ADAPTATION AND EVALUATION OF SURGE IRRIGATION UNDER PHILIPPINE CONDITIONS

By

Jose L. Tabago

Bachelor of Science in Agricultural Engineering
Central Luzon State University
Nueva Ecija, Philippines
1966

Master of Engineering
Asian Institute of Technology
Bangkok, Thailand
1973

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
Doctor of Philosophy
December, 1983

ADAPTATION AND EVALUATION OF SURGE IRRIGATION
UNDER PHILIPPINE CONDITIONS

Thesis Approved:

James E. Garton
Thesis Adviser

C T Haan

Richard N. DeVries

A. D. Barefoot

Ronald L. Elliott

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

The author wishes to thank the sponsors of his study grant through which this research was undertaken, namely, the government of the Republic of the Philippines and the United States Agency for International Development. The assistance and timely advices of Dr. Jim Jorns of the International Agricultural Programs deserve special mention.

My million thanks and appreciation go to my wife, Alicia, and my children Jolizza, Christopher, and Jethro Jose, who bore the same emotional stresses that I had while in Oklahoma State University working hard to earn a degree.

In the same way, I am very grateful to my academic and thesis adviser, Dr. James E. Garton, without whose technical advice and close guidance, this research could not have been undertaken.

The detailed and objective criticisms provided by Dr. Ronald L. Elliott enabled the author to improve the presentation of the entire text. To him, I give my sincere gratitude.

My deep appreciation goes to my friends and students who, in one way or the other, willingly helped the author during the conduct of this study.

To my Professors who painstakingly taught me the courses that are related to my field of study which transformed my limited knowledge into a wider perspective, I give my due acknowledgments.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Relevance of the Research

One of the basic factors in increasing the productivity of Philippine agriculture is irrigation. To date, as a result of the construction and rehabilitation of irrigation systems throughout the Philippines, hundreds of thousands of hectares of arable lands have been irrigated resulting in bountiful harvest of rice and other crops. If we are to sustain agricultural production for our ever growing population, more emphasis should be given to the proper utilization and management of our irrigation water resource.

Surface irrigation will remain the most common method of irrigating our fields. Furrow irrigation is widely used by our farmers. Because of its popularity in terms of land area and volume of water used, there is a need to focus our attention on improving application efficiency to reduce unnecessary water losses.

Surge irrigation is a relatively new concept that can be applied to surface irrigation systems to improve irrigation performance. It is based on the surge flow concept in which water is delivered intermittently to the furrows or borders in a field. In other words, water is allowed to flow into the furrows or border for a period of time and then totally cut off. This procedure is repeated until irrigation is completed.

Prior to the introduction of this new concept in 1980, irrigation engineers have long recognized the cutback system and recovery of tail-water as a means of increasing the application efficiency and uniformity of application in border and furrow irrigation systems. The use of advance ratio as a means of improving irrigation efficiency has been advocated.

The initial results of surging as applied to furrow irrigation showed distinct advantages over the conventional method. By increasing the distance covered for a given volume of water applied in the furrow, losses due to deep percolation along the reach of the furrow are minimized. Further, by controlling the on-off cycle and flow rate under a given set of field conditions, it may be possible to eliminate excessive runoff at the lower end of the field being irrigated. A desirable feature of the surge flow method is that it is amenable to automation, which is desirable from the standpoint of reducing labor requirements and simplifying on-farm water management.

Since the surge flow concept is a relatively new idea in surface irrigation, the design criteria involving the right combination of flow rate, length of furrow, cycle time, infiltration characteristics of the soil, slope, and crop have not been fully established up to the present time. The lack of reliable data and information on surge flow irrigation system performance precludes its adaptation in irrigating furrows and borders. Further testing and evaluation of surge flow delivery systems is a necessary step towards establishing its practical application in the field and understanding its limitations.

Scope of Investigation

This study focused on water advance in the furrows during irrigation using several surge flow cycles and a continuous flow. Two inflow rates were used, namely, 30.2 l/min (8 gpm) and 37.8 l/min (10 gpm). The water advance data were analyzed to compare the surge flow treatments with that of the continuous flow in terms of average rate of water advance and mean depth of water application over a 100-meter irrigated furrows.

A field simulation of surge flow and continuous flow was conducted in the same area to determine whether any differences in the intake rate between the surge flow treatments and the continuous flow exist. The results of this field test were then related to the water advance test from which the conclusions of this study were drawn.

Objectives

General

1. To evaluate the effects of surge irrigation on the overall irrigation performance.
2. To find out the adaptability of the surge irrigation system under Philippine conditions.

Specific

1. To determine the effects of the cycled flows on the rate of water advance, and the average depth of water application.
2. To determine the intake characteristics of the furrow under

surge flows and continuous flow.

Limitations

The results of this study were site specific and were particularly true only under the existing field conditions at the time the data were gathered. The water advance data were affected by a number of field variables including the slope, furrow roughness and shape, and the physical characteristics of the soil. In the same way, the intake rate curves developed for each surge flow and continuous flow treatments from the actual field simulation tests may only apply to the field under study. The coefficients of variation and standard deviations found in each observation can be used as a basis for comparing the variability of other similar data that may be gathered in the future.

CHAPTER II

REVIEW OF LITERATURE

The surge flow concept was introducted in 1979 and first announced in 1980. The objective was to improve the rate of water advance in furrow irrigation. Since then, many surge flow tests were carried out to determine the effect of different cycle ratio and cycle time on the cumulative water advance. Bishop et al. (1981) defined cycle ratio as the ratio of on-time divided by the cycle time. The cycle time is the sum of the on-time and the off-time.

Surge flow is a technique in which irrigation water is delivered intermittently to borders or furrows. This concept came about when researchers at Utah State University found out that the cycled flow has essentially the same effect as cutting back the inflow rate when the water front has reached the end of the field being irrigated. Instead of reducing the inflow rate when the water has reached the end of the furrow to achieve a better efficiency and uniformity of water application, the valves may be controlled to operate at specific cycle period.

Water Advance

Kotter (1981), citing the works of several researchers, reported that the rates of advance at different cycle ratios were significantly faster than the continuous flow over a wide range of furrow and field conditions. Researchers in the field ascribed this phenomenon to a number of causes including the consolidation of the soil and the sealing of the soil pores by smaller and finer soil particles each time the irrigation water is applied in cyclic fashion. Others have the opinion that the water tension of the surface film that builds up at recession and drying time at every cycle affects the furrow intake characteristics (Bishop et al., 1981).

Bishop and Walker (1981) and Bishop et al. (1981) reported some encouraging results from surge flow tests conducted in 1980. They noted that the surge flow completed the 100 m (330 ft) of advance in 83 minutes compared with 108 minutes under continuous flow at an inflow rate of 0.3 l/sec (5 gpm).

Kotter (1981) reported several advantages of surge flow irrigation including a nearly uniform soil penetration of water along the length of the field, and high water application efficiencies comparable to those of sprinkler systems. Citing the works of several researchers, he reported that the shorter on-time with a larger inflow rate produces a better result in terms of longer furrow coverage. The 10 - and 20 - minutes surges at an inflow rate of 0.3 l/sec (5 gpm) required less than half as much water volume as the continuous flow to cover the same furrow length.

A surge flow experiment on level basins was conducted by Walker later in 1980 according to Kotter (1981). Walker noted that the surge flow in borders at 60-minute cycle time and one-half cycle ratio completed the advance phase with less on-time than the continuous flow on an adjacent border.

Control Systems

A number of control systems to produce the automated surge flow delivery have been devised and tested. One such system consists of a conveyance and distribution system fitted with outlet valves that are pneumatically controlled as reported by the Irrinews (1981). The valve openings are manually adjusted for any desired flow rate. The opening and closing of the valves are automatically controlled by a microprocessor according to a desired program. Other control systems make use of solenoid valves that are electrically controlled by a series of timer switches. The latter type was used in this study.

Effect on Intake Rate

Malano (1982) conducted field tests to compare the infiltration process under continuous and surge flow. He used a recycling flow infiltrometer to simulate the surge flow and the continuous flow on silty clay loam and sandy loam soils. His results indicated that the intermittent application of water into the furrow produced a faster decrease in the intake rates than did the continuous application. For equal intake opportunity times, he observed that the cumulative infiltration under intermittent flows was significantly lower than that under continuous applications.

Bishop et al. (1981) found that the cycled flows have a pronounced impact on the temporal and spatial intake variability in the field. It became obvious in the course of their experiments that the surge flow alters the basic intake characteristics of the furrow. Consequently, they theorized that the cycled movement of water along the furrow induces the development of thin surface seals on the furrow bottom surface which are responsible for the reduced basic furrow intake rates in subsequent water applications. They are also of the opinion that the dispersed fine materials at the furrow bottom are compacted by tension forces which build up in the soil during recession and drying.

Application Efficiency and Water Penetration

Santos and Caparas (1981) conducted experiments on Maligaya loam soil to determine the effects of furrow inflow rates on water application efficiency and water penetration on a 50-m furrow length. They noted that, at an inflow rate of 7.5 l/sec, runoff and deep percolation occurred resulting in a rather low application efficiency of only 66%. In a test conducted on Maligaya sandy loam, they were able to attain water application efficiencies of 83% and 95% for inflow rates of 3.18 l/sec and 2.12 l/sec, respectively. The measured water penetration at the head of the furrows was 81.5 cm for the higher flow and 73 cm for the lower flow, while at the end of the furrows, it was 63 cm and 57 cm, respectively.

Musick et al. (1973) conducted tests on a clay loam soil to determine the water intake under graded furrow irrigation and to investigate the effects of length of run and reduced tailwater runoff time on the application and water-use efficiencies. They reported that the intake rates after runoff started were affected by the length of run. As the length of run increased, the average intake rate curve for the wetted furrow length dropped more quickly. Further, the basic intake rate of the longer furrows was reached more quickly than with the shorter furrows. They concluded that deep percolation can occur under graded furrow conditions when the surface soil has a high intake capacity.

Distribution Efficiency

Reddell (1981) presented a method of evaluating distribution efficiency and application efficiency in a furrow irrigation system. His method is based on the mass balance equation and an assumption that the furrow storage volume is small compared with the amount of water infiltrated. He derived the modified rate of advance equation as

$$q/x = BKt_x^{a-1} \tag{1}$$

where q = furrow inflow rate (L^3/T); x = distance the wetting front has advanced (L); t_x = time required for the wetting front to reach position x (T); $B = \gamma(1 + a)\ \gamma(2 - a)$ where γ is a Gamma function. The modified rate of advance equations assumes that the infiltration is described by the Kostiakov - Lewis equation of the form

$$y = Kt^a \tag{2}$$

where y = cumulative volume infiltrated per unit furrow length (L^3/L); t = opportunity time for infiltration (T); and K and a are empirical constants. The same author calculated the distribution efficiency using the expression

$$Ed = 100\left(1 - \frac{\sum_{i=1}^{n} \left| Kt_i^a - y_a \right|}{ny_a}\right) \tag{3}$$

where Ed = distribution efficiency, percent; n = number of equally spaced increments into which the furrow is divided; y_a = average cumulative infiltrated volume (L^3/L); and t_i = measured infiltration opportunity time at point x_i (T).

Intake Functions

Cabauatan (1981) conducted infiltration tests on Maligaya loam soil using a standard cylinder infiltrometer 25.4 cm in diameter and 35.6 cm high. During the test, the cylinder was driven 15 cm into the soil. A plastic lining was installed at the bottom of the cylinder. The cylinder was then filled to a depth of 25.4 cm and the plastic lining removed before the actual measurements were made. The intake rate equations for different initial soil moisture contents were as follows:

Percent Moisture by Weight	Equation	
15	$i = 0.63t^{-0.82}$	(4a)
20	$i = 0.46t^{-0.83}$	(4b)
25	$i = 0.36t^{-0.84}$	(4c)

where i = infiltration rate, cm/min and t = intake opportunity time, minutes. The computed intake rates at time t = 90 minutes for 15, 20, and 25 percent moisture content were 0.16, 0.11, and 0.08 cm/min, respectively.

