Iran Agricultural Research 6:57-71 (1987).

FURROW GEOMETRY UNDER SURGE AND CONTINUOUS FLOW[1]

B. Mostafazadeh and W. R. Walker[2]

ABSTRACT

The results of numerous furrow cross-sectional measurements at three different experimental sites indicate that little or no difference between surge and continuous flow can be expected in the effect of irrigation on furrow geometry. Following the first irrigation, inlet station furrow shapes changed from a typical triangular cross-section to a nearly trapezoidal shape. Both surge and continuous flow showed the same results. It was generally found that cross-sectional areas were increased at the furrow section nearest to the water inlet for both surge and continuous flow.

تحقیقات کشاورزی ایران

۶:۵۷-۷۱ (۱۳۶۶)

شکل هندسی شیار در رابطه با جریان پیوسته و سرج

بهروز مصطفی زاده و دبلیو. آر. واکر

خلاصه

نتایج حاصله از اندازه‌گیری های متعدد نیمرخ عرضی شیار در سه مزرعه مختلف بیانگر این است که انتظار میرود تفاوت جزئی یا عدم تفاوتی بین روش جریان پیوسته و روش جریان سرج در ارتباط با اثر آبیاری روی شکل شیار وجود داشته باشد. بعد از اولین آبیاری، در نقاط نزدیک به راس مزرعه، شکل مثلثی اولیه شیار به شکلی تقریبا "ذوذنقه‌ای تغییر یافت. هردو روش نتایج مشابهی را نشان دادند. بطورکلی مساحت شیار در نقاط نزدیک به راس مزرعه برای هردو روش افزایش پیدا نمود.

---

[1] Contribution from the Department of Agricultural and Irrigation Engineering, Utah State University, Logan, Utah, U.S.A. Received 11 October 1987.

[2] Former Graduate Student (now Assistant Professor, Isfahan University of Technology, Isfahan, Iran) and Professor, respectively.

INTRODUCTION

Furrow irrigation is one of the oldest methods of irrigation in which soil surface is used to convey and infiltrate. Furrow irrigation compared with sprinkler or trickle methods is inexpensive. Therefore, more attention is being paid to improving the efficiency of this irrigation method. For instance, runoff recovery and cut-back technology (6) have been studied to reduce losses. A new alternative based on recent research at Utah State University has produced what is called a surge flow delivery system in which water is delivered to the furrows on an intermittent basis (3). The objective is to decrease the difference in intake opportunity time (by achieving faster advance rate) between the head of the furrow and the lower end, and thereby provide a more uniform distribution of water. Since surge flow is a new technique for applying water, studies at different field conditions are being performed in order to compare surge and continuous flow.

Previous research (1, 2, 3, 4, 5) has indicated that surge flow provides an opportunity for achieving faster advance and more uniform distribution of water in sloping furrows. In surge irrigation, faster advance is achieved because after the first surge soil consolidates and infiltration rate becomes smaller (8).

The geometry of furrow cross-sections and associated hydraulic characteristics change from irrigation to irrigation with the main effects attributable to the first irrigation. The efficient application and distribution of water by furrow irrigation is highly dependent on the rate of water advance, the rate of recession, and on the infiltration rate. Each of these parameters is impacted by changes in the geometry and roughness of the furrow cross-section. Change in furrow cross-section is complicated because it is influenced by soil swelling and consolidation, erosion, and deposition. Field studies (7) on furrow irrigation show that soil swelling may inflate estimates of deposition and dewatering after the first surge may decrease deposition. The focus of this study was to develop furrow geometry functions for both surge and continuous flow under actual field conditions.

MATERIALS AND METHODS

A profilometer with movable rods at 2 cm spacing and graduated in centimeters was used to measure furrow cross-sections. Stakes were used to identify each station and to provide bases on which to place the profilometer for measurements. The profilometer is shown in Fig. 1.

