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Executive Summary

Surface irrigation is the most widely used irrigation method in the world. In Kyrgyzstan, out of 1 million hectare of irrigated land, 85% is under furrow and surface irrigation. However, surface irrigation systems are relatively inefficient and only ~60% of the applied water reaches the root zone immediately after irrigation. The overall aim of the current project is to improve the technology and managerial practices regarding the use of polyacrylamide (PAM). In Israel laboratory studies focused on (i) Polyacrylamide (PAM) and sediments effects on interrupted (surge) flow, (ii) effects of surge application on soil consolidation and hydraulic conductivity, and (iii) effects of exchangeable cations composition and irrigation water quality on erosion and intake rate in continuous and surge type flow furrow irrigation. The results showed that addition of PAM improved the effects of interrupted flow. Conversely in the presence of sediments in the irrigation water, interrupted flow had no advantage over continuous flow. Application of interrupted flow enhanced soil surface consolidation, thereby increasing soil bulk density and decreasing soil hydraulic conductivity. Hence, when interrupted flow is practiced, water permeability in successive irrigation events expected to decrease. In Kyrgyzstan, a field experiment similar to the one performed in the 1st year, but with the addition of crop (sugar beet) was carried out to study the effects of surge irrigation and PAM application on furrow erosion, infiltration rates and crop yield. The results showed that with respect to erosion control and water used efficiency, surge irrigation+PAM was the most effective treatment. With respect to yield, PAM application gave the best root and green yield of sugar beet, irrespective of the irrigation method (continuous vs. surge).

Mr. N. Sharshekeev from Kyrgyzstan spent 10 months in Israel (from October 1999 to August 2000) for training. The studies of Mr. Sharshekeev in Israel will serve as part of his PhD thesis.

Section I

A. Research Objectives

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

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

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

1. In Israel – (laboratory studies)

a. Polyacrylamide (PAM) and sediments effects on interrupted (surge) flow.

b. Effects of surge application on soil consolidation and hydraulic conductivity.

c. Effects of exchangeable cations composition and irrigation water quality on erosion and intake rate in continuous and surge type flow furrow irrigation

2. In Kyrgyzstan - (field experiment)

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

b. The effect of PAM on furrow erosion and infiltration rate.

B. Research Accomplishments

B.1 In Israel

The first study (Polyacrylamide (PAM) and sediments effects on interrupted (surge) flow), has been completed, summarized in a form of a scientific paper, and published in Soil Science Society of America Journal (see appendix A). The second study (Surge impacts on soil consolidation and hydraulic conductivity) has been finished, and data are now summarized (see appendix B for a detailed description of the study and preliminary analysis of the data). The third study (Effects of exchangeable cations composition and irrigation water quality on erosion and intake rate in continuous and surge

type flow furrow irrigation) is near completion. Data are yet to be analyzed and summarized (see appendix C for a detailed description of the study). Studies #2 and #3 were part of the training program of Mr. N. Sharshekeev from Kyrgazstan (see also section I-C&E and Section II-D).

B.2. In Kyrgyzstan

The field experiment that was carried out consisted of two stage, 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, and (4) testing the irrigation with the aim of determining the flow rate of the irrigation stream. In the main stage of the experiment sugar beet was grown. The study consisted of the determination of furrow erosion, and water losses of the flow rates lengthways of a furrow, as well as crop parameters (e.g., yield, green material etc.). The treatments studied were continuous flow, surge flow, each with or without addition of polymer to the irrigation water (all together 4 treatments). A detailed description of the experiment and the results are presented in appendix D.

C. Scientific Impact of Collaboration

Both Dr. Levy and Dr. Zhuravskaya were deeply involved in the project throughout the entire year. The two investigators communicated regularly via electronic media and fax on the scientific and administrative aspects of the project. In addition, Mr. N. Sharshekeev, a PhD candidate at Dr. Zhuravskaya's laboratory, spent 10 months of training in Israel at the laboratory of Dr. Levy

D. Description of Project Impact

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

E. Strengthening of Developing Country Institution

The project enables a large scale field study on the improvement of furrow irrigation efficiency and reduction in furrow erosion with the aid of polymers and introduction of surge irrigation technology. The need for a study of this nature has long been recognized, but lack of funding prevented its execution. A large group of both scientists and technical staff of the Scientific and Research Institute of Irrigation (SRII), Kyrgyzstan, is involved in the project, and is thus exposed to the Israeli

experience and expertise in the understanding of the chemo-physical aspects of soil erosion and infiltration, and the use of polymers to alleviate the latter problems Realization of the project allowed the SRII to retain valuable equipment necessary for conducting this and similar studies.

In addition, the training of Mr. Shashekeev in Israel which was devoted to designing and performing miniflume and hydraulic conductivity studies, will assist the planning and execution of similar studies at SRII, Kyrgyzstan.

F. **Future work**

In the 3rd year of the project, laboratory experiments in Israel (miniflume studies) will continue to focus on the effects of soil conditions (e.g., rate of prewetting and aging), water quality and composition of exchangeable cations on intake rate and erosion, together with testing the efficacy of new PAMs on controlling erosion in furrow irrigation. In Kyrgyzstan, laboratory studies on the hydraulic conductivity of a number of soils varying in their inherent properties will be carried out. In addition the field experiment will continue in a format similar to that of the 2nd year.

Section II

A. Managerial issue: Not applicable

B. Budget: Not applicable

C. Special Concern: Not applicable

D. Collaboration, Travel, Training and Publications:

Mr. N. Sharshekeev from the Scientific and Research Institute of Irrigation, Bishkek, Kyrgyzstan, spent 10 months in Israel (from October 1999 to August 2000) for training. Mr. Sharshekeev trained in miniflume and hydraulic conductivity studies. His work in Israel will serve as part of his PhD thesis. Dr. Zhuravskaya planned to visit Israel in the coarse of November 2000, to discuss the results of the 2nd year field experiment and to plan the 3rd year field experiment and additional laboratory experiments to complement the studies Mr. Sharsheveek did in Israel; the visit was postponed to the beginning of 2001.

The study on the effects of PAM, sediments and surge application on intake rate and rill erosion in furrow irrigation has been published in Soil Sci. Soc. Am. J. 64:1487-1495 (2000) (see appendix A). The study on the impact of surge application on infiltration and erosion in furrow irrigation which has been carried out in the first year of this project is now being considered for publication in Soil Sci. Soc. Am. J.

Appendix "A"

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677 South Segoe Rd., Madison, WI 53711 USA

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

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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

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

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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

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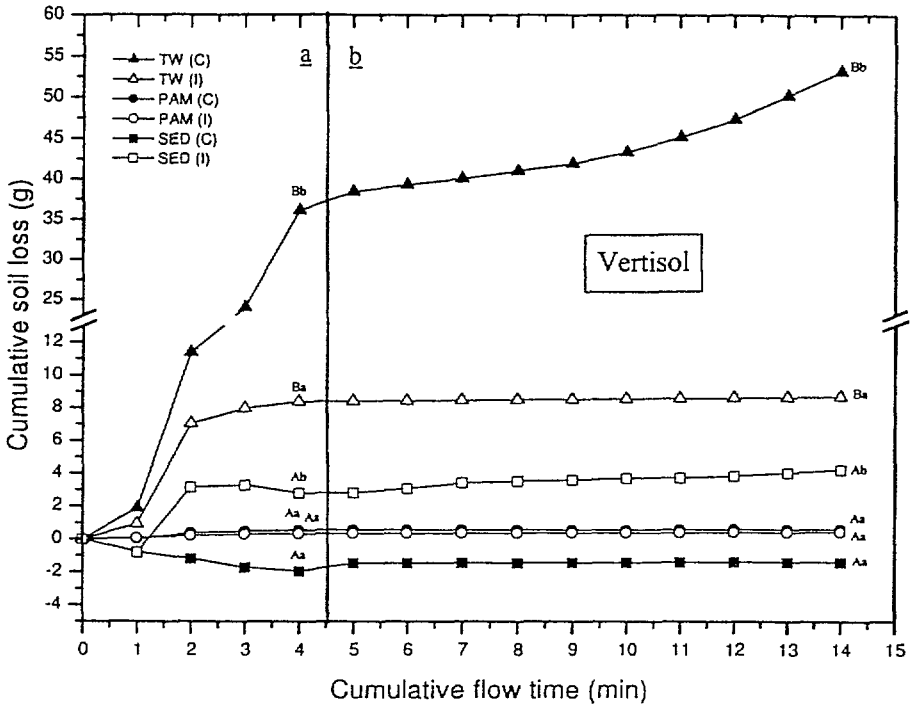

Fig. 1. Cumulative soil loss as a function of cumulative flow time for the Vertisol during (a) Stage 1 and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences 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

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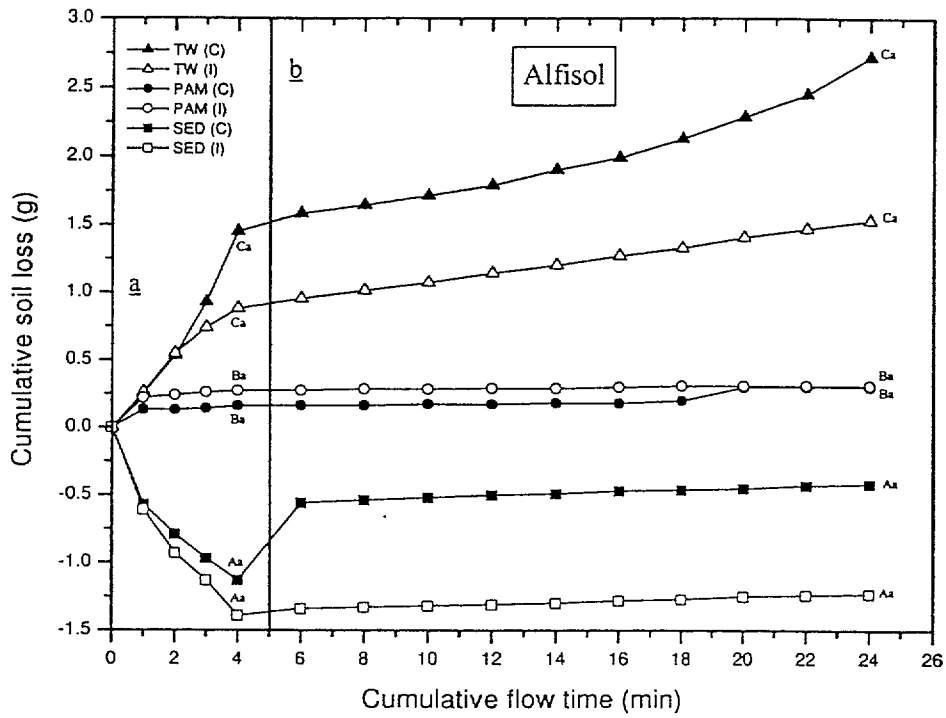

Fig. 2. Cumulative soil loss as a function of cumulative flow time for the Alfisol during (a) Stage 1, and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences 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

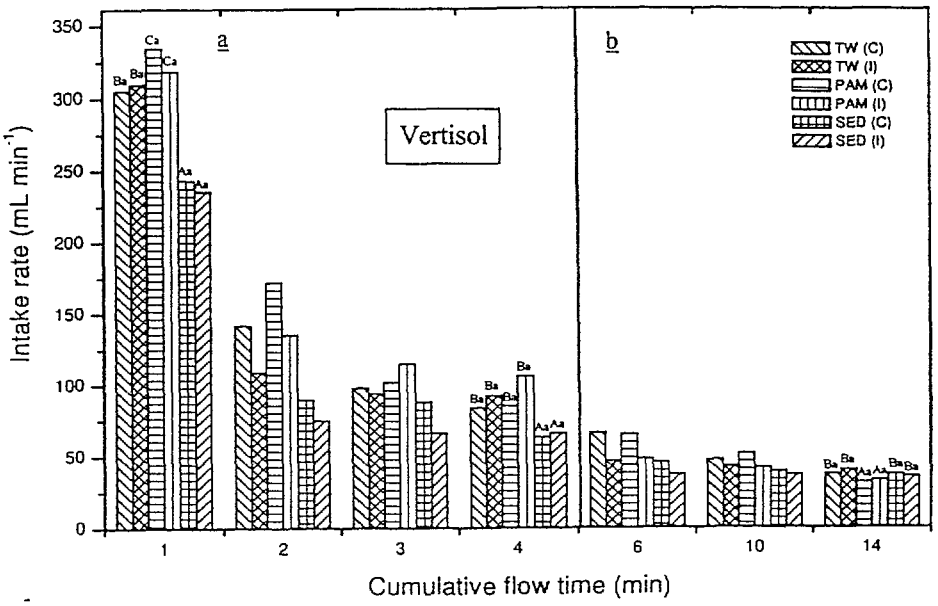

Fig. 3. Intake rate as a function of cumulative flow time for the Vertisol during (a) Stage 1 and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences between 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

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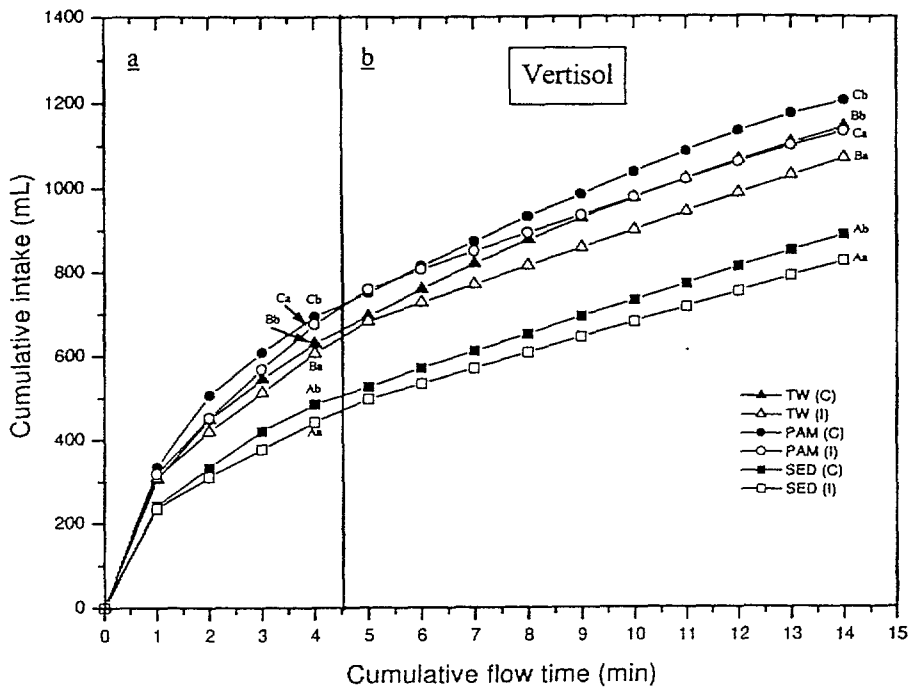

Fig. 4. Cumulative intake as a function of cumulative flow time for the Vertisol during (a) Stage 1 and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences between 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