Quackenbush et al. (1957) reported the typical ranges of basic intake rates for different textured soils. For medium textured soils (silt loams to loams), they reported that the intake rate will normally range from 12.4 l/min to 37.3 l/min per 100 meters of furrow length. They recommended that the proper size of the cutback stream should be the intake rate in l/min per 100 meters multiplied by the length of run in hundreds of meters.

Criddle et al. (1956) used the Kostiakov - Lewis intake function (Eq. 2) to predict water intake along irrigated furrows. The opportunity time t was determined from the water advance data.

Hillel (1971) presented an in-depth analysis and derivation of the Philip infiltration equation expressed as

$$I = St^{\frac{1}{2}} + At \tag{5}$$

where I = cumulative infiltration (L); t = intake opportunity time (T); and S and A are constants which are related to the soil physical characteristics.

Fangmeier and Ramsey (1978) conducted experiments to determine the effect of furrow geometry on infiltration functions and intake characteristics of irrigation furrows. They used the inflow-outflow method to determine the intake rate for every 9.14 m (30 ft) interval along precision furrows 105 meters long. They reported that the Philip and the Kostiakov - Lewis equations gave good estimates of infiltration. The Philip equation provided a slightly better estimate than did the Kostiakov-Lewis equation but the constants were more difficult to obtain according to them.

Using a recycling furrow infiltrometer, Malano (1982) conducted experiments to compare the cumulative infiltration between the cycled flow and the continuous flow on silty clay loam soil in Flowell, Utah. He used the modified Kostiakov-Lewis equation of the form

$$I = Kt^{a} + f_{o}t \tag{6}$$

where I = cumulative intake (L); t = intake opportunity time (T); f_o = basic intake rate ($L^3/L/T$); and K, a are empirical constants. The intake rate equation will be of the form

$$I_r = aKt^{a-1} + f_o \tag{7}$$

where I_r = intake rate at time t (L/T). In presenting the results of the tests, Malano (1982) used a dimensionless unit for the intake rate by the formula

$$I_d = \frac{\text{Ave. intake rate during the time } \Delta t}{\text{Ave. intake rate during the time } t} \tag{8}$$

A graph was drawn between the dimensionless intake rate (ordinate) and the intake opportunity time (abscissa). His results indicated that the cycled flow had a much lower intake rate than the continuous flow at equal opportunity times.

Determination of Intake Rate Constants

Several researchers in the past had published a number of methods of determining intake rate constants such as that of Haise et al. (1956), Christiansen et al. (1966), Lal and Pandya (1972), and Singh and Chauhan (1973) all of which were based on sound theoretical background and valid assumptions.

Elliott and Walker (1982) conducted extensive studies to determine the empirical constants in the modified Kostiakov-Lewis infiltration function based on several methods. They used the inflow - outflow method in which the constant f_o was evaluated using the equation

$$f_o = (Q_{in} - Q_{out})/L \tag{9}$$

where L = the length of the furrow between the points of inflow and outflow measurements; Q_{in} and Q_{out} are the inflow and outflow rates, respectively. The computed average area of surface storage using the Manning's equation, and by knowing the exponent of the power advance function that describe the water advance in the furrow, they determined K and a. They checked the predicted volume infiltrated using Eq. (6) by comparing it with the difference between the total volume of inflow and outflow at the time of cutoff. A numerical integration method was used in determining the volume infiltrated using Eq. (6). They reported that the inflow-outflow method of determining the intake rate constants of Eq. (6) yielded the least average percent error of about 3%.

Summary of Review of Literature

A number of researches had been conducted in the past which were aimed at uncovering the effects of surging on water advance, amount of water applied, and infiltration characteristics of the field. They all agreed that surge irrigation system has a potential for practical application in terms of improving water advance and hence distribution and application efficiency in surface irrigation. The improvement in furrow irrigation under surge flow was indirectly ascribed to the decrease in basic intake rate during surging as compared with the continuous flow which showed a higher intake rate at the same intake opportunity time.

There is no available method yet proposed for the evaluation of irrigation performance under surge flow system. The method offered by Redell (1981) in evaluating distribution efficiency of surface irrigation is applicable mainly on continuous flow. Because of the recurring recession in the furrows under surge irrigation system, the application of Eq. (3) as suggested by Redell (1981) will overestimate the actual volume infiltrated. Nevertheless, when used on surge flow systems, it will be on a more conservative side. Thus far, no attempts has been done to evaluate and compare surge flow irrigation against the conventional system of continuous flow in terms of distribution and application efficiencies.

CHAPTER III

EXPERIMENTAL EQUIPMENT AND SET-UP

The experimental equipment and set-up consisted of 16 valves spaced to match the furrow spacing of 75 cm. The valves were connected to the 6.4 cm (2.5 in) PVC pipeline by suitable tees and adaptors as shown in Figure 1. Irrigation water was delivered by a centrifugal pump with a rated capacity of 1436 l/min (350 gpm) at 10 m head and driven by a 3-HP, 3-phase electric motor. The source of irrigation water was from an open concrete irrigation channel approximately 10 meters away from the edge of the field.

The solenoid valves were grouped into four sets, each set consisting of four valves that could be automatically controlled by a timer switch. The timers could be pre-set so that the valves were automatically closed and opened at specified time intervals in 15-minute increments. The electrical connections and wiring diagram of the control system is shown in Figure 2. Figure 3 shows the system undergoing preliminary tests and Figure 4 shows the system in actual operation in the field.

To check the discharge in each valve during the operation of the system, a flow measuring device was designed based on the principle of orifice flow. The governing equation used in the design of the flow measuring device was:

$$Q = CA\sqrt{2gh} \qquad (13)$$

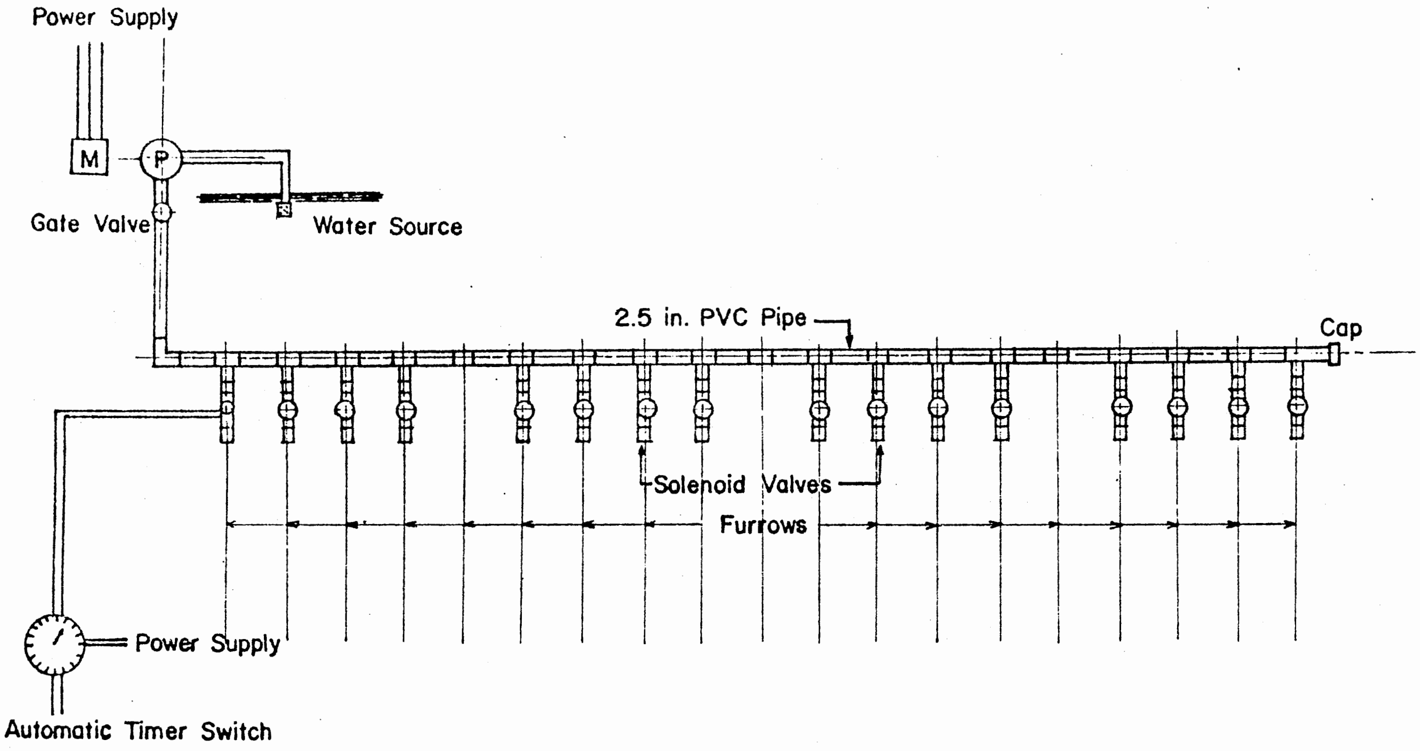

Figure 1. Schematic of Surge Flow Irrigation Delivery System.

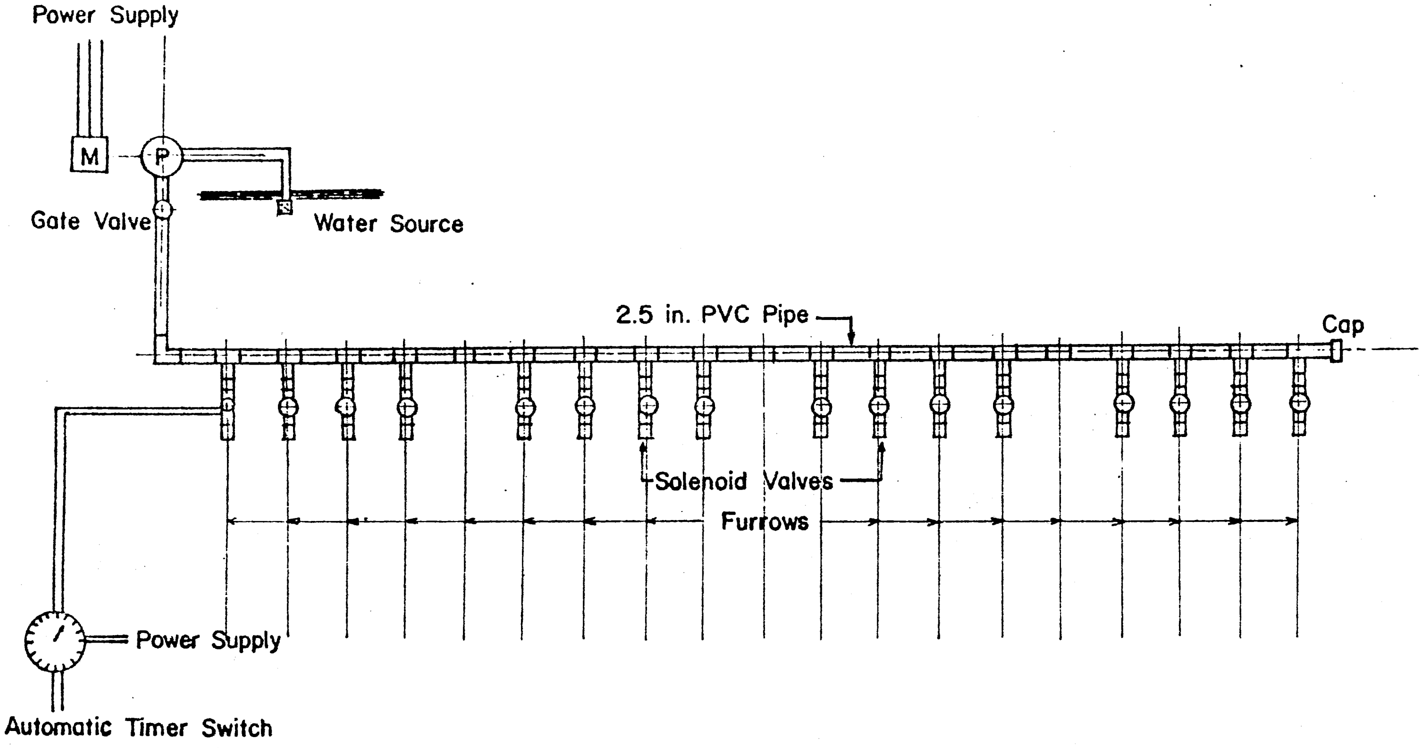

Figure 1. Schematic of Surge Flow Irrigation Delivery System.