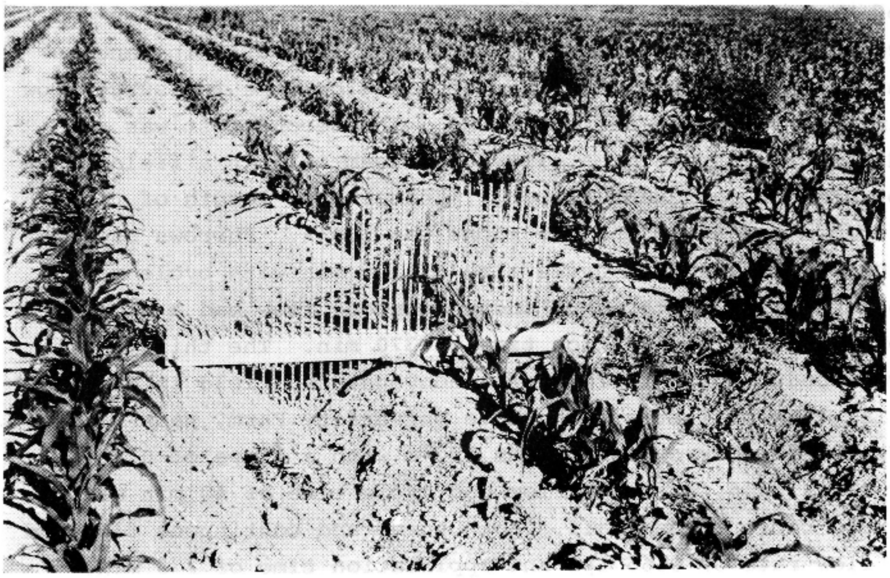

Fig. 1. Furrow profilometer to measure furrow cross-section.

In this study, the same flow rates and application times were used for both surge and continuous flow treatments, but the total volume of applied water under the surge condition was approximately one-half the volume applied to the continuous flow furrows. Field tests were conducted using non-wheel row, non-irrigated furrows at three different experimental sites with at least three replications at each site. The first series of tests were conducted on a furrowed corn field having a sandy loam soil near Flowell, Utah, U.S.A. The length of the field was 370 m and the slope was 0.8%. The furrows were staked at 25 m increments.

Furrows used for surge flow had cycle time (cycle time = on-time + off-time) of 40 min with cycle ratio (cycle ratio of the on-time to cycle time) of one-half. Both surge and continuous flow treatments had a flow rate of 2 lps and application time of 520 min (application time for surge flow include both off- and on-times). The second test was conducted in furrows of a silty clay loam soil in a field planted to corn near Kimberly, Idaho. The length of the furrows was 400 m and the slope was 1.04%. Furrows used for surge flow involved cycle time of 120 min with cycle ratio of one-half. Both surge and continuous flow had a flow rate of 1 lps and application time of 370 min. The third test was conducted in furrows of a nonvegetated field in a silty clay loam soil at a Utah State University Farm, near Nibley, Utah. The furrow length was 150 m with a slope of 0.85%. Furrows used for surge flow had cycle time of 40 min with cycle ratio of one-half. Both surge and continuous flow had a flow rate of 0.65 lps and application time of 275 min.

A computer program was developed and used to compute furrow cross-sections. In this program, data from the furrow profilometer were arranged in x and y coordinate pairs and a straight line equation developed for each pair. Depth of flow was based on distance above the maximum profilometer reading. The intersection of the lines describing the furrow shape and a horizontal line representing depth, provided the information necessary to integrate the cross-section at desired depth increment. Area at each depth increment was computed as the sum of bounded line lengths, while top width was simply the length of the horizontal depth line. Hydraulic radius at each depth increment was computed as the ratio of area to wetted perimeter. The individual integrations were then correlated with depth to yield cross-sectional area, wetted perimeter, top width, and hydraulic radius as a function of depth. More details about the material and methods are given by Mostafazadeh (9). The flow chart of the computer model is shown in Fig. 2.

RESULTS AND DISCUSSION

The cross-sectional area (A, in cm^2), wetted perimeter (WP, in cm), top width (T, in cm), and hydraulic radius (R, in cm) of furrow were represented as functions of depth with the following forms:

$$A = a_1 y^{a_2}$$

$$WP = p_1 y^{p_2}$$

$$T = t_1 y^{t_2}$$

$$R = r_1 y^{r_2}$$

where y is the depth (cm) and a_1, a_2, p_1, p_2, t_1, t_2, r_1, and r_2 are empirical constants. The above equations were developed by numerical integration through the cross-sectional data points as described before. It was found that the nonlinear functions were necessary to adequately fit the data. Second degree polynomial and power function models were fitted to the data. Both models showed high correlation coefficients, but the power function was used because of its mathematical simplicity.