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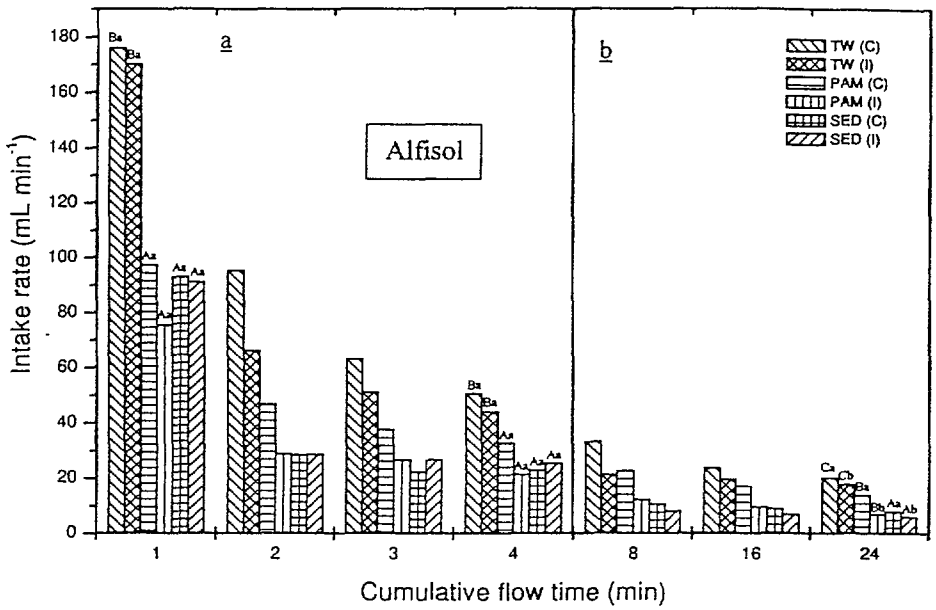

Fig. 5. Intake rate as a function of cumulative flow time for the Alfisol during (a) Stage 1 and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences between 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-

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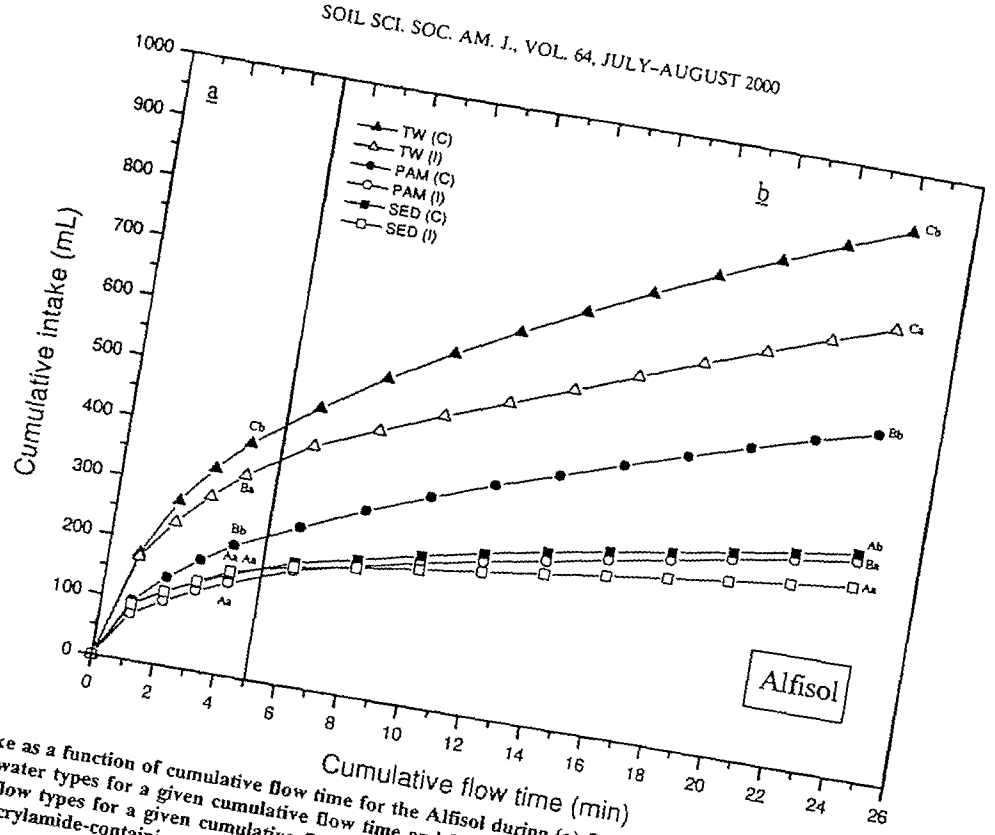

Fig. 6. Cumulative intake as a function of cumulative flow time for the Alfisol during (a) Stage 1 and (b) Stage 2 of the experiment. Significant differences between water types for a given cumulative flow time and flow type are indicated by upper-case letters ($P < 0.05$). Significant differences between 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-

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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

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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").

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Appendix "B"

Impact of surge application on soil consolidation and hydraulic conductivity (HC)

Interrupted irrigation, which is the intermittent application of irrigation water during the advancement stage of furrow irrigation (Stringham, 1988), has the potential to reduce infiltration rate (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). The importance of each of the two mechanisms in determining the IR when interrupted flow is practiced is not clear and may depend on many variables including soil properties and water quality.

A laboratory experiment was conducted to measure the effect of negative pressure, which develops during the off time practiced when surge technique is used in furrow irrigation, on the consolidation and HC of the soil surface layer.

I. Soils

Two types of arable soils of differing textures were chosen for this study: a silty loam alfisol (Calcic Haploxeralf) from Nevatim, in northern Negev, and a clay vertisol (Typic Haploxerert) from Hafetz-Haim and Qedma, in the northern part of the Pleshet Plain, Israel. Samples from Nevatim and

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Hafetz-Haim were taken from adjacent fields in each location, one from a field, irrigated with fresh water (low ESP) and the other from a field irrigated with treated waste water (high ESP). The samples from Qedma were taken from non-irrigated fields having naturally occurring high ESP levels. 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	Location	Classification	Particle-size distribution			CEC	ESP	CaCO3	OM
			Clay	Silt	Sand				
			%	%	%	meq/100g	%	%	%
Alfisol	Nevatim	Calcic	23.4	16 6	60	14.9	2.7	18.2	1.2
		Haploxeralf	22.5	16.5	61	16.4	6.5	18.4	1.2
Vertisol	Hafetz-Haim	Typic	41.9	13.13	45	33.2	1.9	11.3	4.4
		Haploxerert	37.5	15	47.5	31.0	5.0	9.12	2.5
	Qedma		55	20	25	41.6	12.0	13.0	3.0
			60	18.8	21.2	49.4	20.0	12.7	3.0

II Experimental procedure

Air-dried a soil sample (100 g), crushed to pass through a 1.0 mm sieve were placed in a 65 mm i.d. funnel fitted with a fritted disk which had a nominal maximum pore size of 40-60 m. Prior to placing the sample in the funnel, the disk was saturated from the bottom using a peristaltic pump at wetting rate of 14.5 mm h^{-1}. After saturation of the disk, the sample was gently packed and smoothed in the funnel. Initial average height of the dry samples was 2.6 and 2.8 cm, for the alfisol and the vertisol, respectively. Saturation of the soil sample was obtained at a wetting rate of 30.1 mm h^{-1}. After saturation, initial saturated soil height was measured and bulk density (BD) calculated. Thereafter the sample was leached from the top of the funnel with the aid of a constant head device; hydraulic head was maintained at 0.45 m. Leaching lasted for 5 min during which drainage water was collected and its volume recorded. After determining the saturated HC , the sample was allowed to drain till free water reached the soil surface. Then the soil was drained by applying a matric potential of 10 cm, this was obtained by lowering the water column connected to the bottom of the funnel so that the meniscus in the pipette was 10 cm below the surface of the sample. Drainage under matric potential was applied for 6 min. At the end of the draining process the sample height was measured again and the information was used to calculate BD and HC. After measuring the soil thickness, the soil sample was re-saturated again by applying water from the bottom using the same wetting rate as before, and the new saturated

HC of the soil sample was measured. These steps were repeated 5 times, and matric potential was increased each time by 10 cm till it reached 50 cm. The control treatment consisted of 30 min at zero matric potential (i.e., no application of suction). Outflow and thickness of the soil sample were recorded every 5 min of flow.

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

Each treatment (i.e., control or matric potential application, and water quality) was duplicated. Coefficient of variation between replicates was less 10%.

III Results

An example for the BD data obtained from the vertisol Hafetz Haim subjected to leaching with distilled water is given in Figure 1. The data show the changes in BD as a function of leaching duration (upper X-axis) for the case where no suction was applied (control) vs. the changes in BD with the increase in matric potential (lower X-axis). The results show that when no tension was applied the BD increased some what from 1.02 to 1.04 g cm^{-3}. The increase in the BD was attributed to the hydraulic gradient which caused the soil column to consolidate. Conversely when matric potential was applied at each step during the experiment, the soil sample consolidated and thus BD increased. It was noted however that upon re-wetting some swelling took place, but this re-swelling did not bring the soil back to its previous height; thus BD at the end of re-saturation was in general higher than BD at the previous step.

The Results of initial, final and relative BD for the tension and no-tension treatments, and as a function of water quality are presented in Table 1. Final BD data refer to BD measured after matric potential of 50 cm was applied or at the end of the 30 min of leaching in the case of the no-tension treatment. Relative BD is the ratio of the final BD to the initial one.

For all cases final BD was higher than the initial one. However, comparing the relative BD of the treatments when tension was applied to the BD values when no tension was applied indicates that application of tension caused the soil to consolidate and thus to an increase in its BD irrespective of water quality and soil sodicity (Table 1). The effect of matric potential application was greater for the

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vertisol with high sodicity (ESP 12 and 20) compared for the vertisol with low sodicity (ESP 1.86 and 5). Water quality did not seem to have an affect on the BD in the tension tretament.

An example for the HC data obtained from the vertisol Hafetz Haim subjected to leaching with distilled water is given in Figure 2. The data show the changes in HC as a function of leaching duration (upper X-axis) for the case where no tension was applied (control) vs. the changes in HC with the increase in matric potential. The results show that when no matric potential was applied the HC decreased moderately due to swelling which reduced the size of the water conducting pores. Conversely when matric potential was applied at each step during the experiment, the HC decreased sharply to a value which was ~1/4 of the original HC. The decrease in HC was attributed to soil consolidated and the subsequent increase in BD which made the soil less permeable .

The Results of initial, final and relative HC for the tension and no-tension treatments, and as a function of water quality are presented in Table 2. Final HC data refer to HC measured after matric potential of 50 cm was applied or at the end of the 30 min of leaching in the case of the no-tension treatment. Relative HC is the ratio of the final HC to the initial one.

For all treatments, final HC was lower than the initial one. However, relative HC in the case where matric potential was applied were lower than those in the no tension treatment (Table 2). The latter observation clearly indicates that application of matric potential to the soil causes it to consolidate, thereby increasing its BD (see Table 1), and subsequently leading to a decrease in the soil HC. It is further noted that in the tension treatment the relative HC was affected by water quality and sodicity; the lower the electrolyte concentration in the water and the higher the sodicity of the soil, the lower the relative HC (Table 2). Evidently, conditions favoring clay dispersion enhance soil susceptibility to consolidation upon application of matric potential, thus leading to low HC levels. Similar trends, though less pronounced, were noted in the no tension treatment (Table 2).

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Figure legend

Figure 1: Bulk density when matric potential was applied (lower X-axis) and for the no tension treatment (upper X-axis).

Figure 2: Hydraulic conductivity when matric potential was applied (lower X-axis) and for the no tension treatment (upper X-axis).

Table1: Effects of water quality and ESP on soil bulk density

SOIL	ESP	WATER QUALITY	TENSION			WITHOUT TENSION		
			initial BD	final BD	relative BD	initial BD	final BD	relative BD
	%	meq/l	gm/cm3	gm/cm3		gm/cm3	gm/cm3	
Alfisol	2.5	0.01	1.185	1.293	1.091	1.191	1.228	1.031
Alfisol	2.5	0.95	1.169	1.28	1.095	1.191	1.2	1.008
Alfisol	2.5	2	1.185	1.29	1.089	1.188	1.197	1.008
Alfisol	6.5	0.01	1.154	1.226	1.062	1.149	1.162	1.011
Alfisol	6.5	0.95	1.089	1.191	1.094	1.114	1.13	1.014
Alfisol	6.5	2	1.104	1.212	1.098	1.114	1.127	1.012
Alfisol	6.5	4	1.119	1.2	1.072	1.122	1.13	1.007
Vertisol (HH)	1.86	0.01	1.011	1.089	1.077	1.011	1.022	1.011
Vertisol (HH)	1.86	0.95	0.963	1.049	1.089	0.983	0.999	1.016
Vertisol (HH)	1.86	2	1.003	1.053	1.050	1.007	1.02	1.013
Vertisol (HH)	1.86	4	0.987	1.035	1.049	1.003	1.009	1.006
Vertisol (HH)	5	0.01	1.018	1.109	1.089	1.02	1.044	1.024
Vertisol (HH)	5	0.95	1.003	1.102	1.099	1.007	1.024	1.017
Vertisol (HH)	5	2	1.022	1.117	1.093	1.031	1.046	1.015
Vertisol (HH)	5	4	1.018	1.112	1.092	1.024	1.033	1.009
Vertisol (Q)	12	0.95	0.91	1.02	1.121	0.91	0.935	1.027
Vertisol (Q)	12	2	0.917	1.037	1.131	0.928	0.94	1.013
Vertisol (Q)	12	4	0.93	1.05	1.125	0.95	0.97	1.014
Vertisol (Q)	20	0.95	0.86	0.959	1.115	0.863	0.874	1.013
Vertisol (Q)	20	2	0.871	0.993	1.140	0.887	0.902	1 017
Vertisol (Q)	20	4	0.902	1.011	1.121	0.905	0.917	1.013

Table 2: Effects of water quality and ESP on soil hydraulic conductivity (HC)

SOIL	ESP	WATER QUALITY	TENSION			WITHOUT TENSION		
			initial HC	final HC	relative HC	initial HC	final HC	relative HC
	%	dS/m	cm/h	cm/h		cm/h	cm/h	
Alfisol	2.5	0.01	1.9	0.5	0.263	2.59	2.02	0.780
Alfisol	2.5	0.95	2.61	1.18	0.452	2.64	2.26	0.856
Alfisol	2.5	2	2.48	1.04	0.419	2.48	2.18	0.879
Alfisol	6.5	0.01	1.94	0.33	0.170	1.82	1.09	0.599
Alfisol	6.5	0.95	3.72	1.69	0.454	3.87	3.04	0.786
Alfisol	6.5	2	3.51	1.61	0.459	3.22	2.83	0.879
Alfisol	6.5	4	3.37	1.72	0.510	3.21	2.76	0.860
Vertisol (HH)	1.86	0.01	7.89	3.36	0.426	9.35	7.03	0.752
Vertisol (HH)	1.86	0.95	8.43	5.56	0.660	8.81	7.85	0.891
Vertisol (HH)	1.86	2	9.3	6.54	0.703	9.1	8.38	0.921
Vertisol (HH)	1.86	4	9.04	7.49	0.829	9.09	8.63	0.949
Vertisol (HH)	5	0.01	4.75	0.94	0.197	4.70	3.20	0.682
Vertisol (HH)	5	0.95	7.7	3.94	0.512	7.93	7.02	0.885
Vertisol (HH)	5	2	8.1	4.8	0.593	7.84	6.88	0.878
Vertisol (HH)	5	4	7.65	4.14	0.541	8.76	7.92	0.904
Vertisol (Q)	12	0.95	3.97	1.33	0.335	4.41	3.01	0.683
Vertisol (Q)	12	2	4.3	1.54	0.358	4.4	3.44	0.782
Vertisol (Q)	12	4	4.12	1.59	0.385	3.77	2.97	0.786
Vertisol (Q)	20	0.95	1.79	0.42	0.235	1.6	0.95	0.594
Vertisol (Q)	20	2	2.78	0.78	0.281	2.82	1.92	0.681
Vertisol (Q)	20	4	3.77	1.39	0.369	3.01	2.35	0.781

