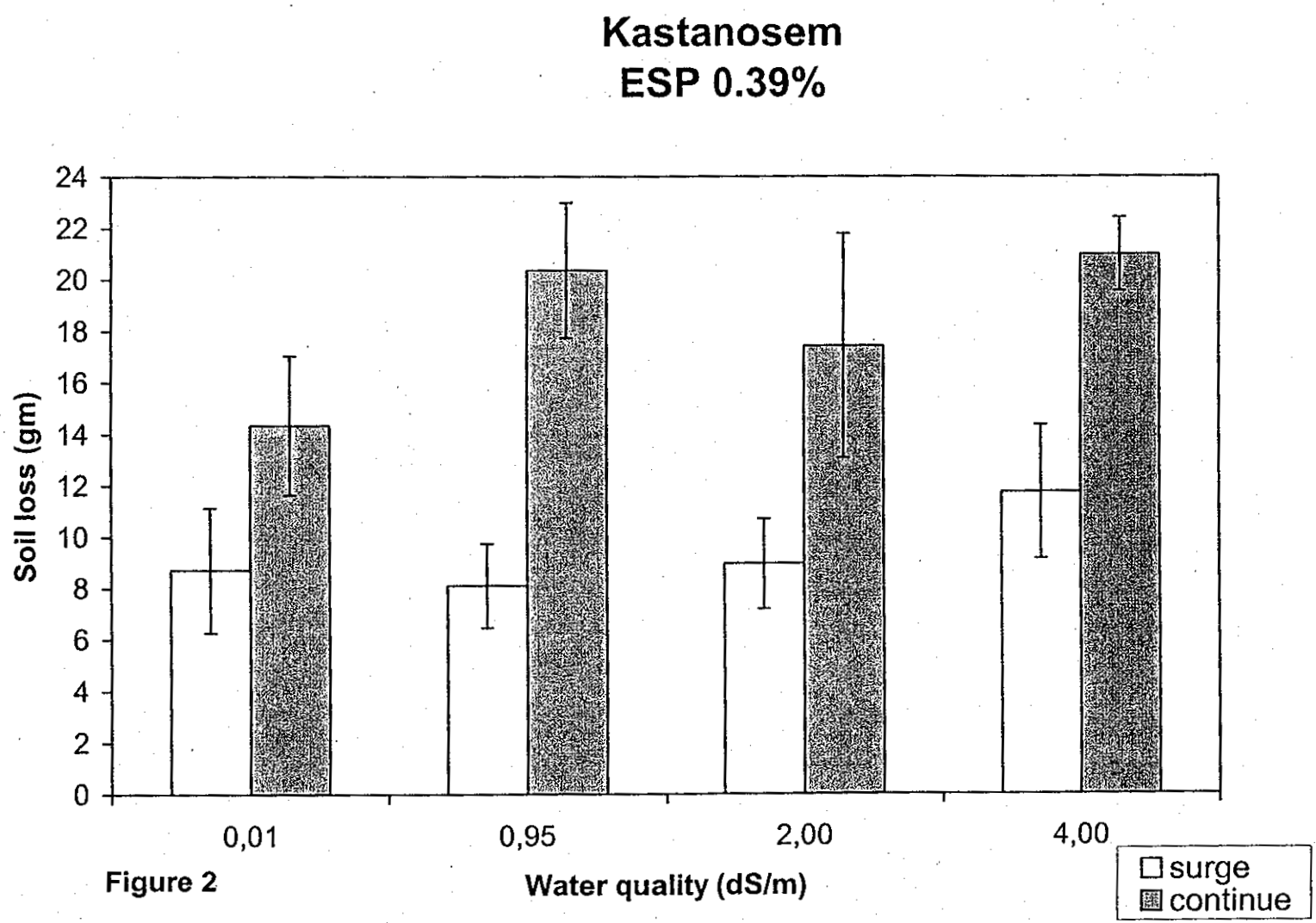

Kastanosem
ESP 0.39%
Soil loss (gm)
24
22
20
18
16
14
12
10
8
6
4
2
0
0,01
0,95
2,00
4,00
Water quality (dS/m)
surge
continue

Figure 2

56

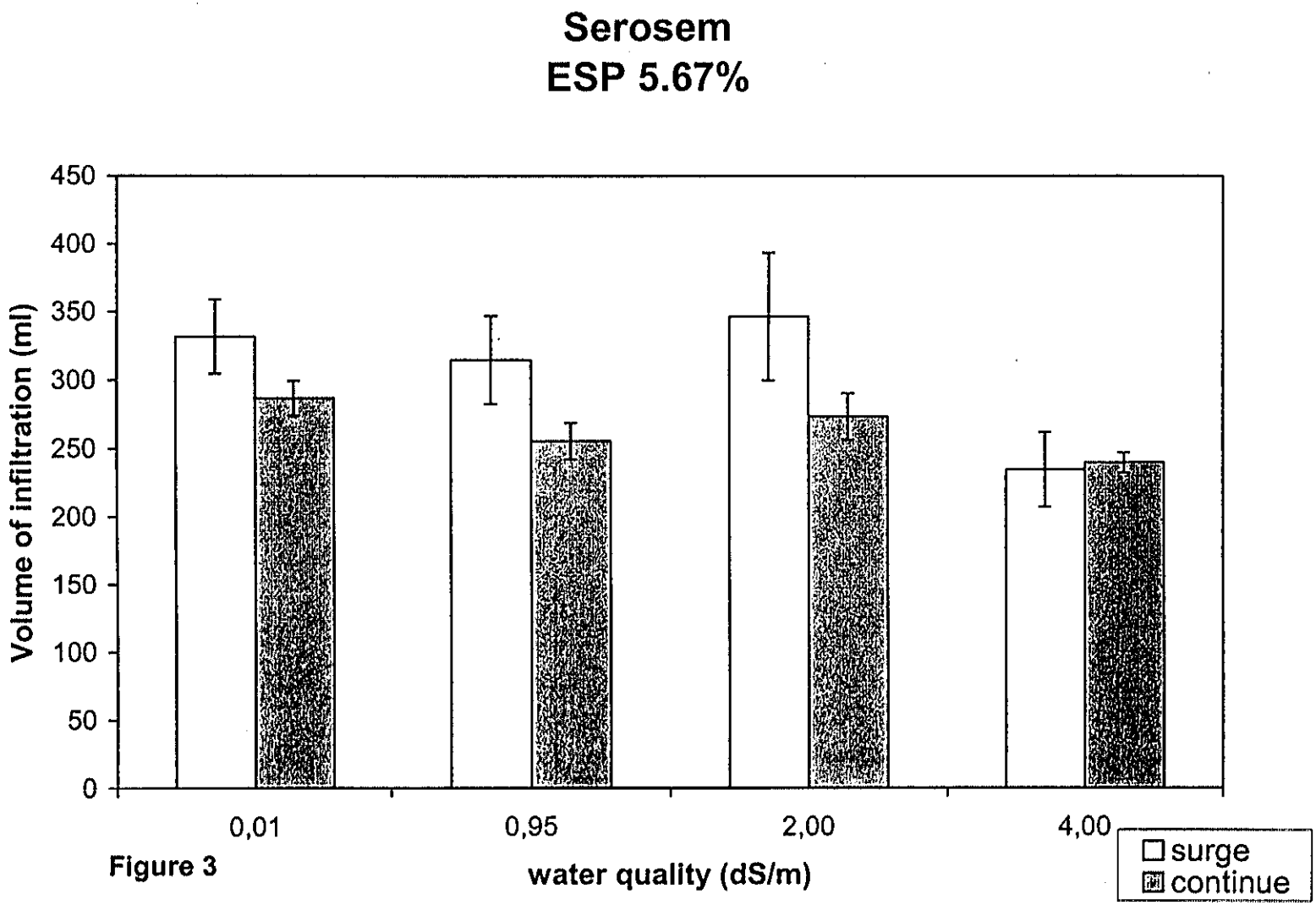

Serosem
ESP 5.67%
Volume of infiltration (ml)
450
400
350
300
250
200
150
100
50
0
0,01
0,95
2,00
4,00
water quality (dS/m)
surge
continue

Figure 3

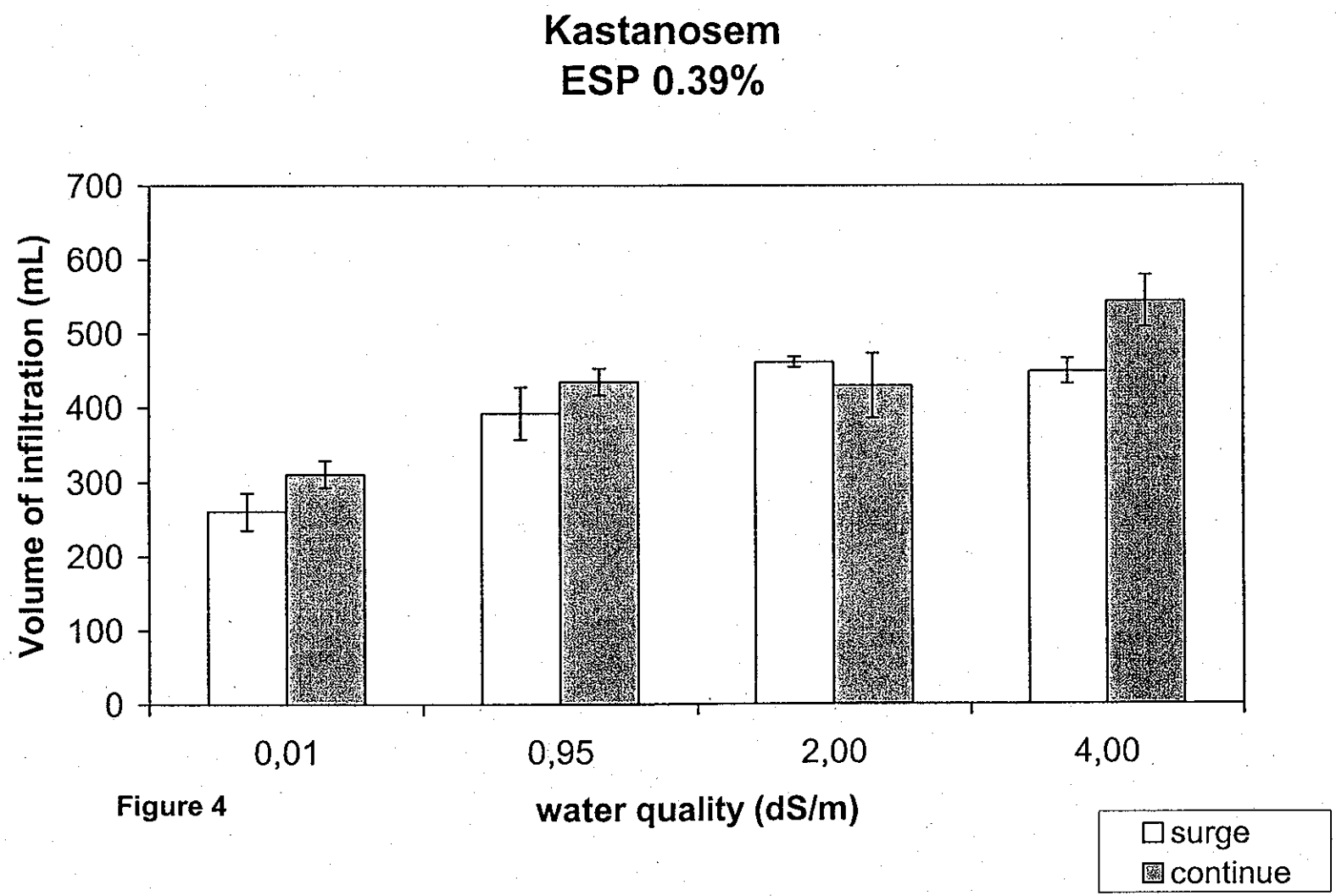

Kastanosem
ESP 0.39%
Volume of infiltration (mL)
700
600
500
400
300
200
100
0
0,01
0,95
2,00
4,00
water quality (dS/m)
surge
continue

Figure 4

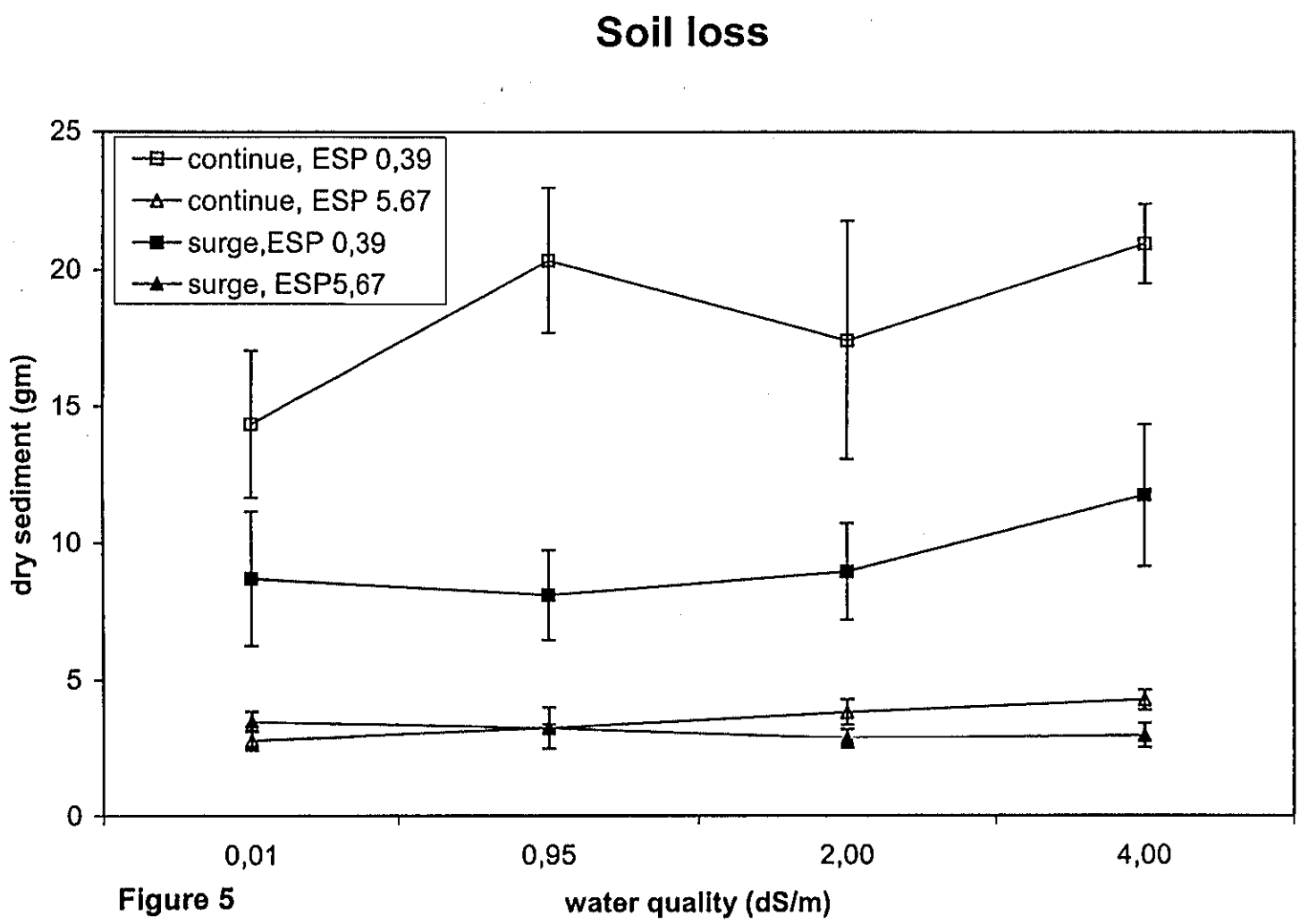

Soil loss
continue, ESP 0,39
continue, ESP 5.67
surge,ESP 0,39
surge, ESP5,67
dry sediment (gm)
25
20
15
10
5
0
0,01
0,95
2,00
4,00
water quality (dS/m)

Figure 5

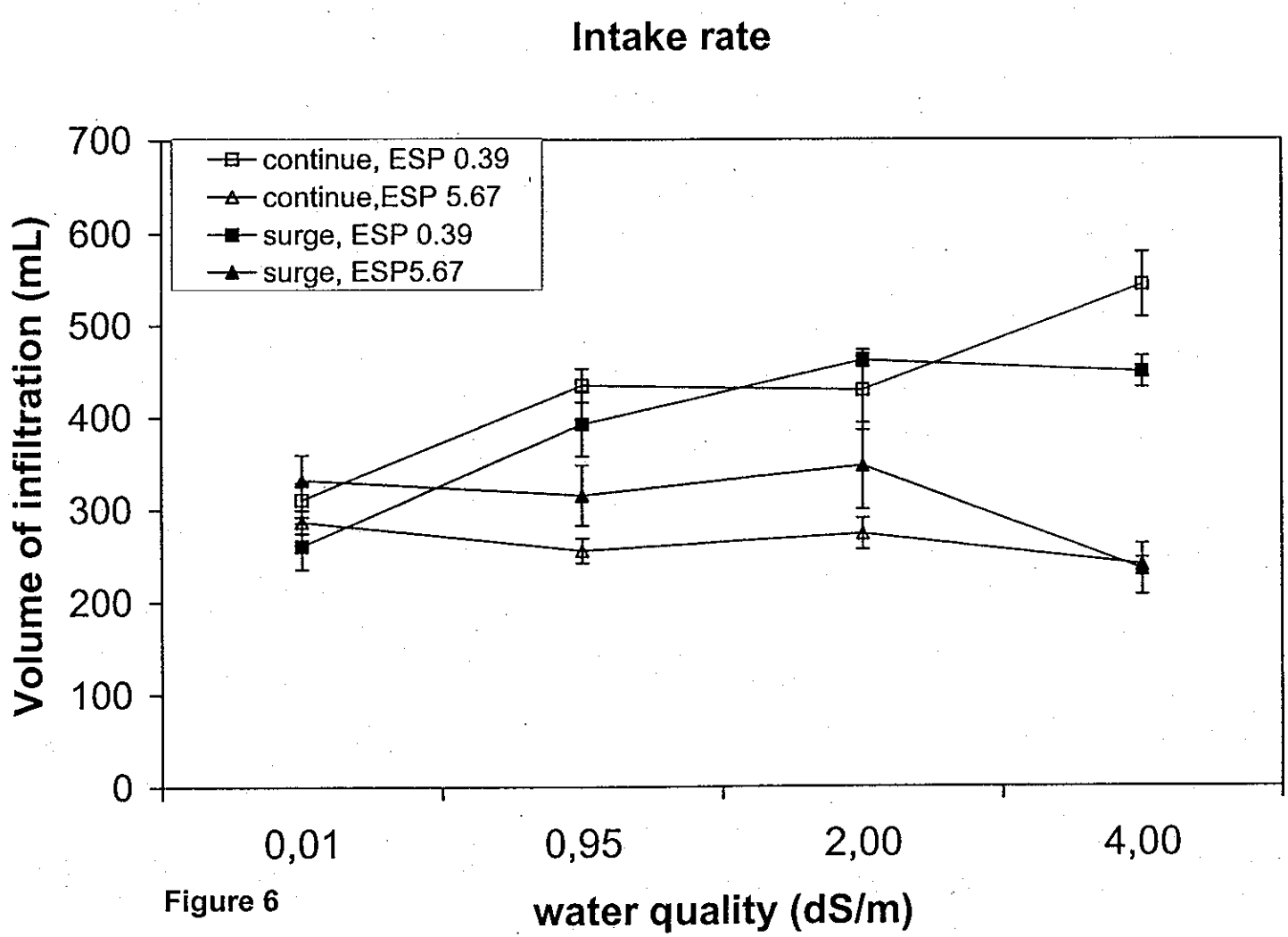

Intake rate
continue, ESP 0.39
continue,ESP 5.67
surge, ESP 0.39
surge, ESP5.67
Volume of infiltration (mL)
700
600
500
400
300
200
100
0
0,01
0,95
2,00
4,00
water quality (dS/m)

Figure 6

USA - ISRAEL - KYRHYZSTAN

APPENDIX 6

"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. Zhuravskaya

Bisnkek 2002

INTRODUCTION

The question application of polyacrylamide (PAM) in an agriculture is not new. The first researches on application PAM for formation of soil structural were conducted in USA in 40 years of the last century. Then was marked, that PAM is most often used preparation in foreign researches for these purposes. Later N. A. Kachinski /1/ confirms, that PAM gives strongest structure forming effect. Applying artificial the structure formational for saturation of natural particles, he has received a increase of quantity steady for water of particles on 67 %.

Data received by E. A. Aripov /2/ K. C. Ahmedov /3 /, V. P. Batuk/4 /, D. Icmatov /5 /, I. V. Matoshko /6/ T. B. Mahlin /7 /, I. A. Romanov /8,9 /, L. H. Taimurzaev /10 /, I. Eshanov /11/ and many others, showed, that with PAM application in soil the quantity of a firm for water of particles is increased and a resistance of soil to erosion, are increased an infitrability of soil and, due to improvement of water-physical properties it, the productivity of agricultural cultures raises. In all described cases, PAM has improved conditions for growth of plants: density of soil has decreased, the soil structure, water and thermal modes of soil were improved, more favorable became conditions for development of microbiological activity and education of nutritious substances accessible to plants. On words of Academician D. L. Turin, the effective use of the artificial the structure - formational in an agriculture, would be the same revolutionary achievement, as opening of mineral fertilizers by Libih.

However, recommended for formation of the structural arable layer a doze PAM reached 1-1,5 t/hec /12/ and there was no less than 0,015 % from weights of air-dry soil. That is for formation of the structural only top 10-cm layer in irrigated area is required not less than 250 kg / hec, that is equivalent to a doze of used fertilizers.

The new Israeli technology differs by Pam's doze: the polyacrylamide at concentration of 10 g/m^3 moves with irrigation water at first irrigation and only until the entire furrow is wetted. The expenditure of PAM has made 2 kg on 1 hectare of irrigated area in the researched us conditions. As have shown our researches during last of five years, structure - forming the effect of PAM was preserved to the end irrigation period, the efficiency of application of polymer amplified at surge technology of irrigation and disappeared at machining to soil.

1. Conditions for realization of the field experiments 2002

The field experiments 2002 were conducted at the upper part plot for field experiments 2001. We realized the one irrigation for a moistening and the four experimental irrigation. Making use of PAM that will in stock from last year, we did not receive of PAM's effect in period the first irrigation. Therefore we repeated an use of other PAM for the second irrigation. This other PAM was in concentrated solution.

The results that we received in 2001 and 2002, do not complement each other. Practically we had the other conditions in 2002 for soil (HC), a weather and a sort of maize even. Twice a rain was watering together with us (the second and the fourth irrigation). Only the third irrigation went without problems and calmly.

We were studying:

1. The effect of surge irrigation on furrow erosion and infiltration raters (IR).
2. The effect of PAM on furrow erosion and IR.
3. The interaction between surge irrigation and PAM in their effects on erosion and IR.
4. The effect of surge irrigation and PAM treatment on water content in the profile along the furrows.

A depth of soil moistening was determined before the first irrigation, after the first irrigation, before the second irrigation and after the second irrigation at the variants of experience and on distance 20 m, 75 m, 130 m from beginning of furrow.

1.1. General conditions for realization of the field experiments in 2001 and 2002.

1. The field experiments were made on peasant farm "Ulan".
2. Experimental area had thickness soils; underlying bed consists of gravel and course gravel from a depth more 3 m.
3. Experiments were conducted with an agricultural culture.
4. The maize were sowed very densely and the space between furrows was made 60 cm.
5. We could determine a productivity of the green mass and the maize on grain.

1.2. Distinctive features of conditions for realization of the field experiments in 2002.

1. The maize for popcorn were sowed of June 4. The sowing will be made late, as April and May 2002 were rainy very.
2. June was rainy also, July and August stood out by unsettled weather and were characterized with rare precipitation and 40^0's heat.
2. The first wetting irrigation was made of July 16 and 17. Then the weeds have went in active growth but a new plants of the maize appeared also. The weeding of the sowing was conducted two times by hand.
3. The cutting of the furrows was made on July 31 for experimental irrigation.
4. We conducted the first experimental irrigation of the maize on July 31 and August 1.

5. Length of an irrigated furrow was 150 m.

6. The sediment concentration in the irrigation water, which is given to the furrow, was not a constant value during vegetative period. It changed during the first irrigation, at the variants of experiment and from irrigation to irrigation.

7. The interruption at the water application was given after wetting by a jet of the entire furrow for two variants of surge irrigation (*surge irrigation* and *surge irrigation + PAM*). After the interruption at the water application, the irrigation was applied continuously with decreasing an inflow rate after 30 minutes.

The field experiments were finished October 20, 2002.

2. THE PREPARATORY WORKS AND THEM RESULTS

The preparatory works included:

1.The leveling of the area with the purpose to make more precise of the surface slope in the direction of the irrigation.

2.The determination of some physical and chemical properties of the irrigation water and irrigated soils of experimental plot.

3.The determination of the soil infiltration capacity.

4.The determination of the soil moisture content.

5.The conducting of test irrigation for more precise of the inflow rates value. However we did not realized the test irrigation. We accepted a results of test irrigation 2001.