To find an overall function for each field, the best fit line through all the data regardless of data station was

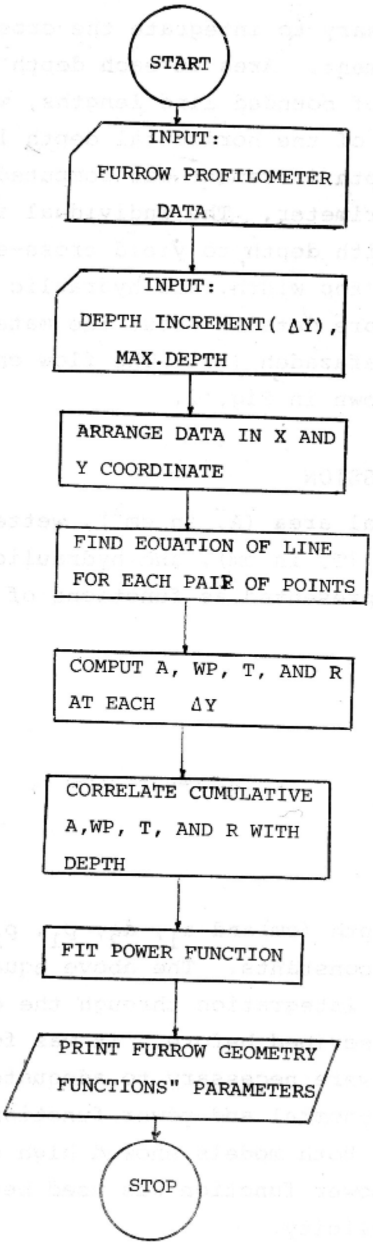

Fig. 2. Flow chart for the computer model.

determined for before irrigation, after continuous flow, and after surge flow (Table 1). Furrow irrigation simulation models (10) require a knowledge of furrow geometry functions. Results presented in Table 1 can be used as input parameter to these models to simulate furrow irrigation.

Selected plots of furrow cross-sectional area vs. depth with related equations (Table 1) for the Flowell test are shown in Figs. 3 and 4. Figures 3 and 4 show no overall significant difference (by overlapping two plots) between surge and continuous flow in relation to change in furrow cross sectional area vs. depth. Similar results in relation to furrow wetted perimeter are shown in Figs. 5 and 6. For other experimental sites and furrow geometry functions also similar results were obtained (9). As shown in Fig. 3 and 4, the greatest range of data points correspond to station 0, which for a given depth, shows a greater cross-sectional area compared to the lower range of data points which belong to the lower end stations. This is because following the first irrigation, inlet station furrow shapes changed (Figs. 7 and 8) from a typical triangular cross-section to a nearly trapezoidal one (a greater cross-sectional area) with a bottom that is hydraulically smooth.

CONCLUSION

Furrow geometry functions were developed for before irrigation, after continuous flow, and after surge flow for three different experimental sites. It was found that the nonlinear functions were necessary to adequately fit the data. The best fit line through all the data regardless of data station showed no overall significant difference between surge and continuous flow in relation to change in furrow geometry. During first irrigation, local erosion and deposition modified the initial triangular furrow shape to a nearly trapezoidal shape with a bottom that is hydraulically smooth. It was generally found that cross-sectional areas were

Table 1. Values of coefficients and exponents for relation between furrow geometry and depth for before and after first irrigation.

	Before irrigation		After continuous flow		After surge flow	
Flowell	Coefficient	Exponent	Coefficient	Exponent	Coefficient	Exponent
A vs. y	3.034	1.790	4.618	1.590	4.711	1.580
wp vs. y	6.110	0.777	8.331	0.587	8.585	0.572
T vs. y	5.641	0.729	7.925	0.507	8.085	0.491
R vs. y	0.498	1.010	0.567	0.981	0.509	1.070
Kimberly						
A vs. y	3.320	1.790	5.259	1.670	6.488	1.440
wp vs. y	6.686	0.773	9.777	0.608	11.023	0.464
T vs. y	6.234	0.734	9.393	0.568	10.591	0.396
R vs. v	0.467	1.060	0.511	1.110	0.550	1.090
U.S.U. Farm						
A vs. y	1.689	2.030	4.263	1.780	4.759	1.700
wp vs. y	4.263	1.000	9.207	0.655	9.116	0.641
T vs. y	3.353	1.040	8.758	0.601	8.671	0.597
R vs. y	0.398	1.030	0.478	1.120	0.493	1.100