Fig. 1

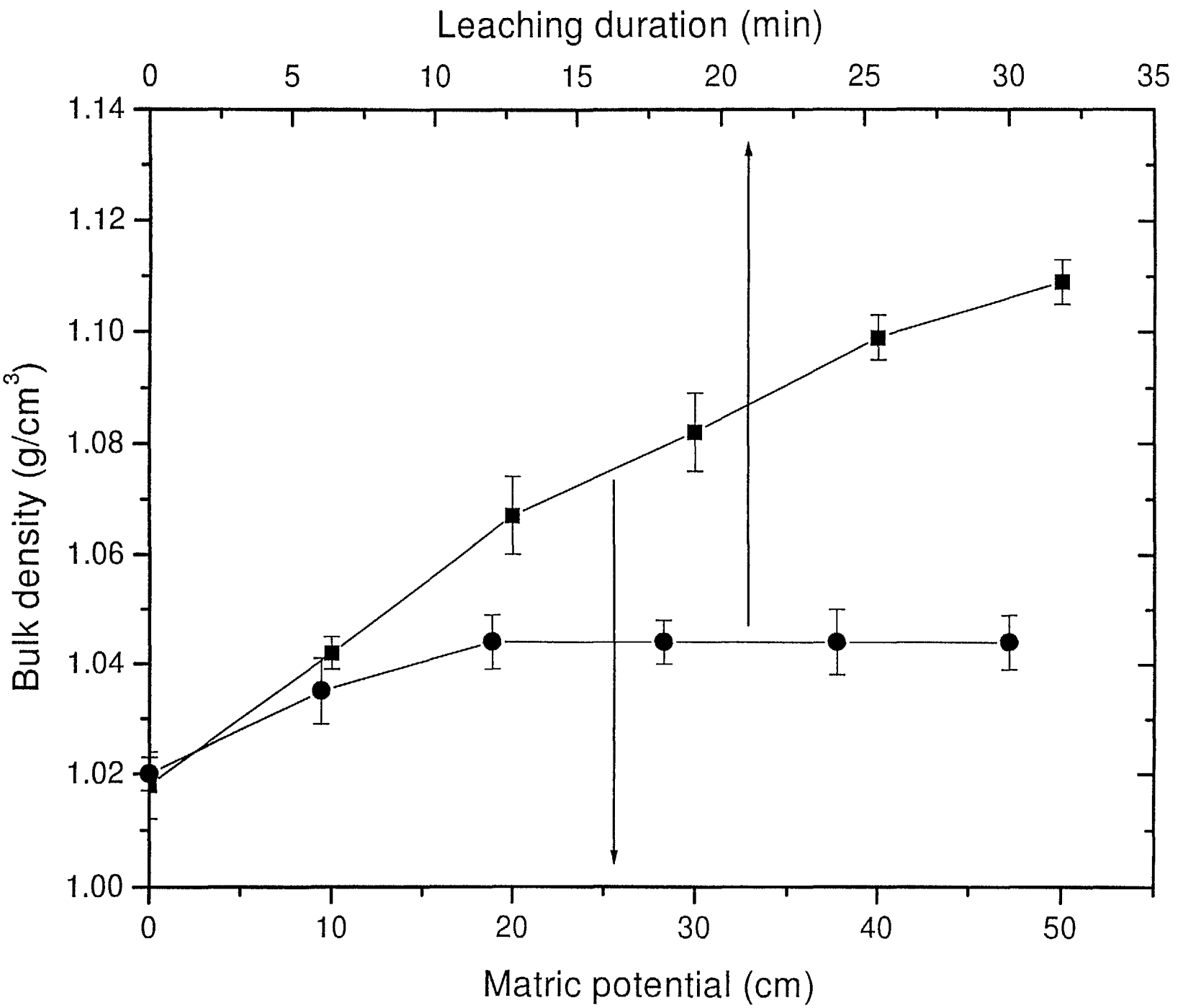
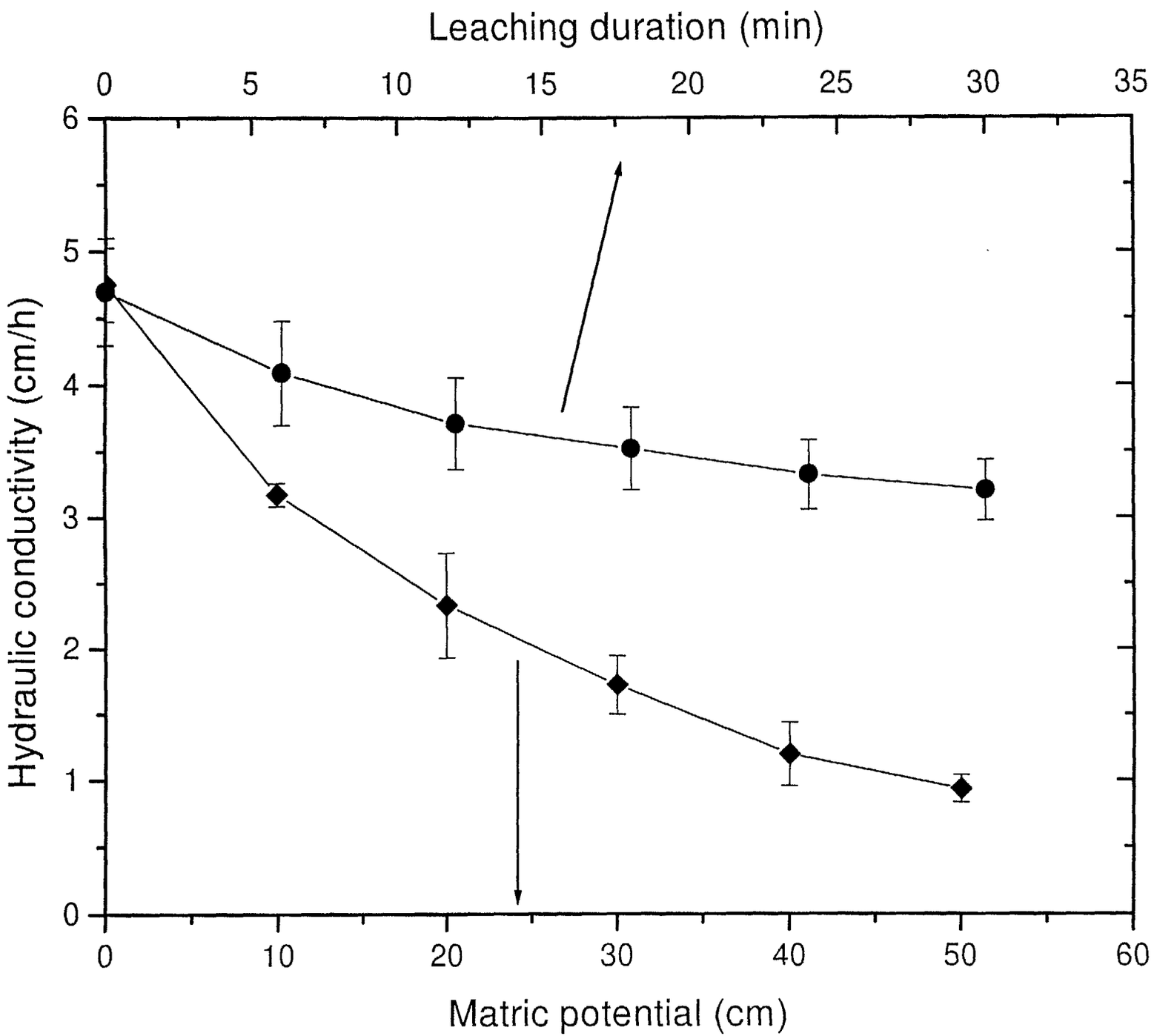

Leaching duration (min)
0
5
10
15
20
25
30
35
Bulk density (g/cm^3)
1.14
1.12
1.10
1.08
1.06
1.04
1.02
1.00
0
10
20
30
40
50
Matric potential (cm)

Fig. 2


Leaching duration (min)
0
5
10
15
20
25
30
35
Hydraulic conductivity (cm/h)
0
1
2
3
4
5
6
Matric potential (cm)
0
10
20
30
40
50
60

Appendix "C"

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

Laboratory experiments with miniflumes were conducted to investigate the effects of water quality and soil sodicity on infiltration rate and rill erosion under continuous and surge type flow.

I. Soils

For this experiment the same soils and the water qualities which were studied in the consolidation and HC experiment were used (see Appendix "B", Table 1).

II 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 its sides. The flume was placed at a 10% slope in order to maintain high flow shear force.

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

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

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

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

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

Another experiment was conducted with alfisol ESP 6.5. In order to test its susceptibility to high shear stress, the velocity in second stage was increased to on inflow of 320mL min^{-1}. The first stage of experiment and the water quality were the same as was indicated above for the alfisol.

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

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

III Results

Data are being currently analyzed.

Appendix "D"

USA - Israel - Scientific and Research
Institute of Irrigation, Kyrghyzstan

"Maintaining"
Deputy director of Institute
_____Dr.J. M. Rakhmanov

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. Жураф G. L. Zhuravskaya

Bishkek – 1999

Introduction

The task which gave Principal Investigator Dr. G. J. Levy and Prof. I.Shainberg during them the visit in Kyrghyzstan in June, 1998 was basis for fulfillment of the field experiments on Project. Program of the field experiments, which cites bellow, is by a result of this visit.

Effect of surge irrigation and PAM on furrow erosion, infiltration rate (IR) and uniformity of water distribution

I. Shainberg and G.J. Levy

Introduction

Surge irrigation is the intermittent application of surface irrigation water. Under some conditions, the technique reduces the application time and volume required to advance flow across the field surface and thus improves irrigation water distribution uniformity.

The reduced advanced times are the result of reduced infiltration rates. The most often cited mechanism for reduced soil permeability is the consolidation of the wetted soil during flow interuption due to increased soil water tension (Trout and Kemper, 1983; Kemper et al., 1988).

Kemper et al. (1988) proposed that intermittent flow can increase aggregate breakdown and sediment erosion and deposition, thus the formation of depositional surface seals. When sediments are present in furrow water the IR is reduced by 50% (compared with water of no sediments).

Polyacrylamide (PAM) at concentration of 10 g/m3 in irrigation water was demonstrated to prevent furrow erosion and to increase IR (Lentz et al., 1992).

Thus the objectives of this study are:

1. To study the effect of surge irrigation on furrow erosion and infiltration rates.
2. To study the effect of PAM on furrow erosion and IR.
3. To study the interaction between surge irrigation and PAM in their effects on erosion and IR.
4. To study the effects of the above treatments on irrigation water distribution uniformity.

It is hypothesized that:

1. Consolidation and aging of furrow surface during the off periods in surge irrigation reduces furrow erosion. Surge irrigation willl be as effective as PAM in preventing furrow erosion.

2. Consolidation of the depositional crust that is formed in the first surge is very effective in reducing IR; thus surge irrigation is effective in decreasing IR.

3. PAM, being effective in preventing furrow erosion and epositional crust formation will be effective in maintaining high IR.

4. Surge irrigation in PAM treatment will be effective in consolidation of soil surface and reducing IR. However, the effect of surge irrigation in PAM treatments will not be as effective as in conventional treatment (i.e., without PAM), because the depositional seal is more susceptible to consolidation.

Procedure

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

1.1. Continous irrigation (Control).

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

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

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

d. Repeat the above measurements in 5 furrows.

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

1.2. Surge irrigation

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

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

2. Effect of PAM on furrow erosion and IR.

2.1. Continuous irrigation

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

2.2. Surge flow with PAM application.

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

Field conditions permited us to execute of program completely.

We have not a difficulty in field experiments of Project.

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

2. Experiments were conducted with an agricultural culture. We shall be determined a productivity on variants of experience.

3. Therefore we used in the experiments only four irrigated furrows in each of the variants as wheeled tractor cut a six furrows at the same time. The tractor cut first and sixth the furrows twice, so that not lose one's track only four furrows had equal a roughness and a geometrical parameters.

We study:

1. The effect of surge irrigation on furrow erosion and infiltration raters.
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.

We continued also to work off a technique of realization of experiments.

The field experiments were conducted from May 1, 99 to October 14, 99.

They are in preparatory and main works.

1. Preparatory works

Preparatory works included:

1. The choice of the area for conducting of field experiments;
2. The leveling of the area with the aim of determination of the surface slope in the direction of the irrigation;
3. The determination of the soil permeability;
4. The test irrigation with an aim of determination of the flow rate of the irrigation stream.

1.1. The area for field researches must to correspond to next requirements:

a) sown with culture in a row;
b) the irrigation must will be fulfilled with method of surface irrigation;
c) to have a big slope of surface;
d) to have a sierozem type of soils of a medium permeability;
e) to have a big thickness of a soil cover;
f) to have good supplying with flooding water.

The area was found with this conditions in Alamedin raion within irrigation system of the Alamedin river on sugar beet field (Photo 1).

1.2The geodetic leveling of the area showed that slops surface of the field fluctuated from 1,2 % to 3,1 % in the direction of the irrigation (Fig.1).

The mean slope equal 2.6 %.

1.3. The method of the determination of the soil permeability.

The circle metallic frames drove in soil, into their we poured a water and take into account the intensity of the imbibition its into soil under pressure H=10 cm in the determinate intervals of the time. The application of the water and maintenance of the determinate level its was accomplished by hand with help of the measure vessels.

Two frames were used for determination of the soil permeability in every veriant:

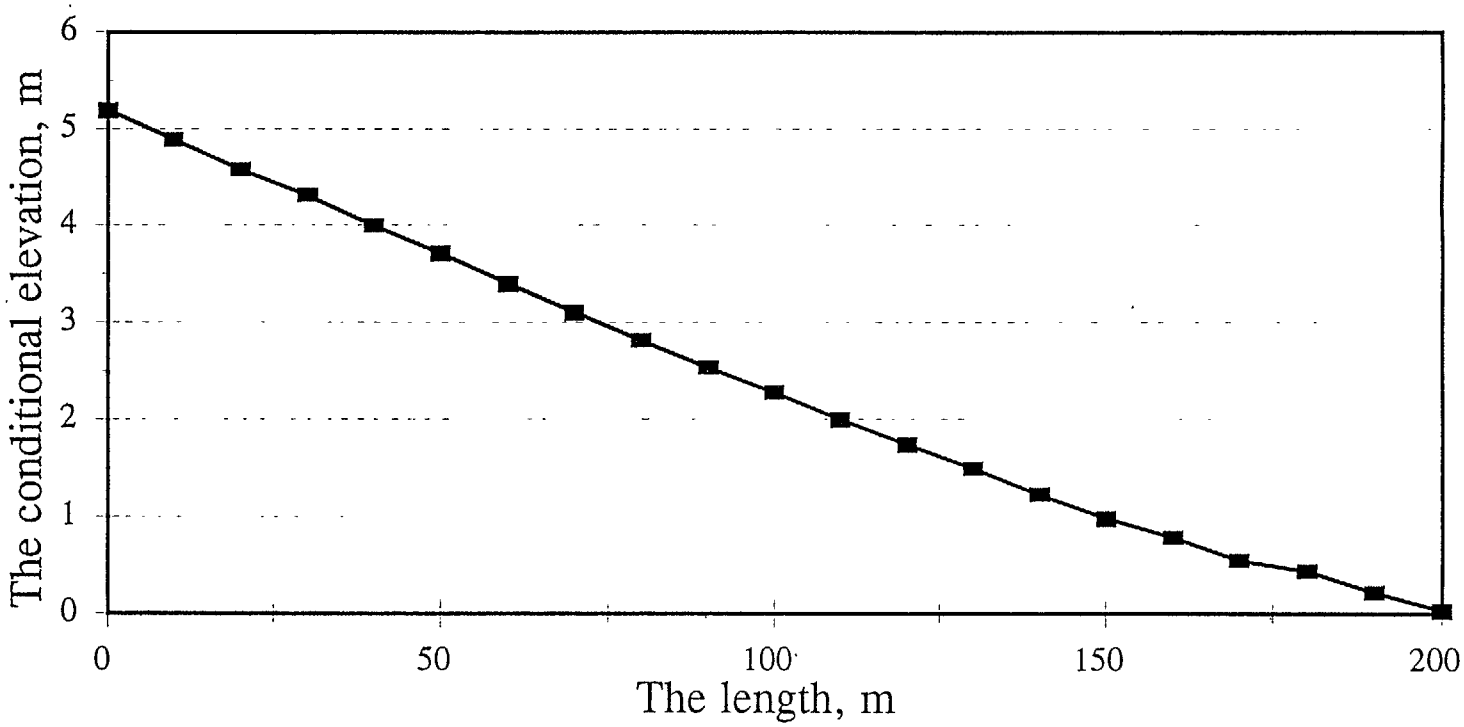
1) the big frame is outward, protective frame, restricting preading of the water from inward frame, its the diameter is 70 cm;

2) the small frame is inward, register frame. The diameter of the inward frame is 30 cm (Photo 2).