2.1. Geodetic leveling of the area showed that a surface slops of a field fluctuated from 2,2% to 3,7% in the direction of the irrigation (Fig.1).

The mean the surface slops of the field was equal 3.0%. The mean slope for 2001 was 2.7%.

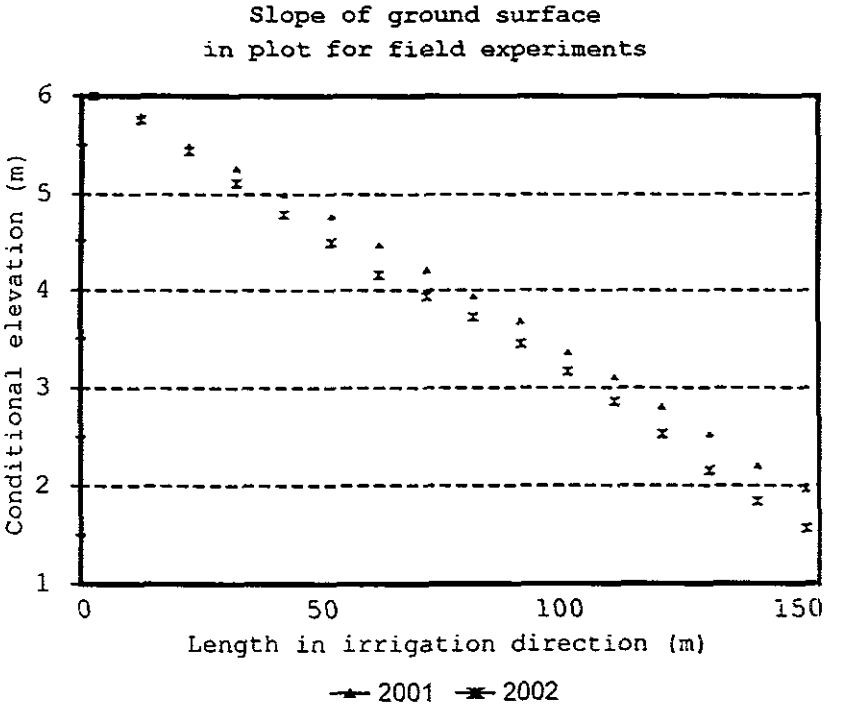


Fig. 1

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

The soil of plot belongs to light-chestnut mountain-flat of type. This type of old-irrigated soils characterized by rather high 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 three times. The results are presented on Table 1. The maximum field carrying capacity changes from 21,99% to 24,80% on the average for the soil stratum 0 … 150 cm. This is more high value than in 2001. The apparent density changes on the average from 1.40 g/cm^3 to 1.56 g/cm^3 and increases with depth [13].

Table 1

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

The depth of soil stratum, cm	The apparent density, g/cm^3	The maximum field carrying capacity, % (to weight)
0-30	1.40	24.34
30-60	1.48	21.99
60-90	1.52	24.08
90-120	1.56	24.74
120-150	*1.55**	24.80
0-150	1.50	23.99

* This is took conditionally

The soil of the plot were selected, were dried, were crushed and sifted through a sieve with diameter of the orifice 2 mm and were deliver to special chemical laboratory for more detailed study. Soil was characterized for their the basic chemical properties and soil texture. The irrigation water was selected and was deliver also to special chemical laboratory for the study. The results of these analyses are presented bellow (Tab.2, Tab.3). The soils of plot are not salinized. They are contained small number of soil particles with size less 0.01 (28.8%). Content of sand composed 35.20 %, clay is 41.1 % and silt is 23.7 %.

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
(The river Alamedin)

The year	PH	SAR	Chemical composition, meq/L						EC, meq/ L
			anion			cation			
			HCO_3	SO_4	Cl	Ca	Mg	Na	
2000	8.3	1.17	0.80	0.96	0.75	1.20	0.30	1.01	2.51
2001	7.8	0.45	0.61	0.56	0.03	0.70	0.20	0.30	1.20
2002	8.1	0.83	0.64	0.72	0.56	0.98	0.28	0.66	1.92
On the average	8.1	0.85	0.68	0.75	0.45	0.96	0.26	0.66	1.88

Table 3

THE SOIL CHEMICAL COMPOSITION OF THE PLOTS
(Name for nomenclature is the light kastanozem, classification is loam)

The year	PH	CEC	ESP, %	Chemical composition, meq/L						Organic mater, %
				anion			cation			
				HCO_3	SO_4	Cl	Ca	Mg	Na	
2000	8.1	1.25	4.00	0.40	0.56	0.29	1.00	0.20	0.05	3.2
2001	7.2	0.43	0.98	0.10	0.33	not	0.20	0.20	0.03	3.14
2002	7.3	1.07	8.41	0.51	0.33	0.23	0.65	0.33	0.09	1.18

Table 3a

THE SOIL PHYSICAL COMPOSITION OF THE PLOTS
(Name for nomenclature is the light kastanozem)

The year	Physical composition, %			Classification of N. A. Kachinski
	slim	silt	sand	
2000	18.10	66.20	15.70	silty clay
2001	13.16	52.20	34.64	sandy loam
2002	23.70	41.10	35.20	silty loam

2.3. Method for determination of a soil infiltration capacity.

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

The two frames were used for determination of the soil infiltration capacity in every variant:

1) a big frame is outward, protective frame, restricting spreading of the water from inward frame, its the diameter is 70 cm;

2) a small frame is inward, register frame, the diameter of the inward frame is 30 cm.

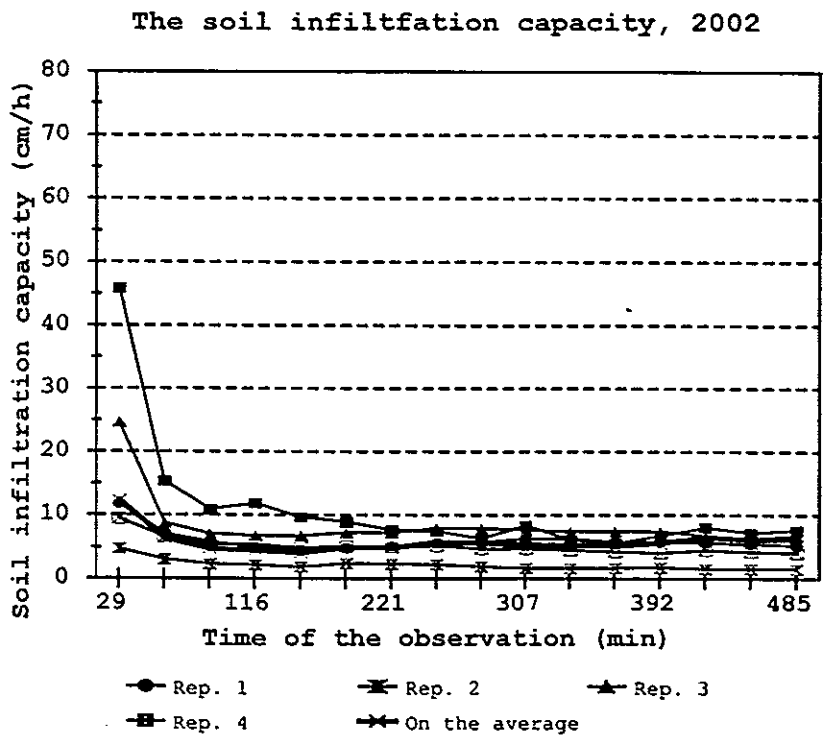
The determination of the infiltration capacity of the soil made with double control. The distance between control circles was equal 0.7 m.

At the first, we installed the big circle, then the small circle. The soil was press well from outward side of the circle. Into every circle installed a ruled line, with which took into account the level of the water for maintenance of the constant pressure its on surface of the soil. The pressure of the water was equal 8 cm. The protective and register circles poured simultaneously. With this moment we began to measure the water, which adds in the register circles from beakers during all period of the observation. We measured the water, which is poured out in inward circle, and maintained on constant level (8 cm) of the water into outward circle. The counting of the time made when the infiltration the volumes of water composed 1000 milliliters. The soil infiltration capacity computed for every interval of the time on formula:

$$V_t = \Delta Q*60/(S*\Delta t), \qquad (1)$$

where V_t is the soil infiltration capacity, cm/h;
ΔQ is a quantity poured out water, cm^3;
60 are a conversion factor from min to hour;
S is a area of the register circle, 706,5 cm^2;
Δt is a interval of time between the measurements of water volumes, min.

The value of the soil infiltration capacity and the intervals of time written down in the table and design in diagram form. Duration of the every experiment was equal in total 480 min (approximately). The experiment was repeated four times. The results are presented on the Fig.2. The data of the figure testified the mean soil infiltration capacity of irrigated land, a stage of filtration came at the first 100 min, steady the soil infiltration capacity composed 5,85 cm/h on the average. Local factors (for example, of consolidation, of soil moisture content), as showed a field experiments then, influenced on value of the soil infiltration capacity at experiments version.


The soil infiltfation capacity, 2002
Soil infiltration capacity (cm/h)
80
70
60
50
40
30
20
10
0
29
116
221
307
392
485
Time of the observation (min)
Rep. 1
Rep. 2
Rep. 3
Rep. 4
On the average

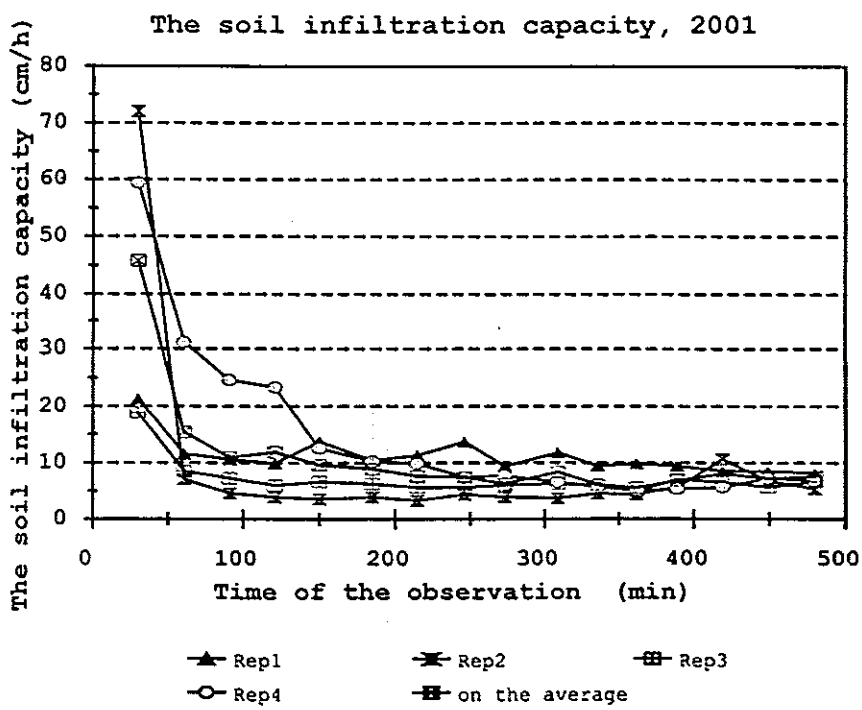

The soil infiltration capacity, 2001
The soil infiltration capacity (cm/h)
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
Time of the observation (min)
Rep1
Rep2
Rep3
Rep4
on the average

Fig. 2

2.4. Soil moisture content. The sample soil collection on the moisture content and the data processing showed that the plot had not uniform water distribution along the contour lines and had uniform water distribution in the depth profile along furrow of July 30 (Fig. 3). Irrigation for a moistening, that will be conducted July 16 and 17 with beg depth, was a cause for uniform the soil moisture content at stratum 45…150 cm and uneven the water distribution along a contour line to start of main field works.

The soil moisture content reduced to 57 % from maximum field carrying capacity in upper stratum 0…30 cm and approached to 85% from maximum field carrying capacity in stratum 80…150 cm. The disparity at the soil moisture content composed less 10 % along a contour line and it composed less 30% along vertical.

July 30 and August 1 was conducted the first experimental irrigation.

2.5. Inflow rate.

We did not conducted test irrigation in 2002. The results of test irrigation 2001 were accepted for base. Water was applied at inflow rate of 30 L/min. Continued the flow at 30 L/min for additional 30 min after water to reach the end of the furrow. Then reduced inflow to 16.8 L/min and continuous irrigation for 5 h. Thus q1=30 L/min for period (Tc+30 min) and q2=16.8 L/min for 5 h.

Conclusions

1.The surface slope of this area is typical for conditions use of the surface irrigation (on the average slope had composed 3,0%).

2. Experiments were conducted with an agricultural culture on the maize silage and the maize on grain, in spite of a hard weather conditions.

3. The maximum field carrying capacity changes on the average from 21.99% to 24,80 for soil stratum from 0 to 150 cm. The apparent density changes on the average from 1.48 g/cm^3 to 1.56 g/cm^3 and increases with depth that is typical for a light-kastanozem type loam and old-irrigated soils of Chui valley.

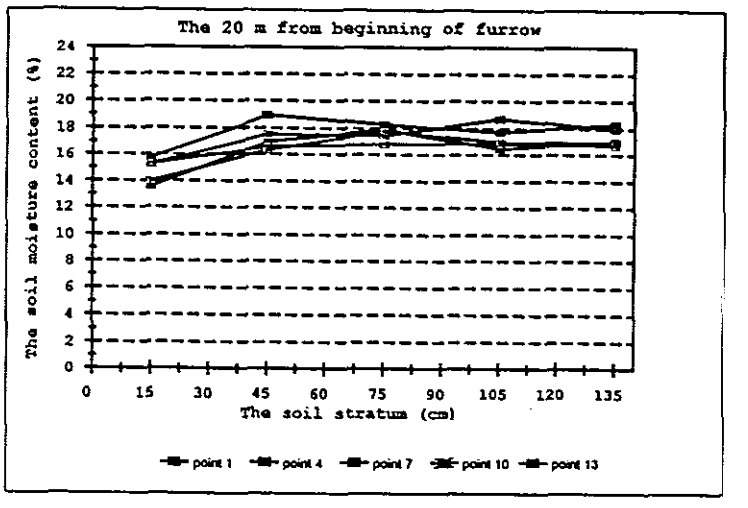
4. The soils of plot are not salinized. They are contained much clay (41.1%). In conformity with classification of N. A. Kachinski [1], they belong to silty loam.

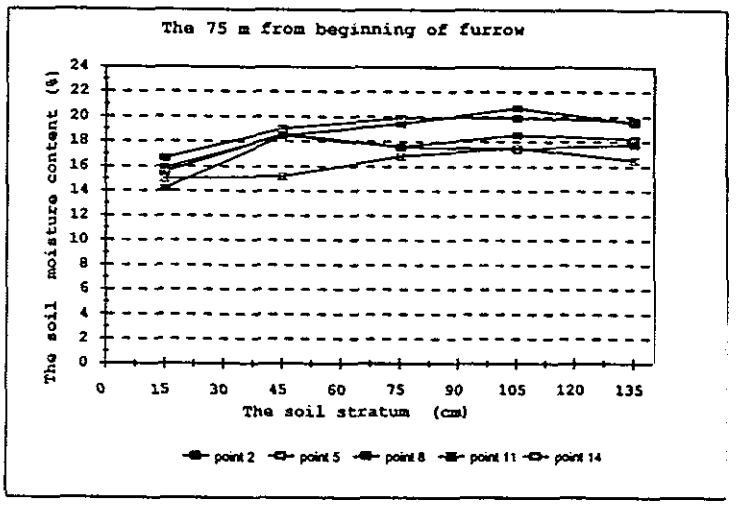
5. The irrigation water has a sulfate-hydro-carbonate-calcium-sodium composition.

6. The infiltration capacity of the soil had composed 5,85 cm/h on an average for 8 hour (it had changed from 8.73 cm/h to 2.44 cm/h in repetitions). This is typical for loam soil with infiltration coefficient 5…10 cm/h [14].

7. The inflow rate was taken q1=30 L/min (0.50 L/s) in experiment version for the wetting period and q2=16.8 L/min (0.28 L/s) for the after wetting period (at results of test irrigation 2001).

The soil moisture content on July 30
before the first irrigation





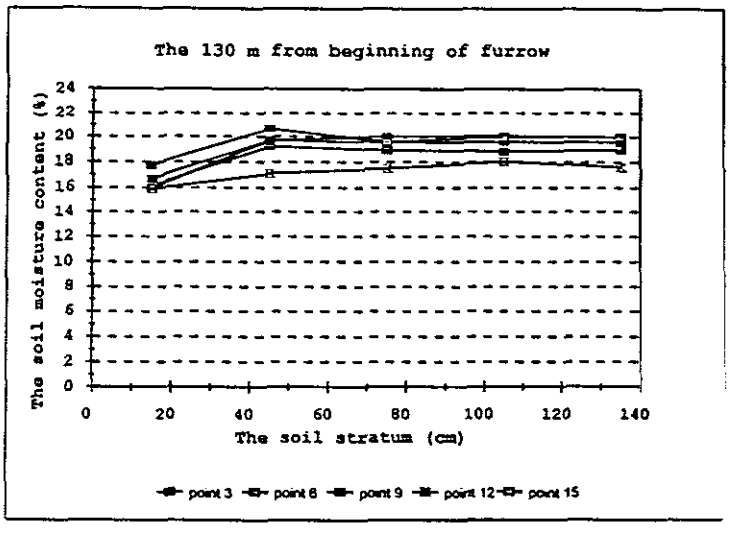


Fig. 3

3. MAIN WORKS AND THEM RESULTS

Were determined:

- the depth and the uniformity of soil moistening after second irrigation, the water distribution in soil on versions;
- the water losses lengthways of a furrow for each version of the experiments;
- the furrow erosion;
- an yield of a maize on variants of experience.

3.1. Method of experiments

3.1.1. Continuous irrigation with q1 (Control).

a. Furrows of 150 m long. Water was applied at inflow rate of q1=30 L/min. We were measuring the time (Tc) for water to reach the end of the furrow.

b. Continued irrigation for 5 h at q1=30 L/min to end irrigation, and took samples of water with sediments from the furrows at distances of 150 m. Dried the water samples to measure sediment concentration. Repeated the measurement of sediment concentration (at the 150 m) at 10, 20, 30, 60, 90, 120, 150, 210, 270 and 330 min after the water reached of the furrow end.

c. Measured inflow and outflow rates during these 5 h at 30 or 60 min intervals. Calculated the change in average IR with time and the total volume of water that infiltrated the furrows.

d. We repeated the above measurements in 4 furrows.

e. When irrigation is completed measure the water content in the profile along the furrows at 20, 75 and 130 m. Determined the uniformity of water distribution in the field after the second irrigation.

3.1.2. Continuous irrigation with q1 and q2.

a. Furrows of 150 m long. Water was applied at inflow rate of q1=30 L/min. We were measuring the time (Tc) for water to reach the end of the furrow.

b. Continued the flow at q1=30 L/min for additional 30 min, and took samples of water with sediments from the furrows at distances of 20, 75 and 130 m. Dried the water samples to measure sediment concentration. Repeated 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, reduced inflow to q2=16,8 L/min and continued irrigation for 5 h. Measured inflow and outflow rates during these 5 h at 60, 90, 120, 150, 210, 270 and 330 min after the water reached the end of the furrow. Repeated the measurement of sediment concentration at 60, 90, 120, 150, 210, 270 and 330 min after the water reached the end of the furrow. Calculated the change in average IR with time and the total volume of water that infiltrated the furrows.

d. We repeated the above measurements in 4 furrows.

e. When irrigation is completed measure the water content in the profile along the furrows at 20, 75 and 130 m. Determined the uniformity of water distribution in the field after the second irrigation.

3.1.3. Surge irrigation with q1 and q2.

a. Divided the time it took for continuous water flow q1=30 L/min to reach the end of the furrow (Tc) into 3 equal time intervals (Tc/3). Applied surge irrigation of Tc/3 ON, and Tc/3 OFF with inflow rate of q1=30 L/min until the surges reach the end of the furrow. Recorded the ON time it took to wet the entire furrow. When the water reaches the end of the furrow continued with continuous flow of q1=30 L/min for additional 30 min and repeated steps "b" through "e" in the continuous flow with q1 and q2 procedure.

3.1.4. Continuous irrigation with PAM application and q1 and q2.

Mixed PAM, 10 mg/L, with the irrigation water and follow step "a" in 3.1.2., but the PAM is mixed with the irrigation water only until the entire furrow was wetted (i.e., the advancement stage was completed). Recorded the advancement time (Tc). Then continued with steps "b" through "e"' in 3.1.2., using PAM-free water.

3.1.5. Surge flow with PAM application and q1 and q2.

The same as 3.1.3. - surge irrigation in conventional water except that PAM in concentration of 10 mg/L was mixed with irrigation water during the surges (i.e., the advancement stage) using Tcp/3 time intervals for the ON and OFF periods.

The balance method was used for determination of water losses lengthways of a furrow. Static head measured with a portable water meter(Photo 1). Employment of the weir particularly is efficient for realization technology of a surge irrigation: orifice in diaphragm is easily re-cover with blind diaphragm in period of the interruption at the water application. Support a constant pressure h=4 cm. Inflow rate changed with an orifice in diaphragm.

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

We researched the five versions in field experiments and conducted the four experimental irrigation. The each of the four irrigation had a duration:

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

where "Tc" is the time to reach the end of the furrow.

Time to reach the end of the furrow is for a version with surge irrigation:

$$T_{cs} = (T_s * n + \Delta t), \qquad (3)$$

$T_s = T_c/3$ (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 30 L/min.

The some conditions and indexes of the field experiments are presented in the Table 4. The scheme of the versions in the field experiment is presented in Fig.5.