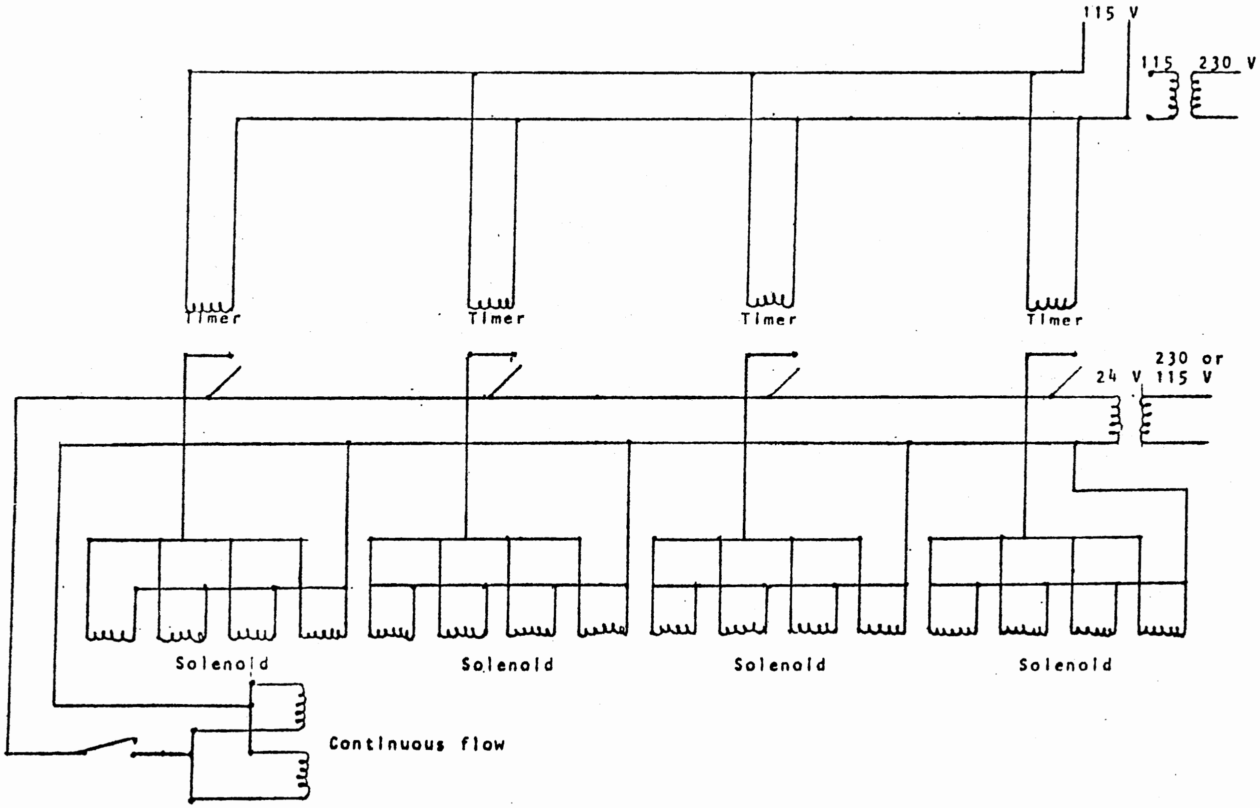

Figure 2. Electrical Connections and Wiring Diagram of the Control System

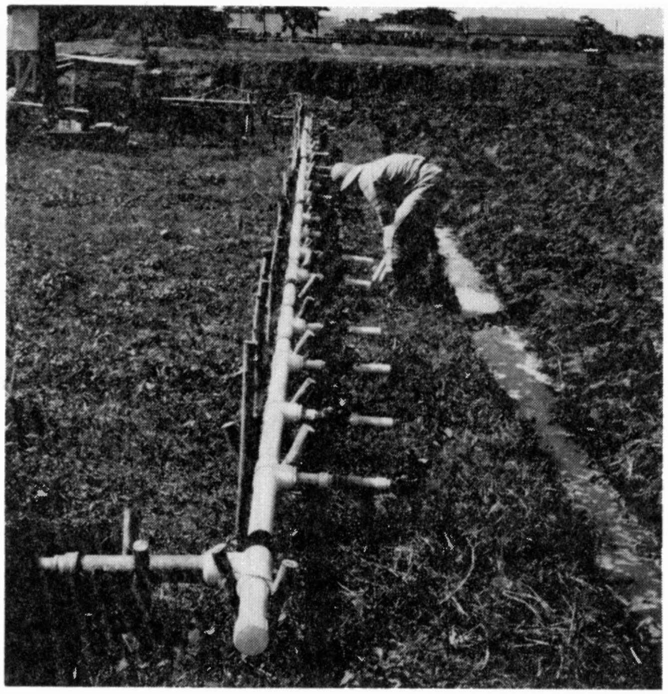

Figure 3. Surge Flow Delivery System Undergoing Preliminary Tests in the Field

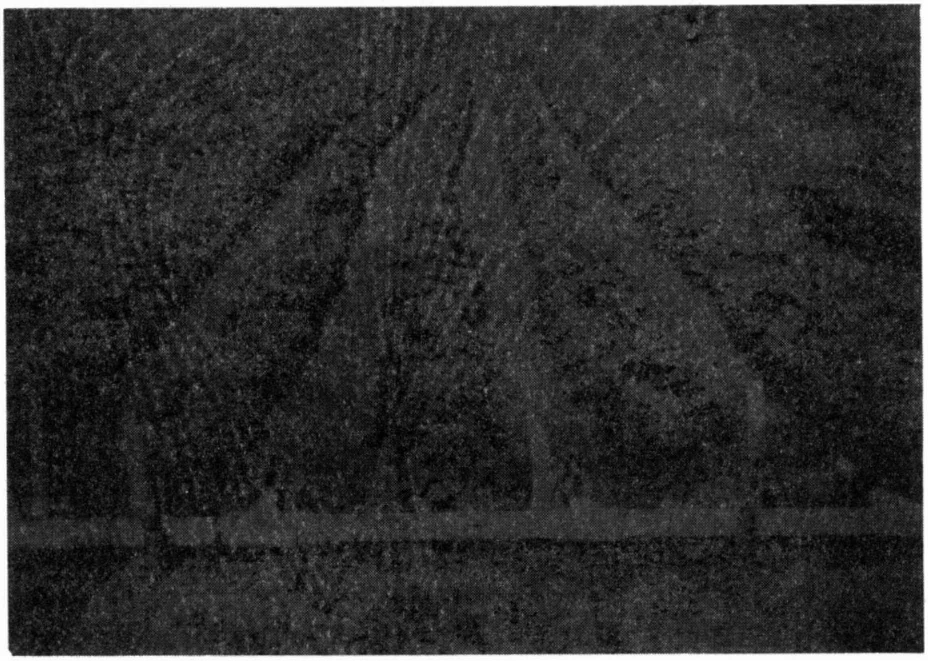

Figure 4. Surge Flow Delivery System in Actual Operation

where Q = flow rate (L^3/T); A = cross sectional area of the orifice (L^2); g = acceleration due to gravity (L/T^2); h = hydraulic head measured from the water surface to the center of the orifice (L); and C = orifice constant which ranges from 0.61 to 0.65. The dimensions of the flow measuring device at different flow rates as recommended by Garton/1 and later on by Epperly, Elliott, and Garton (1983) shown in Table I were followed as closely as possible. The flow measuring devices used in this study are shown in Figure 5.

TABLE I

SUMMARY OF DESIGN VALUES IN METRIC UNITS FOR FLOW MEASURING DEVICE

Flow Rate gpm	Flow Rate l/min	Hole Diameter, cm	Head above Hole Centerline, cm
4	15.1	1.91	8.69
6	22.7	2.54	6.50
8	30.2	2.86	7.52
10	37.8	3.18	8.05
12	45.4	3.49	8.18
14	52.9	3.81	8.03
15	56.7	3.97	9.27
17	64.3	4.13	9.14

Source: Epperly, Elliott, and Garton (1983)

/1 Personal communications

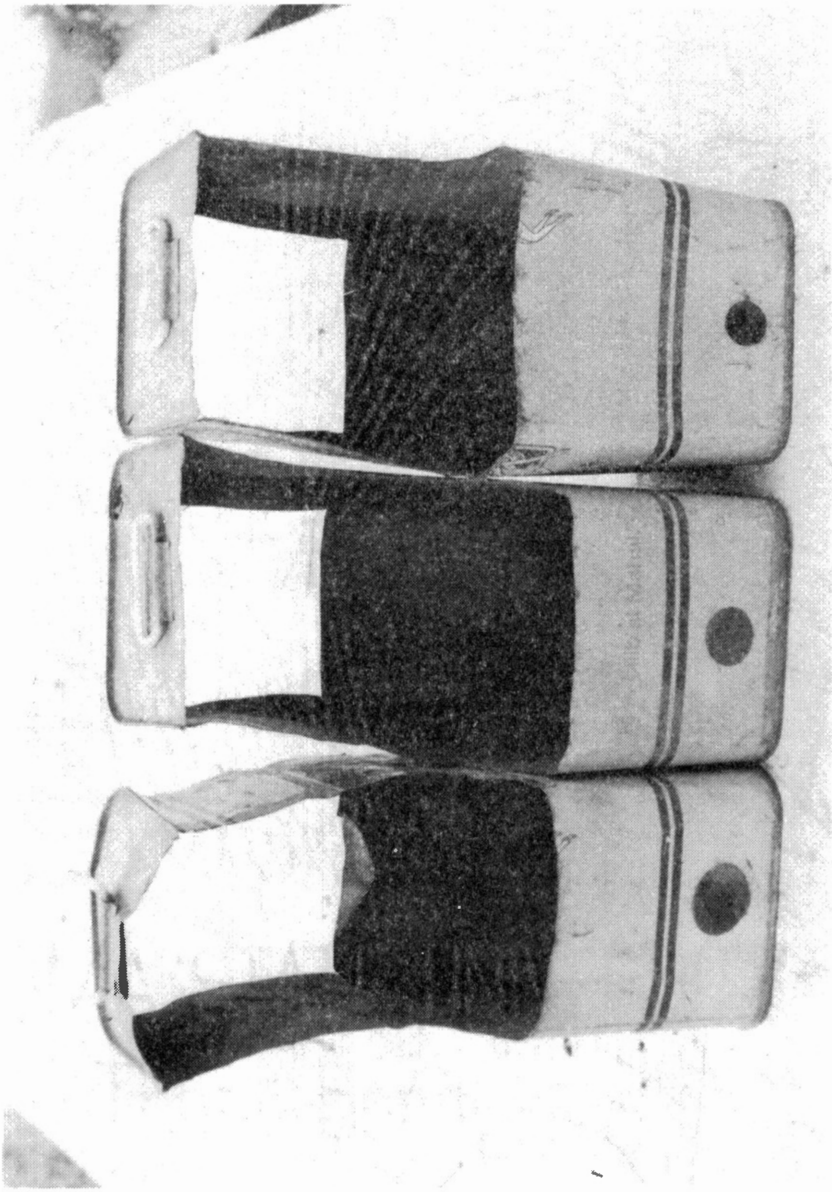

Figure 5. Flow Measuring Device

Location of the Test Site

A test site was selected at the Central Luzon State University research area, Philippines. The test site was located at the forage crop area having an area of approximately 5000 square meters with furrow length of about 180 meters. Since the test site was regularly planted to forage grass in the last few years, it is fairly graded with an average slope along the furrow of 0.3 percent. No land leveling was done prior to the conduct of the study.