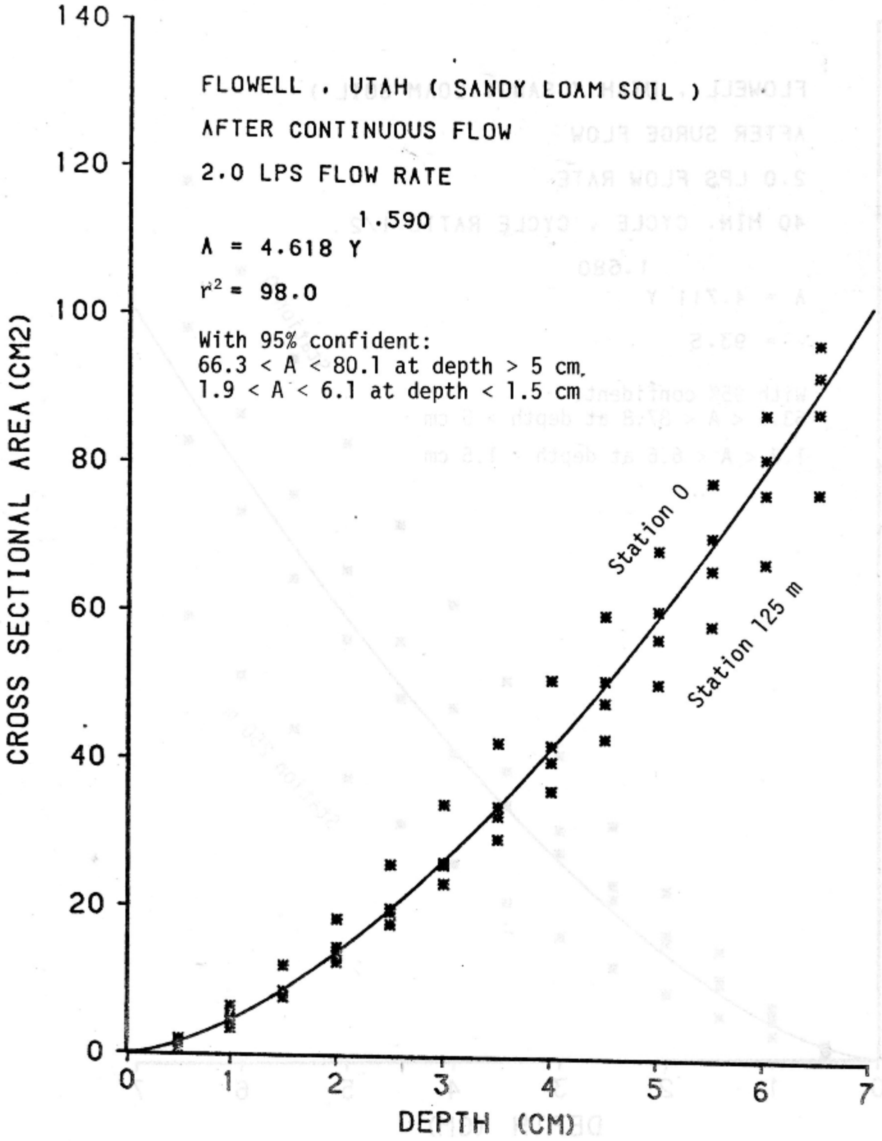

Fig. 3. Furrow cross-sectional area vs. depth after continuous flow for Flowell, Utah, U.S.A.