Table 4

SOME CONDITIONS AND INDEXES OF A FIELD EXPERIMENTS

Rain		Date of cultivation	Date of soil sample collection	Irrigation			
date	norm, mm			number	version of the irrigation technology	date	the water application, m3/hec
06.05	5. 2	07.15	07.30		cont. irr. with q1 (moisten)	07.16 and 07.17	1840
06.05	20.6	07.31	08.04				
06.09	18.7		08.13	1	cont. irr. with q1 and q2	07.31	875
06.10	5.0		08.18		cont. irr. with q1 and q2 + pam	07.31	898
06.15	5.3		08.22		surge irr. with q1 and q2	08.01	924
06.15	21.7				surge irr. with q1 and q2 +pam	08.01	1046
06.23	2.8				cont. irr. with q1	08.01	1321
07.03	7.8						
07.05	5.7			2	cont. irr. with q1 and q2	08.14	1153
07.19	3.6				cont. irr. with q1 and q2 + pam	08.14	1663
07.22	2.8				cont. irr. with q1	08.14	1483
08.14	13.1				surge irr. with q1 and q2	08.19	962
09.15	4.4				surge irr. with q1 and q2 +pam	08.19	886
				3	cont. irr. with q1 and q2	09.01	904
					cont. irr. with q1 and q2 + pam	09.01	1113
					cont. irr. with q1	09.01	1313
					surge irr. with q1 and q2	09.02	863
					surge irr. with q1 and q2 +pam	09.02	923
				4	cont. irr. with q1 and q2	09.15	824
					cont. irr. with q1 and q2 + pam	09.15	880
					cont. irr. with q1	09.15	1223
					surge irr. with q1 and q2	09.16	861
					surge irr. with q1 and q2 + pam	09.16	943
Total	116.7						

The water meter for the water application

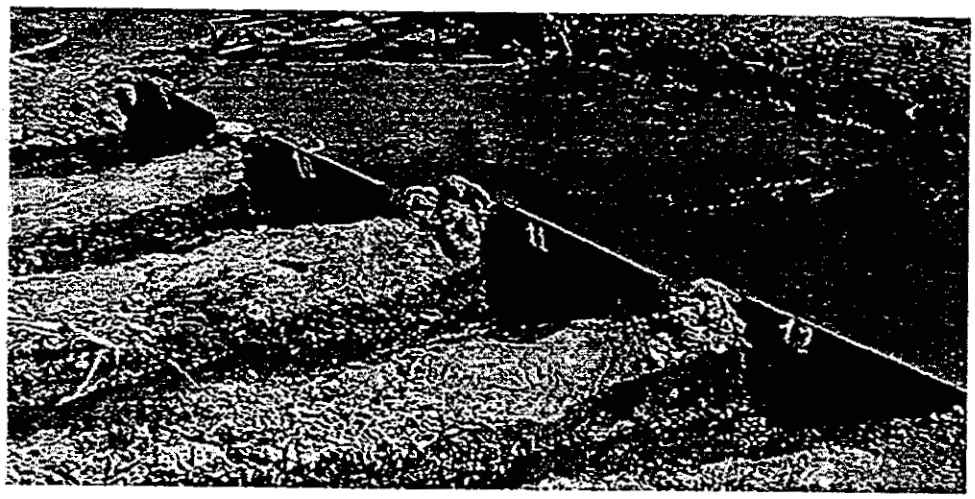


Photo 1

The metallic chute

Photo 2

Scheme arrangement of plots for field experiments

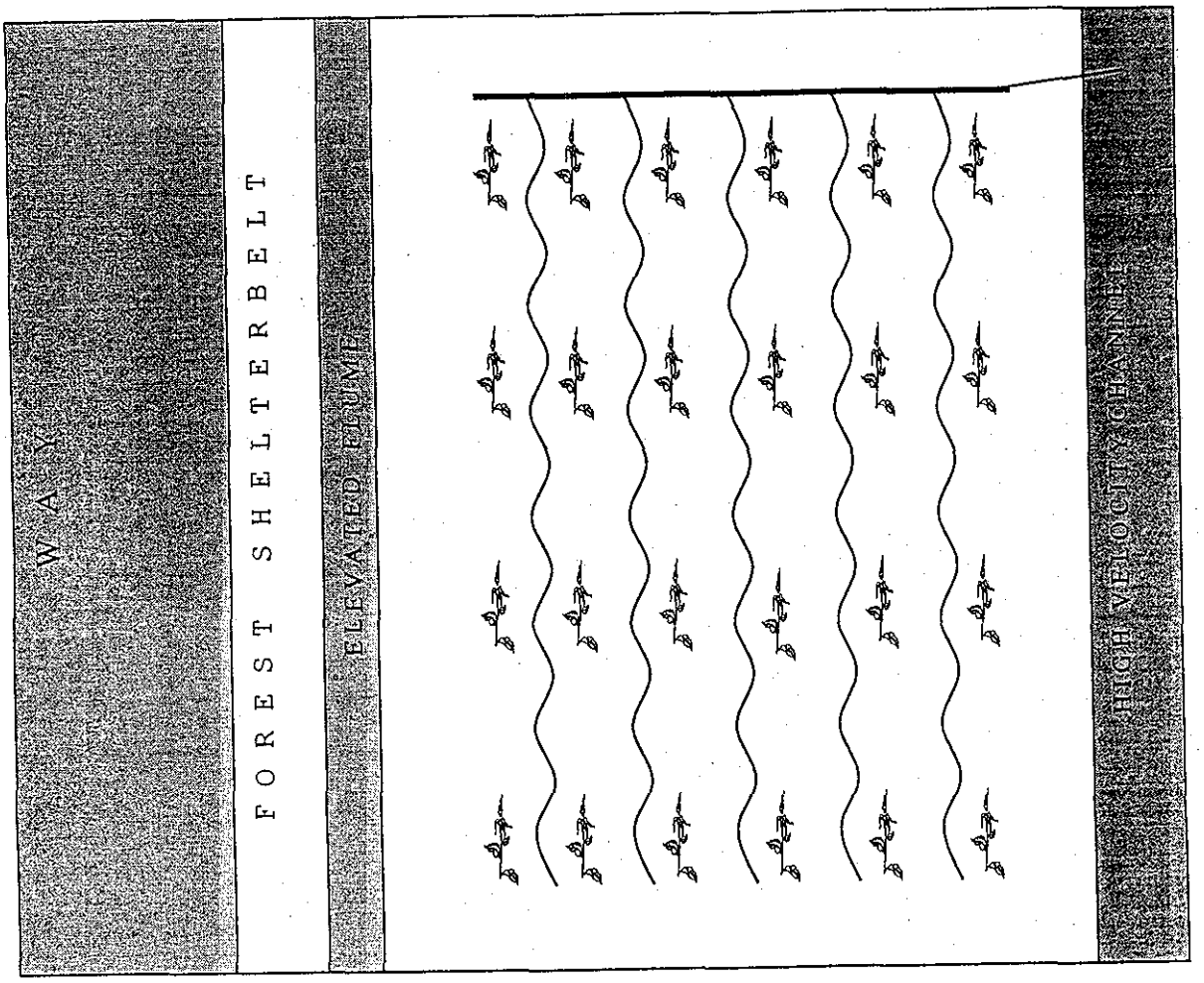


Fig. 4

Table 5

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

The version of the irrigation technology	The 1st irrigation		The 2nd irrigation		The 3rd irrigation		The 4th irrigation	
	Tc, min	Ts, min	Tc, min	Ts, min	Tc, min	Ts, min	Tc, min	Ts, min
Cont. irr.+ PAM	71		301*		136		66	
Cont. irr.	65		148*		73		49	
Cont. irr. with ql	66		115*		64		43	
Surge irr.	79	20	91	45	61	25	60**	15
Surge irr.+ PAM	116	20			79	45	85**	20
Cont. irr.+ PAM			68					

*it is raining
**it is after raining

Diagram arrangement of versions and irrigation inventory

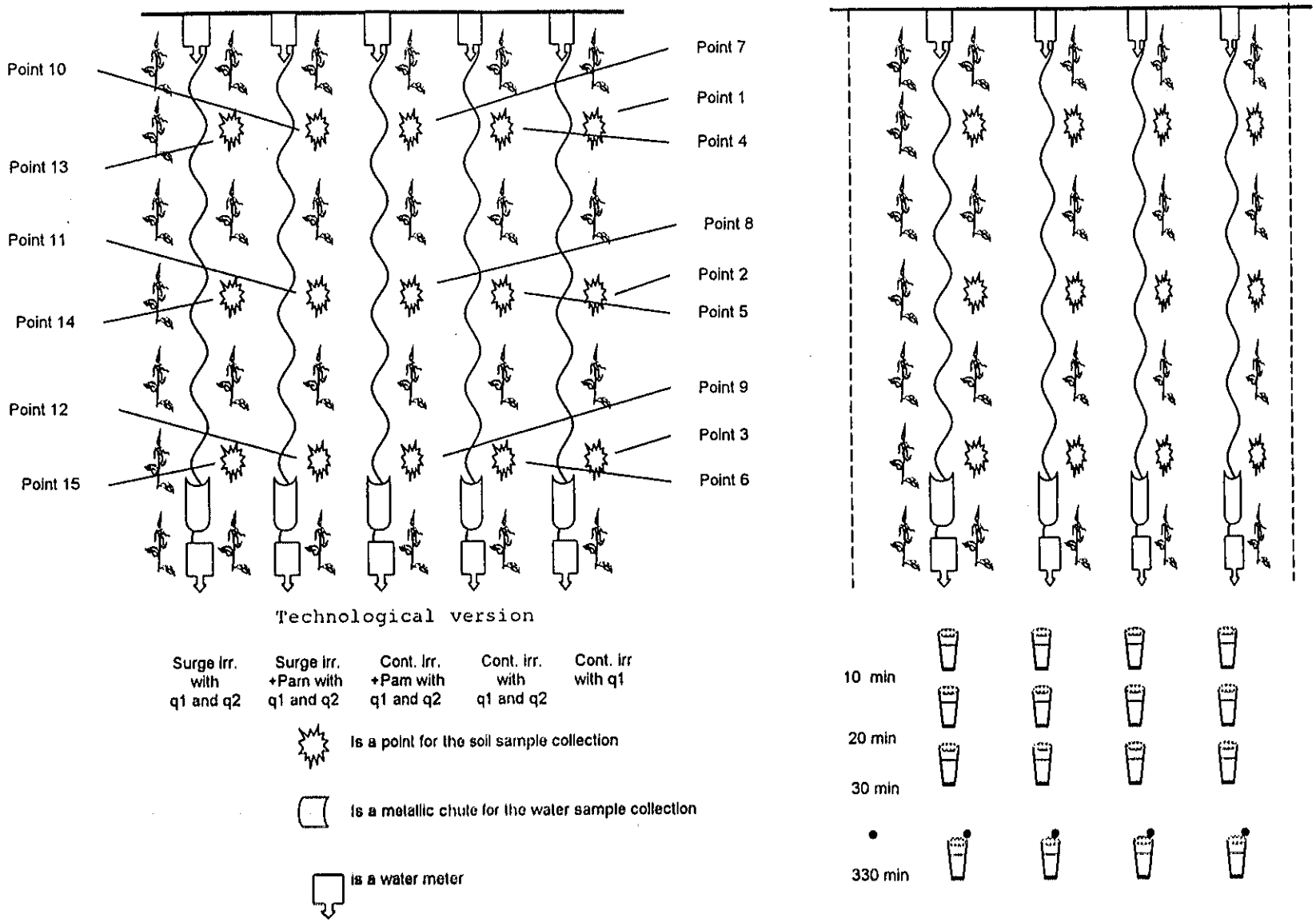


Fig. 5

76

3.2. Selected mode of irrigation

The maize strongly differs from others agricultural plants. It has a large over ground weight and arrangement of a root system in high layers of soil. According to data of V. V. Kolpakov [16], the maize has 65 % of the root zone in the upper 20-cm layer, 29 % has in a layer 20-80 cm and only 6 % has in a layer more than 80 cm. By it the maize differs from other plants, for example, from sugar beet which has, on the one hand, less over ground weight is significant, and with another hand, in the upper 20-cm layer it has only 20 % of root weight, 50 % of the root weight has in a layer 20-80 cm and 30% has of the root weight are deeper than 80 cm [17]. It provides to sugar beet a capability to use a moisture of more steep layers of soil. The maize almost dispossessed of such capability. The sufficient the moisture content of the upper 30 cm layer in critical periods its vegetation (ejection of the sultan, beginning of formation of a grain) is optimal variant of the irrigation. Therefore, in conditions, when we irrigate maize by furrow irrigation, a problem to come to maintenance of a high moisture in the upper layer of the soil. This problem may be solved with big amounts of irrigation and small irrigation rate.

But maize that was showed on plot was earmark for popcorn. She has a thin stem and a weak root system. The maize was falling with winds and from supermoistening. Thus we watered our maize with the four experimental irrigation and the one irrigation were given for moistening too. On an output of green weight and grain it is visible that the moisture content of the soil was sufficient. The rains helped us for this.

The field experiments did not go off smoothly. It is visible from results of Table 5. The advanced time of furrows (Ts) was less of norm during the first irrigation (we did not receive of PAM's effect). The advanced time of furrows (Tc) was increased considerably during the second irrigation because of a rain and has increased during the fourth irrigation (a rain went at night). The data of the third experimental irrigation will the most objective. The intervals for ON and OFF periods are presented in Table 5.

The first irrigation

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

The depth and the uniformity of soil moistening at irrigation was determined with method of a sample collection from different depths of soil stratum. Was used a following formula at 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.

The average geometrical for the increment of soil moisture content was determined on formula:

$$\Delta\beta = (40*\Delta\beta_1+70*\Delta\beta_2+40*\Delta\beta_3)/150, \% \qquad (5)$$

where $\Delta\beta_1$, $\Delta\beta_2$, $\Delta\beta_3$ are increment of the soil moisture content at distances of furrow 20, 75 and 130 m accordance;

150 is the length of furrow in experiments, m.

The samples of soil were collected before and after the first irrigation, before and after the second irrigation. The results for the second irrigation will be subjected to the further analyse how having a science interest. The results of the second irrigation are presented in Annex 1 and Fig. 6 and 7.

Table 6

The increment of the soil moisture content for experimental version (the second irrigation)

The version of the irrigation technology	The increase of a soil moisture content ($\Delta\beta$,%) at furrow length, m				Uniformity of water distribution in soil, K
	20	75	130	on the average	
Cont. irr. + PAM with q1 and q2 (it is raining)	1.87	1.91	2.49	2.06	1.33
Cont. irr. with q1 and q2 (it is raining)	2.11	1.73	1.07	1.65	0.51
Cont. irr. with q1 (it is raining)	2.79	2.15	1.52	2.15	0.54
Surge irr. with q1 and q2 (it does not raining)	0.86	1.41	1.58	1.31	1.84
Cont. irr. + PAM with q1 and q2 (it does not raining)	1.04	1.34	1.44	1.29	1.38

The results for the first irrigation will not be subjected to the further analyse for reason:

1. The sediment concentration of irrigation water greatly differed on version experiments.

2.We did not receive of PAM's effect for erosion. Making use of PAM that will in stock from last year.

The increment of the soil moisture content was determined as a difference between the soil moisture content before and after second irrigation (Please see Table 6). We had not of uniform distribution along furrow and on depth (Annex 1). But we had a deep percolation for all versions of the second irrigation.
On the average the increment of a soil moisture content had composed from 1.29 to 2.15 % in a stratum 0-150 cm. At the most value is related to version *continuous irrigation with q1* (it is raining) and at least value is related to version *continuous irrigation + PAM with q1 and* q2 (it does not raining). The reduced infiltration rates are the result of reduced an advanced times in this version. The reduced the irrigation water distribution uniformity in version *surge irrigation* are the result of increased an advanced times (the advancement stage was a large: Ts=148/3=45 min). The uniformity of soil moistening at irrigation was determined on formula: $K= \Delta\beta_3/\Delta\beta_1$.

The uniformity for the water distribution in the soil along furrow > 1 points to more a high the increment of the soil moisture content to end furrow. Was the two reason for this:

1. The products of erosion was depositing to end furrow and formed a wide shallow water. The perimeter of imbibition and infiltration rates increased.

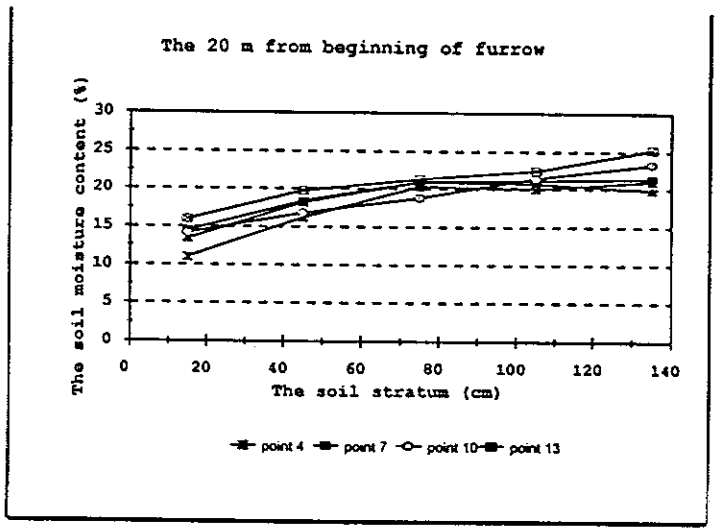
2. PAM, moving with sediments, participated in a forming of the more permeable bed.

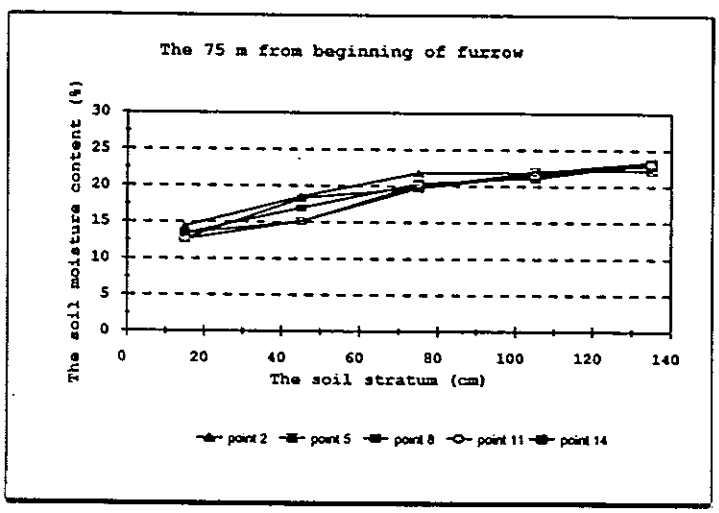
Rain did not influence on improves uniformity of distribution irrigation water along furrow. But the rain influenced on an increase of the soil moisture content.

Polyacrylamide (PAM) at concentration of 10 g/l in irrigation water was demonstrated to increase IR. The rain reinforced this.

The second irrigation
(it is raining)

The soil moisture content
before the second irrigation





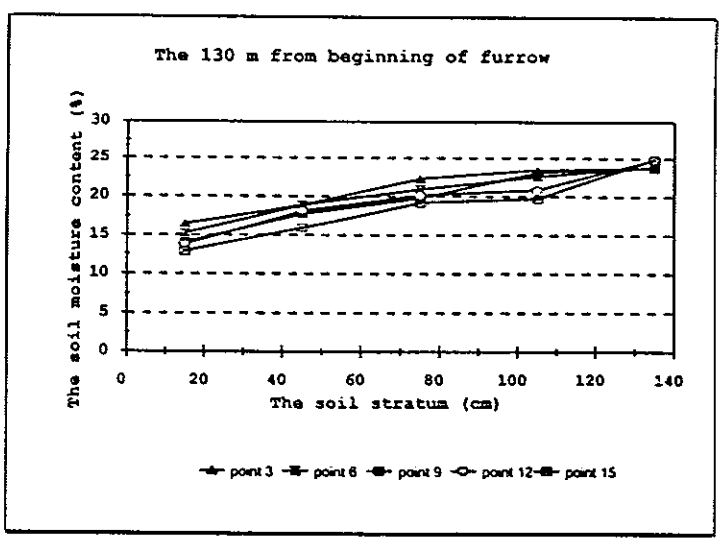
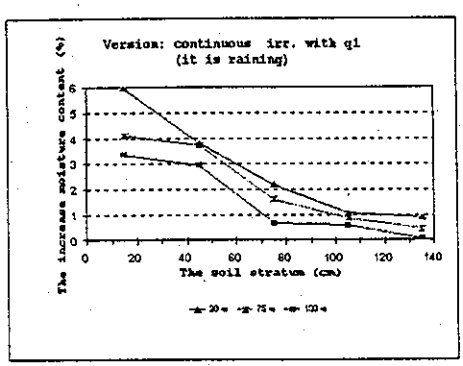
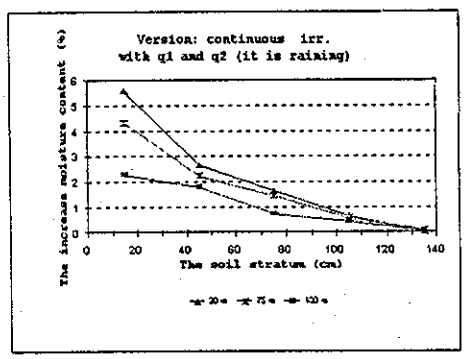
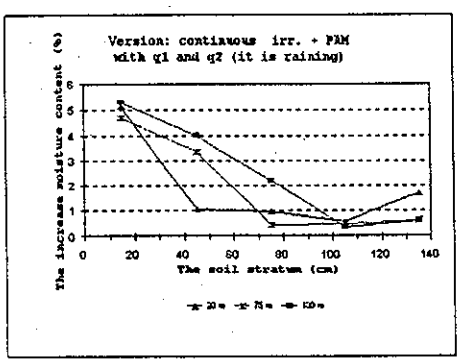


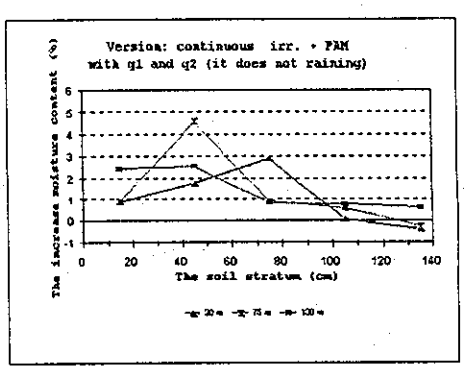
Fig. 6

The increase of soil moisture content
after second irrigation









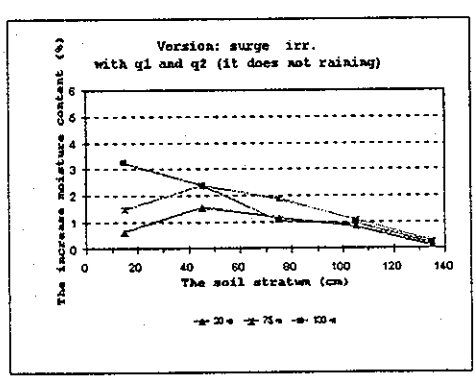


Fig. 7

The water meter is at the furrow end

(the first irrigation)

The metallic shut is at the one of the measuring points

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

The balance method was used for determination of the 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 the 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=30 L/min for the one irrigation period;

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

$W_{app.2}$ is the water application with flow rate q2=16.8 L/min for the one irrigation period;

$W_{app.2}=16.8*300*N/1000$, m^3/hec;

N is number of furrows for the one hectare;

N=10000/(b*L);

b is a space between furrows (b=0.60 m);

L is a length of an experimental furrow (L=150 m);

300 is duration of the one irrigation with a flow rate q2=16.8 L/min, min;

$W_{o.f.}$ is a outflow volume in a furrow end, m^3/hec;

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

$\omega_{o.f.}$ is a outflow volume from one furrow in an observed period,

$\omega_{o.f.}=\Sigma(q_{avr}*\Delta t)$, L.

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

Δt is a time interval between these two measurements, min;

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

q_i is an outflow rate from the one furrow in a moment of time t_i, L/min;

$q_i=f(h_i,t_i)$,

h_i is an observed value of a water head at water meter in a moment of time t_i, cm;

We used following formulae too:

$$q_i=0.254*(h_i)^{0.5}, \text{ L/s and } q_i=0.139*(h_i)^{0.5}, \text{ L/s.}$$

The every irrigation had their particularities.

The first irrigation. We bring in soil a PAM that will in stock from last year, we did not receive of PAM's effect in period the first irrigation.

The second irrigation. We bring in soil a PAM for the second time. It is raining in the first day of irrigation. We continue the irrigation across four days.

The third irrigation has went calmly.

The fourth irrigation. Weak rain has went between the first and the second days of irrigation.

Therefore the results is impossible to summarizing. They will be discerned the every individually. The methods calculations has presented at Annex 2, 3 and 4, the results calculations has presented Table 7, Fig. 8.

Table 7

THE WATER APPLICATION AND WATER INFILTRATION FOR IRRIGATION PERIOD

The version of the irrigation technology	The water application, m^3/hec	The outflow volume, m^3/hec	The water infiltration, m^3/hec	The irrigation application efficiency
The first irrigation				
Cont. irr. + PAM with q1 and q2	898	381	517	0.58
Cont. irr. with q1 and q2	875	446	429	0.49
Cont. irr. with q1	1321	888	433	0.33
Surge irr. with q1 and q2	924	496	428	0.46
Surge irr. + PAM with q1 and q2	1046	424	622	0.59
The second irrigation				
Cont. irr. + PAM with q1 and q2 (it is raining)	1663	330	1333	**0.80***
Cont. irr. with q1 and q2 (it is raining)	1153	548	605	**0.52***
Cont. irr. with q1 (it is raining)	1483	783	700	**0.47***
Surge irr. with q1 and q2 (it does not raining)	962	504	458	0.48
Cont. irr. + PAM with q1 and q2 (it does not raining)	886	506	380	0.43
The third irrigation				
Cont. irr. + PAM with q1 and q2	1113	427	686	0.62
Cont. irr. with q1 and q2	904	516	388	0.43
Cont. irr. with q1	1313	878	435	0.33
Surge irr. with q1 and q2	863	493	370	0.43
Surge irr. + PAM with q1 and q2	923	500	423	0.46
The fourth irrigation				
Cont. irr. + PAM with q1 and q2	880	378	502	0.57
Cont. irr. with q1 and q2	824	487	337	0.41
Cont. irr. with q1	1243	872	371	0.30
Surge irr. with q1 and q2	861	281	580	**0.67***
Surge irr. + PAM with q1 and q2	943	292	651	**0.69***

* the rain had an influence on these results

The data of Table 5 were used for calculations of the water application (Annex 2).

The irrigation application efficiency was rather high for the four version, if shall not take into consideration the results of version *Cont. irr. with q1* . The value 0.36 of this efficiency is ordinary for conditions of Kyrgyzstan. In the whole, a size of the irrigation application efficiency decreases from irrigation to irrigation, as decreases total volume of water that infiltrated furrows: by the end irrigation period the soil is condensed, the roughness surface of a furrow decreases, time (Tc and Ts) for water to reach end of the furrow decreases and outflow rates is increased.

The results that were received in 2002 essentially differ from results 2001 (please, look the table 8). This distinction consists, first of all, in volumes of the water application on irrigation. The time for water to reach end of the and total time for irrigation has changed little with reduction length of furrow from 200 м in 2001 up to 150 м in 2002. Obviously, configuration furrow has affected it: she was deeper and wide in 2002. But the number furrow in one hectare has increased with reduction length of furrow in 2002. In this connection volume of water that application and outflow has increased from unit of the area in the period after the water reached the end of the furrow and for everybody irrigation. In second, if to compare the results of first irrigation, the total volume infiltration practically has not changed in 2002 for the appropriate variants of experiments including for PAN's of versions. Last year's PAM, brought in soil with irrigation water at first irrigation, has given small effect for increase infiltration capacity of soil and increase of the irrigation application efficiency.

We have not received expected effect from surge irrigation in PAM treatment: Surge irrigation in PAM treatment will not be effective in consolidation of soil surface and reducing IR. The surge irrigation in PAM treatment will be effective in increase infiltration rate during all irrigation.