After the land preparation and the construction of the test furrows, a profile survey was conducted for a representative furrow under each treatment.

Soil samples were gathered and analyzed at the soil laboratory of the National Irrigation Administration, Munoz Branch. The results of the textural analysis indicated that the soil was of loam type.

Using a soil auger with a diameter of 6.4 cm (1.5 in) and 1.5 m (5 ft) long, several holes were bored along the furrow running across the field to determine the location of the water table. The water table was found to be well below the 150 cm depth.

The Pipeline

The irrigation Pipeline which served as the conveyance and distributiion line was made of Class 125 Polyvinyl chloride plastic material with a nominal diameter of 6.4 cm (2.5 in). The pipes were cut into lengths of 70 cm, and 6.4 cm x 6.4 cm (2.5 in x 2.5 in) tees were connected and glued as snugly as possible. The individual valves were connected to the distribution pipeline by suitable adaptors and nipples.

The pipeline was divided into four segments, each segment accommodating four valves for easy installation and transportation. A gate valve was installed at the discharge side of the pump to control the flow and the energy of the flowing water in the pipeline during the operation of the system.

The Valves

The valves (Figure 6) used in this experiment have sizes of 3.8 cm (1.5 in) and 5.1 cm (2.0 in). Therefore, adaptors were installed at each tee to accommodate the valves. The discharge from each valve was controlled by a diaphragm with a spring coil. The force imparted by the spring coil to the diaphragm in effect controlled the flow at a more or less uniform discharge. The force of the spring coil was manually adjusted for the desired flow.

The opening and closing of each valve was automatically controlled by the electric coil connected on top of each valve. When the coil was electrically disconnected the water entered into the diaphragm chamber thereby closing the valve and cutting off the flow of water. In the next excitement of the coil, the pressure in the diaphragm was relieved causing the valve to open.

The Automatic Timer Switch

Four automatic timer switches (Figure 7) were installed to control the valves. Each timer controlled four valves. The power source

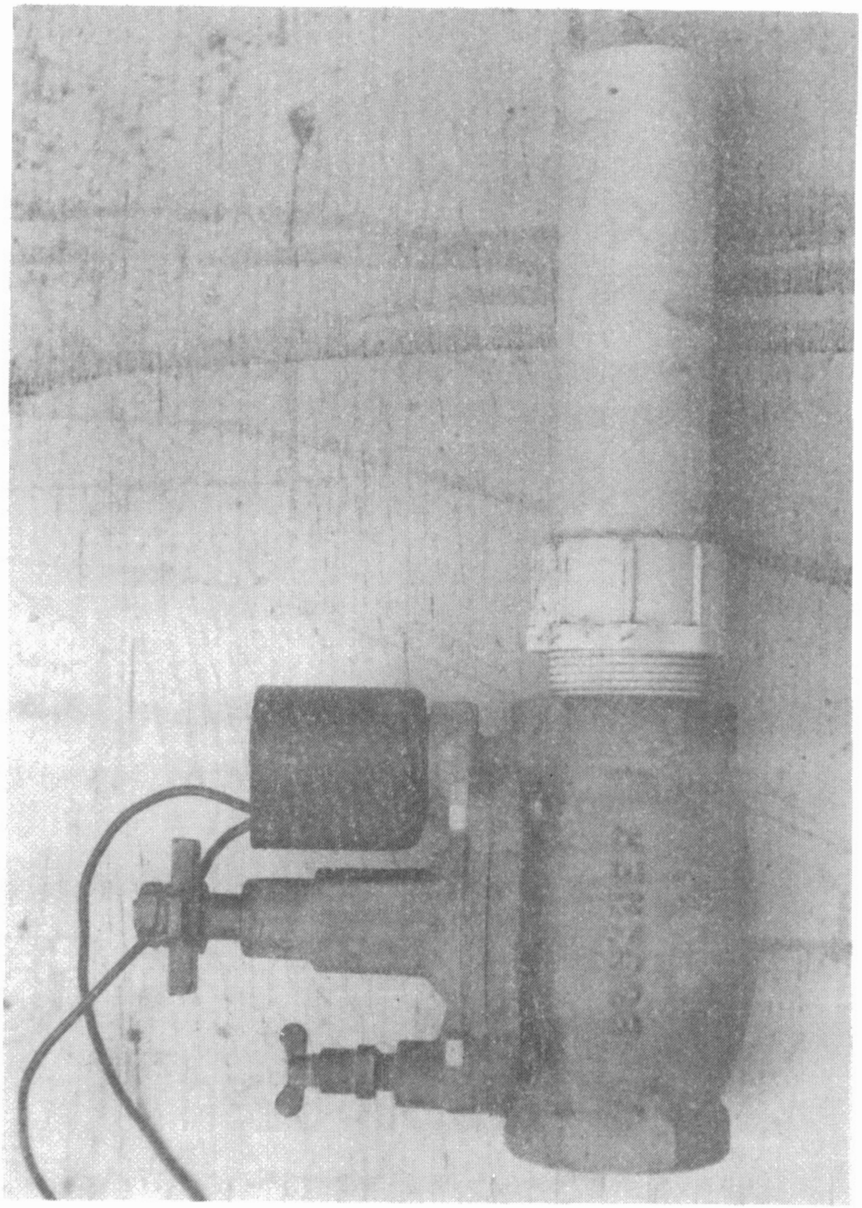

Figure 6. The Solenoid Valve

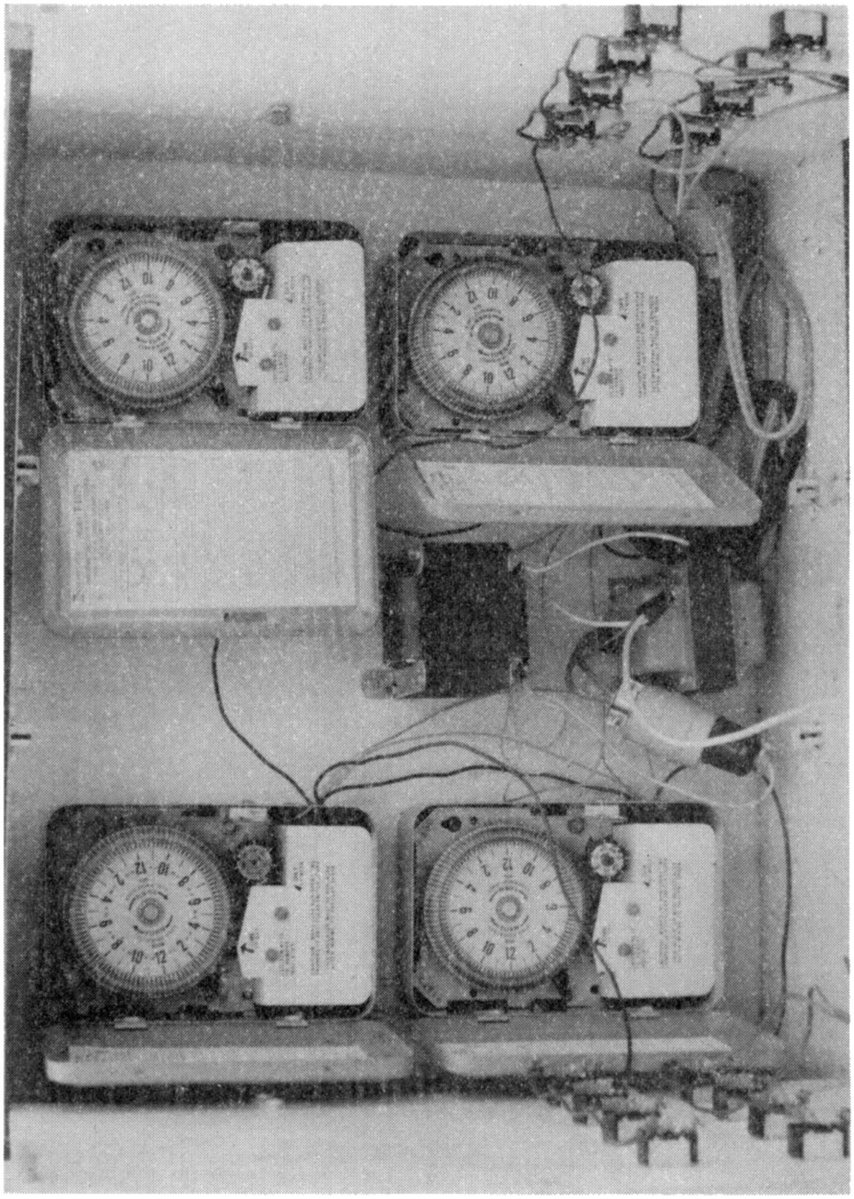

Figure 7. The Timer Switches

came from a 220V, 60 cycle single-phase electric line. Since the timer switch operates at 110 V and 60Hz, a stepdown transformer was installed to convert the 220V power source to 110V. The valves operate at 24V and 8 amperes so that another transformer was installed to convert the 110V to 24V.

Furrow Infiltrometer System

A continuous furrow infiltrometer system consisting of two 55-gallon empty oil drums, two pumps, plastic tubings, and sumps was constructed and tested at the Department of Agricultural Engineering, Central Luzon State University, Philippines. Figure 8 shows the schematic of the system and Figure 9 shows the infiltrometer system being used in the field.

The infiltrometer system was used in simulating surge flow over a 5-meter furrow test segment. The operation of the system consisted of the following steps:

1. Putting the reservoirs in place and filling the reservoirs.
2. Recording the initial water level as indicated by the gauge.
3. Calibrating the discharge of Pump A and setting the opening of the globe valve for the desired flow.
4. Operating Pump A.
5. Operating Pump B as soon as Sump B was filled to a desired level.
6. Maintaining the water level at Sump B by adjusting the globe valve at Pump B accordingly.
7. Recording the time and drawdown in the water level of the