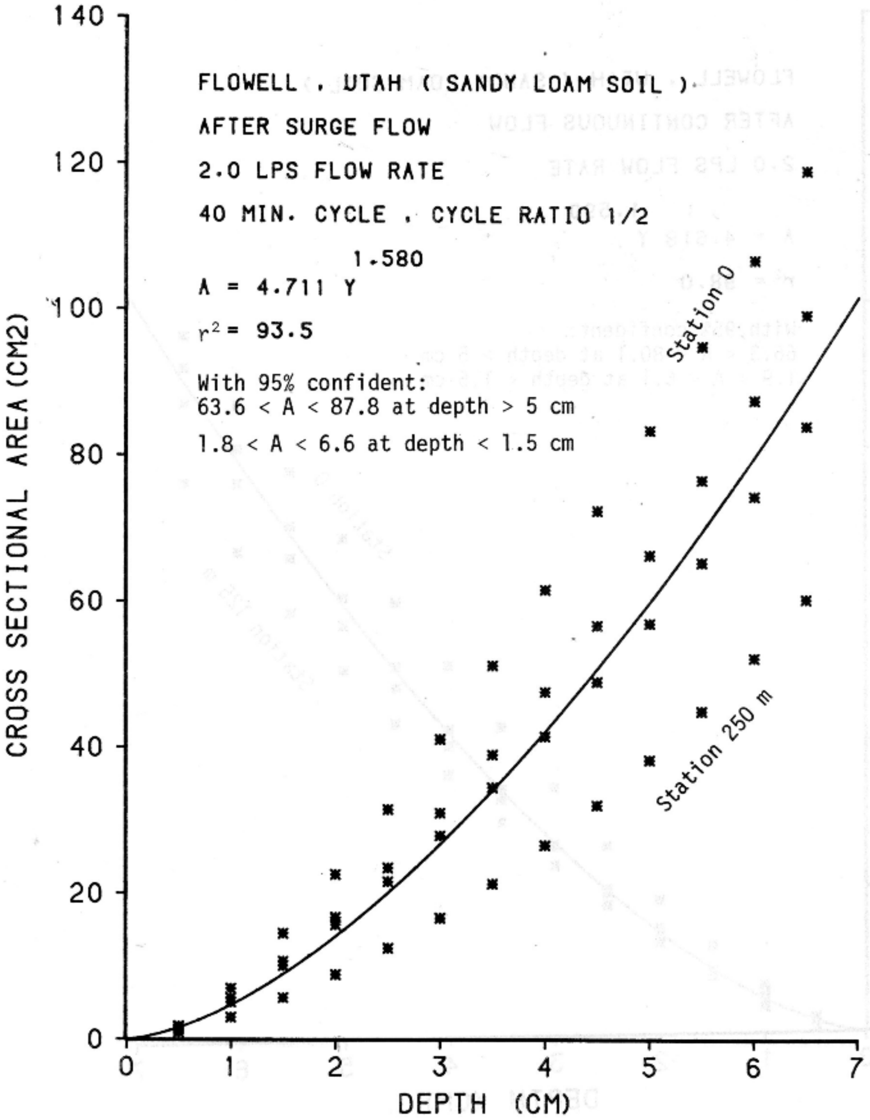

Fig. 4. Furrow cross-sectional area vs. depth after surge flow for Flowell, Utah, U.S.A.