Table 8

THE WATER APPLICATION AND WATER INFILTRATION FOR IRRIGATION PERIOD 2001

The version of the irrigation technology	The water application, m^3/hec	The outflow volume, m^3/hec	The water infiltration, m^3/hec	The irrigation application efficiency
The first irrigation				
Cont.irr.+PAM with q1 and q2	783	280	502	0.64
Cont. irr. with q1 and q2	680	307	373	0.55
Cont. irr. with q1	1010	520	490	0.49
Surge irr. with q1 and q2	755	282	473	0.63
Surge irr.+PAM with q1 and q2	895	236	659	0.74

Water use

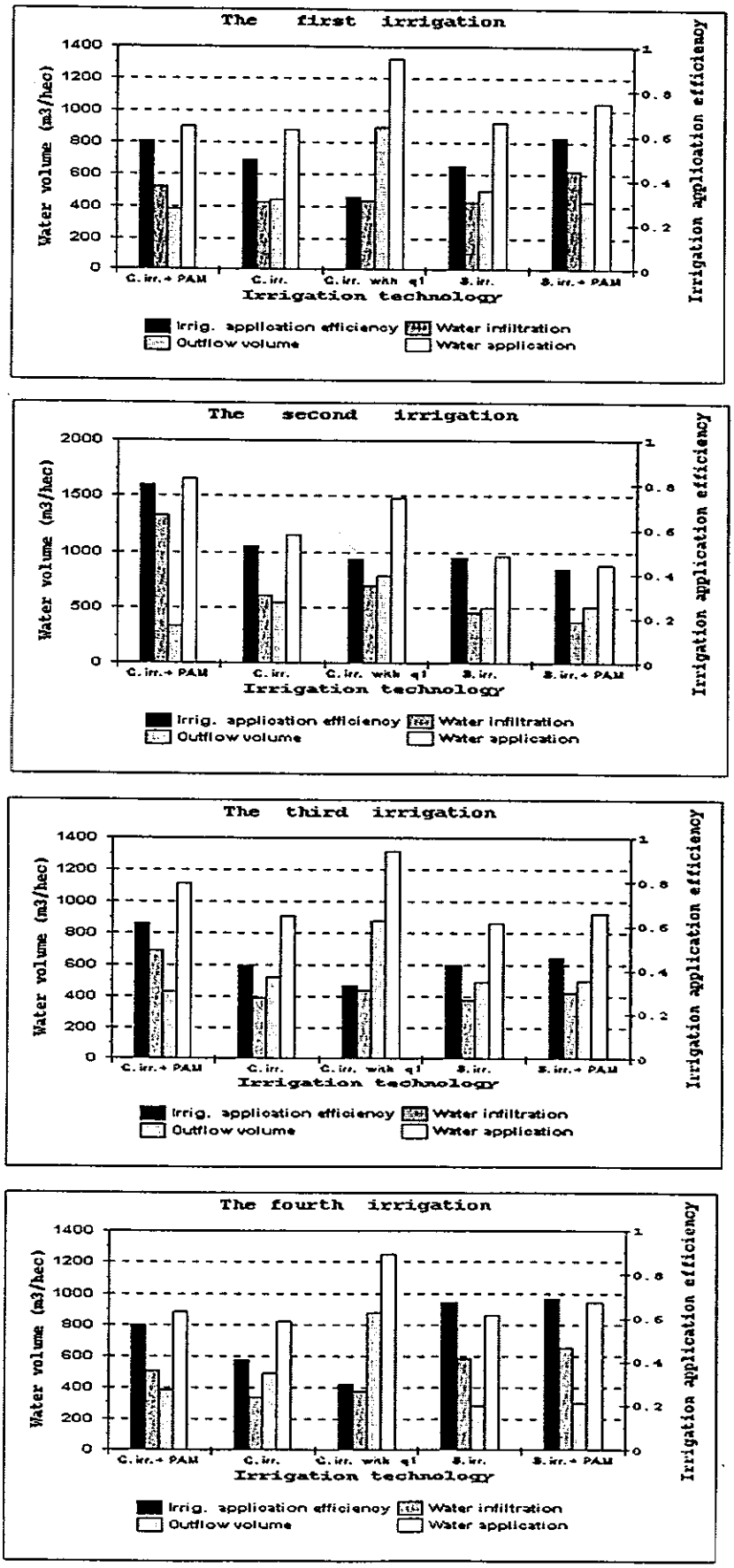


Fig. 8

86

The losses on deep percolation (more 150 cm) are not taken into account in the above given results. But we could appreciate a size those water losses for second irrigation as we have dispose by soil descriptions in vertical profile (please look the Tables 1 and 7).

The water content of soil will be defined on formula for conditional the second irrigation this year:

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

$$W\ d.p.=W\ inf. + Wrain - W\ w.c.,\ m^3/hec, \quad (8)$$

where H is a soil stratum (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;

W rain is the additional moistening by rain, m3/hec.

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

Table 9

THE WATER CONTENT OF SOIL AND THE WATER LOSSES TO DEEP PERCOLATION
(the second irrigation)

The index of irrigation	The version of the irrigation technology				
	cont. irr. + PAM with q1 and q2	cont. irr. with q1 and q2	cont. irr. with q1	surge irr. with q1 and q2	cont. irr. + PAM with q1 and q2
The water application, m3/hec	1663	1153	1483	962	886
The water infiltration, m3/hec	1333	605	700	458	380
The additional moistening by rain, m3/hec	131	131	131		
The water content in soil stratum 0…150 cm, m3/hec	464	371	484	295	290
The water losses on deep percolation, m3/hec %	1000 60.1	365 31.7	347 23.4	163 16.9	90 10.2

The method used by us for an estimation of water losses on deep percolation, does not differ by sufficient accuracy and first of all the method of definition water moisture content in soil by drilling, selection of soil sample from different depth, drying and weighing is not exact. But this method has allowed us to make the important conclusions:

- Efficiency a washing irrigation, an irrigation for accumulation moisture in soil and an irrigation for replenishment of stored soil moisture raise in some, if them to conduct during a rain. Use PAM will strengthen this efficiency.
- The surge irrigation is effective for these purposes too, if time intervals for the ON and OFF periods will be large enough.

Bring the results 2001 for firs irrigation (Table 10).

Table 10

THE WATER CONTENT OF SOIL AND THE WATER LOSSES TO DEEP PERCOLATION
(the first irrigation, 2001)

The index of irrigation	The version of the irrigation technology				
	cont. irr. + PAM with q1 and q2	cont. irr. with q1 and q2	cont. irr. with q1	surge irr. with q1 and q2	surge irr. + PAM with q1 and q2
The water application, m3/hec	783	680	1110	755	895
The water infiltration, m3/hec	502	373	490	473	659
The water content in soil stratum 0…150 cm, m3/hec	409	335	389	391	534
The water losses in deep percolation, m3/hec %	93 11.9	38 5.6	101 10.0	82 10.9	125 13.9

The given results 2001 do not contradict results 2002. The general tendency is saved of influence PAM and surge irrigation on water losses and on deep percolation (more 150 cm): the smaller size of these losses took place at a conducting with variable inflow rite, more took place at surge irrigation with PAM application.

We shall not compare results others irrigation, there were their features (or there was an additional moistening by rain, or the weed vegetation has increased a roughness of furrow surface).

The third irrigation
(PAM's version)

3.5. 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 (30.0 and 16.8 L/min);

b) slope of furrow (on the average 0.03 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:

$$\mu_{1i} = (G_S / G) * 100, \% \quad (9)$$
$$\mu_{2i} = 10*\mu_{1i}, g/L$$
$$P_{\mu}i = Wi*\mu_{2i}, kg$$

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:

$$\sum P_{\mu i} = \sum (W_i * \mu_{2i}), kg \quad (10)$$

The sediment concentration in the irrigation water, that 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 (Fig 9…11). The variable the sediment concentration in the irrigation water was reflected on the results of our experiments. Every experimental irrigation was conducted during 2 days: all the technology versions with *continuous irrigation* were in first day and the versions with *surge irrigation* were in second day (please, look Table 4). In connection with, an analysis of results was carried out on each day of irrigation and not for all versions of experiments. For reception of reliable conclusions, the results of experiments were united to a value of sediment concentration in irrigation water. They are shown in the Table 11 and are selected with identical colour.

The conclusions received as a result of the carried out analysis are come down to the following (Table 11, Fig. 9…11, Annex 3 and 5):

- content of the sediments in furrow water for our conditions

  - decreases from irrigation to irrigation at 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);
  - increases with length of a furrow to the appointed bounds: the dependence E=f(L) has a point of inflection after 150 m (Fig.12).

Table 11

BALANCE OF THE SEDIMENTS.
The summary data

The version of the irrigation technology	Balance of the sediments, kg	Weighted average sediment concentration of irrigation water, %
The first irrigation		
Cont. irr. + PAM with q1 and q2	-40,07	0.954
Cont. irr. with q1 and q2	-7,60	0.785
Cont. irr. with q1	-184,71	1.099
Surge irr. with q1 and q2	-55.59	1.152
Surge irr. + PAM with q1 and q2	53.66	1.025
The second irrigation		
Cont. irr. + PAM with q1 and q2	46.12	0.294
Cont. irr. with q1 and q2	11.51	0.354
Cont. irr. with q1	-64.22	0.366
Surge irr. with q1 and q2	-43,89	0.421
Cont. irr. + PAM with q1 and q2	16,57	0.441
The third irrigation		
Cont. irr. + PAM with q1 and q2	19.90	0.583
Cont. irr. with q1 and q2	-30.06	0.605
Cont. irr. with q1	-115.80	0.614
Surge irr. with q1 and q2	-40.84	0.511
Surge irr. + PAM with q1 and q2	10.13	0.506
The fourth irrigation		
Cont. irr. + PAM with q1 and q2	-25.35	0.179
Cont. irr. with q1 and q2	-57.27	0.179
Cont. irr. with q1	-120.02	0.178
Surge irr. with q1 and q2	-13.76	0.151
Surge irr. + PAM with q1 and q2	-2.77	0.155

- the technology of irrigation in a continuous mode is more preferable at irrigation by muddy water (Table 11, Fig. 10, the third irrigation);

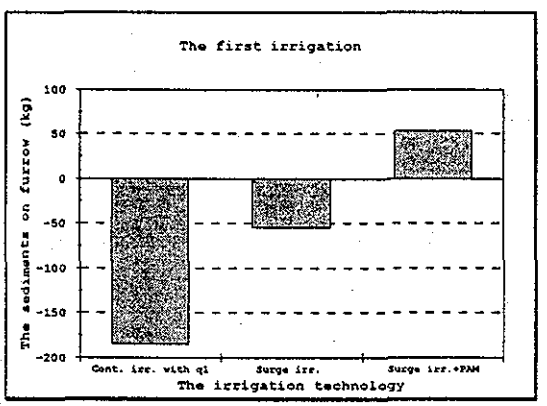
- the technologies irrigation in a surge mode should be given back the preference at irrigation by bright water (Table 11, Fig. 11, the fourth irrigation);

- the balance of sediments develops for the benefit of irrigation by the variable inflow rite at irrigation in a continuous mode (Table 11, Fig. 10, the third irrigation);

- the PAM application strengthens efficiency irrigation by the variable inflow rite (Table 11, Fig. 10 and 11, the third and the fourth irrigation);

- the positive effect is received at irrigation in rainy weather, the balance of sediments has developed as for the benefit of PAM's version and irrigation by the variable inflow rite (Table 11, Fig. 10, the second irrigation).

Balance of the sediments for one furrow



The sediment concentrations of irrigation water

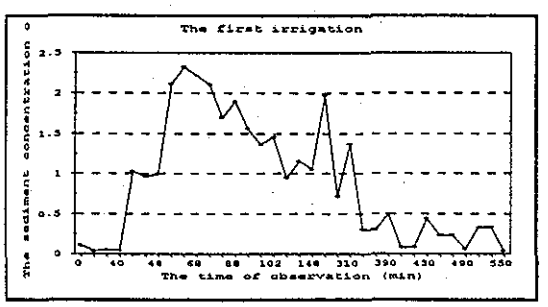
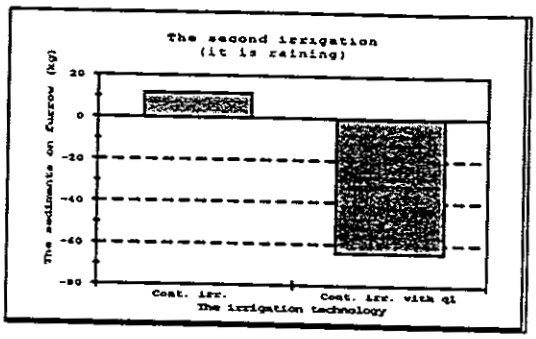
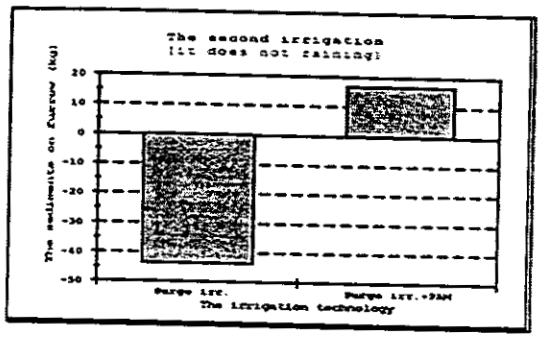


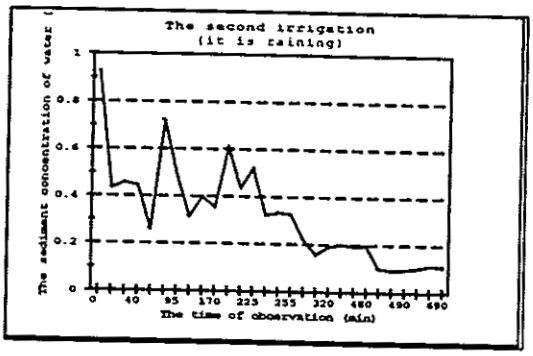
Fig. 9

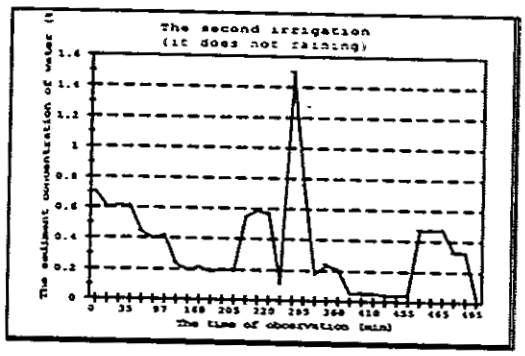
Balance of the sediments for one furrow



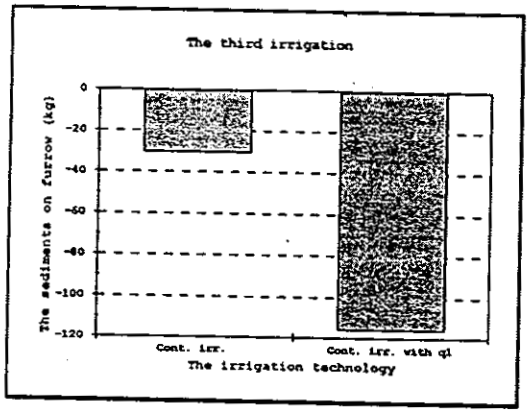


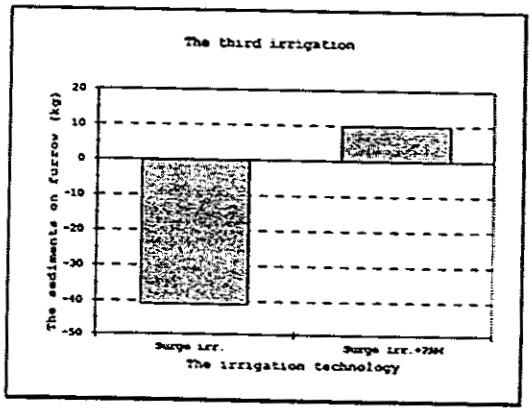
The sediment concentration of irrigation water



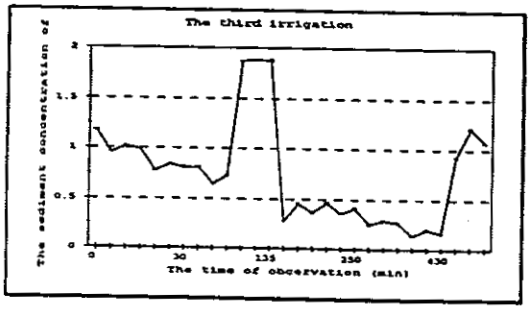


Balance of the sediments for one furrow





The sediment concentrations of irrigation water



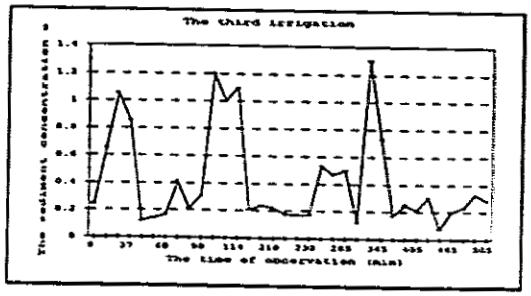
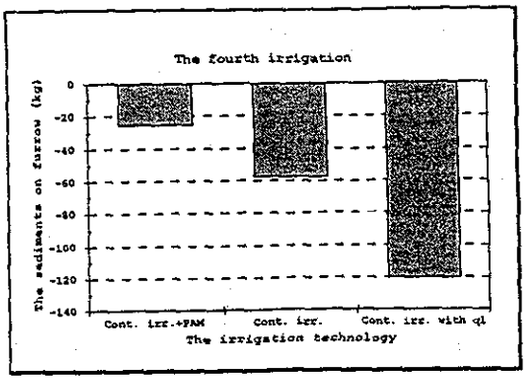
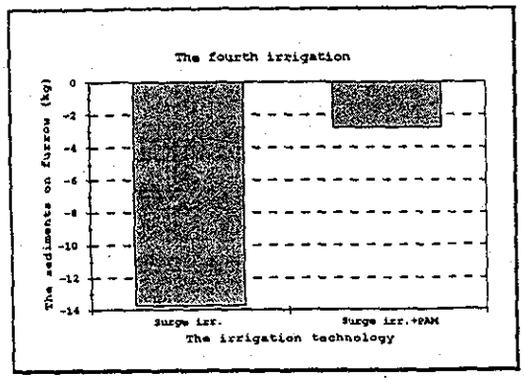


Fig. 10

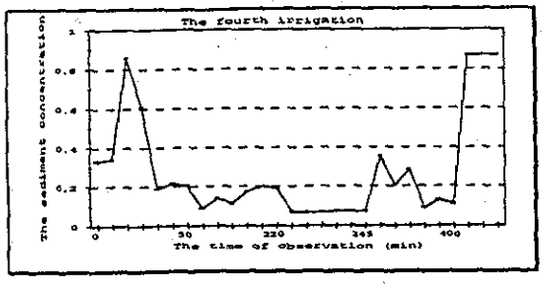
92

Balance of the sediments for one furrow





The sediment concentration of irrigation water



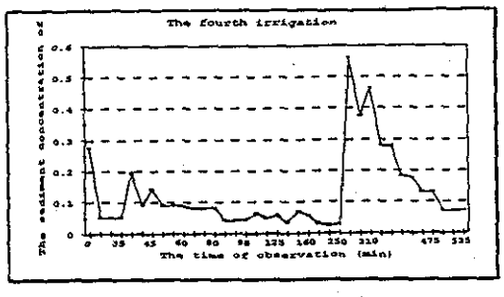


Fig. 11

Let's compare the results 2001 and 2002 for finding - out of influence of furrow length on furrow erosion (Table 12).

Table 12

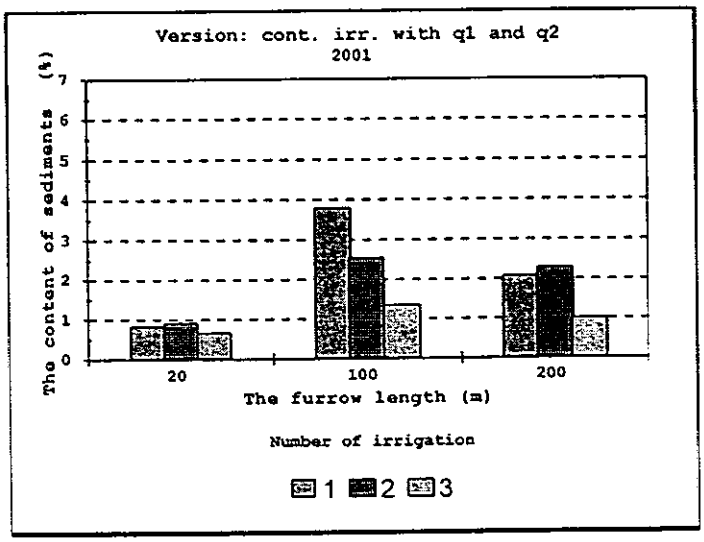
RESULTS INFLUENCE OF FURROW LENGTH ON FURROW EROSION
(version: continuous irrigation with ql)

Number irrigation	2001		2002	
	Weight of sediment in outflow for one furrow, kg	Weighted average sediment concentration of irrigation water, %	Weight of sediment in outflow for one furrow, kg	Weighted average sediment concentration of irrigation water, %
1	129.17	0.621	315.27	1.099
2	120.18	0.392	113.05*	0.366
3	78.00	0.540	188.36	0.614

- it is raining

Thus, the reduction of length furrow increased the volumes sediments, carried out the bounds of furrow. The results of the last researches showed that the intensive sedimentation was observed on distance more 150 м from a beginning furrow (fig. 12). The increased outflow rite too had a meaning in it.

The content of sediments in irrigation water



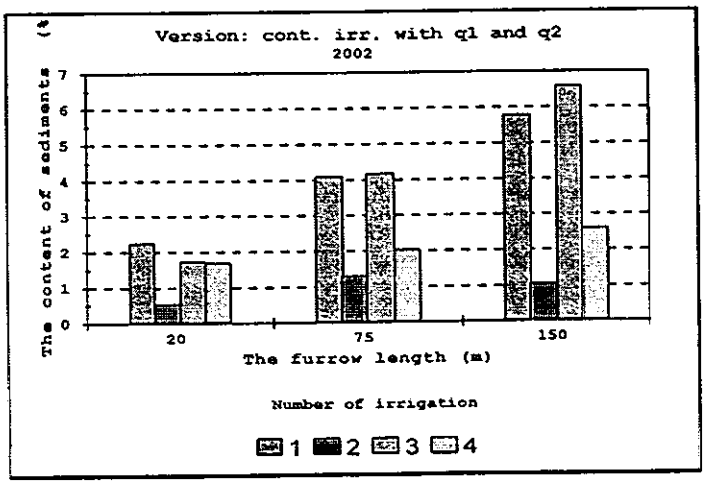
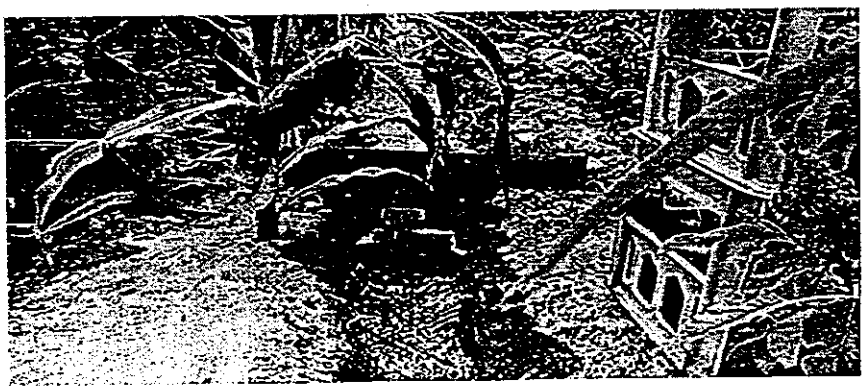


Fig. 12



3.6. Effect of Pam and surge irrigation on maize yield

Maize yield was determined for silage and grain individually at norm 30 thousand plants at hectare.

Distinctive features 2002, influenced on an output of a maize:

* other grades of maize was sown;
* the attention to a leaving of crops (weeding was made twice, carrying of fertilization was made insoil also twice.

The data for a yield are presented in Annex 6, Tables 13 and 14.

The results showed:

Pam's addition in irrigation water was effected an increase of maize yield on silage and grain at her combination with technology irrigation in a continuos mode for all furrow length.

Surge irrigation has ensured a accelerated promotion of fertilizers to the furrow end and increase of yield in her end.

Surge irrigation in PAM treatment was be effective in consolidation of soil surface and reducing IR (and absorbing fertilization by soil) in the furrow beginning. Permeable layer of sediment, mixed with PAM and fertilizers, was formed in the furrow end (PAM and fertilization were inserted at the same time). This permeable and good fertilized layer has ensured increase of yield maize silage and grain in the end of a irrigation plot. The same effect was received on version *continuos irrigation + PAM* but less pronounced.

Surge irrigation without PAM treatment gave a high unevenness distribution of crop along furrow length.

The calculations of the water application on creation of the unit crop, as a complex parameter of influence set of the factors, and, first of all, technologies of irrigation, on yield of maize, showed (Table 13 and 14) that the highest water expenditure on creation of a maize silage and a maize grain took place in version *continuous irrigation with q1 (control)*. The version *surge irrigation* had the most low the indexes of the water expenditure on creation of a crop.

The high value of water infiltration for creation of unit of a maize crop took place in version *continuous irrigation with q1 and q2 + PAM*. The high value of the water expenditure indicates on the large losses to deep percolation to soil (please look Table 9).