The general view of the area

Photo 1

The slope of the ground surface in plot of the field experiments



Meam slope is 2.6 %

Fig. 1

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The observation of the soil permeability

Photo 2

The determination of the water permeability of the soil made with double control. The distance between control circles was equal 1.5 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 10 cm. The protective and register circles poured simultaneously. With this moment we began the take into account of the water which all the time add in the register circles with measuring cylinders. We took into account poured out of the water in inward circle and maintained on constant level (10 cm) of the water into outward circle. Account of the time made on infiltration the volumes of a water in 100 and 200 millilitres at first of an experiment and 300 or 500 millilitres then. The soil permeability computed for every intervals of the time on formula:

$$K_t = dQ*60/S*dt,$$

where K_t - a soil permeability, cm/h;
dQ - a quantity poured out water, cm^3;
60 - conversion factor from min to hour;
S - an area of the register circle, 706,5 cm^2;
dt - the intervals of time among measurements of volume waters, min.

The value of the soil permeability and the intervals of time written down in the table and desigh 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 and in Table 1. Interval of the times and the volumes infiltration, correspondings them, were sumed up (approximately up to 30 min) for construction of a graph.

1.4.Soil of the plot field experiments were selected, were dried, were crushed and sifted through a sieve with diameter of the orifice 2 mm and were deliver to Volcani Center (Israel) for the study. Soil was fully characterized as to their basic chemical and physical properties in laboratory at the Institute of Soil, Water and Environmental Sciences where head Dr. G.J. Levy. The results of an analysises will be presented later.

1.5. The flow rate of the irrigation stream, which was planned (preliminary 0,5 L/s), doesn't suit for condition of this area. The test irrigation displaied that the rated duration of the furrows wetting composed only 46 min under these conditions (Fig.3). That is to say very little. Therefore the flow rate had been decreased to q1=0,36 L/s in period of the wetting and q2=0,20 L/s in the period of the after wetting.

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The dependency H.C. = f(t)

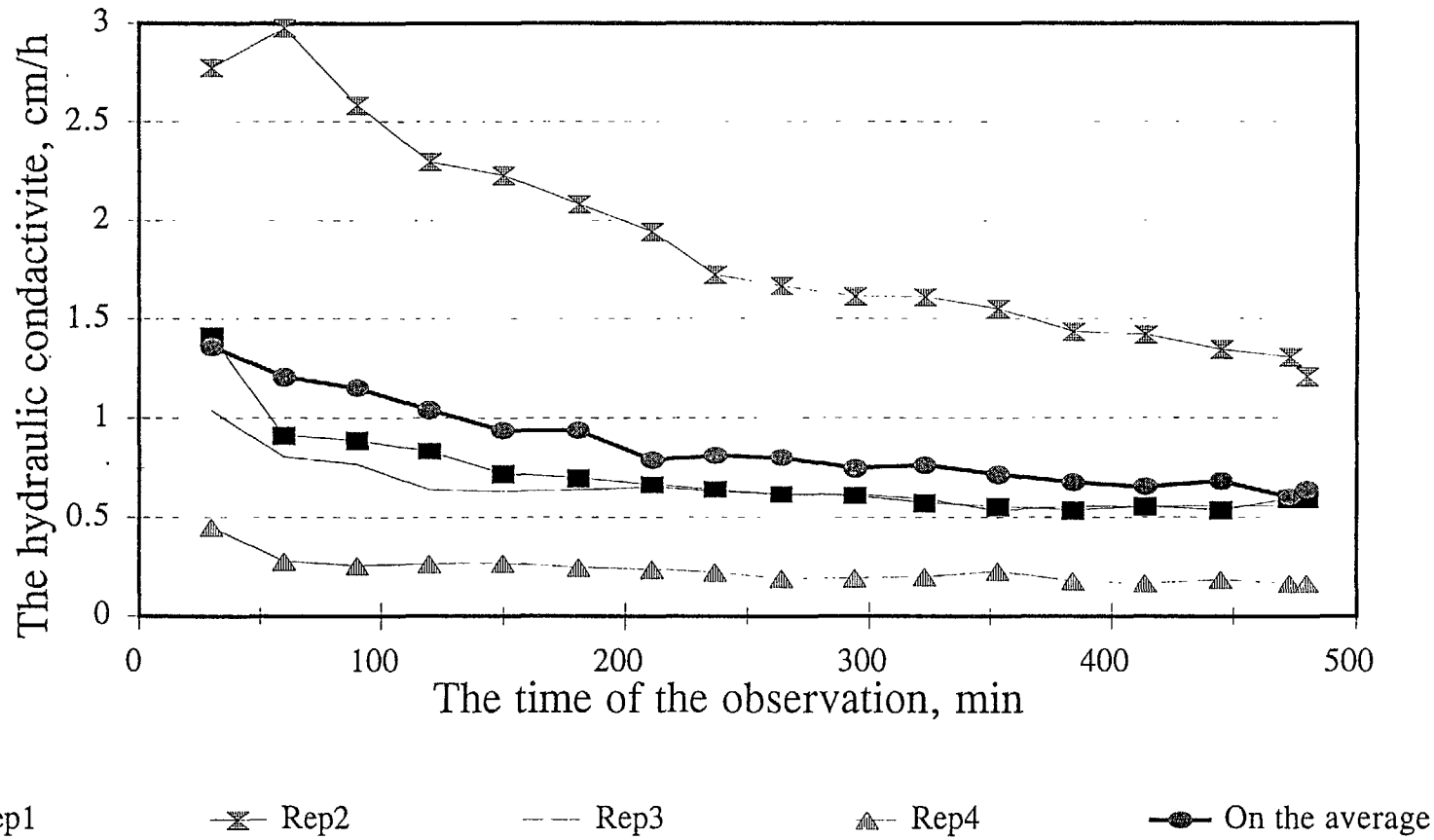


Fig. 2

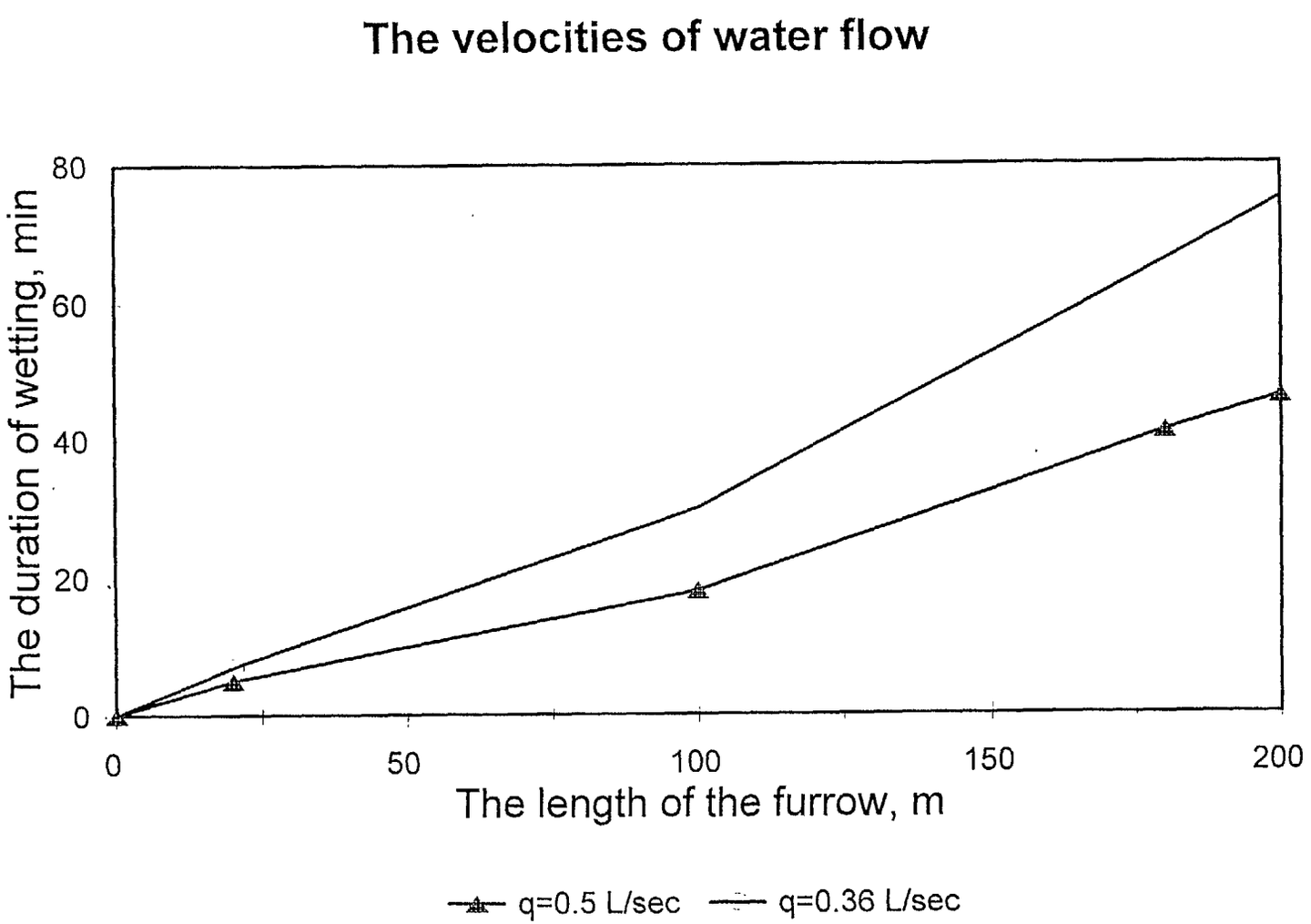

The velocities of water flow
The duration of wetting, min
80
60
40
20
0
0
50
100
150
200
The length of the furrow, m
q=0.5 L/sec
q=0.36 L/sec

Fig. 3

Table 1

THE RESULTS OF OBSERVATION OF THE SOIL PERMEABILITY

Repetition 1

dt, min	Sum t, min	W,ml	V, cm/h
30	30	2550	1.42
30	60	1650	0.92
30	90	1600	0.89
30	120	1500	0.83
30	150	1300	0.72
31	181	1300	0.70
30	211	1200	0.67
26	237	1000	0.64
27	264	1000	0.62
30	294	1100	0.61
29	323	1000	0.57
30	353	1000	0.56
31	384	1000	0.54
30	414	1000	0.56
31	445	1000	0.54
28	473	1000	0.60
7	480	250	0.60
480		20450	

Repetition 2

dt, min	Sum t, min	W,ml	V, cm/h
30	30	5000	2.78
28	58	5000	2.98
29	87	4500	2.59
29	116	4000	2.30
28	144	3750	2.23
32	176	4000	2.08
30	206	3500	1.94
29	235	3000	1.72
30	265	3000	1.67
31	296	3000	1.61
29	325	2800	1.61
29	354	2700	1.55
29	383	2500	1.44
27	410	2300	1.42
31	441	2500	1.34
28	469	2200	1.31
11	480	800	1.21
480		54550	1.89

Repetition 3

dt, min	Sum t, min	W,ml	V, cm/h
32	32	2000	1.04
31	63	1500	0.81
26	89	1200	0.77
26	115	1000	0.64
29	144	1100	0.63
34	178	1300	0.64
28	206	1100	0.65
29	235	1100	0.63
27	262	1000	0.62
27	289	1000	0.62
28	317	1000	0.60
28	345	900	0.54
30	375	1000	0.56
30	405	1000	0.56
30	435	1000	0.56
30	465	1000	0.56
15	480	500	0.56
480		18700	0.65

Repetition 4

dt, min	Sum t, min	W,ml	V, cm/h
37	37	1000	0.45
30	67	500	0.28
26	93	400	0.26
25	118	400	0.27
31	149	500	0.27
27	176	400	0.25
35	211	500	0.24
30	241	400	0.22
26	267	300	0.19
34	301	400	0.20
25	326	300	0.20
29	355	400	0.23
28	383	300	0.18
30	413	300	0.17
27	440	300	0.19
30	470	300	0.17
10	480	100	0.17
480		6800	0.24

Velocity of the advancement a stream to furrow is presented in Table 2 depending on flow rates.

Table 2

DURATION OF WETTING OF THE FURROWS FOR THE FLOW RATE OF THE IRRIGATION STREAM

Length of the furrow, m	The time of the observation (on an average for fourth furrows)				The duration of the wetting, min	
	the first version (q1=0.5 L/sec)		the second version (q1=0.3 L/sec)			
	hour	min	hour	min	the first version	the second version
0	10	30	10	7	0	0
20	10	35	10	14	5	7
100	10	48	10	37	18	30
180	11	11	11	13	41	66
200	11	16	11	22	46	75

Conclusions

1.The slope of the surface of this area is wedespread for Kyrgyzstan under conditions use of the surface irrigation (on the average slope had composed 2,6%).

2. Experiments were conducted with an agricultural culture on sugar beet.

3.The steady infiltration of the soil had composed on the average 0.64 cm/h (it had changed from 1,90 cm/h to 0.24 cm/h in repetitions) or $1,77*10^{-4}$ cm/sec that is characteristic for a sierozem types of loam soils of Chui valley [1].

4.The soil of the area is thick loam.

5.The flow rate of the irrigation stream, which was planned (preliminary 0.50L/s) for condition of this area doesn't suit, that is why in veriants of the experiments the flow rate was took q1=0.36 L/s in the period of the wetting and q2=0.20 L/s in the period of the after wetting.

2. Main works

They consist in the determination:

- of a furrow erosion;
- of a water losses of the flow rates lengthways of a furrow in each veriant of the experiments;
-of a depth of soil moistening on variants of experience before irrigation, after first irrigation and after second irrigation, that is to say the unifomity of water distribution in the field;
-of an yield of a sugar beet on variants of experience.

Besides we did mikroleveling of an irrigated furrow after first irrigation and after fourth irrigation. We also recorded the atmospheric rain in irrigation period.

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

The balance method was used in determination of the water losses of stream lengthways of a furrow. Static head measured in portable water meter for those purposes (Photo 4). Employment of the weir particularly is efficient for technology of a surge irrigation to the furrows, because orifice in diaphragm is easily re-cover with blind diaphragm during surges.

2.1. Specials of the field experiments realization

We have some specials of the field experiments realization.

In the first place we have the rainy summer. In period from July 9 to October 7 fell about 146 mm of a precipitation that could to affect in results of a field experiments. In Table 3 are cited dates and norms of a precipitation, dates of a basic work realization and norms of irrigations. Harvesting of a sugar beet was finished October 10. The most abundant precipitation fell before 3rd irrigation and after 4th irrigation. Possibly sharp an insrease of a sediment concentration in selected samples of a water in period 3rd irrigation finds an explanation in chemical substance of the precipitation.