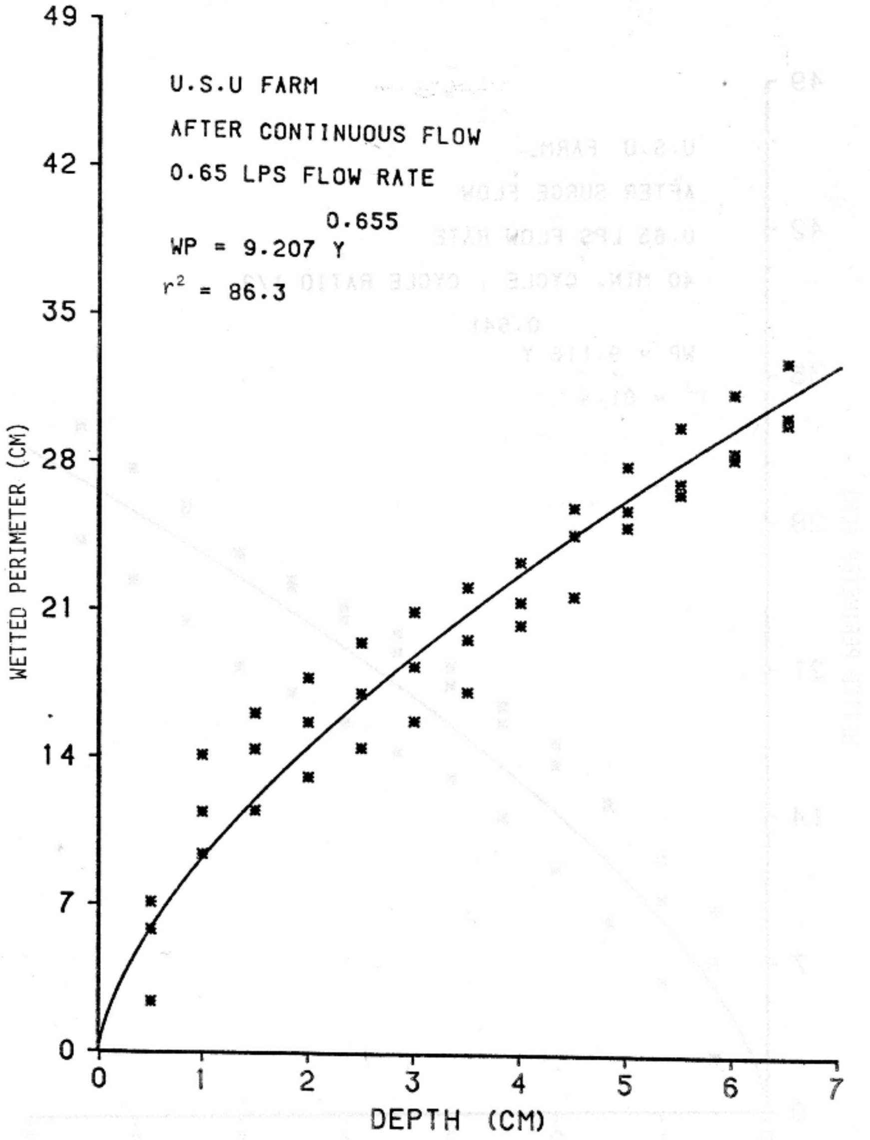

Fig. 5. Furrow wetted perimeter vs. depth for continuous flow for Nibley, Utah, U.S.A.