The results of field experiments 2002 and 2001 differed by yield of maize (especially grains) a little, but differed by value of water expenditure on creation of a crop unit and uniformity of distribution of a crop on furrow length (Table 13…15). Took place a water deficit for furrow end in 2001 and, in connection with this, high unevenness distribution of crop along 200 m furrow length. Coefficient K, which was received as quotient from division of yield in furrow end and furrow beginning, did not exceed 0.79 for maize silage and maize grain in 2001. These the low indexes were by result of a big furrow length. Reduction of furrow length to 150 m in 2002 was reflected effectively on maize yield.

Table 13

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 maize silage (cen/hec) at length of furrow				Water application on the one center of a crop (on the average), m^3/cen	Water infiltration on the one center of a crop (on the average), m3/cen
			20 m	75 m	130 m	on the average		
Cont. irr. with q1 and q2 + PAM	4554	3036	369	383	453	398	11.44	7.63
Cont. irr. with q1 and q2	3756	1759	404	354	344	365	10.29	4.82
Cont. irr. with q1	5360	1938	361	385	354	374	14.33	5.18
Surge irr. with q1 and q2	3610	1836	340	367	381	364	9.92	5.04
Surge irr. with q1 and q2 + PAM	3798	2074	311	354	425	361	10.52	5.75

Table 14

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 grain maize (cen/hec) at length of furrow				Water application on the one center of a crop (on the average), m^3/cen	Water infiltration on the one center of a crop (on the average), m3/cen
			20 m	75 m	130 m	on the average		
Cont. irr. with q1 and q2 + PAM	4554	3036	34	37	39	37	123.08	82.05
Cont. irr. with q1 and q2	3756	1759	33	29	29	30	125.20	58.63
Cont. irr. with q1	5360	1938	35	34	34	34	157.65	57.00
Surge irr. with q1 and q2	3610	1836	32	34	34	33	109.39	55.64
Surge irr. with q1 and q2 + PAM	3798	2074	29	33	38	33	115.09	62.85

Table 15

MAIZE YIELD IN 2001

Version of irrigation technology	Yield of maize grain (cen/hec) at furrow length				Yield of maize silage (cen/hec) at furrow length			
	20 m	100 m	200 m	on the average	20 m	100 m	200 m	on the average
Cont. irr. with q1 and q2 + PAM	47	38	37	40	363	303	278	310
Cont. irr. with q1 and q2	45	29	23	31	326	239	203	249
Cont. irr. with q1	45	35	31	36	348	285	273	295
Surge irr. with q1 and q2	42	33	32	35	361	268	256	284
Surge irr. with q1 and q2 + PAM	47	31	21	32	371	237	154	247

Conclusions

The results 2002 showed that the experiments conditions 2002 has some difference from conditions 2001. This difference was:

- surface slop of a plot increased from 2.7 % to 3.0 %;
- maximum field carrying capacity increase from 20.74% to 24%;
- chemical and physical compositions of soil changed a little;
- infiltration capacity of soil reduced;
- a furrow length reduced from 200 m to 150 m;
- mode of irrigation changed.

However, some general conclusions can are made for field researches 2001 and 2002. They consist in the following:

1. The PAM, is mixed with irrigation water in concentration of 10 g/m3 and given with the irrigation water only until the entire furrow is wetted, increased an infiltration capacity the soil, reduced an advancement speed of stream at furrow, increased a resistance of a surface furrow to erosion and made low field uniformity of the water distribution along furrow.

2. Surge irrigation was not effective at conditions a high infiltration capacity the soil of plot and big furrow length in 2001. The improvement of quality irrigation was reached with diminution of furrow length in 2002. This technology irrigation, in comparison with continuous irrigation, is low effective because take place higher intake at upstream end and low intake at the end

of the field. Surge irrigation generally reduced soil intake rate, reduced value of irrigation application efficiency, improved moisture uniformity over the entire field, and is heavy in performance. However, the technologies irrigation in a surge mode gave positive effect for uniformity distribution of crop along furrow length and should be given an other effects at irrigation by bright water.

3. Surge flow with PAM application (PAM in concentration of 10 g/m3 is mixed with irrigation water during the surges) was be effective in consolidation of soil surface and reducing IR in the furrow beginning. Intermittent flow could increase aggregate breakdown and sediment erosion and deposition, thus the formation of depositional surface seals in the furrow beginning. Sediment, PAM and fertilizers were moved to furrow end. Permeable layer of sediment, mixed with PAM and fertilizers, which was formed near to the furrow end, increased an infiltration capacity the soil, decreased an outflow volume, increased the irrigation application efficiency, increased a resistance of a surface furrow to erosion and increase of productivity maize silage and grain in the end of a irrigation plot. At the same time, surge irrigation in PAM treatment made worse an uniformity of the water distribution and maize crop along furrow.

Discrepancy an inflow rite to furrow length and the other conditions of plot field experiment brought to increased a sediment concentration in furrow end and the other negative effects in 2002. But did not influenced on content of basic conclusions.

References

1. Kachinski N. A. 1966. Structure of soil: 27.

2. Aripov E. A., Hamraev C. C., Sidorova T. M. Etc. 1966. Processes formation of structure in soil under influence dissolved in water of polymers //Book: The Physic-chemical mechanics of soil, ground, clay by him of building materials: 99.

3. Ahmedov K. C., Zaynutdinov C., Pogorelski K.V. 1962. New a structure-forming substance // Work: Anthology of article on agronomical physics. Issue.10: 171.

4. Batuk V. P. 1978. Application of polymers and superficial - active substances in soils: 202-218.

5. Ismatov D. 1966. Influence of polymeric preparations on physical and physical-chemical properties irrigated greyzems. PhD thesis :5-18.

6. Matoshko I. V. 1984. Polymers on a service of an agriculture: 37-41.

7. Mahlin T.V. 1966. Influence of polymers on a drain of deposits and having washed off soil. PhD thesis: 7-4

8. Romanov I. A. 1960. Application polyacrylamide for improvement of physical properties of soils // Bulletin of information on agronomical physics. № 8-9: 23.

9. Romanov I. A. 1962. Influence of polymers on physical properties podzoluvisols clay and crop of agricultural cultures. PhD thesis : 5-17.

10. Taimurzaev L. H. 1966. About a nature of interaction the structure-forming of polymers with soil. PhD thesis : 4-10.

11. Eshanov I. 1966. Application of polymers in cotton growing: 6-29.

12. The Soils of Kyrgyz USR (at editing A. M. Mamytov). 1974: 136

13. Kovda V. A. 1973. The principles of pedology. General theory of soil formation. Second book: 40.

14. Kachinski N. A. 1965. Physics of soils: 192.

15. Kalpakov V. V. 1958. Agro-reclamation analysis and calculations of water usage by agricultural crop in arid districts of European part USSR. Doctorate dissertation. Volume one:86.

16. Birukov K. K., Dorojko P. K. 1965. Irrigation of agricultural crop in steppe regions: 16-18.

Annex 1

The increase of soil moisture content

Soil stratum, cm	Before irrigation 2 Point 1					The soil moisture content, %	After irrigation 2					The soil moisture content, %	Increase of moisture content, %
0-30	016	21.01	54.09	50.19	3.90	13.37	002	22.95	63.96	57.39	6.57	19.08	
	015	20.51	56.40	51.97	4.43	14.08	015	20.51	53.20	47.83	5.37	19.66	
	013	21.27	60.18	55.76	4.42	12.82	006	22.43	54.91	49.63	5.28	19.41	
		62.79	**170.67**	**157.92**	**12.75**	**13.40**		**65.89**	**172.07**	**154.85**	**17.22**	**19.36**	**5.95**
30-60	009	20.79	46.25	42.14	4.11	19.25	014	21.10	51.64	46.10	5.54	22.16	
	008	21.12	62.06	55.76	6.30	18.19	001	20.31	53.79	47.85	5.94	21.57	
	007	21.43	51.10	46.73	4.37	17.27	007	21.43	51.17	45.75	5.42	22.29	
		63.34	**159.41**	**144.63**	**14.78**	**18.18**		**62.84**	**156.60**	**139.70**	**16.90**	**21.99**	**3.81**
60-90	012	19.99	47.02	42.20	4.82	21.70	013	21.27	62.31	54.56	7.75	23.28	
	005	20.79	57.65	51.46	6.19	20.18	008	21.12	56.24	49.72	6.52	22.80	
	015	20.51	53.14	47.48	5.66	20.99	012	19.99	54.18	47.76	6.42	23.12	
		61.29	**157.81**	**141.14**	**16.67**	**20.88**		**62.38**	**172.73**	**152.04**	**20.69**	**23.08**	**2.20**
90-120	003	21.31	70.22	61.64	8.58	21.27	005	20.79	63.50	55.93	7.57	21.54	
	004	23.11	64.33	57.22	7.11	20.84	016	21.01	52.46	46.68	5.78	22.52	
	002	22.95	63.08	56.43	6.65	19.86	003	21.31	69.85	61.25	8.60	21.53	
		67.37	**197.63**	**175.29**	**22.34**	**20.70**		**63.11**	**185.81**	**163.86**	**21.95**	**21.79**	**1.09**
120-150	001	20.31	46.83	42.34	4.49	20.38	009	20.79	53.93	48.24	5.69	20.73	
	014	21.10	50.06	45.41	4.65	19.13	004	23.11	68.66	60.74	7.92	21.05	
	010	21.02	51.41	46.32	5.09	20.12	010	21.02	48.16	43.57	4.59	20.35	
		62.43	**148.30**	**134.07**	**14.23**	**19.86**		**64.92**	**170.75**	**152.55**	**18.20**	**20.77**	**0.91**
											on the average 1		**2.79**

101

Continuation Annex 1

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2						The soil moisture content, %	Increase of moisture content, %
	point 2	August 13					point 2	August 18						
0-30	017	20.26	56.65	52.03	4.62	**14.54**	034	22.80	77.68	69.25	8.43		**18.15**	
	020	21.24	57.13	52.83	4.30	**13.61**	021	21.48	59.49	53.41	6.08		**19.04**	
	032	21.89	67.37	61.50	5.87	**14.82**	017	20.26	56.98	51.29	5.69		**18.34**	
		63.39	**181.15**	**166.36**	**14.79**	**14.36**		**64.54**	**194.15**	**173.95**	**20.20**		**18.46**	**4.10**
30-60	023	22.73	61.74	**55.48**	6.26	**19.11**	024	23.04	58.36	51.97	6.39		**22.09**	
	024	23.04	53.66	48.72	4.94	**19.24**	036	22.48	60.32	53.54	6.78		**21.83**	
	019	19.83	51.97	47.24	4.73	**17.26**	019	19.83	57.51	50.49	7.02		**22.90**	
		65.60	**167.37**	**151.44**	**15.93**	**18.56**		**65.35**	**176.19**	**156.00**	**20.19**		**22.27**	**3.71**
60-90	038	22.15	48.90	44.06	4.84	**22.09**	023	22.73	72.07	62.92	9.15		**22.77**	
	026	22.36	48.25	43.63	4.62	**21.72**	029	22.58	55.69	49.29	6.40		**23.96**	
	018	21.28	68.18	59.82	8.36	**21.69**	037	21.55	63.06	55.08	7.98		**23.80**	
		65.79	**165.33**	**147.51**	**17.82**	**21.81**		**66.86**	**190.82**	**167.29**	**23.53**		**23.43**	**1.62**
90-120	029	22.58	44.93	40.92	4.01	**21.86**	030	21.74	59.12	52.14	6.98		**22.96**	
	021	21.48	35.28	32.87	2.41	**21.16**	038	22.15	60.69	53.54	7.15		**22.78**	
	030	21.74	57.82	51.27	6.55	**22.18**	026	22.36	62.64	55.23	7.41		**22.54**	
		65.80	**138.03**	**125.06**	**12.97**	**21.89**		**66.25**	**182.45**	**160.91**	**21.54**		**22.76**	**0.87**
120-150	036	22.48	53.77	47.81	5.96	**23.53**	018	21.28	69.98	60.65	9.33		**23.70**	
	034	22.80	44.72	40.52	4.20	**23.70**	020	21.24	49.90	44.43	5.47		**23.59**	
	037	21.55	53.32	47.36	5.96	**23.09**	032	21.89	64.87	56.49	8.38		**24.22**	
		66.83	**151.81**	**135.69**	**16.12**	**23.41**		**64.41**	**184.75**	**161.57**	**23.18**		**23.86**	**0.45**
											on the average 2			**2.15**

102

Continuation Annex 1

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	The increas of moisture content, %
	point 3	August 13					point 3	August 18					
0-30	053	21.64	40.32	37.74	2.58	16.02	044	20.96	55.43	49.91	5.52	19.07	
	048	22.68	48.45	44.73	3.72	16.87	043	22.72	65.66	58.18	7.48	21.09	
	055	23.11	46.94	43.56	3.38	16.53	045	21.58	61.00	54.62	6.38	19.31	
		67.43	**135.71**	**126.03**	**9.68**	**16.52**		**65.26**	**182.09**	**162.71**	**19.38**	**19.89**	**3.37**
30-60	049	20.60	51.65	46.47	5.18	20.02	042	21.66	51.90	46.42	5.48	22.13	
	039	22.25	66.39	59.63	6.76	18.08	055	23.11	71.89	63.14	8.75	21.86	
	042	21.66	61.29	54.97	6.32	18.97	040	20.48	49.87	44.66	5.21	21.55	
		64.51	**179.33**	**161.07**	**18.26**	**18.91**		**65.25**	**173.66**	**154.22**	**19.44**	**21.85**	**2.94**
60-90	044	20.96	61.05	53.85	7.20	21.89	048	22.68	60.31	53.26	7.05	23.05	
	052	22.60	57.35	51.01	6.34	22.32	047	22.80	58.33	51.64	6.69	23.20	
	047	22.80	58.94	52.26	6.68	22.67	039	22.25	55.14	49.09	6.05	22.54	
		66.36	**177.34**	**157.12**	**20.22**	**22.28**		**67.73**	**173.78**	**153.99**	**19.79**	**22.94**	**0.66**
90-120	045	21.58	66.07	57.48	8.59	23.93	052	22.60	59.23	52.09	7.14	24.21	
	046	23.25	69.53	60.82	8.71	23.18	049	20.60	59.30	51.85	7.45	23.84	
	041	22.50	69.92	61.00	8.92	23.17	053	21.64	48.47	43.29	5.18	23.93	
		67.33	**205.52**	**179.30**	**26.22**	**23.42**		**64.84**	**167.00**	**147.23**	**19.77**	**24.00**	**0.58**
120-150	040	20.48	70.41	60.78	9.63	23.90	041	22.50	65.85	57.58	8.27	23.57	
	043	22.72	70.34	61.14	9.20	23.95	054	22.53	56.83	50.19	6.64	24.01	
	054	22.53	75.29	65.35	9.94	23.21	046	23.25	63.48	55.78	7.70	23.67	
		65.73	**216.04**	**187.27**	**28.77**	**23.67**		**68.28**	**186.16**	**163.55**	**22.61**	**23.73**	**0.06**
											on the average 3		**1.52**

Continuation Annex 1

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	Increase of moisture content, %
	point 4	August 13					point 4	August 18					
0-30	056	22.80	68.03	63.40	4.63	11.40	056	22.80	60.79	55.40	5.39	16.53	
	063	21.51	47.91	45.42	2.49	10.41	071	22.82	50.63	46.49	4.14	17.49	
	060	21.09	69.85	65.06	4.79	10.89	069	22.72	51.46	47.56	3.90	15.70	
		65.40	**185.79**	**173.88**	**11.91**	**10.98**		**68.34**	**162.88**	**149.45**	**13.43**	**16.56**	**5.58**
30-60	058	22.54	45.02	41.86	3.16	16.36	065	21.85	42.99	39.56	3.43	19.37	
	067	22.99	58.16	53.26	4.90	16.19	066	22.39	53.36	48.53	4.83	18.48	
	062	22.69	54.46	50.05	4.41	16.12	058	22.54	53.95	48.95	5.00	18.93	
		68.22	**157.64**	**145.17**	**12.47**	**16.21**		**66.78**	**150.30**	**137.04**	**13.26**	**18.87**	**2.67**
60-90	059	21.92	48.60	44.10	4.50	20.29	067	22.99	48.05	43.58	4.47	21.71	
	065	21.85	44.79	40.96	3.83	20.04	072	20.98	60.33	53.21	7.12	22.09	
	066	22.39	59.56	53.26	6.30	20.41	063	21.51	45.86	41.49	4.37	21.87	
		66.16	**152.95**	**138.32**	**14.63**	**20.27**		**65.48**	**154.24**	**138.28**	**15.96**	**21.92**	**1.65**
90-120	064	22.85	50.48	45.84	4.64	20.18	062	22.69	49.93	45.33	4.60	20.32	
	072	20.98	58.28	51.96	6.32	20.40	070	22.55	56.87	50.95	5.92	20.85	
	069	22.72	50.40	45.92	4.48	19.31	060	21.09	48.32	43.65	4.67	20.70	
		66.55	***159.16***	***143.72***	***15.44***	***20.01***		***66.33***	***155.12***	***139.93***	***15.19***	***20.64***	***0.63***
120-150	070	22.55	60.65	53.91	6.74	21.49	064	22.85	57.33	51.42	5.91	20.69	
	071	22.82	66.17	58.65	7.52	20.99	059	21.92	48.69	44.08	4.61	20.80	
	061	21.60	56.04	50.16	5.88	20.59	061	21.60	61.44	54.38	7.06	21.54	
		66.97	**182.86**	**162.72**	**20.14**	**21.03**		**66.37**	**167.46**	**149.88**	**17.58**	**21.05**	**0.02**
											on the average 4		**2.11**

104

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	Increase of moisture content, %
	point 5	August 13					point 5	August 18					
0-30	073	22.48	51.39	47.59	3.80	15.13	086	22.67	57.53	52.55	4.98	16.67	
	075	21.89	56.74	52.92	3.82	12.31	091	20.88	52.64	47.68	4.96	18.51	
	081	22.56	53.50	50.51	2.99	10.70	075	21.89	59.80	54.60	5.20	15.90	
		66.93	161.63	151.02	**10.61**	**12.62**		**65.44**	**169.97**	**154.83**	**15.14**	**16.94**	**4.32**
30-60	091	20.88	47.27	43.26	4.01	17.92	090	21.83	63.76	56.50	7.26	20.94	
	093	20.42	57.25	51.45	5.80	18.69	094	21.49	75.90	66.62	9.28	20.56	
	087	20.57	52.88	47.92	4.96	18.14	095	21.34	60.97	54.35	6.62	20.05	
		61.87	157.40	142.63	**14.77**	**18.29**		**64.66**	**200.63**	**177.47**	**23.16**	**20.53**	**2.24**
60-90	090	21.83	48.28	43.94	4.34	19.63	085	21.16	54.11	48.35	5.76	21.18	
	084	22.43	52.29	47.36	4.93	19.78	078	22.20	55.24	49.51	5.73	20.98	
	078	22.20	61.29	54.83	6.46	19.80	092	21.05	59.12	52.43	6.69	21.32	
		66.46	161.86	146.13	**15.73**	**19.74**		**64.41**	**168.47**	**150.29**	**18.18**	**21.17**	**1.43**
90-120	094	21.49	49.80	44.75	5.05	21.71	093	20.42	50.45	44.96	5.49	22.37	
	082	22.68	60.84	54.15	6.69	21.26	087	20.57	63.91	56.14	7.77	21.84	
	085	21.16	44.68	40.44	4.24	21.99	073	22.48	66.27	58.28	7.99	22.32	
		65.33	155.32	139.34	**15.98**	**21.59**		**63.47**	**180.63**	**159.38**	**21.25**	**22.16**	**0.56**
120-150	086	22.67	54.93	48.78	6.15	23.55	082	22.68	61.48	54.23	7.25	22.98	
	095	21.34	68.89	60.32	8.57	21.99	081	22.56	60.92	53.82	7.10	22.71	
	092	21.05	59.11	51.86	7.25	23.53	084	22.43	68.80	60.04	8.76	23.29	
		65.06	182.93	160.96	**21.97**	**22.91**		**67.67**	**191.20**	**168.09**	**23.11**	**23.01**	**0.10**
											on the average 5		**1.73**

105

Continuation Annex 1

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	The increas of moisture content, %
	point 6	August 13					point 6	August 18					
0-30	099	22.54	63.69	58.02	5.67	15.98	110	23.04	56.20	51.36	4.84	17.09	
	109	21.32	58.12	53.20	4.92	15.43	102	21.61	60.52	54.90	5.62	16.88	
	106	22.79	45.45	42.74	2.71	13.58	101	22.75	58.15	52.59	5.56	18.63	
		66.65	167.26	153.96	**13.30**	15.23		**67.40**	**174.87**	**158.85**	**16.02**	**17.52**	**2.28**
30-60	100	23.04	56.81	51.19	5.62	19.96	109	21.32	59.23	52.77	6.46	20.54	
	101	22.75	51.56	47.03	4.53	18.66	108	23.42	58.82	52.68	6.14	20.98	
	098	21.38	59.80	53.87	5.93	18.25	106	22.79	54.38	48.96	5.42	20.71	
		67.17	168.17	152.09	**16.08**	18.94		**67.53**	**172.43**	**154.41**	**18.02**	**20.74**	**1.81**
60-90	111	22.45	64.90	57.55	7.35	20.94	103	22.35	60.69	53.90	6.79	21.52	
	108	23.42	82.46	72.24	10.22	20.93	097	21.90	47.06	42.56	4.50	21.78	
	096	21.18	61.75	54.75	7.00	20.85	100	23.04	58.10	51.86	6.24	21.65	
		67.05	209.11	184.54	**24.57**	20.91		**67.29**	**165.85**	**148.32**	**17.53**	**21.63**	**0.72**
90-120	103	22.35	54.33	48.42	5.91	22.67	096	21.18	65.72	57.26	8.46	23.45	
	107	22.84	58.57	51.92	6.65	22.87	105	22.73	58.78	52.03	6.75	23.04	
	097	21.90	63.66	56.07	7.59	22.21	099	22.54	58.12	51.61	6.51	22.39	
		67.09	176.56	156.41	**20.15**	22.56		**66.45**	**182.62**	**160.90**	**21.72**	**23.00**	**0.44**
120-150	102	21.61	54.49	48.07	6.42	24.26	107	22.84	62.40	54.83	7.57	23.66	
	105	22.73	54.77	48.68	6.09	23.47	098	21.38	67.87	58.94	8.93	23.78	
	110	23.04	60.40	53.26	7.14	23.63	111	22.45	69.56	60.41	9.15	24.10	
		67.38	169.66	150.01	**19.65**	23.78		**66.67**	**199.83**	**174.18**	**25.65**	**23.86**	**0.08**
											on the average 6		**1.07**

106

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	Increase of moisture content, %
	point 7	August 13					point 7	August 18					
0-30	113	22.64	64.12	58.65	5.47	15.19	122	21.66	49.56	44.96	4.60	19.74	20 m
	121	22.71	66.44	61.24	5.2	13.50	112	22.91	58.34	52.57	5.77	19.45	
	126	21.99	54.96	50.71	4.25	14.80	119	22.24	61.39	54.98	6.41	19.58	
		67.34	**185.52**	**170.60**	**14.92**	**14.45**		**66.81**	**169.29**	**152.51**	**16.78**	**19.58**	**5.13**
30-60	118	22.18	51.06	46.57	4.49	18.41	121	22.71	53.00	48.07	4.93	19.44	
	114	21.89	56.66	51.13	5.53	18.91	126	21.99	54.02	48.76	5.26	19.65	
	112	22.91	59.8	54.21	5.59	17.86	127	21.91	50.04	45.52	4.52	19.14	
		66.98	**167.52**	**151.91**	**15.61**	**18.38**		**66.61**	**157.06**	**142.35**	**14.71**	**19.42**	**1.04**
60-90	125	22.13	51.88	46.70	5.18	21.08	118	22.18	61.41	54.43	6.98	21.64	
	117	22.95	51.13	46.26	4.87	20.89	120	22.49	64.77	57.08	7.69	22.23	
	123	21.53	60.08	53.43	6.65	20.85	125	22.13	67.33	59.25	8.08	21.77	
		66.61	**163.09**	**146.39**	**16.70**	**20.93**		**66.80**	**193.51**	**170.76**	**22.75**	**21.88**	**0.95**
90-120	115	22.86	54.5	49.01	5.49	20.99	123	21.53	60.74	53.79	6.95	21.54	
	120	22.49	54.33	48.82	5.51	20.93	115	22.86	60.50	53.68	6.82	22.13	
	124	22.28	70.39	61.91	8.48	21.40	124	22.28	67.13	59.21	7.92	21.45	
		67.63	**179.22**	**159.74**	**19.48**	**21.15**		**66.67**	**188.37**	**166.68**	**21.69**	**21.69**	**0.54**
120-150	119	22.24	44.14	40.31	3.83	21.20	114	21.89	71.48	62.09	9.39	23.36	
	127	21.91	48.93	44.13	4.8	21.60	117	22.95	51.21	45.90	5.31	23.14	
	122	21.66	48.97	44.17	4.8	21.32	113	22.64	57.74	51.26	6.48	22.64	
		65.81	**142.04**	**128.61**	**13.43**	**21.39**		**67.48**	**180.43**	**159.25**	**21.18**	**23.08**	**1.69**
											on the average 6		**1.87**