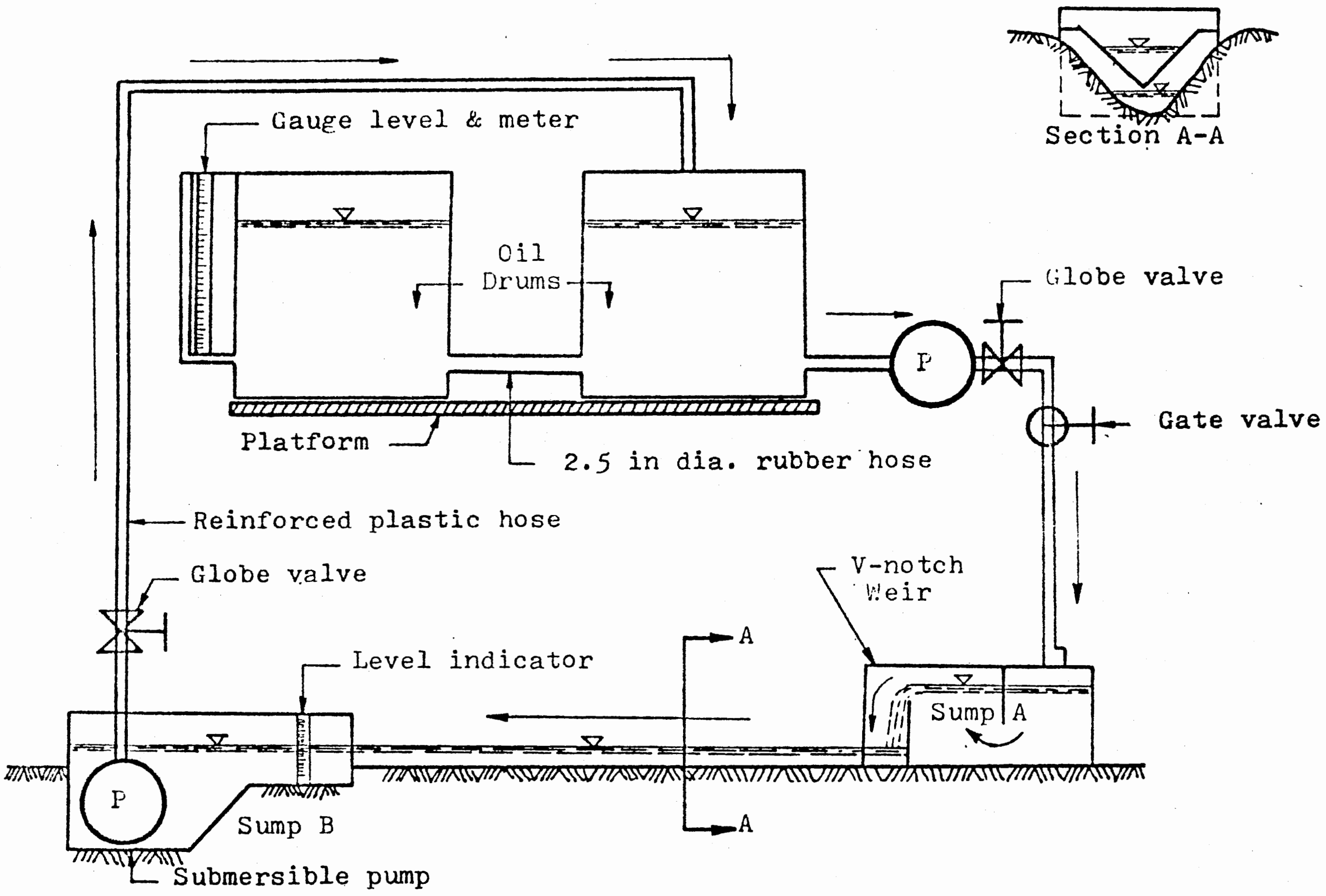

Figure 8. Schematic of the Continuous Furrow Infiltrometer System

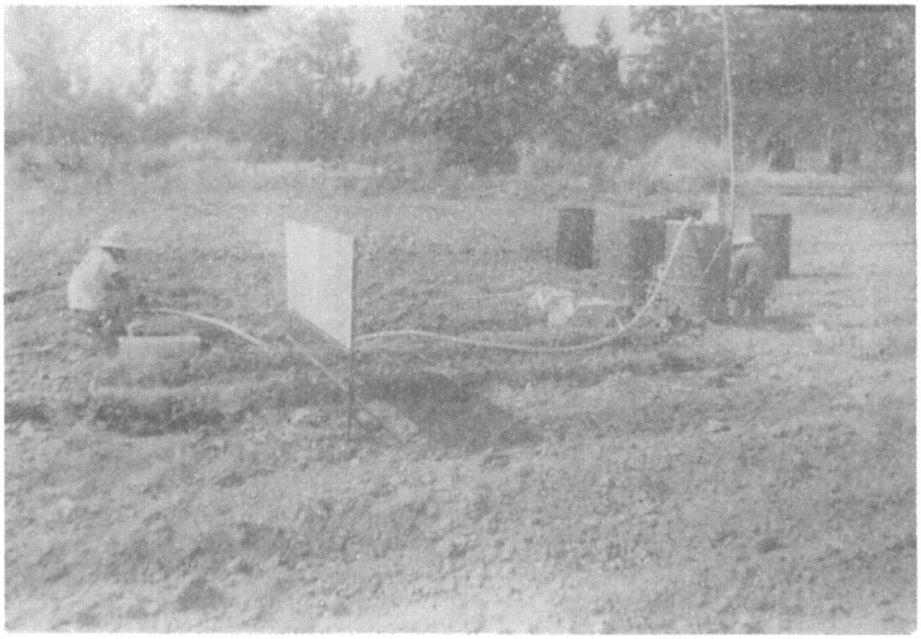

Figure 9. The Infiltrometer System in Actual Use in the Field

reservoir with a digital watch.

8. Measuring the wetted perimeter.

The Furrow Cross Section Meter

The furrow cross section meter was made of 0.64 cm ($\frac{1}{4}$ in) plywood 80 cm wide and 160 cm long, anchored on 1.27 cm x 1.27 cm ($\frac{1}{2}$ in x $\frac{1}{2}$ in) angle bar as shown in Figure 9. Grids were constructed at 5 cm interval with rigid movable rods running on the vertical lines. To measure the cross section of the furrow, the furrow cross section meter was carefully placed perpendicularly with the direction of the furrow in such a way that the centerline fell directly on the center of the furrow bottom. A carpenter's level was used to check the level of the top edge of the board. The rods were then adjusted in such a way that they barely touched the ground surface. The furrow cross section was reflected on the board by the top ends of the rods. The coordinates were then recorded and plotted on standard cross section paper.

Figure 10. Furrow Cross Section Meter

CHAPTER IV

METHOD AND PROCEDURES

Preliminary Test of the Surge Flow Delivery System

Several dry runs were conducted to determine the operating characteristics of the surge flow delivery system. Only three of the timer switches were set to control the 12 valves, each timer controlling 4 valves at a time. The rest of the four valves were left uncontrolled for the continuous flow treatment. The three timer switches were set to operate the valves at three settings namely, 15 min on - 15 min off (T1), 30 min on - 15 min off (T2), and 45 min on - 15 min off (T3). All the 12 valves were properly controlled in accordance with the time setting. Due to the varying total discharge of the valves in operation, it was observed that the pressure in the conveyance and delivery pipe also varied resulting in a considerable fluctuation of discharge in the four valves with continuous flow. It was also observed that some of the valves have delayed response of as much as 1 to 2 minutes. A few other valves failed to close totally.

During the succeeding trials, some debris got lodged into the valves which prevented the valves from closing completely when the switches were activated. To prevent the debris from getting into the valves, a screen box was constructed using #16 gage mesh wire. the screen box was securely placed at the water supply channel from which the pump drew water free of floating and suspended debris through the foot valve. This eventually solved the problem of clogging which made the system worked as desired.

Because of the delayed response of some of the valves and the varying pressure in the conveyance pipe which could affect the outcome of the water advance tests, it was decided to control the surge flow delivery system manually during the conduct of the experiment. Two treatments were conducted at a time so that only 8 out of 16 valves were being operated at a time during the actual test run until the advance tests were completed.

Surge Flow Tests

Two test runs were conducted successively at the test site at the Central Luzon State University's field research area. Land preparation was started in mid-December of 1982. The area was disk plowed once to a depth of 15 to 20 centimeters (6 to 8 inches) followed by thorough harrowing 2 to 3 days later. The furrows were spaced at 100 centimeters.

On the day following the construction of the furrows, the test site was planted to napier grass. A week later when the soil surface had become relatively dry, the actual tests were conducted to provide supplemental moisture for the germinating plants.

To facilitate the recording of the cumulative distance covered by the advancing water front, stakes were driven along the furrows at every 5 meters interval. The stakes were marked at every 10 meters indicating the distance in meters from the furrow inlet. The cumulative distance covered in each treatment was recorded every 15 minutes interval to the nearest 1 meter.

Experimental Design

The advance tests were conducted using three irrigation cycles and a continuous flow as control. The irrigation cycles applied were 1) T1 (15 min on - 15 min off), 2) T2 (30 min on - 15 min off), and 3) T3 (45 min on - 15 min off). Inflow rates of 30.2 l/min (8 gpm) and 37.8 l/min (10 gpm) were used for each test run. Each treatment combination was replicated three times.

During the test, the inflow rates at each valve were checked from time to time (about every 5 minutes) with the use of the flow measuring devices (Figure 5). The valve openings were adjusted whenever necessary. The tests were continued until practically the entire furrow length was irrigated.

Field Simulation of Surge Irrigation

In order to gain an insight on the effect of cycled flow on the furrow intake characteristics, a field simulation of surge irrigation was undertaken with the use of the infiltrometer system. The length of the test furrow was fixed at 5 meters and inflow rate of 30.2 l/min (8 gpm) was applied. The off-time used was maintained at 15 minutes throughout the experiment with on-times varied at 10, 15, and 20 minutes. A randomized complete block design with three replications was used.

Recording and Processing of Field Data

Field data on time and drawdown were recorded for each treatment from which the average infiltration at every surge was computed. The furrow intake curve under continuous flow was also determined following the same procedure as in the surge flow treatments.

To avoid the error in sampling during the time interval from the beginning and end of every surge applied, the total difference in the reservoir before and after the end of the surge was used in determining the average furrow intake rate. The following equation was used to convert the readings into its equivalent furrow intake rate:

$$I = \frac{2 \times Rd \times 10}{FL \times WP \times t} \tag{10}$$

where I = furrow intake rate, mm/min; $A = 3.1416 \times D^2/4$, cm^2; D = diameter of the reservoir (57.5 cm); FL = furrow length (500 cm); WP = furrow wetted perimeter, cm; and t = intake opportunity time in minutes. Rd is the cumulative depth reading in cm corresponding to the time t.

For each treatment, the average furrow intake rate was determined at 5-minute intervals. These data were combined and presented to see the characteristic trends between the treatments. The 10-minute and the 40-minute intake opportunity times were considered as a basis for comparing the observed intake rates in each treatment.

CHAPTER V

RESULTS AND DISCUSSION

The results and discussion presented in this chapter were grouped into two main topics, namely, a) surge flow tests, and b) surge flow field simulation. Each of the above experiments was conducted independently of each other within the same test site. The interrelated results were integrated later on to give an over-all view of the processes involved in surge flow irrigation.

Surge Flow Test

Water Advance

The water advance data gathered include the time in minutes from the beginning of irrigation and the cumulative water advance in meters observed in each test furrow. The advance data were recorded every 15 minutes in which the valves were actually open. These are shown in Appendix A. The sample standard deviations and coefficients of variation of the individual observations in each treatment are shown in Appendix B.

Table II and Table III which were taken from Appendix B show the mean standard deviation and coefficient of variation in each treatment at 30.2 l/min and 37.8 l/min, respectively. At the inflow rate of 30.2 l/min, the coefficients of variation ranged from 3.9% to 21.6%

TABLE II

STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF WATER ADVANCE DATA, Q = 30.2 L/MIN

Treatments	Std. Dev., meters			Coeff. of Variation (%)		
	Min.	Max	Mean	Min	Max.	Mean
TC	2.3	8.3	6.6	3.9	21.6	10.4
T1	5.5	11.5	9.1	6.8	19.5	13.3
T2	3.1	15.5	10.3	11.4	19.6	17.2
T3	6.8	11.4	9.8	10.1	29.2	16.6

TABLE III

STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF WATER ADVANCE DATA, Q = 37.8 L/MIN

Treatments	Std. Dev., meters			Coeff. of Variation (%)		
	Min.	Max.	Mean	Min.	Max.	Mean
TC	5.5	10.3	8.4	7.8	22	10.4
T1	5.0	16.2	9.9	5.0	22.7	9.7
T2	4.5	13.2	9.5	8.3	12.6	9.3
T3	6.7	15.1	10.9	5.3	18.6	12.8

in treatment TC (continuous flow), 6.8% to 19.5% in treatment T1 (15 min on - 15 min off), 11.4% to 27.4% in treatment T2 (30 min on - 15 min off), and 10.1% to 29.2% in treatment T3 (45 min on - 15 min off) with averages of 10.4%, 13.3%, 17.2%, and 16.6%, respectively. The mean standard deviations for TC, T1, T2, and T3 were 6.6 m, 9.1 m, 10.3 m, and 9.8 m, respectively.

In the second test with a higher inflow rate of 37.8 l/min, the coefficients of variation ranged from 7.8% to 22% (TC), 5% to 22.7% (T1), 7.2% to 12.6% (T2), and 5.4% to 18.6% (T3) with means of 10.4%, 9.7%, 9.3%, and 12.8%, respectively. The mean standard deviations were 8.4 m, 9.9 m, 9.5 m, and 10.9 m corresponding to treatments TC, T1, T2, and T3, respectively.

The ratio of the coefficient of variation and the mean distance covered (CV/Y) as shown in Appendix B tends to become constant as the length of irrigated furrow increases. This is an indication that the variation in the observed furrow coverage in each treatment is a function of time and also of the length of irrigated furrow.