In the second place we have a cultivation after 1st irrigation in versions *continuous irrigation* and *surge irrigation.* In connection with cultivation an analysis of various factors influence on erosion is realized for 2nd, 3rd and 4th in those versions. In versions *continuous + PAM* and *surge + PAM* the cultivation was not conducted. Therefore an analysis of various factors influence on erosion is realized for all irrigations. But we may not to compare of a version results among oneselves for this reason.

We did not conduct the observations in period 5th irrigation.

The metallic chute

Photo 3

The water meter

Photo 4

Table 3

THE SOME CONDITIONS AND INDEXES OF A FIELD EXPERIMENTS

The rain		The date of cultiva-tion	The date of sample collection of soil	The irrigation				The date mikro-leveling
date	norm, mm			num-ber	version	date	norm, mm	
09.07	7.9	19.07	18.07		test	20.07		26.07
10.07	9.6	01.08	26.07	1	cont.	22.07	1400	14.09
13.07	1.5		09.08		cont+p	22.07	1406	
14.07	1.8				surge+p	23.07	1476	
18.07	0.5				surge	23.07	1458	
19.07	0.8			2	cont.	03.08	1460	
21.07	6.6				cont+p	03.08	1402	
26.07	0.1				surge+p	04.08	1428	
31.07	0.7				surge	04.08	1454	
2.08	5.4			3	cont.	18.08	1513	
12.08	6.5				cont+p	18.08	1466	
13.08	31.9				surge+p	19.08	1516	
14.08	0.4				surge	19.08	1551	
01.09	7.0			4	cont.	30.08	1484	
05.09	27.4				cont+p	30.08	1451	
06.09	1.8				surge+p	31.08	1497	
24.09	14.3				surge	31.08	1509	
25.09	3.9			5	cont.	17.09	1214	
26.09	1.0				cont+p	17.09	1214	
30.09	7.9				surge+p	17.09	1214	
06.10	5.6				surge	17.09	1214	
07.10	3.1							
10.10	0.1							
Total	145.8							

2.2. Results of field experiments

We researched four of versions in field experiments and conducted the experiments with 4 irrigations.

Contents in the versions of field experiments are presented in the table below (Table 4).

Table 4

CONTENTS IN THE VERSIONS OF THE FIELD EXPERIMENTS

Version	Contents in the version	Footnoote
Cont. + Pam	Irrigation No 1. Continuous irrigation with PAM application (10 g/ m^3). T1c	Furrow of 200 m long. Samples collection of water with sediments from the furrows at distances of 20, 100, 180 and 200 m. Repeat the measurement of sediment concentration at 10, 20, and 30 min after the water reached the end of the furrow. The flow rate q1=0.36 L/s in the period of the wetting and q2=0.2 L/s in the period of the after wetting. Measure inflow and outflow rates during 3 h at 30 min intervals. Repeat - in 4 furrows
Cont.	Irrigation No 1. Control, continuous irrigation T2c	
Surge+Pam	Irrigation No 1. Surge irrigation with PAM application (10 g/ m^3). Ts=T1c/4	
Surge	Irrigation No 1. Surge irrigation Ts=T2c/4	
Cont.+Pam	Irrigations from No 2 to No 4. Continuous irrigation. T1c	
Cont.	Irrigations from No 2 to No 4. Continuous irrigation. T2c	
Surge+Pam	Irrigations from No 2 to No 4. Surge irrigation Ts=T2c/4	
Surge	Irrigations from No 2 to No 4. Surge irrigation Ts=T1c/4	

During each of fourth irrigations was realized a dosage of a water application in furrows, were determined the sediment concentration in the irrigation water and in the furrow flow, the water losses to infiltration lengthways of a furrow.

Results of field experiments are presented below in Figures 4-10 and on the Supplements in a full scope. Durations the surges in the period of the wetting of furrows are presented in Table 5.

Table 5

DURATIONS OF THE WETTING OF FURROWS AND THE SURGES

Version	1st irrigation		2nd irrigation		3rd irrigation		4th irrigation	
	T	Ts	T	Ts	T	Ts	T	Ts
Cont.+Pam	100		95		53		84	
Continuous	75		167		112		124.8	
Surge +Pam	103	25	98.5	25	65	15	97	20
Surge	59	15	131	40	109	25	113	25

2.2.1. Furrow erosion

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

a) flow rates (0.36 and 0.20 L/sec);
b) slope of furrow (on the average 0.026 m/m);
c) irrigation method (continuous irrigation and surge irrigation);
d) water quality (without PAM and with PAM 10 g/m^3);
e) without cultivation and with cultivation.

Following formula was used:

$$E = (G_s / G) * 100, \%$$

where E - erosion, %;
G_s - total mass of the sample after drying, g;
G - total mass of the sample before drying, g.

Our field experiments demonstrated (Fig. 4, Annex 1) that percent of the sediment concentration in water

- decrease from irrigation to irrigation in versions a continuous irrigation and a surge irrigation and increase from irrigation to irrigation in Pam's versions;
- decrease with increase of an observation time;
- increase with length of a furrow to the appointed limits, the dependence E=f(L) has a point of inflection.

Surge irrigation, in comparison with continuous irrigation, increased a percent of the sediment concentration in a water flow, reduces the time of furrow wetting (Table 5) and value required to advance flow over the field surface. The furrows were eroded bigger (Fig. 5) in versions with surge irrigation if to compare the versions *surge irrigation* and *continuous irrigation*. Our observation (Photo 5, Photo 6) demonstrated that surge irrigation influences on surface of the furrow as if emery paper influences on a wood: the process of erosion continues until will be formed a smooth furrow surface or will be completed a potential possibility of the flow rate. For the latter case we have a sedimentation (Fig. 5)

We had a sedimentation in the furrow end also in versions *surge irrigation + Pam.*

Dependence E=f(Qo.r.), that has been cited in Fig. 6, demonstrated increase of the sediment concentration percent in water flow with increase a outflow rate.

The first irrigation

to the left of us is version surge irrigation + Pam, to the right of us is version surge irrigation

Photo 5

After of a first irrigation
the version surge irrigation

Photo 6

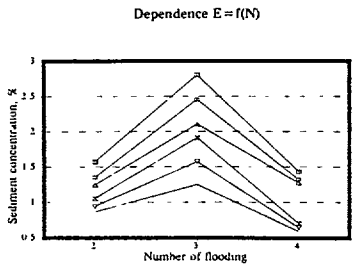
The second irrigation

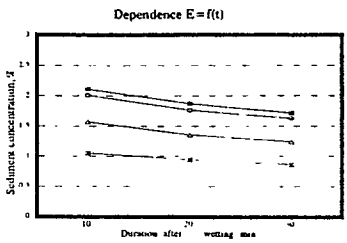
to the left of us is version continuous irrigation + Pam, to the right of us is version continuous irrigation (after of a cultivation)

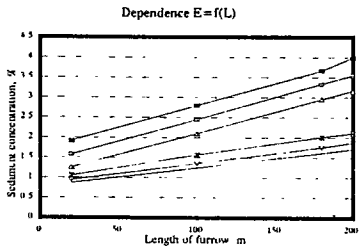
Photo 7

The typical dependences

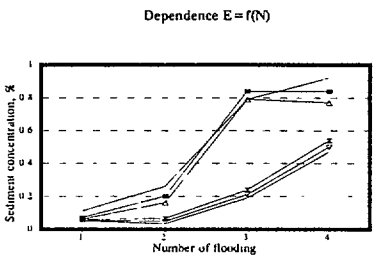
Cont. irrigation

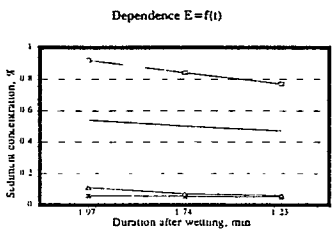


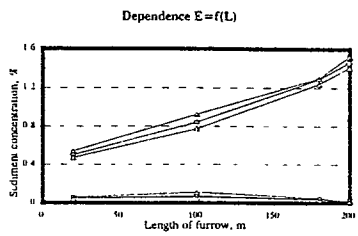




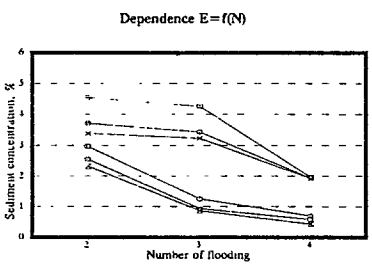
Cont. irrigation + Pam

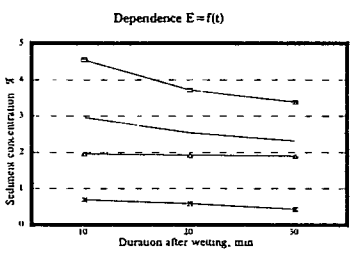


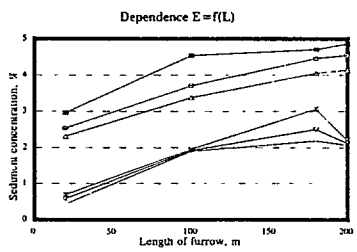




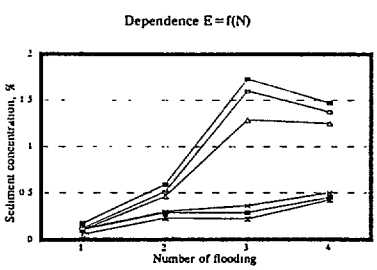
Surge irrigation

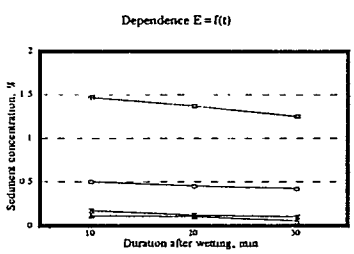






Surge irrigation +Pam





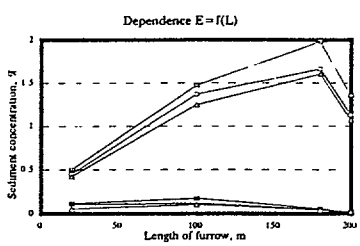
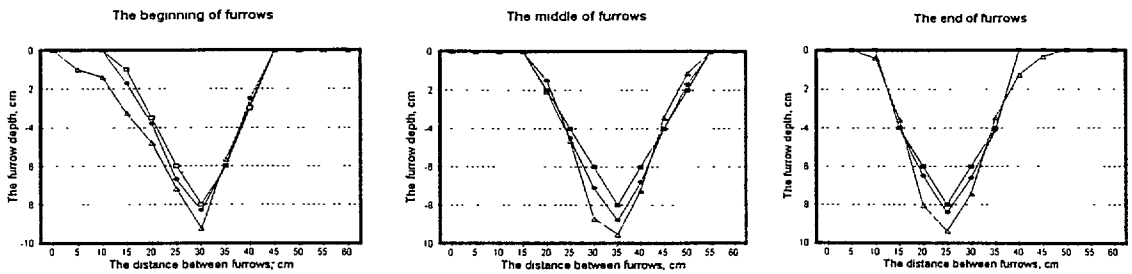


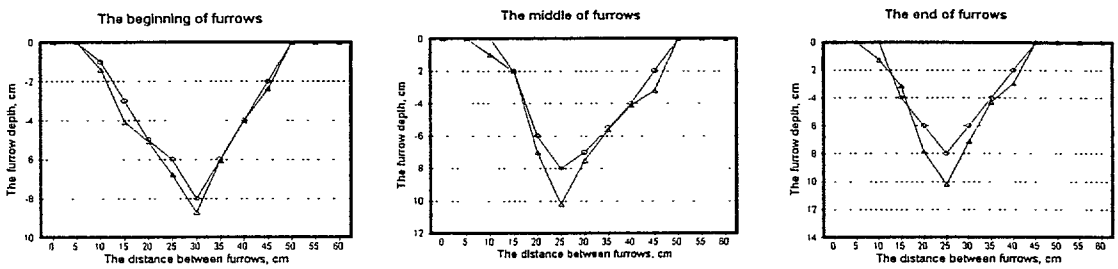
Fig. 4

The results of mikroleveling

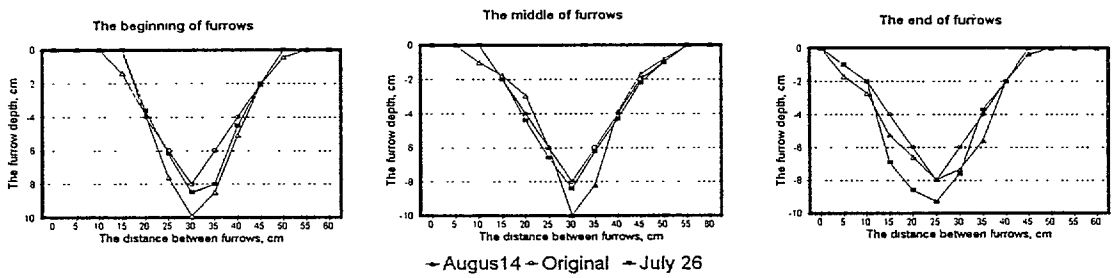
Cont. irrigation +Pam



Cont. irrigation



Surge irrigation +Pam



Surge Irrigation

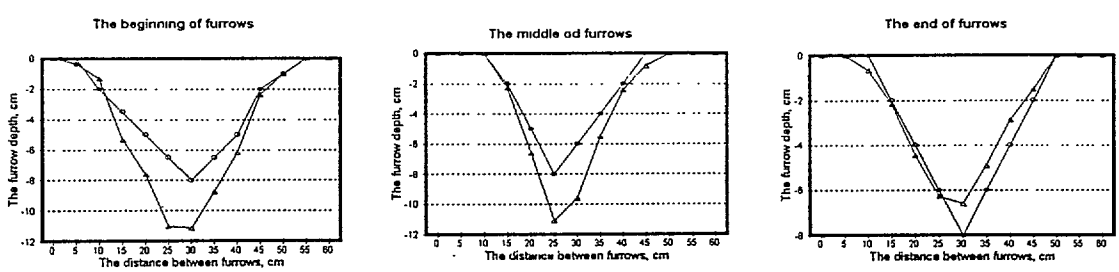


Fig. 5

The dependence E=f(Qo.r)