Continuation Annex 1

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	Increase of moisture content, %
	point 8	August 13					point 8	August 18					
0-30	141	22.60	59.88	55.7	4.18	12.63	134	22.62	73.81	65.92	7.89	18.22	75 m
	139	21.40	61.18	56.53	4.65	13.24	139	21.40	53.94	48.84	5.10	18.59	
	133	20.80	60.16	55.24	4.92	14.29	133	20.80	48.27	44.23	4.04	17.24	
		64.80	**181.22**	**167.47**	**13.75**	**13.39**		**64.82**	**176.02**	**158.99**	**17.03**	**18.08**	**4.69**
30-60	135	22.43	64.57	57.79	6.78	19.17	135	22.43	52.36	47.40	4.96	19.86	
	140	22.91	63.89	58.22	5.67	16.06	137	22.91	53.97	48.76	5.21	20.15	
	137	22.91	50.6	46.99	3.61	14.99	128	22.82	59.51	53.19	6.32	20.81	
		68.25	**179.06**	**163.00**	**16.06**	**16.95**		**68.16**	**165.84**	**149.35**	**16.49**	**20.31**	**3.36**
60-90	142	22.87	50.22	45.61	4.61	20.27	132	22.73	62.67	55.72	6.95	21.07	
	131	21.05	60.11	53.49	6.62	20.41	130	22.76	59.55	53.16	6.39	21.02	
	130	22.76	67.41	59.84	7.57	20.42	131	21.05	51.93	46.74	5.19	20.20	
		66.68	**177.74**	**158.94**	**18.80**	**20.38**		**66.54**	**174.15**	**155.62**	**18.53**	**20.80**	**0.42**
90-120	129	22.81	52.44	47.26	5.18	21.19	136	23.24	55.12	49.44	5.68	21.68	
	134	22.62	48.17	43.67	4.50	21.38	141	22.60	54.13	48.55	5.58	21.50	
	136	23.24	50.38	45.74	4.64	20.62	138	21.79	55.03	49.18	5.85	21.36	
		68.67	**150.99**	**136.67**	**14.32**	**21.06**		**67.63**	**164.28**	**147.17**	**17.11**	**21.51**	**0.45**
120-150	138	21.79	57.29	50.75	6.54	22.58	140	22.91	64.78	56.46	8.32	24.80	
	128	22.82	65.62	57.49	8.13	23.45	129	22.81	44.73	40.65	4.08	22.87	
	132	22.73	54.71	48.47	6.24	24.24	142	22.87	61.34	53.94	7.40	23.82	
		67.34	**177.62**	**156.71**	**20.91**	**23.40**		**68.59**	**170.85**	**151.05**	**19.80**	**24.01**	**0.61**
											on the average 8		**1.91**

108

Continuation Annex 1

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	Increase of moisture content, %
	point 9	August 13					point 9	August 18					
0-30	151	22.90	52.58	48.58	4.00	15.58	146	22.06	55.20	49.86	5.34	19.21	135 m
	143	22.25	69.43	63.82	5.61	13.50	152	21.73	69.70	61.91	7.79	19.39	
	158	22.84	50.9	47.62	3.28	13.24	158	22.84	64.74	57.96	6.78	19.31	
		67.99	**172.91**	**160.02**	**12.89**	**14.01**		**66.63**	**189.64**	**169.73**	**19.91**	**19.31**	**5.31**
30-60	157	22.44	50.63	46.4	4.23	17.65	157	22.44	45.27	41.13	4.14	22.15	
	145	21.39	60.85	54.57	6.28	18.93	147	22.69	69.59	61.10	8.49	22.10	
	155	22.75	49.97	46.16	3.81	16.28	155	22.75	50.86	45.99	4.87	20.96	
		66.58	**161.45**	**147.13**	**14.32**	**17.78**		**67.88**	**165.72**	**148.22**	**17.50**	**21.78**	**4.00**
60-90	144	21.80	59.75	53.35	6.40	20.29	159	20.64	61.48	54.01	7.47	22.39	
	152	21.73	46.23	42.24	3.99	19.45	154	22.49	64.24	56.64	7.60	22.25	
	149	22.47	52.23	47.4	4.83	19.37	149	22.47	55.59	49.81	5.78	21.14	
		66.00	**158.21**	**142.99**	**15.22**	**19.77**		**65.60**	**181.31**	**160.46**	**20.85**	**21.98**	**2.21**
90-120	156	21.16	47.03	42.07	4.96	23.72	143	22.25	67.45	58.74	8.71	23.87	
	147	22.69	68.81	60.08	8.73	23.35	144	21.80	58.11	51.37	6.74	22.79	
	146	22.06	52.36	46.88	5.48	22.08	156	21.16	72.69	62.91	9.78	23.43	
		65.91	**168.20**	**149.03**	**19.17**	**23.06**		**65.21**	**198.25**	**173.02**	**25.23**	**23.40**	**0.34**
120-150	153	22.17	52.79	46.91	5.88	23.77	153	22.17	68.64	59.58	9.06	24.22	
	159	20.64	52.21	46.17	6.04	23.66	145	21.39	65.74	57.05	8.69	24.37	
	154	22.49	64.00	56.00	8.00	23.87	151	**22.90**	**76.41**	**65.86**	10.55	24.56	
		65.30	**169.00**	**149.08**	**19.92**	**23.78**		**66.46**	**210.79**	**182.49**	**28.30**	**24.39**	**0.61**
											on the average 9		**2.49**

Continuation Annex 1

Soil stratum, cm	Before irrigation 2 point 10	August 18				The soil moisture content, %	After irrigation 2 point 10	August 22				The soil moisture content, %	Increase of moisture content, %
0-30	167	21.98	50.39	46.92	3.47	13.91	173	22.58	49.61	45.98	3.63	15.51	20 m
	171	21.66	53.57	49.58	3.99	14.29	164	22.06	42.44	39.82	2.62	14.75	
	173	22.58	51.92	48.29	3.63	14.12	170	21.92	45.58	42.56	3.02	14.63	
		66.22	**155.88**	**144.79**	**11.09**	**14.11**		**66.56**	**137.63**	**128.36**	**9.27**	**15.00**	**0.89**
30-60	174	22.44	46.58	43.12	3.46	16.73	165	22.87	46.14	42.51	3.63	18.48	
	165	22.87	44.84	41.83	3.01	15.88	168	21.13	41.11	38.10	3.01	17.74	
	168	21.13	55.1	50.05	5.05	17.46	160	21.50	48.50	44.13	4.37	19.31	
		66.44	**146.52**	**135.00**	**11.52**	**16.80**		**65.50**	**135.75**	**124.74**	**11.01**	**18.59**	**1.78**
60-90	169	22.35	51.54	46.47	5.07	21.02	166	21.90	56.37	50.12	6.25	22.15	
	166	21.90	57.94	51.94	6.00	19.97	161	23.16	52.29	47.16	5.13	21.38	
	164	22.06	50.15	46.46	3.69	15.12	174	22.44	53.93	48.35	5.58	21.54	
		66.31	**159.63**	**144.87**	**14.76**	**18.79**		**67.50**	**162.59**	**145.63**	**16.96**	**21.71**	**2.92**
90-120	160	21.50	56.78	50.58	6.20	21.32	169	22.35	69.09	60.79	8.30	21.59	
	170	21.92	56.38	50.36	6.02	21.17	167	21.98	48.36	43.74	4.62	21.23	
	161	23.16	58.54	52.19	6.35	21.87	172	22.01	64.32	56.81	7.51	21.58	
		66.58	**171.70**	**153.13**	**18.57**	**21.46**		**66.34**	**181.77**	**161.34**	**20.43**	**21.51**	**0.05**
120-150	172	22.01	58.93	51.93	7.00	23.40	175	22.74	68.15	59.62	8.53	23.13	
	163	23.15	61.68	54.25	7.43	23.89	163	23.15	66.29	58.15	8.14	23.26	
	175	22.74	61.74	54.52	7.22	22.72	171	21.66	59.35	52.49	6.86	22.25	
		67.90	**182.35**	**160.70**	**21.65**	**23.33**		**67.55**	**193.79**	**170.26**	**23.53**	**22.91**	**-0.42**
											on the average 10		**1.04**

110

Continuation Annex 1

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	Increase of moisture content, %
	point 11	August 18					point 11	August 22					
0-30	189	21.99	56.67	52.83	3.84	12.45	181	22.58	58.93	54.58	4.35	13.59	75 m
	179	23.18	74.83	69.03	5.80	12.65	182	22.09	60.91	56.27	4.64	13.58	
	180	21.94	66.24	61.31	4.93	12.52	188	22.87	56.38	52.46	3.92	13.25	
		67.11	**197.74**	**183.17**	**14.57**	**12.55**		**67.54**	**176.22**	**163.31**	**12.91**	**13.48**	**0.93**
30-60	176	22.39	67.98	61.97	6.01	15.18	190	22.84	56.58	50.92	5.66	20.16	
	190	22.84	54.04	50.01	4.03	14.83	176	22.39	59.20	53.23	5.97	19.36	
	184	22.79	51.11	47.36	3.75	15.26	187	22.70	64.16	57.37	6.79	19.58	
		68.02	**173.13**	**159.34**	**13.79**	**15.10**		**67.93**	**179.94**	**161.52**	**18.42**	**19.68**	**4.58**
60-90	183	22.27	60.39	53.62	6.77	21.59	189	21.99	57.31	51.17	6.14	21.04	
	181	22.58	67.21	59.66	7.55	20.36	180	21.94	66.58	58.64	7.94	21.63	
	178	22.85	68.93	61.62	7.31	18.85	184	22.79	58.90	52.75	6.15	20.53	
		67.70	**196.53**	**174.90**	**21.63**	**20.18**		**66.72**	**182.79**	**162.56**	**20.23**	**21.11**	**0.93**
90-120	177	21.83	54.89	48.92	5.97	22.04	179	23.18	61.84	54.98	6.86	21.57	
	193	22.99	55.12	49.57	5.55	20.88	183	22.27	68.33	59.85	8.48	22.57	
	185	22.60	64.43	57.03	7.40	21.49	178	22.85	54.83	49.10	5.73	21.83	
		67.42	**174.44**	**155.52**	**18.92**	**21.48**		**68.30**	**185.00**	**163.93**	**21.07**	**22.03**	**0.56**
120-150	188	22.87	53.54	47.72	5.82	23.42	185	22.60	55.37	49.36	6.01	22.46	
	187	22.70	56.96	50.65	6.31	22.58	177	21.83	51.21	45.68	5.53	23.19	
	182	22.09	52.64	46.87	5.77	23.28	193	22.99	72.55	63.35	9.20	22.79	
		67.66	**163.14**	**145.24**	**17.90**	**23.07**		**67.42**	**179.13**	**158.39**	**20.74**	**22.80**	**-0.27**
											on the average 11		**1.34**

///

Continuation Annex 1

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	Increase of moisture content, %
	point 12	August 18					point 12	August 22					
0-30	208	21.83	50.91	47.34	3.57	13.99	197	22.55	57.50	52.51	4.99	16.66	130 m
	210	22.95	61.41	56.85	4.56	13.45	210	22.95	58.08	53.38	4.70	15.45	
	209	23.19	58.84	54.53	4.31	13.75	204	22.65	72.83	65.80	7.03	16.29	
		67.97	**171.16**	**158.72**	**12.44**	**13.71**		**68.15**	**188.41**	**171.69**	**16.72**	**16.15**	**2.44**
30-60	207	21.11	56.38	51.13	5.25	17.49	205	20.28	55.34	49.40	5.94	20.40	
	203	22.14	63.8	57.6	6.20	17.48	206	21.82	55.07	49.26	5.81	21.17	
	195	21.03	56.2	50.38	5.82	19.83	207	21.11	59.02	52.50	6.52	20.77	
		64.28	**176.38**	**159.11**	**17.27**	**18.21**		**63.21**	**169.43**	**151.16**	**18.27**	**20.77**	**2.56**
60-90	201	22.86	68.01	60.56	7.45	19.76	199	22.26	57.80	51.67	6.13	20.84	
	202	21.84	59.81	53.38	6.43	20.39	195	21.03	62.29	55.10	7.19	21.10	
	196	21.24	62.38	55.42	6.96	20.36	203	22.14	61.00	54.26	6.74	20.98	
		65.94	**190.20**	**169.36**	**20.84**	**20.15**		**65.43**	**181.09**	**161.03**	**20.06**	**20.98**	**0.83**
90-120	197	22.55	61.3	54.78	6.52	20.23	201	22.86	63.18	56.03	7.15	21.56	
	194	22.26	62.06	55.19	6.87	20.86	208	21.83	74.10	64.83	9.27	21.56	
	205	20.28	57.33	50.81	6.52	21.36	209	23.19	62.86	**55.81**	7.05	21.61	
		65.09	**180.69**	**160.78**	**19.91**	**20.81**		**67.88**	**200.14**	**176.67**	**23.47**	**21.57**	**0.77**
120-150	206	21.82	58.12	50.95	7.17	24.61	202	21.84	85.72	72.85	12.87	25.23	
	204	22.65	57.03	49.97	7.06	25.84	196	21.24	67.39	58.04	9.35	25.41	
	199	22.26	63.87	55.78	8.09	24.13	194	22.26	68.46	59.03	9.43	25.65	
		66.73	**179.02**	**156.70**	**22.32**	**24.81**		**65.34**	**221.57**	**189.92**	**31.65**	**25.41**	**0.60**
											on the average 12		**1.44**

112

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	Increase of moisture content, %
	point 13	August 18					point 13	August 22					
0-30	262	23.38	66.66	60.65	6.01	16.13	223	21.97	53.75	49.15	4.60	16.92	
	272	22.59	48.37	44.74	3.63	16.39	259	22.83	55.82	51.12	4.70	16.61	
	273	22.24	51.96	47.99	3.97	15.42	273	22.24	60.55	55.17	5.38	16.34	
		68.21	**166.99**	**153.38**	**13.61**	**15.98**		**67.04**	**170.12**	**155.44**	**14.68**	**16.61**	**0.63**
30-60	253	21.28	46.46	42.41	4.05	19.17	260	22.75	42.91	39.51	3.40	20.29	
	216	21.76	62.21	55.28	6.93	20.67	272	22.59	50.22	45.30	4.92	21.66	
	222	22.23	58.57	52.76	5.81	19.03	231	22.54	50.79	45.78	5.01	21.56	
		65.27	**167.24**	**150.45**	**16.79**	**19.71**		**67.88**	**143.92**	**130.59**	**13.33**	**21.26**	**1.55**
60-90	242	22.51	44.40	40.46	3.94	21.95	275	20.69	52.80	47.04	5.76	21.86	
	246	22.77	58.36	52.16	6.20	21.10	246	22.77	47.41	42.74	4.67	23.39	
	223	21.97	49.81	44.96	4.85	21.10	262	23.38	45.73	41.65	4.08	22.33	
		67.25	**152.57**	**137.58**	**14.99**	**21.31**		**66.84**	**145.94**	**131.43**	**14.51**	**22.46**	**1.15**
90-120	231	22.54	63.95	56.19	7.76	23.06	248	22.23	52.64	46.92	5.72	23.17	
	259	22.83	57.19	50.80	6.39	22.85	253	21.28	45.88	41.16	4.72	23.74	
	248	22.23	53.22	47.77	5.45	21.34	222	22.23	54.73	48.62	6.11	23.15	
		67.60	**174.36**	**154.76**	**19.60**	**22.49**		**65.74**	**153.25**	**136.70**	**16.55**	**23.32**	**0.84**
120-150	211	22.12	49.01	43.47	5.54	25.95	216	21.76	50.47	44.65	5.82	25.43	
	260	22.75	48.10	43.00	5.10	25.19	242	22.51	65.22	56.55	8.67	25.47	
	275	20.69	42.13	37.93	4.20	24.36	211	22.12	57.56	50.44	7.12	25.14	
		65.56	**139.24**	**124.40**	**14.84**	**25.22**		**66.39**	**173.25**	**151.64**	**21.61**	**25.35**	**0.13**
											on the average 13		**0.86**

Continuation Annex 1

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	Increase of moisture content, %
	point 14	August 18					point 14	August 22					
0-30	328	22.61	69.73	64.48	5.25	12.54	307	21.51	64.86	59.23	5.63	14.93	
	306	20.72	79.32	72.20	7.12	13.83	300	20.72	50.18	46.44	3.74	14.54	
	305	19.66	53.62	49.50	4.12	13.81	292	22.11	51.16	47.35	3.81	15.10	
		62.99	**202.67**	**186.18**	**16.49**	**13.39**		**64.34**	**166.20**	**153.02**	**13.18**	**14.86**	**1.48**
30-60	292	22.11	38.54	36.34	2.20	15.46	306	20.72	47.30	43.37	3.93	17.35	
	324	20.49	49.81	46.05	3.76	14.71	282	22.25	52.32	47.79	4.53	17.74	
	285	19.84	39.55	36.92	2.63	15.40	298	21.72	65.68	59.17	6.51	17.38	
		62.44	**127.90**	**119.31**	**8.59**	**15.10**		**64.69**	**165.30**	**150.33**	**14.97**	**17.48**	**2.38**
60-90	327	23.24	55.30	49.87	5.43	20.39	324	20.49	53.00	47.19	5.81	21.76	
	298	21.72	49.89	45.33	4.56	19.31	318	20.67	56.01	49.68	6.33	21.82	
	313	20.42	49.65	44.90	4.75	19.40	313	20.42	61.13	53.99	7.14	21.27	
		65.38	**154.84**	**140.10**	**14.74**	**19.73**		**61.58**	**170.14**	**150.86**	**19.28**	**21.59**	**1.87**
90-120	325	22.41	56.44	50.34	6.10	21.84	305	19.66	57.46	50.47	6.99	22.69	
	318	20.67	54.30	48.12	6.18	22.51	328	22.61	50.57	45.22	5.35	23.66	
	321	22.98	50.07	45.21	4.86	21.86	285	19.84	59.98	52.40	7.58	23.28	
		66.06	**160.81**	**143.67**	**17.14**	**22.08**		**62.11**	**168.01**	**148.09**	**19.92**	**23.17**	**1.08**
120-150	300	20.72	62.66	55.28	7.38	21.35	325	22.41	54.44	48.60	5.84	22.30	
	307	21.51	56.50	50.01	6.49	22.77	327	23.24	72.16	63.15	9.01	22.58	
	282	22.25	62.28	54.91	7.37	22.57	321	22.98	57.08	50.83	6.25	22.44	
		64.48	**181.44**	**160.20**	**21.24**	**22.19**		**68.63**	**183.68**	**162.58**	**21.10**	**22.46**	**0.27**
											on the average 14		**1.41**

114

Soil stratum, cm	Before irrigation 2					The soil moisture content, %	After irrigation 2					The soil moisture content, %	Increase of moisture content, %
	point 15	August 18					point 15	August 22					
0-30	334	20.07	55.77	51.64	4.13	13.08	351	22.53	63.98	58.23	5.75	16.11	
	349	23.30	56.66	53.04	3.62	12.17	349	23.30	58.01	53.36	4.65	15.47	
	332	22.73	62.31	57.75	4.56	13.02	333	22.93	58.37	53.35	5.02	16.50	
		66.10	**174.74**	**162.43**	**12.31**	**12.78**		**68.76**	**180.36**	**164.94**	**15.42**	**16.03**	**3.25**
30-60	338	22.93	59.23	54.27	4.96	15.83	346	20.49	57.85	52.16	5.69	17.97	
	330	23.04	54.64	50.15	4.49	16.56	330	23.10	57.05	51.74	5.31	18.54	
	361	22.48	56.80	52.17	4.63	15.59	334	20.07	53.62	48.34	5.28	18.68	
		68.45	**170.67**	**156.59**	**14.08**	**15.97**		**63.66**	**168.52**	**152.24**	**16.28**	**18.38**	**2.40**
60-90	335	22.39	58.72	52.83	5.89	19.35	357	22.98	53.63	48.45	5.18	20.34	
	351	22.53	53.60	48.66	4.94	18.91	338	22.93	49.99	45.38	4.61	20.53	
	346	20.49	49.63	44.91	4.72	19.33	335	22.39	65.49	58.30	7.19	20.02	
		65.41	**161.95**	**146.40**	**15.55**	**19.20**		**68.30**	**169.11**	**152.13**	**16.98**	**20.26**	**1.06**
90-120	357	22.98	47.96	43.93	4.03	19.24	356	23.14	56.35	50.64	5.71	20.76	
	360	21.60	59.90	53.41	6.49	20.40	361	22.48	65.64	58.27	7.37	20.59	
	356	23.14	52.39	47.68	4.71	19.19	366	23.09	59.70	53.43	6.27	20.67	
		67.72	**160.25**	**145.02**	**15.23**	**19.70**		**68.71**	**181.69**	**162.34**	**19.35**	**20.67**	**0.96**
120-150	333	23.10	59.16	52.00	7.16	24.78	360	21.60	63.91	55.19	8.72	25.96	
	355	22.85	56.73	49.96	6.77	24.97	355	22.85	64.32	56.02	8.30	25.02	
	366	23.09	59.72	52.44	7.28	24.80	332	22.73	67.08	58.42	8.66	24.26	
		69.04	**175.61**	**154.40**	**21.21**	**24.85**		**67.18**	**195.31**	**169.63**	**25.68**	**25.07**	**0.22**
											on the average 15		**1.58**

115

The calculation of the water aplication for irrigation period

Irrigation 1

Version	Duration of furrow wetting, min	Duration of irrigation, min	Duration of irrigation (min) with flow rate		The water aplication (m3/hec) with flow rate		
			q1=30 L/min	q2=16.8 L/min	q1=30 L/min	q2=16.8 L/min	Total
Cont. irr. +PAM with q1 and q2	71	401	101	300	338	560	898
Cont. irr. with q2 and q2	65	395	95	300	315	560	875
Cont. irr. with q1	66	396	396	0	1321	0	1321
Surge irr. with q1 and q2	79	409	109	300	364	560	924
Surge irr. + PAM with q1 and q2	116	446	146	300	486	560	1046

Irrigation 2

Version	Duration of furrow wetting, min	Duration of irrigation, min	Duration of irrigation (min) with flow rate		The water aplication (m3/hec) with flow rate		
			q1=30 L/min	q2=16.8 L/min	q1=30 L/min	q2=16.8 L/min	Total
Cont. irr. +PAM with q1 and q2*	301	631	331	300	1103	560	1663
Cont. irr. with q2 and q2	148	478	178	300	593	560	1153
Cont. irr. with q1	115	445	445	0	1483	0	1483
Surge irr. with q1 and q2	91	421	121	300	402	560	962
Cont. irr. + PAM with q1 and q2**	68	398	98	300	326	560	886

* it is rainning ** it does not raining

Irrigation 3

Version	Duration of furrow wetting, min	Duration of irrigation, min	Duration of irrigation (min) with flow rate		The water aplication (m3/hec) with flow rate		
			q1=30 L/min	q2=16.8 L/min	q1=30 L/min	q2=16.8 L/min	Total
Cont. irr. +PAM with q1 and q2	136	466	166	300	553	560	1113
Cont. irr. with q2 and q2	73	403	103	300	344	560	904
Cont. irr. with q1	64	394	394	0	1313	0	1313
Surge irr. with q1 and q2	61	391	91	300	303	560	863
Surge irr. + PAM with q1 and q2	79	409	109	300	363	560	923

Irrigation 4

Version	Duration of furrow wetting, min	Duration of irrigation, min	Duration of irrigation (min) with flow rate		The water aplication (m3/hec) with flow rate		
			q1=30 L/min	q2=16.8 L/min	q1=30 L/min	q2=16.8 L/min	Total
Cont. irr. +PAM with q1 and q2	66	396	96	300	320	560	880
Cont. irr. with q2 and q2	49	379	79	300	264	560	824
Cont. irr. with q1	43	373	373	0	1243	0	1243
Surge irr. with q1 and q2*	60	390	90	300	301	560	861
Surge irr. + PAM with q1 and q2*	85	415	115	300	383	560	943

*it is after raining

Annex 3

The outflow volume, the sediments

2002

Irrigation 1 July 31

The irrigation tehnology: continuous irrigation + PAM with q1 and q2 Furrows 5, 6, 7, 8

		The water					The sediments	
		Out flow rate		Outflow				
		qi	q av	volume, L	m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.			g/L	
10		0.200			6.98	69.8		
	10		0.209	125.45			66.831	8.38
20		0.218			6.39	63.9		
	10		0.223	133.81			63.763	8.53
30		0.228			6.36	63.6		
	30		0.195	350.25			49.057	17.18
60		0.161			3.45	34.5		
	30		0.171	307.05			36.187	11.11
90		0.180			3.79	37.9		
	30		0.187	336.26			36.368	12.23
120		0.194			3.48	34.8		
	30		0.188	337.80			34.443	11.63
150		0.182			3.40	34.0		
	60		0.179	646.04			32.017	20.68
210		0.177			3.00	30.0		
	60		0.170	610.78			30.960	18.91
270		0.162			3.19	31.9		
	60		0.161	578.84			29.339	16.98
330		0.160			2.67	26.7		
TOTAL				**3426**	**L**			**125.65**
				381	**m3/hec**			