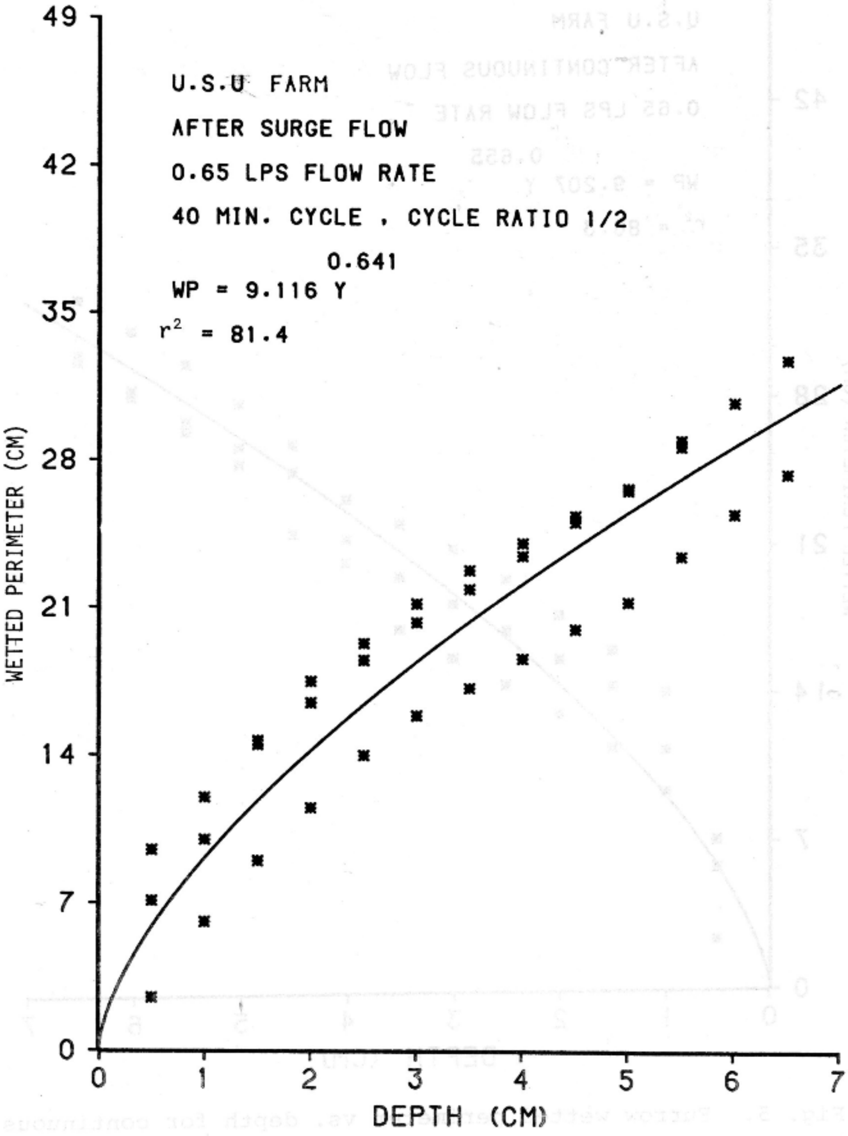

Fig. 6. Furrow wetted perimeter vs. depth after surge flow for Nibley, Utah, U.S.A.

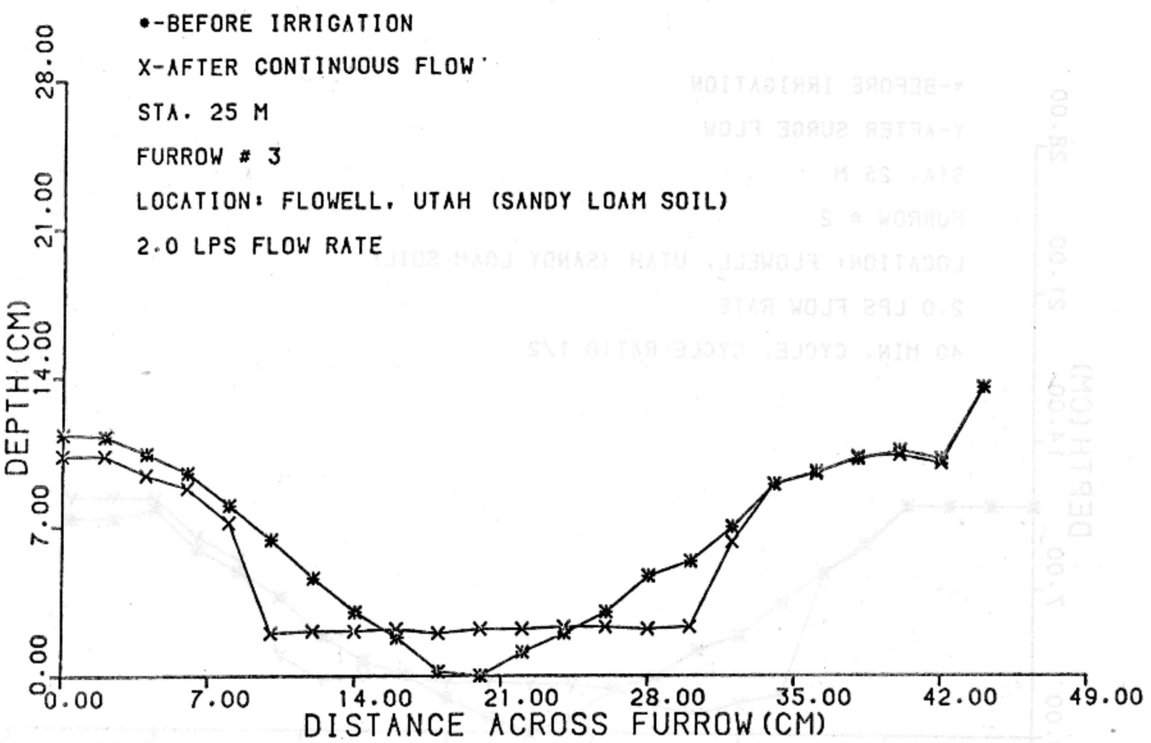

Fig. 7. Furrow cross-sectional plot before and after continuous flow at station 25 m.