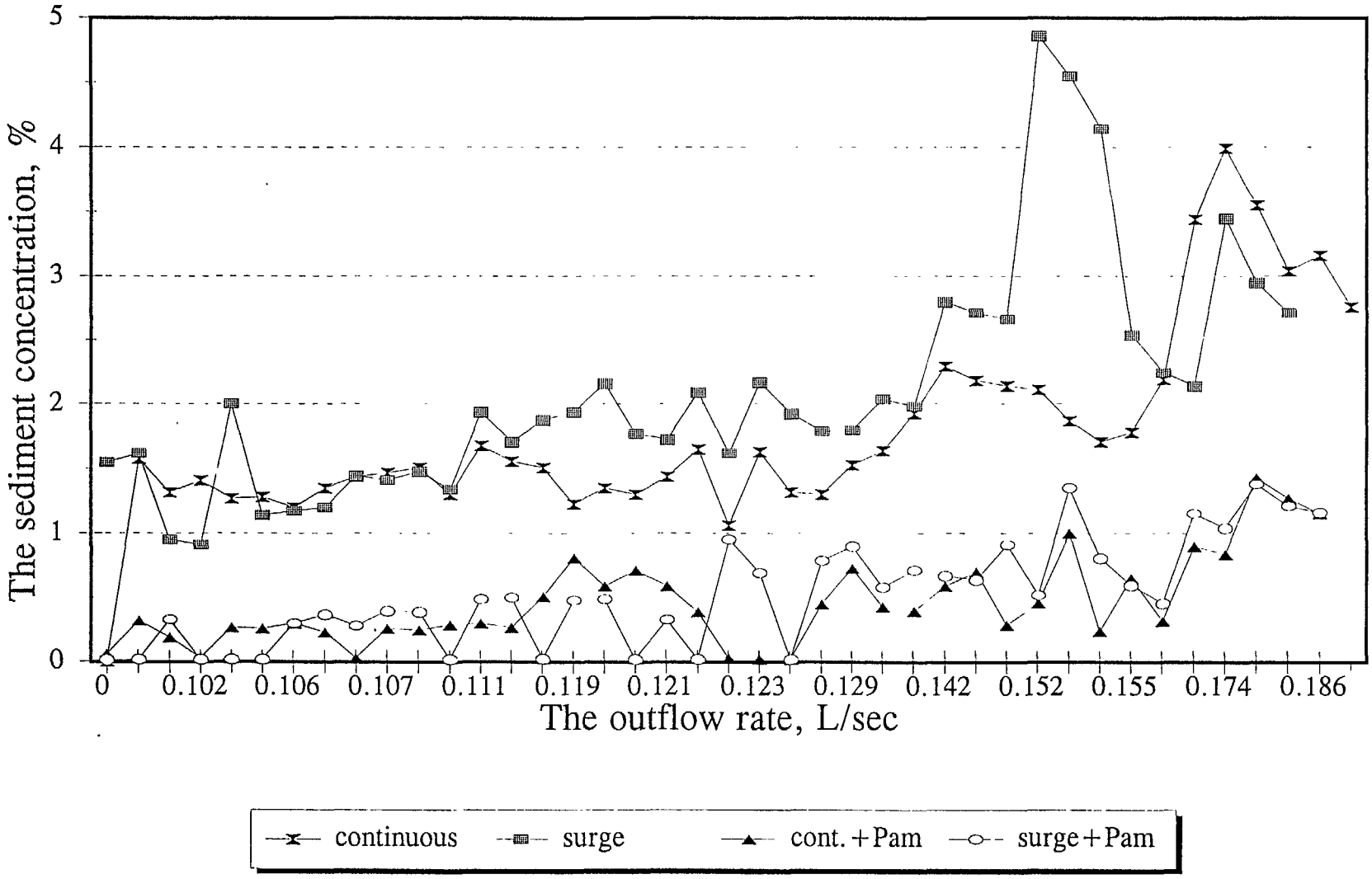


Fig. 6

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The erosion continued all the experience. To end of irrigations the process of erosion was stabilized, but the version with *surge irrigation* maintained "leadership" after decrease of a flow rate to Q2=0.20 L/sec. Effectiveness of the PAM treatment decreased in 20 times (Annex 1). In intensity of the erosion the *surge irrigation* obviously surpassed *continuous irrigation*. But if to compare the versions *surge irrigation+Pam* and *continuous irrigation+Pam* the superiority of the first was minimum (Fig. 6). Velocity of a jet advancement in version *surge irrigation+Pam* was a little smaller in comparison with *continuous irrigation+Pam* (Table 5) that demonstrate a creation on furrow surface of a bed with permeable silting deposits where is the Pam. This drift bed with PAM addition protected a furrow surface from erosion and increased an infiltration capacity of the furrow.

2.2.2. Soil moistening

Determination of a soil moistening depth is conducted with method of a sample collection from different depth of soil stratum. The sample collection is conducted before first irrigation, after first irrigation and after second irrigation. The results are presented in Annex 3 and Fig. 7. We had deep soil moistening in all versions. Now we may say that our irrigations continued unwarranted a long time (Annex 4, Annex 5). Below we will demonstrate (Fig. 11) that effective moisture settle down in depth to 90 cm for sugar beet crops. We observed very high uniformity of a soil moistening for furrow length in versoins *continuous irrigation+Pam* and *continuous irrigation* (Fig. 8).

We observed uneven a soil moistening for furrow length in versoin *surge irrigation.* Possibly we have a different soil conditions in middle of the part field.

2.2.3. Water managenent

The balance method was used in determination of the water losses to infiltration lengthways of a furrow. Following formulae were used:

$$dq = q_n - q, \text{ L/sec}$$

where g_n - the flow rate of the flooding stream (q1=0.36 L/sec in the period of the wetting and q2=0.20 L/sec in the period of the after wetting);

q - the inflow rate in the portable water meter rectangular weir, L/sec.

The soil moisture content

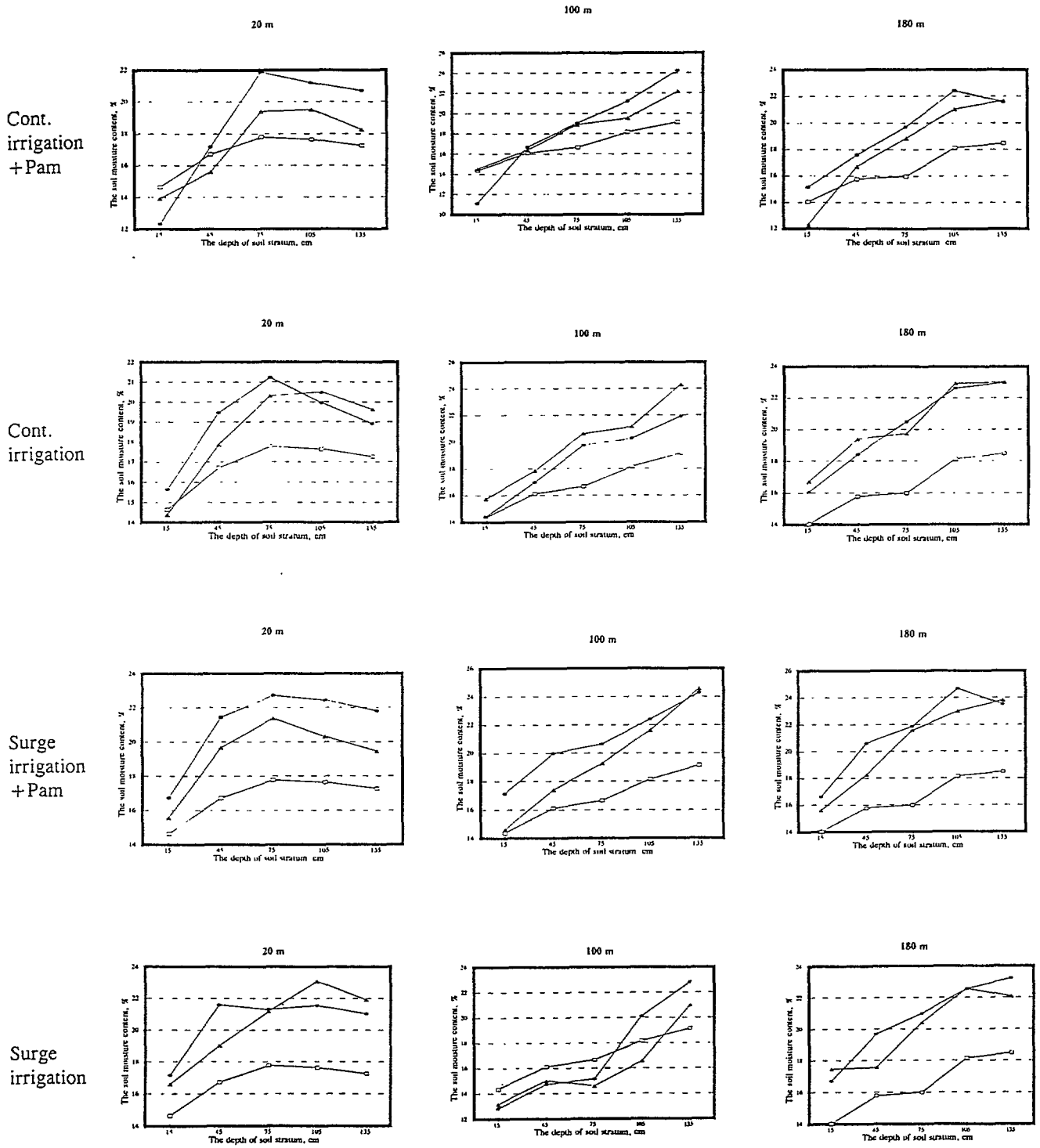

Fig. 7

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The soil moisture content

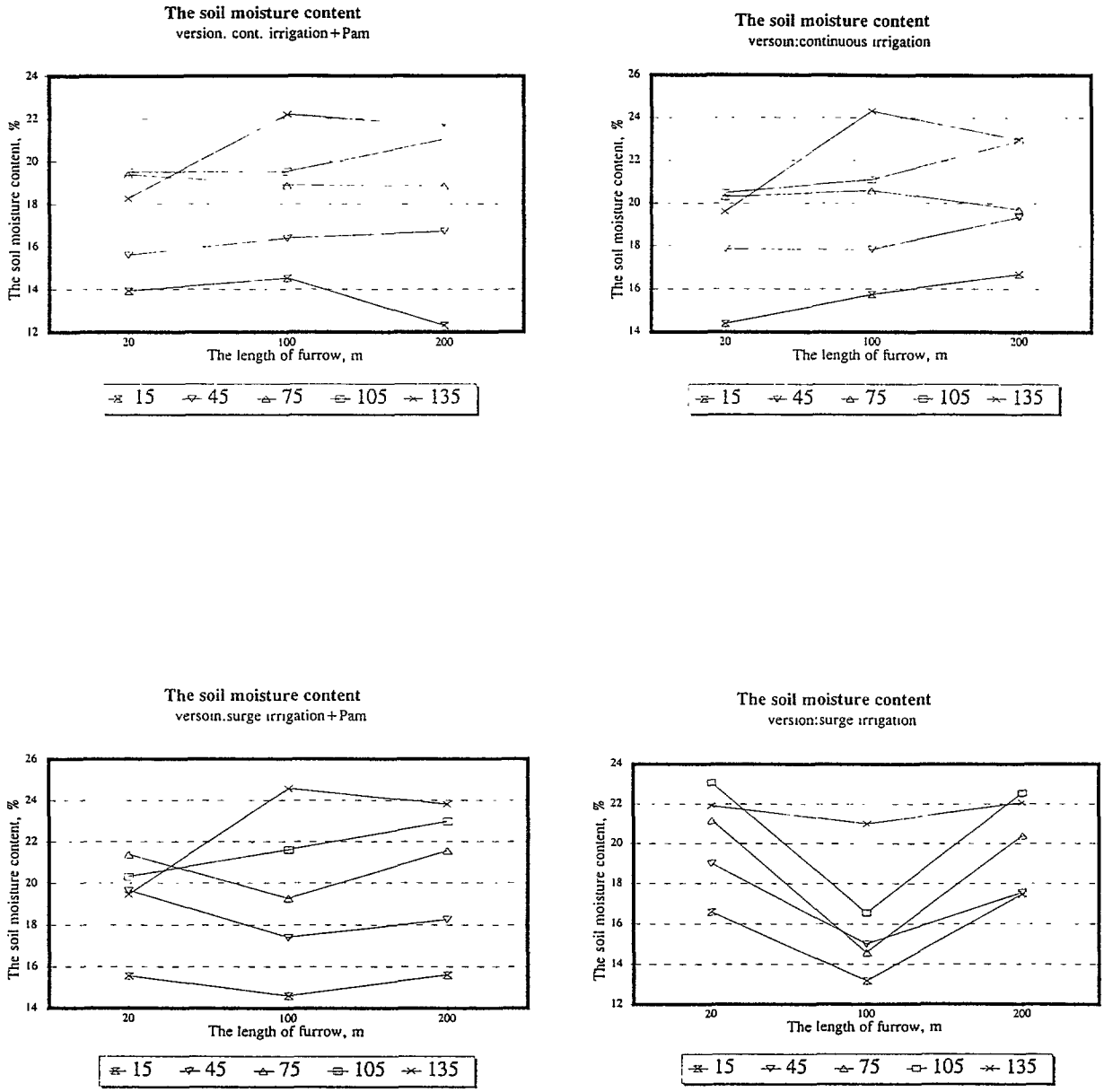


Fig. 8

55

The working point

Photo 8

The fourth irrigation
the Pam's version

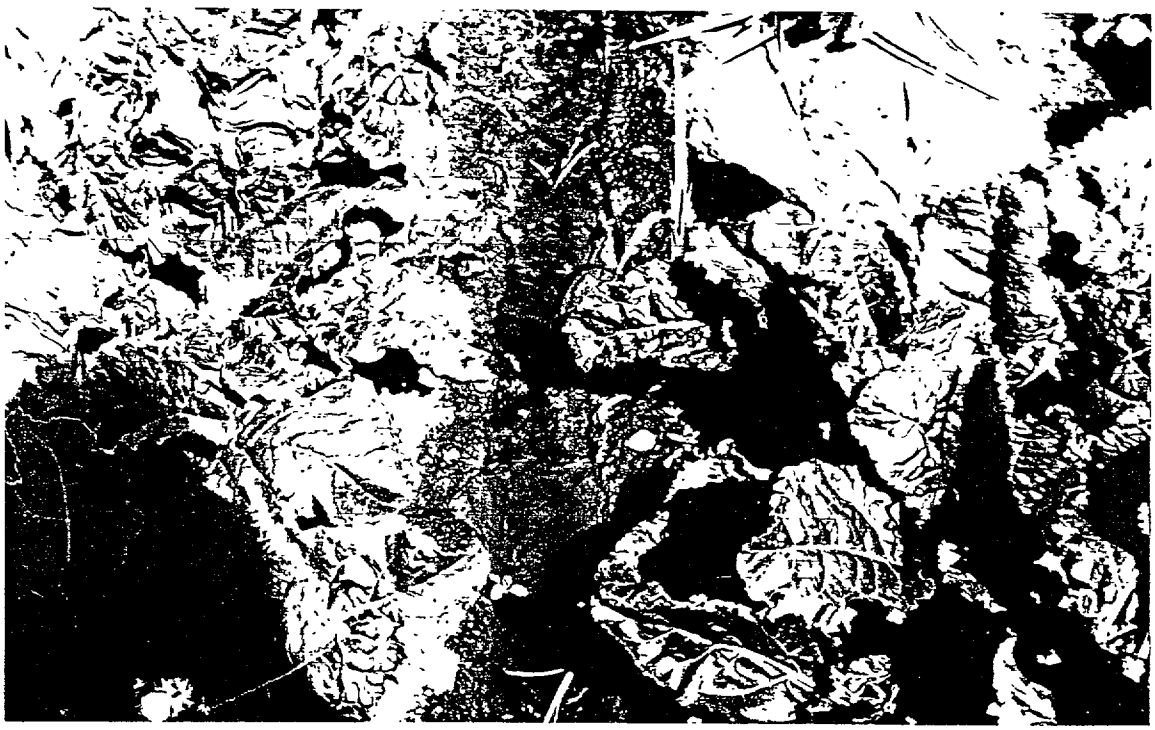


Photo 9

The irrigation application efficiency was rather high for all fourth irrigations (Table 6, Fig.9), if shall not take into consideration a water losses of the flow rates lengtways of a furrow in deep percolation. We could not appreciate a size those water losses as we does not dispose by soil descriptions in vertical profile.

In water management a versions *surge irrigation+Pam and continuous irrigation+Pam* was more effective. We have less of a water losses for furrow end.

Data ara presented in Table 6 and Fig. 9 without consideration of the fifth irrigation data. We did not conduct an observation in period of the fifth irrigation.