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2	0.197	2.3	0.211	2.3	0.211	2.7	0.158	2.5	0.152
1.9	0.192	2.8	0.233	3	0.241	3.8	0.187	4.2	0.197
2.4	0.215	2.8	0.233	3.1	0.245	2.2	0.142	3.3	0.174
2	0.197	2	0.197	2.4	0.215	2.7	0.158	4.2	0.197
	0.200		**0.218**		**0.228**		**0.161**		**0.180**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
4.6	0.206	3.8	0.187	4	0.192	2.8	0.161	2.4	0.149
4.6	0.206	4.4	0.201	4.3	0.199	3	0.166	3.4	0.177
4.2	0.197	3.2	0.172	3	0.166	2.7	0.158	2.5	0.152
3	0.166	3	0.166	2.5	0.152	2.9	0.163	2.8	0.161
	0.194		**0.182**		**0.177**		**0.162**		**0.160**

117

Irrigation 1 July 31 Continuation of Annex 3

The irrigation tehnology: continuous irrigation with q1 and q2 Furrows 1, 2, 3, 4

		The water					The sediments	
		Out flow rate		Outflow				
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.232				4.77	47.73		
	10		0.238	142.92				52.789	7.54
20		0.245				5.78	57.85		
	10		0.250	149.94				62.685	9.40
30		0.255				6.75	67.52		
	30		0.236	424.83				49.190	20.90
60		0.217				3.09	30.86		
	30		0.213	383.22				31.402	12.03
90		0.209				3.19	31.95		
	30		0.213	383.68				21.550	8.27
120		0.217				1.12	11.15		
	30		0.212	380.94				10.249	3.90
150		0.206				0.93	9.34		
	60		0.202	727.70				9.040	6.58
210		0.198				0.87	8.74		
	60		0.198	714.43				7.705	5.50
270		0.199				0.67	6.67		
	60		0.196	706.55				6.936	4.90
330		0.194				0.72	7.20		
TOTAL				**4014**	**L**				**79.03**
				446	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2.8	0.233	3	0.241	3.4	0.256	1.9	0.192	2.9	0.237
2.1	0.201	2.8	0.233	3	0.241	2.3	0.211	1.9	0.192
3	0.241	3.4	0.256	3.6	0.264	2.6	0.224	2.1	0.201
3.3	0.253	3.2	0.249	3.5	0.260	3	0.241	2.2	0.206
	0.232		**0.245**		**0.255**		**0.217**		**0.209**

T, min	120		150		210		270		330
	q	h	q	h	q	h	q	h	q
2.5	0.220	2	0.197	1.5	0.170	1.6	0.176	1.6	0.176
2.8	0.233	2.5	0.220	2.3	0.211	2.2	0.206	2.7	0.228
2.2	0.206	2.3	0.211	2.2	0.206	2.1	0.201	1.5	0.170
2.3	0.211	2	0.197	2.2	0.206	2.3	0.211	2.1	0.201
	0.217		**0.206**		**0.198**		**0.199**		**0.194**

Continuation of Annex 3

Irrigation 1 August 1

The irrigation tehnology: continuous irrigation with q1 Furrows 17, 18, 19, 20

		The water				The sediments			
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.379				4.20	41.99		
	10		0.387	232.49				43.913	10.21
20		0.396				4.58	45.84		
	10		0.407	244.33				46.525	11.37
30		0.418				4.72	47.21		
	30		0.416	749.63				47.930	35.93
60		0.415				4.87	48.65		
	30		0.422	759.35				46.164	35.05
90		0.429				4.37	43.68		
	30		0.422	758.85				40.608	30.82
120		0.414				3.75	37.54		
	30		0.415	747.53				38.594	28.85
150		0.416				3.96	39.65		
	60		0.415	1495.13				36.519	54.60
210		0.414				3.34	33.39		
	60		0.416	1498.03				36.519	54.71
270		0.418				3.96	39.65		
	60		0.419	1507.56				35.648	53.74
330		0.420				3.16	31.65		
TOTAL				**7993**	**L**				**315**
				888	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2.5	0.402	2.3	0.385	3	0.440	3	0.440	2.9	0.433
2	0.359	2.3	0.385	2.1	0.368	2.3	0.385	2.8	0.425
2.3	0.385	3.1	0.447	3.2	0.454	2.8	0.425	2.8	0.425
2.1	0.368	2.1	0.368	2.6	0.410	2.6	0.410	2.9	0.433
	0.379		**0.396**		**0.418**		**0.415**		**0.429**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
3	0.440	3.2	0.454	3.1	0.447	3.2	0.454	3.3	0.461
3	0.440	2.7	0.417	2.8	0.425	3.1	0.447	3.1	0.447
2.1	0.368	2.1	0.368	2.1	0.368	2.1	0.368	2.2	0.377
2.6	0.410	2.8	0.425	2.7	0.417	2.5	0.402	2.4	0.393
	0.414		**0.416**		**0.414**		**0.418**		**0.420**

Continuation of Annex 3

Irrigation 1 August 1

The irrigation tehnology: surge irrigation with q1 and q2 Furrows 13, 14, 15, 16

		The water					The sediments		
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.338				4.82	48.18		
	10		0.357	214.25				53.824	11.53
20		0.376				5.95	59.47		
	10		0.383	229.91				61.017	14.03
30		0.390				6.26	62.56		
	30		0.307	552.47				46.882	25.90
60		0.224				3.12	31.20		
	30		0.230	413.90				30.137	12.47
90		0.236				2.91	29.08		
	30		0.237	425.73				31.677	13.49
120		0.237				3.43	34.28		
	30		0.230	414.19				33.515	13.88
150		0.223				3.28	32.75		
	60		0.213	765.89				31.984	24.50
210		0.202				3.12	31.22		
	60		0.201	724.98				28.450	20.63
270		0.201				2.57	25.68		
	60		0.202	726.01				21.834	15.85
330		0.203				1.80	17.99		
TOTAL				**4467**	**L**				**152.28**
				496	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.8	0.341	2.2	0.377	1.8	0.341	1.6	0.176	1.6	0.176
1.5	0.311	1.8	0.341	2.8	0.425	1.5	0.311	1.6	0.321
1.9	0.350	2.4	0.393	2.4	0.393	2.2	0.206	2.4	0.215
1.9	0.350	2.4	0.393	2.5	0.402	2.1	0.201	2.8	0.233
	0.338		**0.376**		**0.390**		**0.224**		**0.236**

T, min	120		150		210		270		330
h	q	h	q	h	q		q	h	q
2.1	0.201	2.2	0.206	1.5	0.170	1.5	0.170	1.6	0.176
1.5	0.311	1.1	0.266	1.7	0.181	1.6	0.176	1.8	0.186
2.2	0.206	2.1	0.201	2.8	0.233	2.7	0.228	2.7	0.228
2.7	0.228	2.5	0.220	2.6	0.224	2.7	0.228	2.5	0.220
	0.237		**0.223**		**0.202**		**0.201**		**0.203**

Continuation of Annex 3

Irrigation 1 August 1

The irrigation tehnology: surge irrigation + PAM with q1 and q2 9, 10, 11, 12

Furrows		The water Out flow rate		Outflow			The sediments		
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.260				2.94	29.4		
	10		0.240	144.28				26.811	3.87
20		0.221				2.42	24.2		
	10		0.222	133.01				23.160	3.08
30		0.223				2.21	22.1		
	30		0.200	359.77				18.631	6.70
60		0.177				1.52	15.2		
	30		0.179	322.03				12.086	3.89
90		0.181				0.90	9.0		
	30		0.191	344.54				18.616	6.41
120		0.202				2.82	28.2		
	30		0.198	356.38				20.218	7.21
150		0.194				1.22	12.2		
	60		0.196	705.43				9.768	6.89
210		0.198				0.73	7.3		
	60		0.199	716.90				5.749	4.12
270		0.200				0.42	4.2		
	60		0.203	731.07				3.018	2.21
330		0.206				0.19	1.9		
TOTAL				**3813**	**L**				**44.38**
				424	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2.4	0.393	2.8	0.233	2.7	0.228	1.8	0.186	1.8	0.186
2.3	0.211	2.3	0.211	2.6	0.224	1.4	0.164	1.5	0.170
3	0.241	2.8	0.233	2.8	0.233	1.5	0.170	1.5	0.170
2	0.197	2.2	0.206	2.2	0.206	1.8	0.186	2	0.197
	0.260		**0.221**		**0.223**		**0.177**		**0.181**

T, min	120		150		210		270		330
h	q	h	q	h	q		q	h	q
1.7	0.181	1.7	0.181	2	0.197	1.9	0.192	1.8	0.186
2.6	0.224	2.8	0.233	2.8	0.233	3	0.241	2.6	0.224
1.9	0.192	1.8	0.186	1.8	0.186	2.3	0.211	2.2	0.206
2.3	0.211	1.6	0.176	1.6	0.176	1.3	0.158	2.2	0.206
	0.202		**0.194**		**0.198**		**0.200**		**0.206**

Continuation of Annex 3

The outflow volume, the sediments

Irrigation 2 August 14

The irrigation tehnology: continuous irrigation + PAM with q1 and q2 Furrows 9, 10, 11, 12

		The water					The sediments		
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.100				0.31	3.1		
	10		0.149	89.68				3.259	0.29
20		0.199				0.34	3.4		
	10		0.207	124.34				3.226	0.40
30		0.215				0.30	3.0		
	30		0.183	328.82				2.312	0.76
60		0.150				0.16	1.6		
	30		0.146	263.22				1.347	0.35
90		0.142				0.11	1.1		
	30		0.144	259.02				1.041	0.27
120		0.146				0.10	1.0		
	30		0.147	264.83				0.979	0.26
150		0.149				0.10	1.0		
	60		0.150	541.11				0.915	0.49
210		0.152				0.08	0.8		
	60		0.152	546.60				0.830	0.45
270		0.152				0.08	0.8		
	60		0.154	554.94				0.658	0.37
330		0.157				0.05	0.5		
TOTAL				**2973**	**L**				**3.65**
				330	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
0.3	0.076	0.9	0.132	1.2	0.152	1	0.139	0.9	0.132
0.5	0.098	1.3	0.158	1.6	0.176	1	0.139	1	0.139
0.7	0.116	1.7	0.331	1.8	0.341	1.4	0.164	1.2	0.152
0.6	0.108	1.6	0.176	1.9	0.192	1.3	0.158	1.1	0.146
	0.100		**0.199**		**0.215**		**0.150**		**0.142**

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
1.3	0.158	1.2	0.152	1.3	0.158	1.4	0.164	1.4	0.164
1.1	0.146	1.4	0.164	1.4	0.164	1.4	0.164	1.5	0.170
1	0.139	1	0.139	1.1	0.146	1	0.139	1.1	0.146
	0.146		**0.149**		**0.152**		**0.152**		**0.157**

132

Continuation of Annex 3

Irrigation 2 August 14

The irrigation tehnology: continuous irrigation with q1 and q2 Furrows 13, 14, 15, 16

		The water					The sediments		
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.323				0.99	9.92		
	10		0.339	203.35				9.477	1.93
20		0.355				0.90	9.03		
	10		0.377	226.26				8.784	1.99
30		0.399				0.85	8.54		
	30		0.326	587.13				7.206	4.23
60		0.253				0.59	5.88		
	30		0.226	407.45				4.967	2.02
90		0.200				0.41	4.06		
	30		0.220	395.81				4.117	1.63
120		0.240				0.42	4.18		
	30		0.251	452.66				5.450	2.47
150		0.263				0.67	6.72		
	60		0.253	911.28				6.077	5.54
210		0.243				0.54	5.43		
	60		0.242	869.64				5.073	4.41
270		0.240				0.47	4.72		
	60		0.244	877.50				5.010	4.40
330		0.248				0.53	5.30		
TOTAL				**4931**	**L**				**28.61**
				548	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.3	0.290	1.1	0.266	2.3	0.385	1	0.254	2.3	0.211
1.6	0.321	2.3	0.385	2.7	0.417	1.3	0.290	2.4	0.215
1.9	0.350	2.7	0.417	3.2	0.454	0.9	0.241	1.8	0.186
1.7	0.331	1.9	0.350	1.8	0.341	0.8	0.227	1.8	0.186
	0.323		**0.355**		**0.399**		**0.253**		**0.200**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
3.8	0.271	6.8	0.362	4	0.278	2.9	0.237	3.3	0.253
2.8	0.233	3.6	0.264	3.3	0.253	3.4	0.256	3.6	0.264
2.9	0.237	2.6	0.224	3.4	0.256	3.5	0.260	3.6	0.264
2.5	0.220	2.1	0.201	1.8	0.186	2.2	0.206	2.3	0.211
	0.240		**0.263**		**0.243**		**0.240**		**0.248**

Continuation of Annex 3

Irrigation 2 August 14

The irrigation tehnology: continuous irrigation with q1 Furrows 17, 18, 19, 20

		The water					The sediments		
		Out flow rate		Outflow					
T, min	dti,min	qi L/s	q av L/s	volume, L W o. f.		m, %	m, g/l	m av, g/L	Pmi, kg
10		0.325				0.88	8.85		
	10		0.340	203.84				9.929	2.02
20		0.354				1.10	11.01		
	10		0.353	211.94				10.260	2.17
30		0.352				0.95	9.51		
	30		0.366	659.37				10.799	7.12
60		0.380				1.21	12.09		
	30		0.384	691.48				11.974	8.28
90		0.388				1.19	11.86		
	30		0.370	665.59				15.865	10.56
120		0.352				1.99	19.87		
	30		0.363	653.32				17.142	11.20
150		0.374				1.44	14.41		
	60		0.369	1327.73				17.505	23.24
210		0.363				2.06	20.60		
	60		0.367	1319.44				19.296	25.46
270		0.370				1.80	18.00		
	60		0.365	1314.24				17.492	22.99
330		0.361				1.70	16.99		
TOTAL				**7047**	L				**113**
				783	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2	0.359	2.2	0.377	1.9	0.350	2.2	0.377	2.8	0.425
1.5	0.311	1.9	0.350	2.1	0.368	2.5	0.402	2.5	0.402
1.3	0.290	2	0.359	2	0.359	2.4	0.393	2.4	0.393
1.8	0.341	1.7	0.331	1.7	0.331	1.9	0.350	1.7	0.331
	0.325		**0.354**		**0.352**		**0.380**		**0.388**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
2.2	0.377	2.5	0.402	2.3	0.385	2.5	0.402	2.2	0.377
1.8	0.341	2	0.359	1.9	0.350	2	0.359	2.4	0.393
1.6	0.321	2	0.359	2	0.359	1.8	0.341	1.7	0.331
2.1	0.368	2.2	0.377	2	0.359	2.2	0.377	1.8	0.341
	0.352		**0.374**		**0.363**		**0.370**		**0.361**

Continuation of Annex 3

Irrigation 2 August 19

The irrigation tehnology: surge irrigation with q1 and q2 Furrows 1, 2, 3, 4

		The water				The sediments			
		Out flow rate		Outflow					
T, min	dti,min	qi L/s	q av L/s	volume, L W o. f.		m, %	m, g/l	m av, g/L	Pmi, kg
10		0.397				2.96	29.6		
	10		0.397	237.91				32.050	7.63
20		0.396				3.45	34.5		
	10		0.387	232.25				30.334	7.05
30		0.378				2.62	26.2		
	30		0.296	532.67				21.746	11.58
60		0.214				1.73	17.3		
	30		0.216	388.26				18.124	7.04
90		0.218				1.89	18.9		
	30		0.217	390.03				16.663	6.50
120		0.216				1.44	14.4		
	30		0.217	390.34				14.535	5.67
150		0.218				1.47	14.7		
	60		0.219	789.29				15.569	12.29
210		0.221				1.65	16.5		
	60		0.219	789.94				15.545	12.28
270		0.218				1.46	14.6		
	60		0.217	782.54				15.118	11.83
330		0.217				1.56	15.6		
TOTAL				**4533**	**L**				**81.86**
				504	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2.8	0.425	2.9	0.433	2.5	0.402	2.7	0.228	2.6	0.224
2.6	0.410	2.8	0.425	3	0.440	2	0.197	2.4	0.215
2	0.359	2.1	0.368	1.5	0.311	2.3	0.211	2.5	0.220
2.4	0.393	2	0.359	2	0.359	2.5	0.220	2.3	0.211
	0.397		**0.396**		**0.378**		**0.214**		**0.218**

T, min	120		150		210		270		330
h	q	h	q	h	q		q	h	q
3	0.241	3.1	0.245	3	0.241	3	0.241	2.9	0.237
2.5	0.220	2.5	0.220	2.5	0.220	2.2	0.206	2.2	0.206
2.1	0.201	2.9	0.237	3	0.241	3.1	0.245	2.9	0.237
2.1	0.201	1.5	0.170	1.7	0.181	1.7	0.181	1.8	0.186
	0.216		**0.218**		**0.221**		**0.218**		**0.217**

Continuation of Annex 3

Irrigation 2 August 19

The irrigation tehnology: continuous irrigation + PAM with q1 and q2 Furrows 5, 6, 7, 8

		The water					The sediments		
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.361				0.25	2.46		
	10		0.370	221.93				3.021	0.67
20		0.379				0.36	3.59		
	10		0.386	231.32				4.179	0.97
30		0.392				0.48	4.77		
	30		0.309	556.85				4.264	2.37
60		0.226				0.38	3.76		
	30		0.222	400.30				3.500	1.40
90		0.219				0.32	3.24		
	30		0.216	388.46				4.322	1.68
120		0.213				0.54	5.40		
	30		0.215	387.16				5.809	2.25
150		0.217				0.62	6.22		
	60		0.218	786.36				5.538	4.36
210		0.220				0.49	4.86		
	60		0.220	791.05				4.685	3.71
270		0.220				0.45	4.51		
	60		0.221	794.93				3.417	2.72
330		0.222				0.23	2.32		
TOTAL				**4558**	**L**				**20.12**
				506	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.8	0.341	2	0.359	2.2	0.377	2.5	0.220	2.2	0.206
2	0.359	2.4	0.393	2.3	0.385	2.6	0.224	2.6	0.224
2.2	0.377	2.4	0.393	3	0.440	2.7	0.228	2.5	0.220
2.1	0.368	2.1	0.368	2.1	0.368	2.8	0.233	2.6	0.224
	0.361		**0.379**		**0.392**		**0.226**		**0.219**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
2.4	0.215	2.4	0.215	2.5	0.220	2.4	0.215	2.5	0.220
2.3	0.211	3	0.241	2.6	0.224	2.7	0.228	2.7	0.228
2.4	0.215	2.2	0.206	2.4	0.215	2.5	0.220	2.4	0.215
2.3	0.211	2.2	0.206	2.5	0.220	2.4	0.215	2.6	0.224
	0.213		**0.217**		**0.220**		**0.220**		**0.222**

Continuation of Annex 3

The outflow volume, the sediments

Irrigation 3 September 1

The irrigation tehnology: continuous irrigation + PAM with q1 and q2 Furrows 9,10,11,12

		The water Out flow rate		Outflow			The sediments		
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.191				1.88	18.8		
	10		0.223	133.78				20.109	2.69
20		0.255				2.14	21.4		
	10		0.265	159.26				24.500	3.90
30		0.276				2.76	27.6		
	30		0.228	409.93				21.436	8.79
60		0.179				1.53	15.3		
	30		0.185	333.63				15.862	5.29
90		0.191				1.64	16.4		
	30		0.192	345.52				13.785	4.76
120		0.193				1.12	11.2		
	30		0.189	340.72				10.249	3.49
150		0.186				0.93	9.3		
	60		0.187	672.38				9.040	6.08
210		0.188				0.87	8.7		
	60		0.200	721.23				7.705	5.56
270		0.213				0.67	6.7		
	60		0.203	729.95				6.936	5.06
330		0.193				0.72	7.2		
TOTAL				**3846**	**L**				**45.62**
				427	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.3	0.290	1.9	0.336	1.6	0.321	1.3	0.158	1.3	0.158
1	0.139	1.2	0.152	1.5	0.170	2.5	0.220	1.1	0.146
2	0.197	2.3	0.385	2.5	0.402	1.7	0.181	3	0.241
1	0.139	1.1	0.146	2.3	0.211	1.3	0.158	2.5	0.220
	0.191		**0.255**		**0.276**		**0.179**		**0.191**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
1.2	0.152	1	0.139	0.7	0.116	0.5	0.098	0.5	0.098
1.1	0.146	1.1	0.146	1.3	0.158	4.1	0.281	2.7	0.228
3.2	0.249	3.3	0.253	3.9	0.275	3.3	0.253	2.8	0.233
2.6	0.224	2.2	0.206	2.1	0.201	2.5	0.220	2.3	0.211
	0.193		**0.186**		**0.188**		**0.213**		**0.193**

Continuation of Annex 3

Irrigation 3 September 1

The irrigation tehnology: continuous irrigation with q1 and q2 Furrows 13,14,15,16

		The water					The sediments		
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.336				2.27	22.65		
	10		0.339	203.17				23.087	4.69
20		0.341				2.35	23.52		
	10		0.352	210.92				24.609	5.19
30		0.362				2.57	25.70		
	30		0.279	502.27				23.896	12.00
60		0.196				2.21	22.09		
	30		0.202	362.72				23.013	8.35
90		0.207				2.39	23.93		
	30		0.219	393.85				20.738	8.17
120		0.231				1.75	17.54		
	30		0.229	412.26				17.172	7.08
150		0.227				1.68	16.80		
	60		0.228	821.44				16.483	13.54
210		0.229				1.62	16.17		
	60		0.237	852.22				14.496	12.35
270		0.244				1.28	12.83		
	60		0.245	883.07				12.228	10.80
330		0.246				1.16	11.63		
TOTAL				**4642**	**L**				**82.17**
				516	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.6	0.321	1.3	0.290	1.1	0.266	2.5	0.220	2.3	0.211
1.7	0.331	2.2	0.377	2.3	0.385	1.5	0.170	2.8	0.233
1.8	0.341	2.1	0.368	2.5	0.402	2.5	0.220	1.8	0.186
1.9	0.350	1.7	0.331	2.4	0.393	1.6	0.176	2	0.197
	0.336		**0.341**		**0.362**		**0.196**		**0.207**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
3.2	0.249	2.8	0.233	3.8	0.271	3.3	0.253	3.8	0.271
3.1	0.245	3	0.241	3.9	0.275	3.7	0.267	4.1	0.281
2.5	0.220	2.6	0.224	1.5	0.170	2.7	0.228	2	0.197
2.3	0.211	2.3	0.211	2.1	0.201	2.7	0.228	2.9	0.237
	0.231		**0.227**		**0.229**		**0.244**		**0.246**

Continuation of Annex 3

Irrigation 3 September 1

The irrigation tehnology: continuous irrigation with q1 Furrows 17,18,19,20

		The water					The sediments		
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.370				2.57	25.71		
	10		0.374	224.56				27.587	6.20
20		0.379				2.95	29.47		
	10		0.379	227.59				27.249	6.20
30		0.380				2.50	25.03		
	30		0.395	710.21				24.933	17.71
60		0.409				2.48	24.84		
	30		0.408	734.76				24.855	18.26
90		0.407				2.49	24.87		
	30		0.411	740.31				24.866	18.41
120		0.415				2.49	24.86		
	30		0.417	750.26				25.287	18.97
150		0.418				2.57	25.71		
	60		0.418	1503.24				24.651	37.06
210		0.417				2.36	23.59		
	60		0.418	1504.39				22.656	34.08
270		0.419				2.17	21.72		
	60		0.418	1504.41				20.924	31.48
330		0.417				2.01	20.12		
TOTAL				**7900**	**L**				**188**
				878	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.8	0.341	2.1	0.368	2.5	0.402	2.8	0.425	2.8	0.425
2.3	0.385	2.4	0.393	2.5	0.402	2.8	0.425	2.8	0.425
2.3	0.385	2.1	0.368	1.7	0.331	2.5	0.402	2.4	0.393
2.1	0.368	2.3	0.385	2.3	0.385	2.3	0.385	2.3	0.385
	0.370		**0.379**		**0.380**		**0.409**		**0.407**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
2.7	0.417	2.8	0.425	2.3	0.385	2.4	0.393	2.4	0.393
2.8	0.425	3	0.440	3	0.440	3	0.440	2.9	0.433
2.6	0.410	3	0.440	2.8	0.425	2.9	0.433	3	0.440
2.6	0.410	2.1	0.368	2.7	0.417	2.6	0.410	2.5	0.402
	0.415		**0.418**		**0.417**		**0.419**		**0.417**