The relatively high coefficients of variation in the advance data could be due to a number of factors including furrow roughness, furrow gradient, intake characteristics, and the errors inherent in sampling. The standard deviations and coefficients of variation encountered in this study can be used as a basis of comparison with similar studies that may be conducted in the future.

The actual advance curves for the surge and continuous flow treatments at inflow rates of 30.2 l/min and 37.8 l/min are shown in Appendix C. The figures include the minimum, maximum, and mean coefficient of variation in each treatment as taken from Appendix B. It will be observed that a higher coefficient of variation occurred during the early stages of the water advance test and that the variation became more or less stable during the later portion of the test. The standard deviations in meters however, were observed to be smaller in the early period than in the later part of the water advance test.

In the first advance test at an inflow rate of 30.2 l/min, treatment T1 (15 min on - 15 min off) demonstrated a slightly longer furrow coverage at any given time from the start of irrigation than the rest of the treatments as shown in Figure 11. Although treatments T2 and T3 had initially shorter furrow coverage than the continuous flow, these treatments eventually caught up with the continuous flow at the end of 4 hours and 2½ hours, respectively.

In the succeeding test using a higher inflow rate of 37.8 l/min, the surge flow treatments gave a slightly longer furrow coverage than the continuous flow treatment. This advantage became more distinct with time and number of surges applied as shown in Figure 12.

Average Rate of Water Advance. For the purpose of statistical comparison, the average rate of advance were computed by dividing the cumulative water advance by the recorded time in each treatment. The time was selected at 180 minutes in the lower inflow rate and 210 minutes in the higher inflow rate. These times represent the least actual operation time among the treatments.

The average rate of water advance are listed in Table IV and Table V. The analysis of variance (Appendix D) indicated significant

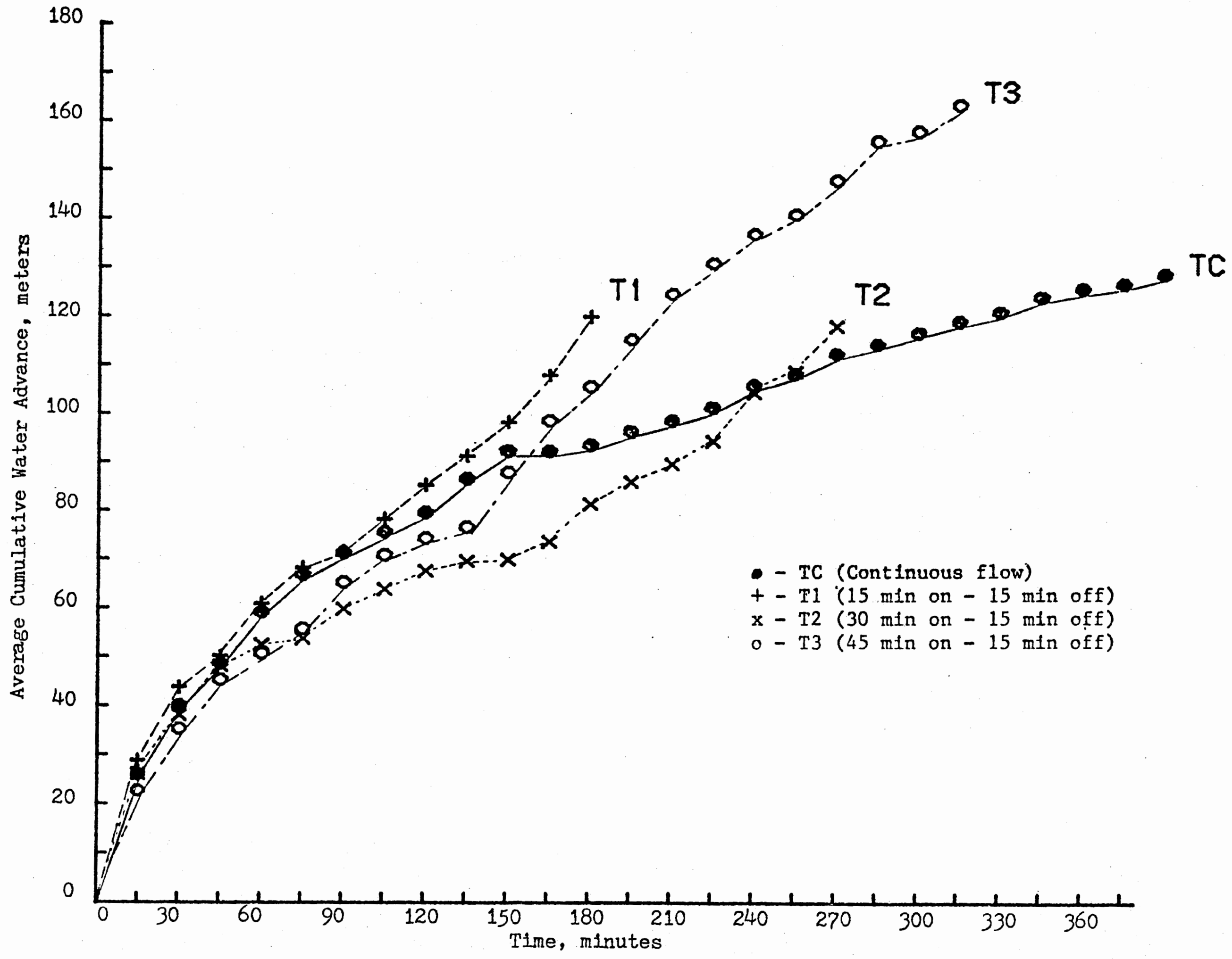

Figure 11. Average Cumulative Water Advance Curves Along the Furrow Under Surge and Continuous Flow Treatments, Q = 30.2 l/min

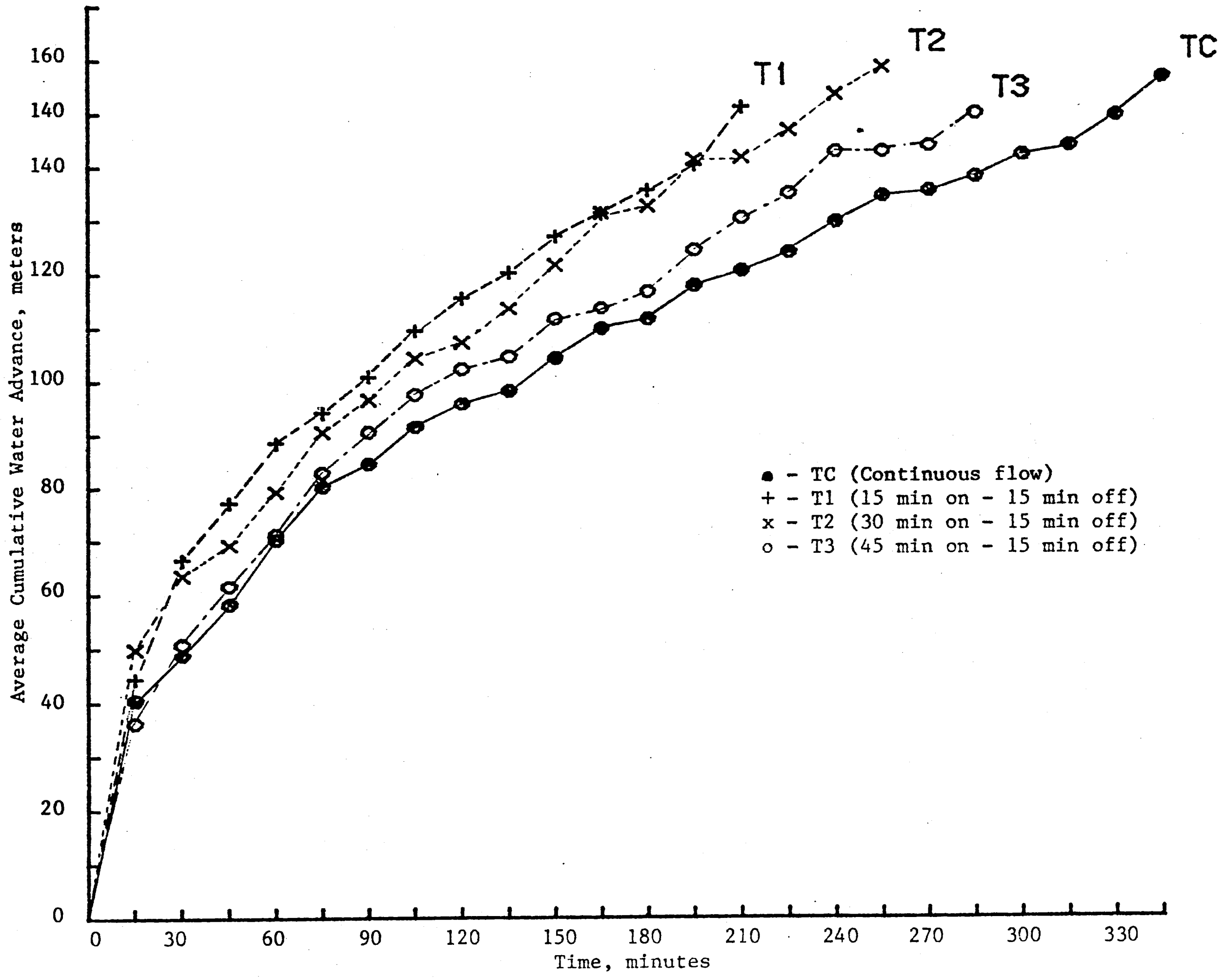

Figure 12. Average Cumulative Water Advance Curves Along the Furrow Under Surge and Continuous Flow Treatments, Q = 37.8 l/min

TABLE IV

AVERAGE RATE OF WATER ADVANCE ALONG THE FURROW AT THE END OF 180 MINUTES, Q = 30.2 L/MIN

Treatment	Water Advance Rate, m/min Replication 1	2	3	Total	Mean
TC	0.53	0.48	0.56	1.57	0.52
T1	0.62	0.73	0.64	1.99	0.66
T2	0.55	0.38	0.43	1.36	0.45
T3	0.57	0.66	0.54	1.77	0.59

TABLE V

AVERAGE RATE OF WATER ADVANCE ALONG THE FURROW AT THE END OF 210 MINUTES, Q = 37.8 L/MIN

Treatment	Water Advance Rate, m/min Replication 1	2	3	Total	Mean
TC	0.52	0.68	0.62	1.82	0.61
T1	0.89	0.73	0.89	2.51	0.84
T2	0.78	0.85	0.74	2.37	0.79
T3	0.71	0.69	0.78	2.18	0.73

differences among the treatment means. The comparison among treatment means (Table XXV and Table XXVI, Appendix D) indicated that only treatment T1 had a significantly higher rate of water advance than the continuous flow at an inflow rate of 30.2 l/min. The computed rate of water advance was 0.66 m/min compared with 0.52 m/min of treatment TC (continuous flow). At the higher inflow rate of 37.8 l/min, treatment T1 had also a significantly higher average rate of water advance than the continuous flow treatment. Treatments T2 and T3 did not show any significant differences in the rate of advance over that of the continuous flow treatment in both tests.

The results of the above analysis pointed out that short and frequent surges in the furrow effected a faster rate of water advance than long but less frequent surges.

Average Depth of Water Application. The average depth of water application in each treatment was computed by the formula

$$Da = \frac{Q \times 1000 \times t}{Fs \times Fl \times 100} \tag{11}$$

where Da = average water application depth over the length of the irrigated furrow (Fl), cm; Q = inflow rate, l/min; t = time, minutes; Fs = furrow spacing, cm; and Fl = furrow length irrigated at the end of time t, meters. In using Eq. (11), the furrow length was fixed at 100 meters so that only the time t varies from treatment to treatment.