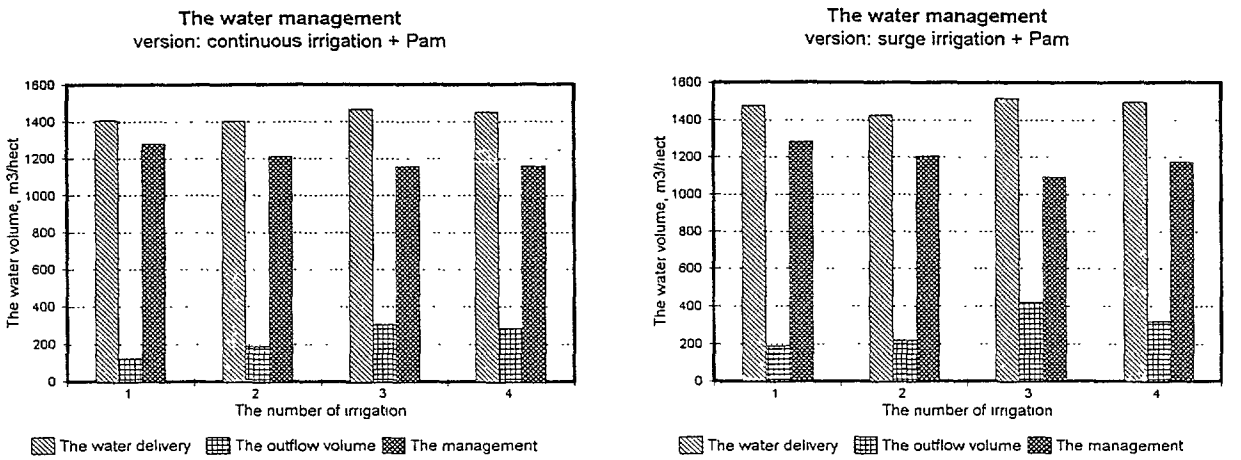
Technological descriptions are presented in Annex 4 and Annex 5 of our irrigations of the sugar beet.

Table 6

THE WATER MANAGEMENT FOR PERIOD OF OBSERVATION

The index of irrigation	Version	The water volumes for number of irrigations				
		1	2	3	4	total
The water delivery m3/hectare	continuous irrig.+Pam	1406	1402	1466	1451	5726
	continuous irrigigation	1400	1460	1513	1484	5857
	surge irrigation+Pam	1476	1428	1516	1497	5916
	surge irrigation	1458	1454	1551	1509	5973
The outflow volume m3/hectare	continuous irrig.+Pam	125	189	306	287	908
	continuous irrigation	336	292	345	288	1261
	surge irrigation+Pam	190	220	420	321	1151
	surge irrigation	424	339	405	334	1502
The management of water, m3/hectare	continuous irrig.+Pam	1281	1213	1160	1164	4818
	continuous irrigation	1064	1168	1169	1196	4596
	surge irrigation+Pam	1286	1208	1096	1176	4766
	surge irrigation	1034	1115	1146	1176	4470
The irrigation application efficiency	continuous irrig.+Pam	0.911	0.865	0.791	0.802	0.841
	continuous irrigation	0.760	0.800	0.772	0.806	0.785
	surge irrigation+Pam	0.871	0.846	0.723	0.786	0.806
	surge irrigation	0.709	0.767	0.739	0.779	0.748

The water management



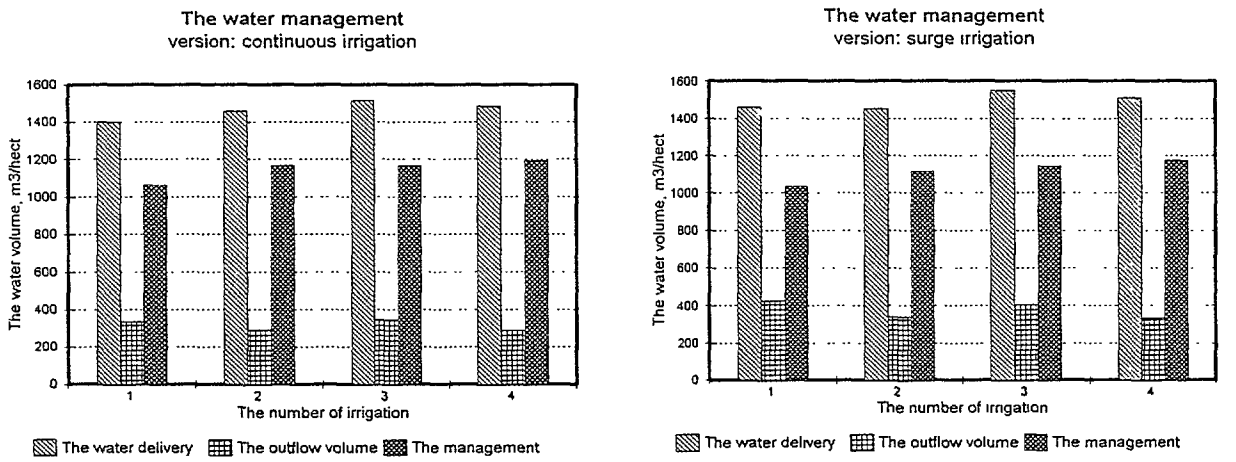


Fig. 9

2.2.4. Yield capacity of sugar beet

Yield capacity of sugar beet was determined for root crops and for green tops separately. The data of a yield capacity are presented in Annex 6.
Yield capacity of sugar beet was determined for sowing with norm 50 thousand plants at hectare.

Uniform of root crops yield capacity took place in version of surge irrigation+Pam for furrow length. Relative uniform of root crops yield capacity took place and in different of versions (Fig. 10). Pam addition in irrigation water did not give of an increase of root crops yield capacity. In a forming of root crops yield capacity paticipated a water and soil condition of field with low content of humus, low erosion resistance and impoverished by sowing of sugar beet lately in the course 3^{rds} years. However is a tendency of a green top increase in versions of *continuous irrigation+Pam* and of *surge irrigation+Pam* (Table 7).

Calculations of water delivery in creation of a crop showed (Table 7) that the highest water discharge in creation of a root crops took place in versions of *continuous irrigation+Pam* and *surge irrigation.* The version *surge irrigation+Pam* had the most low the indexes of the water discharge in creation of a sugar crops (the root crops+ the green tops). If to take into consideration only the effective water delivery (as stated above this efficiency is aggreed as we did not take stock of the deep percolation loss) then versions the *continuous irrigation+Pam* and the *surge irrigation*+Pam were effective more.

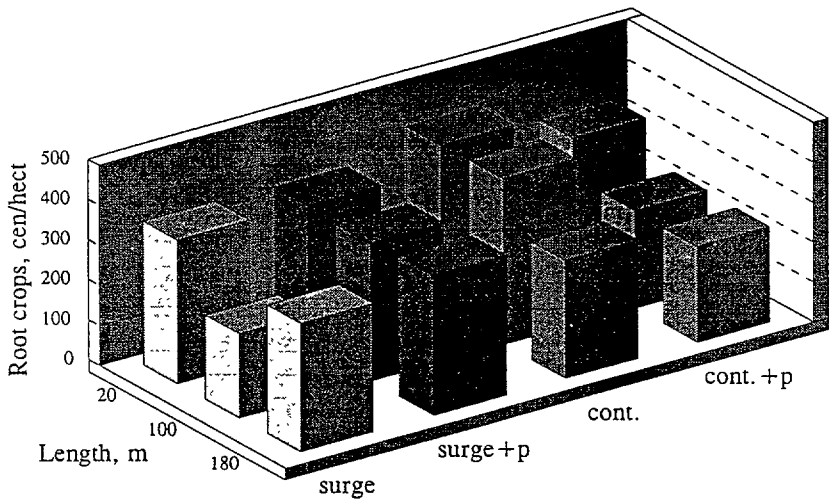
The data, presented in Fig. 11, showed that exist a correlation between soil moisture content in stratum 30-90 cm (on date August 19) and yield capacity of the root crops. But does not exist a correlation between soil moisture content in stratum 0-15 cm (on date August 19) and yield of the green tops. Does not exist also a correlation between yield capacity of the root crops and yield of the green tops (Annex 6) in our experiments. We obtained already in 1996 that kind conclusions.

Table 7

THE WATER DELIVERIY IN CREATION OF A CROP

Version	Place selection of crop, m	The crops				Total cen/hec	The irrigation norm, m3/hec	The water delivery in one centner of a crop, m3/cen		The irrigation application efficiency	The effective water delivery in one centner of a crop, m3/cen	
		root crop, kg	green top, kg	root crops, cen/hect	green tops cen/hect			root crops	total		root crops	total
Continuous irrigation+ Pam	20	0.677	0.674	338.5	336.8							
	100	0.487	1.011	243.5	505.4							
	180	0.480	0.747	240.0	373.6							
	mean	0.548	0.810	274.0	405.0	679	7071	25.81	10.41	0.841	21.70	8.76
Continuous irrigation	20	0.821	0.531	410.5	265.3							
	100	0.827	0.580	413.5	290.1							
	180	0.591	0.249	295.5	124.5							
	mean	0.746	0.453	373.0	227.0	600	6939	18.60	11.57	0.785	14.60	9.08
Surge irrigation+ Pam	20	0.705	0.556	352.5	277.8							
	100	0.690	0.587	345.0	293.5							
	180	0.701	0.708	350.5	354.0							
	mean	0.699	0.617	349.0	308.0	657	7131	20.43	10.85	0.806	16.47	8.75
Surge irrigation	20	0.717	0.389	358.5	194.4							
	100	0.420	0.344	210.0	172.1							
	180	0.641	0.384	320.5	192.0							
	mean	0.593	0.372	296.0	186.0	482	7186	24.28	14.91	0.748	18.16	11.15

The root crops of a sugar beet



The green top of a sugar beet

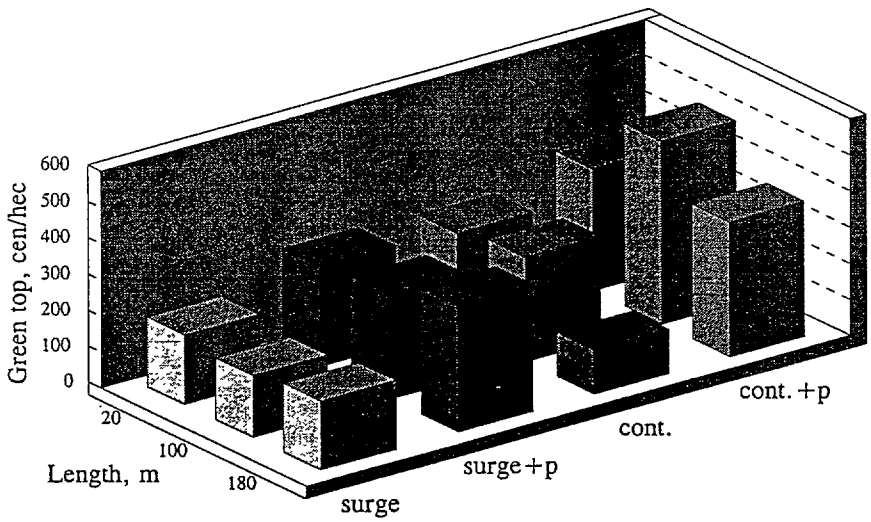


Fig. 10

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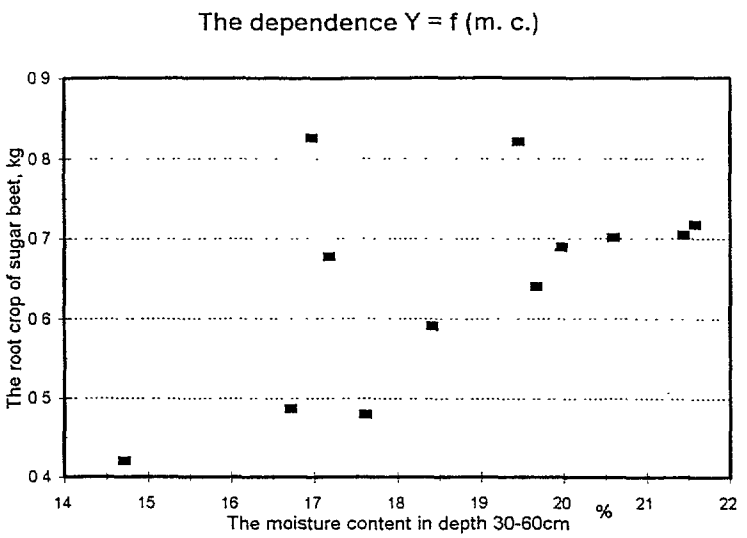
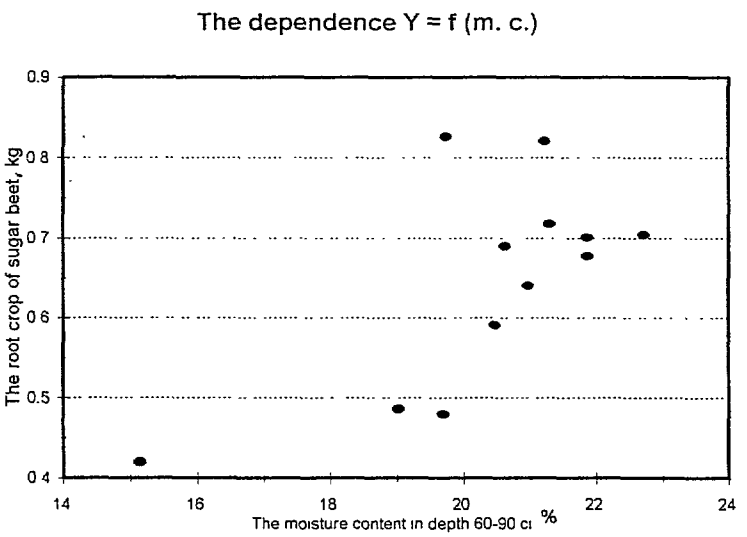

The dependence Y = f (m. c.)
The root crop of sugar beet, kg
0 9
0 8
0 7
0 6
0 5
0 4
14
15
16
17
18
19
20
21
22
%
The moisture content in depth 30-60cm


The dependence Y = f (m. c.)
The root crop of sugar beet, kg
0.9
0 8
0 7
0 6
0.5
0 4
14
16
18
20
22
24
%
The moisture content in depth 60-90 cı

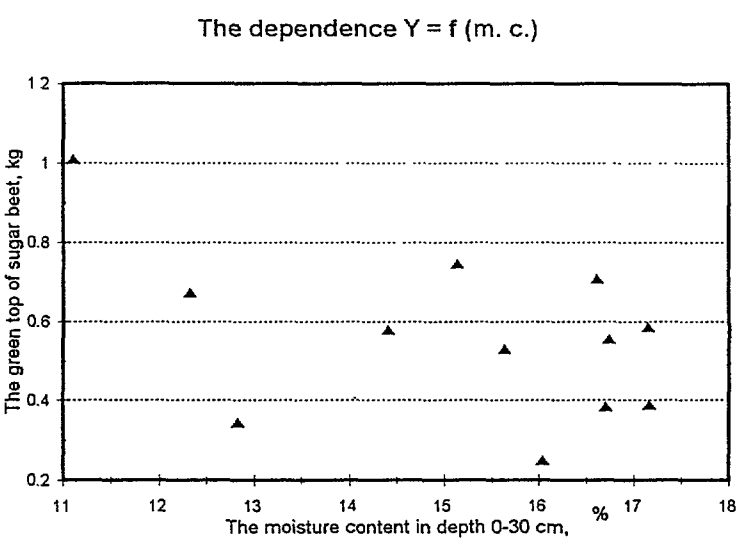

The dependence Y = f (m. c.)
The green top of sugar beet, kg
1 2
1
0.8
0.6
0.4
0.2
11
12
13
14
15
16
17
18
%
The moisture content in depth 0-30 cm,

Fig. 11

Conclusions

The researches 1999 showed that in conditions of experiments:

1.The PAM is the effective anti -erosion method.
2. Surge irrigation is effective in decreasing IR.
3. The effect of surge irrigation in PAM treatments is not as effective as in conventional treatment (i.e., without PAM).
4.Surge irrigation in PAM treatments is effective in maintaining high infiltration rate.
5. Surge irrigation +Pam is better version in general of an indexes.