Continuation of Annex 3

Irrigation 3 September 2

The irrigation tehnology: surge irrigation with q1 and q2 Furrows 1,2,3,4

		The water					The sediments	
		Out flow rate		Outflow				
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.377				3.17	31.7		
	10		0.387	232.33				31.450	7.31
20		0.397				3.12	31.2		
	10		0.398	238.79				30.944	7.39
30		0.399				3.07	30.7		
	30		0.298	536.93				25.217	13.54
60		0.198				1.98	19.8		
	30		0.203	365.39				18.314	6.69
90		0.208				1.68	16.8		
	30		0.211	379.84				18.380	6.98
120		0.214				1.99	19.9		
	30		0.214	385.73				18.803	7.25
150		0.215				1.77	17.7		
	60		0.214	769.43				15.906	12.24
210		0.213				1.41	14.1		
	60		0.213	765.32				12.369	9.47
270		0.213				1.06	10.6		
	60		0.213	767.31				11.414	8.76
330		0.214				1.22	12.2		
TOTAL				**4441**	**L**				**79.63**
				493	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2.7	0.417	2.8	0.425	2.8	0.425	2.7	0.228	3.2	0.249
2.7	0.417	2.1	0.368	2.7	0.417	1.5	0.170	1.3	0.158
2.3	0.385	2.5	0.402	2.3	0.385	2.3	0.211	2.4	0.215
1.3	0.290	2.4	0.393	2.1	0.368	1.7	0.181	2.3	0.211
	0.377		**0.397**		**0.399**		**0.198**		**0.208**

T, min	120		150		210		270		330
h	q	h	q	h	q		q	h	q
2.9	0.237	2.7	0.228	2.5	0.220	2.4	0.215	2.7	0.228
2.3	0.211	2.4	0.215	2.8	0.233	2.8	0.233	2.7	0.228
2	0.197	1.9	0.192	2	0.197	1.9	0.192	2	0.197
2.3	0.211	2.6	0.224	2.1	0.201	2.3	0.211	2.1	0.201
	0.214		**0.215**		**0.213**		**0.213**		**0.214**

Continuation of Annex 3

Irrigation 3 September 2

The irrigation tehnology: surge irrigation + PAM with q1 and q2 Furrows 5,6,7,8

		The water					The sediments		
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.354				2.22	22.17		
	10		0.363	217.95				19.679	4.29
20		0.372				1.72	17.19		
	10		0.375	225.22				18.076	4.07
30		0.378				1.90	18.96		
	30		0.293	526.79				14.019	7.39
60		0.207				0.91	9.07		
	30		0.211	379.67				8.903	3.38
90		0.215				0.87	8.73		
	30		0.216	389.17				7.072	2.75
120		0.217				0.54	5.41		
	30		0.220	395.28				3.196	1.26
150		0.222				0.10	0.98		
	60		0.219	790.16				2.910	2.30
210		0.217				0.48	4.84		
	60		0.218	785.99				4.466	3.51
270		0.219				0.41	4.09		
	60		0.220	792.19				3.248	2.57
330		0.221				0.24	2.40		
TOTAL				**4502**	**L**				**31.52**
				500	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2.1	0.368	2	0.359	1.9	0.350	2.2	0.206	2.4	0.215
2.2	0.377	2.3	0.385	2.5	0.402	2.6	0.224	2.8	0.233
1.7	0.331	2.2	0.377	2.2	0.377	2.3	0.211	2.4	0.215
1.8	0.341	2.1	0.368	2.3	0.385	1.8	0.186	2	0.197
	0.354		**0.372**		**0.378**		**0.207**		**0.215**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
2.3	0.211	2.6	0.224	2.5	0.220	2.7	0.228	2.6	0.224
2.7	0.228	2.6	0.224	2.6	0.224	2.8	0.233	2.8	0.233
2.5	0.220	2.8	0.233	2.7	0.228	2.4	0.215	2.5	0.220
2.3	0.211	2.2	0.206	2	0.197	2.1	0.201	2.2	0.206
	0.217		**0.222**		**0.217**		**0.219**		**0.221**

Continuation of Annex 3

The outflow volume, the sediments

Irrigation 4 September 15

The irrigation tehnology: continuous irrigation + PAM with q1 and q2 Furrows 9, 10, 11, 12

		The water Out flow rate		Outflow			The sediments		
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.207				1.83	18.3		
	10		0.230	137.87				20.172	2.78
20		0.253				2.20	22.0		
	10		0.260	155.78				22.325	3.48
30		0.266				2.26	22.6		
	30		0.232	416.73				15.357	6.40
60		0.197				0.81	8.1		
	30		0.191	343.13				9.972	3.42
90		0.185				1.19	11.9		
	30		0.174	313.48				11.659	3.65
120		0.164				1.15	11.5		
	30		0.165	297.66				10.724	3.19
150		0.167				1.00	10.0		
	60		0.161	578.91				10.795	6.25
210		0.155				1.16	11.6		
	60		0.159	571.45				10.511	6.01
270		0.163				0.94	9.4		
	60		0.164	588.77				9.870	5.81
330		0.164				1.03	10.3		
TOTAL				**3404**	**L**				**40.99**
				378	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.2	0.278	1.3	0.278	1.3	0.290	1	0.139	1	0.139
1.6	0.176	2	0.197	2.5	0.220	2.7	0.228	3	0.241
1.9	0.192	1.9	0.350	1.9	0.350	2.8	0.233	2.5	0.220
1.7	0.181	1.8	0.186	2.2	0.206	1.8	0.186	1	0.139
	0.207		**0.253**		**0.266**		**0.197**		**0.185**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
0.5	0.098	0.5	0.098	0.5	0.098	0.5	0.098	0.5	0.098
2.6	0.224	2.8	0.233	2.5	0.220	2.1	0.201	1.9	0.192
1.8	0.186	1.9	0.192	1.6	0.176	2.2	0.206	2	0.197
1.1	0.146	1.1	0.146	0.8	0.124	1.1	0.146	1.5	0.170
	0.164		**0.167**		**0.155**		**0.163**		**0.164**

Continuation of Annex 3

Irrigation 4 September 15

The irrigation tehnology: continuous irrigation with q1 and q2 Furrows 13, 14, 15, 16

		The water					The sediments		
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.352				2.34	23.36		
	10		0.358	215.07				24.359	5.24
20		0.365				2.54	25.36		
	10		0.364	218.39				27.185	5.94
30		0.363				2.90	29.01		
	30		0.293	526.69				19.245	10.14
60		0.223				0.95	9.48		
	30		0.219	394.53				12.378	4.88
90		0.216				1.53	15.28		
	30		0.217	389.87				17.243	6.72
120		0.217				1.92	19.21		
	30		0.215	387.06				17.975	6.96
150		0.213				1.67	16.74		
	60		0.211	758.35				16.512	12.52
210		0.209				1.63	16.28		
	60		0.207	746.05				14.314	10.68
270		0.206				1.23	12.34		
	60		0.208	750.56				11.921	8.95
330		0.211				1.15	11.50		
TOTAL				**4387**	**L**				**72.02**
				487	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2.3	0.385	2.4	0.393	2	0.359	3.3	0.253	3.3	0.253
2	0.359	2.2	0.377	2.2	0.377	2.7	0.228	2.5	0.220
1.8	0.341	1.9	0.350	2.4	0.393	3.1	0.245	2.8	0.233
1.6	0.321	1.8	0.341	1.6	0.321	1.4	0.164	1.3	0.158
	0.352		**0.365**		**0.363**		**0.223**		**0.216**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
2.8	0.233	2.6	0.224	3	0.241	2.6	0.224	3.2	0.249
2.7	0.228	2.5	0.220	2.5	0.220	2.6	0.224	2.6	0.224
2.8	0.233	2.9	0.237	2.4	0.215	2.3	0.211	2.8	0.233
1.6	0.176	1.5	0.170	1.3	0.158	1.4	0.164	1	0.139
	0.217		**0.213**		**0.209**		**0.206**		**0.211**

Irrigation 4 September 15

The irrigation tehnology: continuous irrigation with q1 Furrows 17, 18, 19, 20

		The water				The sediments			
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.380				2.93	29.26		
	10		0.401	240.49				28.569	6.87
20		0.422				2.79	27.88		
	10		0.424	254.12				31.088	7.90
30		0.425				3.43	34.30		
	30		0.419	754.98				24.020	18.13
60		0.413				1.37	13.74		
	30		0.414	745.53				15.957	11.90
90		0.415				1.82	18.17		
	30		0.419	754.99				17.388	13.13
120		0.424				1.66	16.61		
	30		0.426	766.32				17.077	13.09
150		0.428				1.75	17.55		
	60		0.426	1532.56				17.226	26.40
210		0.424				1.69	16.90		
	60		0.400	1441.54				16.234	23.40
270		0.377				1.56	15.56		
	60		0.378	1359.58				14.087	19.15
330		0.378				1.26	12.61		
TOTAL				**7850**	**L**				**140**
				872	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
2.2	0.377	2.4	0.393	2.7	0.417	2.4	0.393	2.3	0.385
2.7	0.417	3.5	0.475	3.6	0.482	3.4	0.468	3	0.440
2.3	0.385	2.9	0.433	2.7	0.417	2.9	0.433	2.7	0.417
1.8	0.341	2.3	0.385	2.3	0.385	2	0.359	2.7	0.417
	0.380		**0.422**		**0.425**		**0.413**		**0.415**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
2.4	0.393	2.4	0.393	2.7	0.417	1.9	0.350	1.8	0.341
3.1	0.447	3.5	0.475	3	0.440	3	0.440	3	0.440
3.3	0.461	3	0.440	3.3	0.461	2.7	0.417	3.2	0.454
2.4	0.393	2.5	0.402	2.2	0.377	1.4	0.301	1.2	0.278
	0.424		**0.428**		**0.424**		**0.377**		**0.378**

Continuation of Annex 3

Irrigation 4 September 16

The irrigation tehnology: surge irrigation with q1 and q2 Furrows 1, 2, 3, 4

		The water				The sediments			
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.326				2.30	23.0		
	10		0.312	187.00				21.695	4.06
20		0.298				2.04	20.4		
	10		0.295	176.95				18.752	3.32
30		0.292				1.71	17.1		
	30		0.214	385.89				12.943	4.99
60		0.137				0.88	8.8		
	30		0.127	228.85				7.941	1.82
90		0.118				0.71	7.1		
	30		0.114	205.48				7.825	1.61
120		0.111				0.85	8.5		
	30		0.112	201.05				8.128	1.63
150		0.113				0.77	7.7		
	60		0.109	391.53				6.829	2.67
210		0.105				0.59	5.9		
	60		0.103	370.73				6.213	2.30
270		0.101				0.65	6.5		
	60		0.106	382.77				6.889	2.64
330		0.111				0.73	7.3		
TOTAL				**2530**	**L**				**25.04**
				281	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
1.8	0.341	1.3	0.290	1.3	0.290	0.5	0.098	0.3	0.076
1.4	0.301	1.3	0.290	1.3	0.290	1	0.139	0.8	0.124
1.9	0.350	1.4	0.301	1.5	0.311	1	0.139	0.8	0.124
1.5	0.311	1.5	0.311	1.2	0.278	1.5	0.170	1.1	0.146
	0.326		**0.298**		**0.292**		**0.137**		**0.118**

T, min	120		150		210		270		330
h	q	h	q	h	q		q	h	q
0.2	0.062	0.4	0.088	0.5	0.098	0.4	0.088	0.4	0.088
0.9	0.132	0.6	0.108	0.5	0.098	0.3	0.076	0.4	0.088
0.8	0.124	0.7	0.116	0.5	0.098	0.8	0.124	0.8	0.124
0.8	0.124	1	0.139	0.8	0.124	0.7	0.116	1.1	0.146
	0.111		**0.113**		**0.105**		**0.101**		**0.111**

Irrigation 4 September 16 Continuation of Annex 3

The irrigation tehnology: surge irrigation + PAM with q1 and q2 Furrows 5, 6, 7, 8

		The water					The sediments		
		Out flow rate		Outflow					
		qi	q av	volume, L		m, %	m, g/l	m av,	Pmi, kg
T, min	dti,min	L/s	L/s	W o. f.				g/L	
10		0.277				0.92	9.22		
	10		0.278	166.76				10.085	1.68
20		0.279				1.10	10.95		
	10		0.275	165.27				10.595	1.75
30		0.272				1.02	10.24		
	30		0.206	371.36				9.710	3.61
60		0.141				0.92	9.18		
	30		0.137	247.13				7.969	1.97
90		0.134				0.68	6.75		
	30		0.123	222.21				5.682	1.26
120		0.113				0.46	4.61		
	30		0.113	202.50				4.021	0.81
150		0.112				0.34	3.43		
	60		0.112	403.63				3.323	1.34
210		0.112				0.32	3.21		
	60		0.116	416.00				3.276	1.36
270		0.119				0.33	3.34		
	60		0.119	429.79				3.208	1.38
330		0.120				0.31	3.08		
TOTAL				**2625**	**L**				**15.17**
				292	**m3/hec**				

T, min	10		20		30		60		90
h	q	h	q	h	q	h	q	h	q
0.6	0.197	0.8	0.227	0.7	0.213	0.7	0.116	0.8	0.124
1.7	0.331	1.6	0.321	1.3	0.290	1.9	0.192	1.5	0.170
1.3	0.290	1.2	0.278	1	0.254	0.7	0.116	0.7	0.116
1.3	0.290	1.3	0.290	1.7	0.331	1	0.139	0.8	0.124
	0.277		**0.279**		**0.272**		**0.141**		**0.134**

T, min	120		150		210		270		330
h	q	h	q	h	q	h	q	h	q
0.8	0.124	0.7	0.116	0.6	0.108	0.6	0.108	0.5	0.098
1.6	0.176	1.7	0.181	1.7	0.181	1.7	0.181	1.7	0.181
0.3	0.076	0.2	0.062	0.2	0.062	0.4	0.088	0.3	0.076
0.3	0.076	0.4	0.088	0.5	0.098	0.5	0.098	0.8	0.124
	0.113		**0.112**		**0.112**		**0.119**		**0.120**

Annex 4

The calculation of the water infiltration for irrigation period

Irrigation 1

Version	Water application, m3/hec	Outflow volume, m3/hec	Water infiltration, m3/hec	Irrigation application efficiency
Cont. irr. +PAM with q1 and q2	898	381	517	0.58
Cont. irr. with q2 and q2	875	446	429	0.49
Cont. irr. with q1	1321	888	433	0.33
Surge irr. with q1 and q2	924	496	428	0.46
Surge irr. + PAM with q1 and q2	1046	424	622	0.59

Irrigation 2

Version	Water application, m3/hec	Outflow volume, m3/hec	Water infiltration, m3/hec	Irrigation application efficiency
Cont. irr. +PAM with q1 and q2*	1663	330	1333	0.80
Cont. irr. with q2 and q2	1153	548	605	0.52
Cont. irr. with q1	1483	783	700	0.47
Surge irr. with q1 and q2	962	504	458	0.48
Cont. irr. + PAM with q1 and q2*	886	506	380	0.43

* it is rainning ** it does not raining

Irrigation 3

Version	Water applicatio m3/hec	Outflow volume, m3/hec	Water infiltration, m3/hec	Irrigation application efficiency
Cont. irr. +PAM with q1 and q2	1113	427	686	0.62
Cont. irr. with q2 and q2	904	516	388	0.43
Cont. irr. with q1	1313	878	435	0.33
Surge irr. with q1 and q2	863	493	370	0.43
Surge irr. + PAM with q1 and q2	923	500	423	0.46

Irrigation 4

Version	Water application, m3/hec	Outflow volume, m3/hec	Water infiltration, m3/hec	Irrigation application efficiency
Cont. irr. +PAM with q1 and q2	880	378	502	0.57
Cont. irr. with q2 and q2	824	487	337	0.41
Cont. irr. with q1	1243	872	371	0.30
Surge irr. with q1 and q2*	861	281	580	0.67
Surge irr. + PAM with q1 and q2*	943	292	651	0.69

*it is after raining

Annex 5

Balance of sediments for one furrow

Irrigation 1

Version	Duration, min			Application		Weight of sediments, kg		
	wetting	iririgation with q1= 30 L/min	iririgation with q2= 16.8 L/min	sedimen., %	water, L	applic.	outflow	balance
Cont. irr. +PAM with q1 and q2	71	101	300	1.589 0.740	3030 5040 8070	48.28 37.30 85.58	125.65	-40.07
Cont. irr. with q2 and q2	65	95	300	1.556 0.542	2850 5040 7890	44.35 27.08 71.43	79.03	-7.60
Cont. irr. with q1	66	396	0	1.099 0.000	11880 0 11880	130.56 0.00 130.56	315.27	-184.71
Surge irr. with q1 and q2	79	109	300	1.214 1.129	3270 5040 8310	39.70 56.99 96.69	152.28	-55.59
Surge irr. + PAM with q1 and q2	116	146	300	1.105 0.986	4380 5040 9420	48.40 49.64 98.04	44.38	53.66

Irrigation 2

Version	Duration, min			Application		Weight of sediments, kg		
	wetting	iririgation with q1= 30 L/min	iririgation with q2= 16.8 L/min	sedimen., %	water, L	applic.	outflow	balance
Cont. irr. +PAM with q1 and q2 (it is raining)	301	331	300	0.426 0.150	9930 5040 14970	42.30 7.47 49.77	3.65	46.12
Cont. irr. with q2 and q2 (it is raining)	148	178	300	0.498 0.269	5340 5040 10380	26.59 13.53 40.12	28.61	11.51
Cont. irr. with q1 (it is raining)	115	445	0	0.366 0.000	13350 0 13350	48.83 0.00 48.83	113.05	-64.22
Surge irr. with q1 and q2 (it does not raining)	91	121	300	0.515 0.384	3630 5040 8670	18.69 19.28 37.97	81.86	-43.89
Cont. irr. + PAM with q1 and q2 (it does not raining)	68	98	300	0.561 0.401	2940 5040 7980	16.49 20.20 36.69	20.12	16.57

Continuation of Annex 5

Balance of sediments for one furrow

Irrigation 3

Version	Duration, min			Application		Weight of sediments, kg		
	wetting	irrigation with q1= 30 L/min	irrigation with q2= 16.8 L/min	sedimen., %	water, L	applic.	outflow	balance
Cont. irr. +PAM with q1 and q2	136	166	300	0.909 0.403	4980 5040 10020	45.27 20.25 65.52	45.62	19.90
Cont. irr. with q2 and q2	73	103	300	0.814 0.534	3090 5040 8130	25.15 26.96 52.11	82.17	-30.06
Cont. irr. with q1	64	394	0	0.614 0.000	11820 0 11820	72.56 0.00 72.56	188.36	-115.80
Surge irr. with q1 and q2	61	91	300	0.435 0.534	2730 5040 7770	11.88 26.91 38.79	79.63	-40.84
Surge irr. + PAM with q1 and q2	79	109	300	0.479 0.516	3270 5040 8310	15.64 26.01 41.65	31.52	10.13

Irrigation 4

Version	Duration, min			Application		Weight of sediments, kg		
	wetting	irrigation with q1= 30 L/min	irrigation with q2= 16.8 L/min	sedimen., %	water, L	applic.	outflow	balance
Cont. irr. +PAM with q1 and q2	66	96	300	0.292 0.143	2880 5040 7920	8.41 7.23 15.64	40.99	-25.35
Cont. irr. with q2 and q2	49	79	300	0.321 0.141	2370 5040 7410	7.61 7.14 14.75	72.02	-57.27
Cont. irr. with q1	43	373	0	0.178 0.000	11190 0 11190	19.95 0.00 19.95	139.97	-120.02
Surge irr. with q1 and q2 (it is after raining)	60	90	300	0.119 0.160	2700 5040 7740	3.21 8.06 11.28	25.04	-13.76
Surge irr. + PAM with q1 and q2 (it is after raining)	85	115	300	0.105 0.174	3450 5040 8490	3.62 8.78 12.40	15.17	-2.77

Yield capacity of maize silage

Number of stalk	Weight grain (g) for version														
	cont. irr. with q1 and q2 + PAM			cont. irr. with q1 and q2			cont. irr. with q1			surge irr. with q1 and q2			surge irr. with q1 and q2 + PAM		
	distance from furrow beginning, m														
	20	75	130	20	75	130	20	75	130	20	75	130	20	75	130
1	1512	1713	2281	2010	1550	1320	1705	2155	2125	1485	2005	1755	1505	1595	2295
2	1499	1669	2244	1980	1540	1290	1540	2085	1895	1445	1675	1700	1120	1500	1830
3	1451	1400	1906	1575	1520	1265	1510	1420	1425	1260	1490	1670	1400	1300	1675
4	1391	1313	1663	1575	1265	1255	1510	1375	1290	1240	1380	1445	1310	1270	1600
5	1377	1294	1519	1440	1250	1245	1405	1315	1280	1225	1340	1445	1090	1230	1500
6	1377	1288	1494	1415	1140	1205	1190	1270	1120	1205	1325	1420	1045	1215	1455
7	1161	1294	1481	1310	1125	1200	1070	1175	1045	1130	1210	1335	1035	1205	1390
8	1154	1244	1400	1245	1125	1165	1065	1140	1035	1065	1130	1205	955	1150	1340
9	1141	1238	1369	1180	1115	1110	1065	1120	1025	1045	1190	1140	930	1145	1295
10	1121	1206	1344	1130	1100	1085	1060	1060	950	1035	1015	1130	925	1115	1235
11	1107	1181	1331	1105	1015	1035	1055	1060	935	1025	985	1035	900	1100	1165
12	1067	1144	1256	1100	1015	1035	1045	1055	920	990	965	1020	890	1090	1155
13	1067	1125	1225	1075	1015	1030	1025	1045	910	980	945	1000	885	940	1135
14	1019	1056	1181	1050	975	990	905	1035	880	960	890	885	785	920	1125
15	1006	1006	956	1015	955	960	900	930	870	920	800	875	750	905	1045
16	952	900	938	970	930	930	880	930	815	895	775	845	750	835	1045
17	952	831	906	965	895	865	865	890	805	870	780	840	735	825	1010
18	932	750	894	910	885	855	860	845	725	845	730	750	690	820	985
19	918	731	875	880	875	840	820	835	700	840	690	735	655	775	980
20	905	650	725	830	800	810	755	795	685	690	570	730	610	745	980
Total 1-20, kg	23.11	23.03	26.99	24.76	22.09	21.49	22.23	23.54	21.44	21.15	21.89	22.96	18.97	21.68	26.24
On the average	1.16	1.15	1.35	1.24	1.10	1.07	1.11	1.18	1.07	1.06	1.09	1.15	0.95	1.08	1.31
Total 1-15, kg	18.45	19.17	22.65	20.21	17.71	17.19	18.05	19.24	17.71	17.01	18.35	19.06	15.53	17.68	21.24
On the average	1.23	1.28	1.51	1.35	1.18	1.15	1.20	1.28	1.18	1.13	1.22	1.27	1.04	1.18	1.42
Total 1...15, cen/hec	369	383	453	404	354	344	361	385	354	340	367	381	311	354	425
On the average cen/hec			398			365			374			364			361
k			1.23			0.85			0.98			1.12			1.37

Yield capacity of grain maize

Number of stalk	Weight grain (g) for version														
	cont. irr. with q1 and q2 + PAM			cont. irr. with q1 and q2			cont. irr. with q1			surge irr. with q1 and q			surge irr. with q1 and q2 + PAM		
	distance from furrow beginning, m														
	20	75	130	20	75	130	20	75	130	20	75	130	20	75	130
1	171	160	204	156	171	137	167	196	131	143	180	173	164	164	219
2	134	154	178	143	122	134	159	195	125	142	166	154	140	142	163
3	129	139	163	138	118	100	146	157	120	134	152	138	128	151	155
4	118	138	162	130	108	96	143	132	119	110	149	135	122	121	139
5	114	136	153	125	104	93	139	127	119	108	116	129	111	112	131
6	114	129	141	112	90	92	125	106	118	103	116	126	88	107	130
7	110	126	135	104	90	91	111	100	117	101	109	125	87	106	129
8	109	118	131	101	89	89	108	94	117	100	106	110	86	101	110
9	106	118	117	98	87	88	102	93	114	98	98	100	85	101	108
10	101	114	105	95	86	85	100	89	108	95	96	98	81	99	106
11	99	109	105	95	85	85	96	89	106	94	95	93	80	98	103
12	98	105	98	92	85	85	93	82	105	94	88	88	78	86	101
13	93	104	89	90	82	85	91	82	101	91	77	81	76	86	101
14	91	104	88	89	78	83	90	79	90	91	74	80	74	86	98
15	90	101	81	87	77	83	90	78	89	90	73	76	70	83	95
16	88	94	79	87	75	80	90	78	89	88	71	72	68	82	91
17	83	86	72	83	73	77	87	77	83	85	68	72	68	72	90
18	83	81	69	75	71	75	84	68	83	82	63	72	64	70	89
19	78	76	68	67	68	71	80	58	81	80	59	70	63	71	89
20	76	60	66	28	68	68	75	58	77	72	58	70	53	66	88
Total 1-20, kg	2.08	2.25	2.30	2.00	1.83	1.80	2.18	2.04	2.09	2.00	2.01	2.06	1.79	2.00	2.34
On the average	0.10	0.11	0.12	0.10	0.09	0.09	0.11	0.10	0.10	0.10	0.10	0.10	0.09	0.10	0.12
Total 1-15, kg	1.68	1.85	1.95	1.66	1.47	1.43	1.76	1.70	1.68	1.59	1.70	1.71	1.47	1.64	1.89
On the average	0.11	0.12	0.13	0.11	0.10	0.10	0.12	0.11	0.11	0.11	0.11	0.11	0.10	0.11	0.13
Total 1...15, cen/hec	34	37	39	33	29	29	35	34	34	32	34	34	29	33	38
On the average cen/hec			37			30			34			33			33
k			1.16			0.86			0.95			1.07			1.28