The computed average water application over 100 meters of irrigated furrow are shown in Table VI and Table VII at an inflow rate of 30.2 l/min and 37.8 l/min, respectively. The average water application depths were 4.51 cm (T1), 5.07 cm (T3), 6.65 cm (TC), and 6.78 cm

TABLE VI

AVERAGE DEPTH OF WATER APPLIED IN 100 METERS OF IRRIGATED FURROW IN CM, Q = 30.2 l/MIN

Treatment	Average Depth, cm Replication			Total	Mean
	1	2	3		
TC	6.80	7.70	5.44	19.94	6.65
T1	4.92	4.08	4.53	13.53	4.51
T2	5.44	7.79	7.10	20.33	6.78
T3	5.10	4.56	5.56	15.22	5.02

TABLE VII

AVERAGE DEPTH OF WATER APPLIED IN 100 METERS OF IRRIGATED FURROW IN CM, Q = 37.8 L/MIN

Treatment	Average Depth, cm Replication			Total	Mean
	1	2	3		
TC	4.89	4.26	3.17	12.32	4.11
T1	2.63	3.53	3.17	9.33	3.11
T2	3.05	2.27	3.90	9.22	3.07
T3	2.99	4.53	2.72	10.24	3.41

(T2) at an inflow rate of 30.2 l/min. At the higher inflow rate of 37.8 l/min, the average water application depth over the 100-meter irrigated furrow were 3.07 cm (T2), 3.11 cm (T1), 3.41 cm (T3), and 4.11 cm (TC). The higher average water application depths observed in the first test at an inflow rate of 30.2 l/min were due to the fact that the water travelled down the furrows in a much longer time period than at a higher inflow rate.

The analysis of variance (Appendix E) indicated that only treatment T1 had a significantly lower average water application depth than the continuous flow. In the second test with a higher inflow rate of 37.8 l/min, no significant differences among the treatment means were detected. This suggests that the data gathered in the second test were not senstive enough to show any significant differences between the mean application depths in each treatment.

Except for treatment T2 in the first test, all the surge flow treatments exhibited a lower water application depth over the 100 - meter irrigated furrow length. It can therefore be deduced from the above results that a slightly higher water application efficiency should be achievable under surge flow.

Surge Flow Field Simulation

In order to uncover the possible reasons why the surge flow gave a seemingly better furrow coverage than the continuous flow as per results obtained in the surge flow tests presented earlier in this chapter, a surge flow field simulation was conducted. Appendix F shows the observed furrow intake rates at different intake opportunity times in 5-minute interval. The sample standard deviations and coefficients of variation for each observation in the treatments are shown in Table XXXIV and Table XXXV, Appendix G.

Table VIII presents the mean standard deviation and coefficient of variation in each treatment including their minimum and maximum values. The coefficients of variation vary widely from observation to observation in each treatment ranging from 8.9% to 12.7% (SC, continuous flow), 13.9% to 50% (S1, 10 min on - 15 min off), 11.5% to 30.6% (S2, 15 min on - 15 min off), and 7.7% to 30.7% (S3, 20 min on - 15 min off). The average coefficients of variation for treatments SC, S1, S2, and S3 were 16.9%, 28.7%, 20.1%, and 17.7%, respectively. The mean standard deviation of furrow intake rate in each treatment were 0.43 mm/min, 0.82 mm/min, 0.51 mm/min, and 0.41 mm/min for treatment SC, S1, S2, and S3, respectively.

TABLE VIII

STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF FURROW INTAKE RATE DATA UNDER SURGE FLOW AND CONTINUOUS FLOW

Treatments	Std. Dev. (mm/min)			Coeff. of Variation (%)		
	Min.	Max.	Mean	Min.	Max.	Mean
SC	0.20	0.93	0.43	8.89	23.04	16.94
S1	0.46	1.73	0.82	13.89	49.97	28.70
S2	0.18	1.04	0.51	11.47	30.55	20.11
S3	0.12	1.10	0.41	7.67	30.70	17.74

Since the measurements were made from different furrows, the variability in the measurement of average furrow intake rate can not be discounted. The shortness of the test furrows (5 meters) plus the end effects in the furrows could have contributed to the wide variability encountered during the actual test. Since the plots of the individual observations in each treatment followed the normal expected trend, the observed data in this experiment were reasonable and were valid within certain limits.

The observed furrow intake curves for each of the surge flow treatments and the continuous flow treatment are shown in Appendix H. Figure 13 presents the average furrow intake curves for each treatment. Except for treatment T1, the intake rates of both the continuous and surge flow treatments tend to assume uniform values after 50 minutes intake opportunity time.

Table IX and Table X show the observed furrow intake rate at 10-minute and 40-minute intake opportunity times in all the treatments, respectively. At 10-minute opportunity time, the average furrow intake rates were 6.74 mm/min, 6.44 mm/min, 6.24 mm/min, and 6.24 mm/min for treatments SC, S1, S2, and S3, respectively. At the higher intake opportunity time of 40 minutes, the average intake rates were 1.79 mm/min (SC), 2.16 mm/min (S1), 1.67 mm/min (S2), and 1.58 mm/min (S3). The analysis of variance (Table XXXIV and Table XXXV, Appendix I) of the observed furrow intake rates in both the 10-minute and 40-minute intake opportunity time failed to show any significant differences among the treatment means. Although some differences in the observed intake rates between the surge flow and the continuous flow treatments

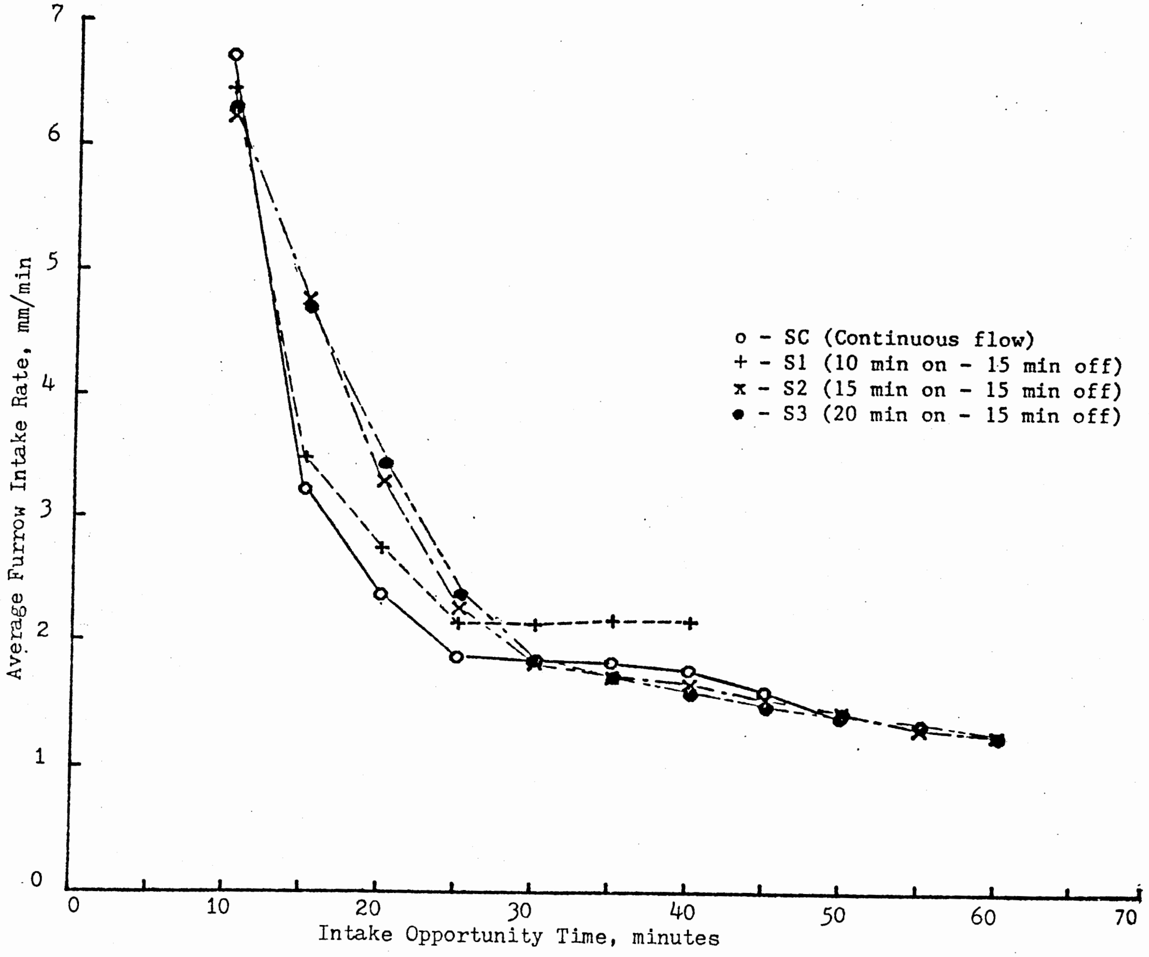

Figure 13. Average Furrow Intake Curves Under Surge and Continuous Flow Treatments

TABLE IX

FURROW INTAKE RATE AT 10 MINUTES INTAKE OPPORTUNITY TIME, MM/MIN

Treatment	Intake Rate, mm/min Replication 1	 2	 3	Total	Mean
SC	6.06	6.99	7.18	20.23	6.74
S1	7.38	6.33	5.60	19.31	6.44
S2	6.06	5.31	7.36	18.73	6.24
S3	7.48	5.31	6.11	18.90	6.30

TABLE X

FURROW INTAKE RATE AT 40 MINUTES INTAKE OPPORTUNITY TIME, MM/MIN

Treatment	Intake Rate, mm/min Replication 1	 2	 3	Total	Mean
SC	2.05	1.46	1.86	5.37	1.79
S1	2.38	2.57	1.52	6.47	2.16
S2	2.05	1.35	1.61	5.01	1.67
S3	1.63	1.34	1.76	4.73	1.58

were apparent, the statistical evidence was not sufficient to conclude that the surge flow treatments have higher intake rates than the continuous flow.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The experiments conducted in this study covered several important aspects of surge irrigation. This study consisted of two experiments namely, a) surge flow tests, and b) field simulation of surge flow in furrows.

The results of the water advance test showed that the shorter and more frequent surges in the furrows effected a comparatively higher rate of water advance in the furrow than did the continuous flow. Treatment T1 (15 min on - 15 min off) had an average rate of water advance of 0.7 m/min compared with 0.5 m/min in the continuous flow at an inflow rate of 30.2 l/min. At the higher inflow rate of 37.8 l/min, treatment T1 had an average water advance rate of 2.5 m/min as against 1.8 m/min in the continuous flow. The relatively higher water advance rate exhibited by treatment T1 compared with the continuous flow resulted to a lower average water application depth over the irrigated furrows. It follows that the distribution uniformity and application efficiency should be higher in treatment T1 than in continuous flow.

Based on the results of the surge flow field simulation using the furrow infiltrometer, the surge flow treatments and the continuous flow treatment tended to have uniform furrow intake rates at equal intake opportunity times. Therefore the relative improvement in furrow coverage of surge flow could not be ascribed wholly to the change in basic intake rates at subsequent surges during irrigation. This improvement could be due partly to the instantaneous surging with its accompanying inertia of water from the valves that pushed the remaining water farther down the furrow at every surge.

Despite the potential improvements of furrow irrigation in terms of furrow coverage, uniformity, and application efficiency by surge irrigation method, its practical application in the field can be offset by the capital investment that goes with the system. Therefore, its adaptability under Philippine conditions can not be firmly established at this stage until such time when its technical and economic aspects have been fully justified.

Field tests using short surges and larger inflow rates should be conducted to further verify the effects of surging on water advance following the methodology used herein. Separate studies may be conducted to determine furrow intake characteristics of the field under conditions of surge flow and continuous flow in order to be able to compare the furrow intake profiles between surge flow and continuous flow treatments.

LITERATURE CITED

1. Bishop, A. A. and W. R. Walker. 1981. "Surge Flow Update." Agricultural and Irrigation Engineering Department, Utah State University, Logan, Utah.

2. Bishop, A. A., W. R. Walker, N. L. Allen, and G. J. Poole. 1981. "Furrow Advance Rates Under Surge Flow Systems." PROCEEDINGS of the ASCE, Vol. 107, No. IR3, September, 1981.