We had not of problems in conducted of field experiments.

Unfortunately, we conducted the PAM treatment of furrows in version *continuous irrigation+Pam* and *of surge irrigation+Pam* only in the first irrigation. After first irrigation was conducted a cultivation in versions of *continuous irrigation* and *of surge irrigation.* The cultivation had an influence on furrow erosion, on soil moisture content, on water management and yield capacity of sugar beet in those versions. Possibly the conclusions, that we do for all versions, are not correct in connection with this. We shall not do the cultivation of crops in season 2000.

We have also big consumptions of the Pam. Possibly expediency to realize the Pam application solution at strict the appointed interval of time.

References

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

Annex 1

The results of a furrow erosion observation

The first irrigation

Duration after wetting, min	Sediment concentration (%) for length of furrow															
	20 m				100 m				180 m				200 m			
	version				version				version				version			
	Cont.+P	Cont.	Surge+P	Surge	Cont.+P	Cont.	Surge+P	Surge	Cont.+P	Cont.	Surge+P	Surge	Cont.+P	Cont.	Surge+P	Surge
10	0.059	2.33	0.114	3.47	0.11	4.67	0.174	5.6	0.052	3.92	0.058	5.13	0.027	3.44	0.022	3.45
20	0.054	2.02	0.104	2.78	0.07	3.95	0.121	4.8	0.045	3.53	0.048	4.77	0.021	3.04	0.02	2.95
30	0.05	1.79	0.056	2.59	0.06	3.21	0.103	4.25	0.039	3.27	0.043	4.54	0.02	2.76	0.019	2.71
60													0.029	2.19	0.023	2.17
90													0.033	1.68	0.02	2.16
120													0.057	1.58	0.017	2.09
150													0.19	1.51	0.021	1.94
210													0.32	1.3	0.02	1.77
270													0.3	1.32	0.02	1.73
330													0.3	1.3	0.021	1.72

The second irrigation

10	0.064	1.05	0.3	2.96	0.26	1.57	0.59	4.54	0.48	2.01	1.22	4.7	0.45	2.11	0.81	4.86
20	0.047	0.94	0.29	2.54	0.2	1.35	0.51	3.71	0.43	1.76	1	4.46	0.43	1.87	0.6	4.55
30	0.032	0.86	0.23	2.31	0.16	1.24	0.46	3.38	0.4	1.62	0.88	4.05	0.4	1.71	0.46	4.14
60													0.27	1.93	0.33	2.04
90													0.29	1.65	0.39	2
120													0.25	1.56	0.4	1.94
150													0.26	1.47	0.37	1.88
210													0.27	1.32	0.33	1.71
270													0.23	1.28	0.3	1.62
330													0.26	1.2	0.28	1.55

The results of a furrow erosion observation

The third irrigation

Duration after wetting, min	Sediment concentration (%) for length of furrow															
	20 m				100 m				180 m				200 m			
	version				version				version				version			
	Cont.+P	Cont.	Surge+P	Surge	Cont.+P	Cont.	Surge+P	Surge	Cont.+P	Cont.	Surge+P	Surge	Cont.+P	Cont.	Surge+P	Surge
10	0.24	1.91	0.36	1.24	0.91	2.8	1.73	4.26	1.1	3.67	1.97	4.6	1	3.99	1.38	2.54
20	0.21	1.57	0.29	0.92	0.84	2.45	1.6	3.42	0.8	3.354	1.74	4.53	0.9	3.55	1.21	2.24
30	0.19	1.25	0.22	0.86	0.79	2.1	1.29	3.22	0.77	2.96	1.23	4.47	0.84	3.16	1.16	2.14
60													0.59	1.78	0.69	1.98
90													0.51	1.64	0.95	1.93
120													0.46	1.53	0.91	1.79
150													0.39	1.44	0.79	1.8
210													0.32	1.35	0.71	1.62
270													0.29	1.23	0.67	1.48
330													0.24	1.06	0.58	1.41

The fourth irrigation

10	0.54	0.7	0.5	0.69	0.92	1.43	1.47	1.96	1.3	2.13	1.98	3.07	1.52	2.29	1.35	2.2
20	0.5	0.64	0.45	0.58	0.84	1.32	1.37	1.92	1.29	1.99	1.66	2.5	1.46	2.18	1.13	2.11
30	0.47	0.59	0.42	0.43	0.77	1.27	1.25	1.9	1.24	1.94	1.6	2.18	1.41	2.14	1.07	2.06
60													0.81	1.63	0.9	1.45
90													0.71	1.51	0.64	1.34
120													0.73	1.44	0.52	1.2
150													0.7	1.41	0.49	1.14
210													0.65	1.35	0.48	1.17
270													0.59	1.3	0.5	0.95
330													0.59	1.27	0.49	0.91

Annex 2

The results of outflow rate observation

T, min	The outflow rate (L /sec) for version															
	continuous irrigation+Pam				continuous irrigation				surge irrigation+Pam				surge irrigation			
	number of irrigation				number of irrigation				number of irrigation				number of irrigation			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
10	0.111	0.117	0.131	0.173	0.174	0.152	0.174	0.142	0.125	0.195	0.216	0.184	0.232	0.204	0.22	0.189
20	0.113	0.121	0.134	0.181	0.183	0.154	0.18	0.146	0.135	0.198	0.229	0.205	0.235	0.211	0.226	0.192
30	0.115	0.123	0.135	0.193	0.197	0.155	0.186	0.149	0.143	0.203	0.241	0.214	0.238	0.214	0.23	0.197
60	0.05	0.084	0.1	0.097	0.159	0.139	0.155	0.123	0.11	0.126	0.141	0.145	0.17	0.183	0.186	0.122
90	0.035	0.068	0.093	0.1	0.111	0.122	0.136	0.117	0.098	0.087	0.138	0.162	0.146	0.118	0.173	0.129
120	0.028	0.063	0.129	0.118	0.09	0.112	0.129	0.106	0.043	0.078	0.162	0.167	0.155	0.132	0.178	0.121
150	0.033	0.062	0.103	0.126	0.109	0.107	0.121	0.102	0.053	0.072	0.144	0.12	0.146	0.139	0.183	0.12
210	0.029	0.039	0.133	0.132	0.121	0.102	0.119	0.106	0.061	0.058	0.15	0.111	0.149	0.133	0.165	0.12
270	0.042	0.046	0.127	0.126	0.127	0.105	0.119	0.1	0.061	0.07	0.156	0.101	0.152	0.114	0.128	0.117
330	0.073	0.041	0.132	0.101	0.128	0.106	0.122	0.104	0.068	0.077	0.147	0.101	0.152	0.114	0.123	0.118

Annex 3

The observation results of a soil moisture content

July, 18

The depth of soil stratum, cm	The average depth of a soil, cm	The soil moisture content (%) for version											
		continuous irrigation+Pam			continuous irrigation			surge irrigation+Pam			on the average		
		The distance from beginning of a furrow, m											
		20	100	200	20	100	200	20	100	200	20	100	200
0-30	15	14.86	14.03	14.25	14.82	14.91	13.5	14.23	14.12	14.31	14.64	14.35	14.02
30-60	45	16.34	16.87	15.45	16.16	16	14.64	17.63	15.48	17.23	16.71	16.12	15.77
60-90	75	17.11	16.54	16.44	17.78	17.28	13.66	18.41	16.11	17.82	17.77	16.64	15.97
90-120	105	17.49	19.8	17.88	17.76	17.35	17.64	17.63	17.27	18.89	17.63	18.14	18.14
120-150	135	17.38	19.56	18.97	17.54	18.69	17.69	16.84	19.19	18.75	17.25	19.15	18.47

July, 26

The depth of soil stratum, cm	The average depth of a soil, cm	The soil moisture content (%) for version											
		continuous irrigation+Pam			continuous irrigation			surge irrigation+Pam			surge irrigation		
		The distance from beginning of a furrow, m											
		20	100	200	20	100	200	20	100	200	20	100	200
0-30	15	13.91	14.52	12.3	14.37	15.73	16.69	15.55	14.6	15.6	16.6	13.17	17.46
30-60	45	15.6	16.39	16.73	17.86	17.83	19.37	19.65	17.39	18.26	19	15.01	17.56
60-90	75	19.37	18.88	18.86	20.3	20.59	19.72	21.37	19.26	21.56	21.17	14.57	20.4
90-120	105	19.5	19.51	21.02	20.5	21.11	22.92	20.31	21.6	22.98	23.08	16.55	22.55
120-150	135	18.26	22.18	21.66	19.62	24.32	22.99	19.45	24.57	23.81	21.9	21	22.06

August, 9

0-30	15	12.32	11.1	15.13	15.63	14.4	16.03	16.73	17.14	16.61	17.16	12.82	16.7
30-60	45	17.18	16.71	17.61	19.45	16.97	18.41	21.44	19.97	20.59	21.58	14.72	19.66
60-90	75	21.86	19.02	19.69	21.22	19.73	20.47	22.72	20.62	21.86	21.3	15.14	20.98
90-120	105	21.19	21.17	22.41	19.95	20.23	22.62	22.44	22.39	24.69	21.55	20.1	22.54
120-150	135	20.71	24.26	21.57	18.9	21.91	22.96	21.8	24.28	23.5	21.02	22.84	23.22

The calculation of a total outflow valume

Version	The fact outflow volume from one furrow (L) for period of observation(it is 5.5 hour) for number of irrigation				
	1	2	3	4	total
continuous irrig.+Pam	983	1667	2416	2411	7477
continuous irrigigation	2532	2265	2595	2184	9576
surge irrigation+Pam	1470	1745	3042	2555	8813
surge irrigation	3162	2704	3200	2511	11577

Version	The fact outflow volume from one furrow (m3/hectare) for period of observation for number of irrigation				
	1	2	3	4	total
continuous irrig.+Pam	82	139	201	201	623
continuous irrigigation	211	189	216	182	798
surge irrigation+Pam	122	145	254	213	734
surge irrigation	263	225	267	209	965

Version	The steady outflow rate from one furrow (L/sec) in end of a observation period for number of irrigation				
	1	2	3	4	
continuous irrig.+Pam	0.044	0.052	0.098	0.084	
continuous irrigigation	0.127	0.106	0.12	0.103	
surge irrigation+Pam	0.065	0.075	0.15	0.101	
surge irrigation	0.152	0.114	0.125	0.117	

Version	The duration of irrigation (hour) for number of irrigation				
	1	2	3	4	
continuous irrig.+Pam	21.7	21.7	23.33	22.67	
continuous irrigigation	21.92	21.7	23.33	22.67	
surge irrigation+Pam	22.83	22.08	24	23.25	
surge irrigation	23.12	22.08	24	23.25	

Version	The duration after wetting (hour) for number of irrigation				
	1	2	3	4	
continuous irrig.+Pam	16.2	16.2	17.83	17.17	
continuous irrigigation	16.42	16.2	17.83	17.17	
surge irrigation+Pam	17.33	16.58	18.5	17.75	
surge irrigation	17.62	16.58	18.5	17.75	

Version	The outflow volume after wetting (m3/hectare) for number of irrigation				
	1	2	3	4	total
continuous irrig.+Pam	43	51	105	87	285
continuous irrigigation	125	103	128	106	463
surge irrigation+Pam	68	75	167	108	416
surge irrigation	161	113	139	125	537

Version	The total outflow volume (m3/hectare) for number of irrigation				
	1	2	3	4	total
continuous irrig.+Pam	125	189	306	287	908
continuous irrigigation	336	292	345	288	1261
surge irrigation+Pam	190	220	420	321	1151
surge irrigation	424	339	405	334	1502

Annex 5

The calculation of a water delivery for period of observation

The first irrigation

Version	Duration of furrow wetting, min	Duration of irrigation, hour	Duration of irrigation by flow rate (L/sec)		The water delivery by flow rate (L/sec)		
			Q1=0.36, min	Q2=0.20, min	Q1=0.36, m3/hect.	Q2=0.20, m3/hect.	Total m3/hect.
continuous irrig.+Pam	100	21.7	130	1172	234	1172	1406
continuous irrigigation	75	21.92	105	1210	189	1210	1399
surge irrigation+Pam	103	22.83	133	1237	239	1237	1476
surge irrigation	59	23.12	89	1298	160	1298	1458

The second irrigation

continuous irrig.+Pam	95	21.7	125	1177	225	1177	1402
continuous irrigigation	167	21.7	197	1105	355	1105	1460
surge irrigation+Pam	98.5	22.08	128.5	1196	231	1196	1428
surge irrigation	131	22.08	161	1164	290	1164	1454

The third irrigation

continuous irrig.+Pam	53	23.33	83	1317	149	1317	1466
continuous irrigigation	112	23.33	142	1258	256	1258	1513
surge irrigation+Pam	65	24	95	1345	171	1345	1516
surge irrigation	109	24	139	1301	250	1301	1551

The fourth irrigation

continuous irrig.+Pam	84	22.67	114	1246	205	1246	1451
continuous irrigigation	124.8	22.67	154.8	1205	279	1205	1484
surge irrigation+Pam	97	23.25	127	1268	229	1268	1497
surge irrigation	113	23.25	143	1252	257	1252	1509

Annex 6

Crops of sugar beet

Number root crops	Crops of sugar beet (kg) for version											
	continuous irrigation+Pam			continuous irrigation			surge irrigation+Pam			surge irrigation		
	The distance from beginning of a furrow, m											
	20	100	200	20	100	200	20	100	200	20	100	200
1	0.47	0.37	0.621	0.82	1.276	0.517	0.432	0.49	0.887	0.927	0.35	0.423
2	0.418	0.438	0.602	0.359	0.673	1.11	0.503	0.692	0.646	0.733	0.286	0.507
3	0.511	0.449	0.488	0.53	0.599	0.55	0.578	0.544	0.667	0.717	0.454	0.42
4	0.953	0.883	0.471	0.666	1.094	0.934	0.488	0.924	0.84	0.47	0.334	0.431
5	0.951	0.406	0.409	1.171	0.828	0.423	0.628	0.856	0.327	0.607	0.656	0.652
6	0.431	0.572	0.292	0.992	1.011	0.589	0.707	0.441	1.034	0.817	0.231	0.615
7	0.726	0.556	0.396	0.829	0.501	0.425	1.006	0.372	0.679	0.534	0.569	1.437
8	0.636	0.441	0.34	0.815	0.815	1.113	1.169	0.753	0.779	0.546	0.303	0.954
9	0.845	0.418	0.54	0.839	0.902	0.971	0.868	0.789	0.784	0.525	0.358	0.517
10	1.028	0.48	0.45	1.058	0.57	0.528	0.569	0.733	0.805	0.698	0.663	0.763
11	0.992	0.581	0.478	0.952	0.866	0.284	1.282	1.498	0.899	0.747	0.388	0.614
12	0.41	0.349	0.741	0.816	0.885	0.202	0.769	0.599	0.385	0.941	0.502	0.624
13	0.888	0.415	0.517	0.871	0.717	0.352	0.405	0.454	0.619	0.884	0.467	0.546
14	0.489	0.612	0.302	0.947	1.12	0.52	0.592	0.504	0.56	0.549	0.315	0.693
15	0.411	0.33	0.555	0.651	0.542	0.351	0.574	0.697	0.605	1.063	0.426	0.417
The root crops total, kg	10.16	7.30	7.20	12.32	12.40	8.87	10.57	10.35	10.52	10.76	6.30	9.61
Mean, kg	0.677	0.487	0.480	0.821	0.827	0.591	0.705	0.690	0.701	0.717	0.420	0.641
The green top total, kg	10.11	15.16	11.21	7.96	8.70	3.74	8.34	8.81	10.62	5.83	5.16	5.76
Mean, kg	0.674	1.011	0.747	0.531	0.580	0.249	0.556	0.587	0.708	0.389	0.344	0.384