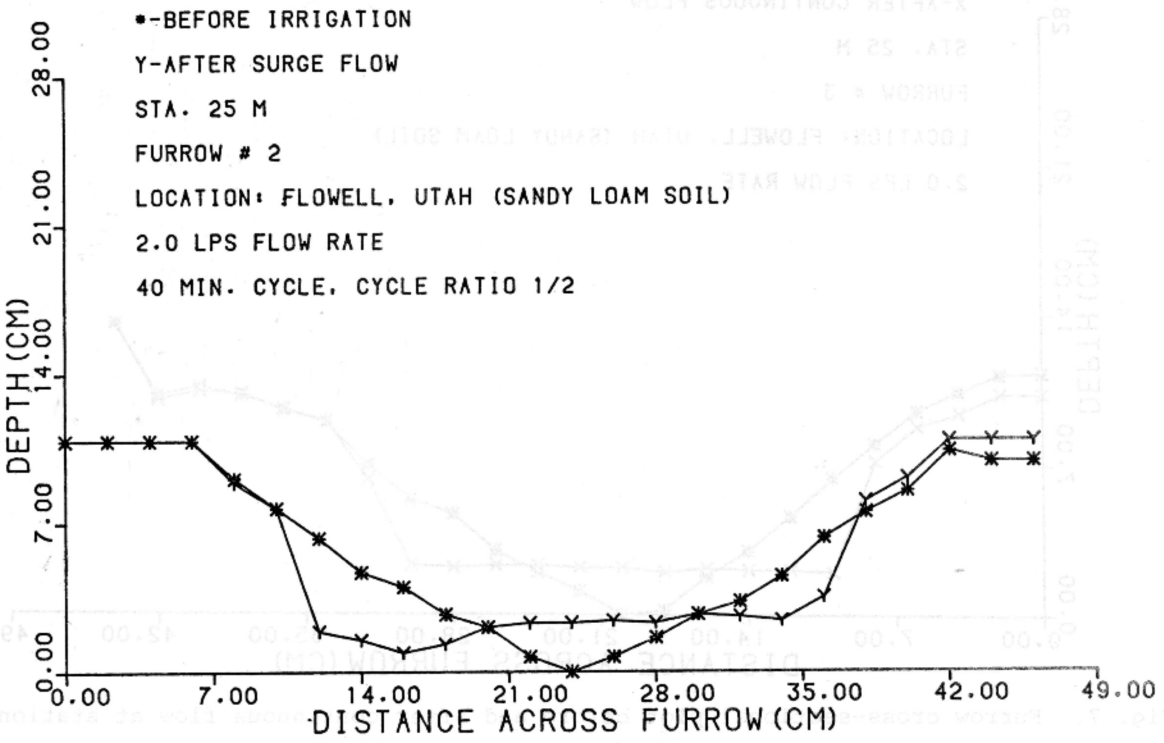

Fig. 8. Furrow cross-sectional plot before and after surge flow at station 25 m.

increased at the furrow section nearest to the water inlet for both continuous and surge flow.

LITERATURE CITED

1. Allen, L.N. 1980. Advance rates in furrow irrigation for cycled flow. M.S. Thesis, Utah State University, Logan, Utah, U.S.A.
2. Bishop, A.A. 1980. Surge flow the most efficient irrigation system. Crops Soils Mg. pp. 13-16.
3. Bishop, A.A., W.R. Walker, L.N. Allen and J. Poole. 1981. Furrow advance rates under surge flow systems. J. Irrig. Drain, Div. ASCE. 107: (IR3) 257-264.
4. Collidge, P.S. 1981. Advance rate under an automated pulsed flow irrigation system. M.S. Thesis, Utah State University, Logan, Utah, U.S.A.
5. Collidge, P.S., W.R. Walker and A.A. Bishop. 1982. Advance and runoff-surge flow furrow irrigation. J. Irrig. Drain. Div. ASCE. 108: (IR1) 35-41.
6. Garton, J.E. 1966. Designing an automatic cut-back furrow irrigation systems. Oklahoma Agric. Exp. Sta. Bull. B-651.
7. Izadi, B. and W.W. Wallender. 1985. Furrow hydraulic characteristics and infiltration. Transactions ASAE. 28(6): 1901-1908.
8. Malano, H.M. 1983. Comparison of infiltration process under continuous and surge flow. M.S. Thesis, Utah State University, Logan, Utah, U.S.A.
9. Mostafazadeh, B. 1982. Furrow geometry and roughness under surge and continuous flow. M.S. Thesis, Utah State University, Logan, Utah, U.S.A.
10. Walker, W.R. and A.S. Humphreys. 1983. Kinematic-Wave furrow irrigation model. J. Irrig. Drain, Div. ASCE. 109 (IR4): 377-392.