3. Cabauatan, P. Z. 1981. Infiltration Rate of Cultivated Soils at Different Moisture Contents. (Unpub. Undergraduate Thesis, Central Luzon State University, Philippines).

4. Christiansen, J. E., A. A. Bishop, F. W. Kiefer Jr., and Yu-Si Fok. 1966. "Evaluation of Intake Rate Constants as Related to Water in Surface Irrigation." TRANSACTIONS of the ASAE, Vol. 3, No. 5, pp. 671 - 674.

5. Criddle, W. D., S. Davis, C. H. Pair, and D. G. Shockley. 1956. Methods for Evaluating Irrigation Systems. Agricultural Handbook No. 82, Soil Conservation Service, United States Department of Agriculture.

6. Elliott, R. L. and W. R. Walker. 1982. "Field Evaluation of Furrow Infiltration and Advance Functions." TRANSACTIONS of the ASAE, Vol. 25, No. 2, pp. 397 - 400.

7. Epperly, D. R., R. Elliott, and J. E. Garton. 1983. "An improved Furrow Flow Meter for Gated Pipe." Mimeo., Agricultural Engineering Department, Oklahoma State University.

8. Fangmeier, D. D. and M. K. Ramsey. 1978. "Intake Characteristics of Irrigation Furrows." TRANSACTIONS of the ASAE, Special Edition, Vol. 21SW 1978, pp. 696 - 700 and p. 705.

9. Haise, H. R., W. W. Donnan, J. T. Phelan, L. F. Lawhon, and D. G. Shockley. 1956. Cylinder Infiltrometers to Determine the Intake Characteristics of Irrigated Soils. Agricultural Research Service and Soil Conservation Service, United States Department of Agriculture, ARS 41-7, May, 1956.

10. Hillel, D. I. 1971. Soil and Water: Physical Principles and Practices. Academic Press Inc., New York, N. Y.

11. Irrinews. 1981. "Surge Flow." Newsletter of the International Irrigation Information Center, ISSN 0304-3606 No. 23, Canada.

12. Kotter, C. M. 1981. "Surge Flow Concept Causes Big Ripples in Surface Irrigation." Irrigation Age, March, 1981, pp. 22-23 and p. 28.

13. Lal, R. and A. C. Pandya. 1972. "Volume Balance Method for Computing Infiltration Rates in Surface Irrigation." TRANSACTIONS of the ASAE, Vol. 15, No. 1, pp. 69 - 72.

14. Malano, H. M. 1982. Comparison of the Infiltration Process Under Continuous and Surge Flow. (Unpub. Master's Thesis, Agricultural and Irrigation Engineering Department, Utah State University, Logan, Utah).

15. Musick, J. T., W. H. Sletten, and D. A. Dusek. 1973. "Evaluation of the Graded Furrow Irrigation with Length of Run on a Clay Loam Soil." TRANSACTIONS of the ASAE, Vol. 16, No. 6, pp. 1075 - 1080.

16. Quackenbush, T. H., G. M. Renfro, K. H. Beauchamp, L. F. Lawhon, and G. W. Eley. 1957. Conservation Irrigation in Humid Areas. Agriculture Handbook No. 107, Soil Conservation Service, United States Department of Agriculture, January, 1957.

17. Santos, A. H. and E. G. Caparas. 1981. Evaluation of Furrow Irrigation System in Cultivated Cropped and Uncropped Areas. (Unpub. Undergraduate Thesis, Department of Agricultural Engineering, Central Luzon State University, Philippines).

18. Singh, P. and H. S. Chauhan. 1973. "Determination of Water Intake Rate from Rate of Advance." TRANSACTIONS of the ASAE, Vol. 16, No. 6, pp. 1081 - 1084.

APPENDIX A

WATER ADVANCE DATA

TABLE XI

WATER ADVANCE DATA OF TREATMENT TC (CONTINUOUS FLOW), Q = 30.2 L/MIN

Time, min	Water Advance, m			Time, min	Water Advance, m		
	Replication				Replication		
	1	2	3		1	2	3
15	30	20	30	240	106	98	115
30	46	31	45	255	110	100	116
45	51	46	51	270	116	104	118
60	61	57	61	285	118	105	121
75	66	62	74	300	121	106	124
90	70	65	80	315	123	108	127
105	72	71	85	330	125	109	130
120	77	74	89	345	129	111	133
135	89	79	93	360	130	112	136
150	95	84	99	375	132	113	136
165	95	84	99	390	134	114	139
180	96	86	100				
195	96	90	104				
210	97	92	108				
225	100	95	110				

TABLE XII

WATER ADVANCE DATA OF TREATMENT T1 (15 min on - 15 min off)
Q = 30,2 L/MIN

Time, min	Water Advance, m Replication 1	 2	 3	Time, min	Water Advance, m Replication 1	 2	 3
15	25	35	26	195	67	89	78
45	35	52	44	225	73	93	89
75	42	58	50	255	78	100	95
105	55	68	59	285	87	107	100
135	61	78	65	315	102	116	105
165	62	84	68	375	112	131	116

TABLE XIII

WATER ADVANCE DATA OF TREATMENT T2 (30 min on - 15 min off)
Q = 30.2 L/MIN

Time, min	Water Advance, m Replication 1	 2	 3	Time, min	Water Advance, m Replication 1	 2	 3
15	30	24	26	210	86	60	65
30	50	29	37	240	90	63	69
60	56	42	48	255	99	69	77
75	60	48	51	285	102	74	83
105	62	49	52	300	103	78	89
120	71	53	57	330	109	81	94
150	77	55	61	345	116	95	103
165	82	58	64	375	120	97	110
195	85	60	65	390	123	113	119

TABLE XIV

WATER ADVANCE DATA OF TREATMENT T3 (45 min - 15 min off), Q = 30.2 L/MIN

Time, min	Water Advance, m Replication 1	2	3	Time, min	Water Advance, m Replication 1	2	3
15	21	31	18	225	103	118	97
30	32	46	30	255	114	125	108
45	40	58	40	270	121	140	114
75	52	60	42	285	127	149	118
90	58	64	47	315	135	156	121
105	68	75	54	330	138	160	126
135	75	78	61	345	147	165	133
150	77	84	63	375	156	176	137
165	82	85	64	390	158	177	140
195	89	99	77				
210	99	109	89				

TABLE XV

WATER ADVANCE DATA OF TREATMENT TC (CONTINUOUS FLOW), Q = 37.8 L/MIN

Time, min	Water Advance, m Replication 1	2	3	Time, min	Water Advance, m Replication 1	2	3
15	32	41	50	195	107	121	127
30	42	48	58	210	110	123	130
45	56	55	65	225	114	126	133
60	67	66	79	240	120	130	140
75	77	76	89	255	124	138	142
90	80	80	95	270	125	139	143
105	86	90	100	285	129	141	145
120	89	95	105	300	132	145	150
135	90	97	109	315	133	147	152
150	96	105	113	330	138	148	153
165	101	111	119	345	152	158	160
180	102	113	121				

TABLE XVI

WATER ADVANCE DATA OF TREATMENT T1 (15 min on - 15 min off), Q = 37.8 L/MIN

Time, min	Water Advance, m			Time, min	Water Advance, m		
	Replication				Replication		
	1	2	3		1	2	3
15	55	35	43	225	125	106	115
45	75	61	63	255	130	110	120
75	85	70	76	285	139	113	128
105	96	83	86	315	143	117	133
135	101	90	91	345	145	120	141
165	106	96	100	375	150	127	143
195	117	101	110	405	160	132	160

TABLE XVII

WATER ADVANCE DATA OF TREATMENT T2 (30 min on - 15 min off), Q = 37.8 L/MIN

Time, min	Water Advance, m			Time, min	Water Advance, m		
	Replication				Replication		
	1	2	3		1	2	3
15	46	55	50	210	120	134	112
30	62	70	60	240	128	145	122
45	70	77	62	255	130	145	124
75	78	89	72	285	140	153	132
105	88	100	85	300	140	153	133
120	95	106	90	330	147	153	141
150	102	119	93	345	148	163	150
165	109	119	95	375	153	170	153
195	114	125	103				

TABLE XVIII

WATER ADVANCE DATA OF TREATMENT T3 (45 min on - 15 min off), Q = 37.8 L/MIN

Time, min	Water Advance, m Replication 1	2	3	Time, min	Water Advance, m Replication 1	2	3
15	42	29	39	210	114	102	126
30	58	42	54	225	118	105	128
45	67	48	71	255	123	119	132
75	78	62	75	270	128	124	140
90	90	70	90	285	132	130	144
105	95	77	101	315	135	140	154
135	103	81	110	330	135	140	154
150	107	87	114	345	137	141	154
165	109	90	116	375	142	150	158
195	112	100	124	390	142	150	158
				405	144	150	158

APPENDIX B

SAMPLE STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION OF WATER ADVANCE DATA

TABLE XIX

STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF WATER ADVANCE DATA OF TREATMENT TC AND T1, Q = 30.2 L/MIN

Time, min	Treatment TC				Treatment T1			
	Y	S(m)	CV(%)	CV/Y	Y	S(m)	CV(%)	CV/Y
15	26.7	5.80	21.62	0.81	28.7	5.51	19.19	0.67
30	40.7	8.39	20.61	0.51	43.7	8.50	19.46	0.45
45	49.3	2.89	5.86	0.12	50.0	8.00	16.00	0.32
60	59.7	2.31	3.87	0.06	60.7	6.66	10.97	0.18
75	67.3	6.11	9.08	0.13	68.0	8.89	13.07	0.19
90	71.7	7.64	10.65	0.15	71.3	11.37	15.95	0.22
105	76.0	7.81	10.28	0.14	78.0	11.00	14.10	0.18
120	80.0	7.94	9.92	0.12	85.0	10.58	12.45	0.15
135	87.0	7.21	8.29	0.10	91.0	11.53	12.67	0.14
150	92.7	7.77	8.38	0.09	98.0	10.15	10.36	0.11
165	92.7	7.77	8.38	0.09	107.7	7.37	6.84	0.06
180	94.0	7.21	7.67	0.08	119.7	10.02	8.37	0.07
Mean		6.57	10.38	0.20		9.13	13.29	0.23

Y = water advance, m; S(m) = Std. dev. in meters; CV = Coeff. of Var. in percent.

TABLE XX

STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF WATER ADVANCE DATA OF TREATMENT T2 AND T3, Q = 30.2 L/MIN

Time, min	Treatment T2				Treatment T3			
	Y	S(m)	CV(%)	CV/Y	Y	S(m)	CV(%)	CV/Y
15	26.7	3.06	11.44	0.43	23.3	6.81	29.21	1.25
30	38.7	10.60	27.39	0.71	36.0	8.72	24.20	0.45
45	48.7	7.02	14.42	0.30	46.0	10.39	22.59	0.49
60	53.0	6.25	11.78	0.22	51.3	9.02	17.58	0.34
75	54.3	6.81	12.54	0.23	56.3	8.62	15.31	0.27
90	60.3	9.45	15.67	0.26	65.7	10.69	16.28	0.25
105	64.3	11.37	17.68	0.28	71.3	9.07	12.73	0.18
120	68.0	12.49	18.37	0.27	74.7	10.69	14.31	0.19
135	70.0	13.23	18.90	0.27	77.0	11.36	14.75	0.19
150	70.3	13.80	19.62	0.28	88.3	11.02	12.47	0.14
165	74.0	14.18	19.16	0.26	99.0	10.00	10.10	0.10
180	81.7	15.53	19.01	0.23	106.0	10.82	10.20	0.10
Mean		10.32	17.17	0.31		9.77	16.64	0.33

Y = water advance, m; S(m) = Std. dev. in meters; CV = Coeff. of Var. in percent

TABLE XXI

STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF WATER ADVANCE DATA OF TREATMENT TC AND T1, Q = 37.8 L/MIN

Time, min	Treatment TC				Treatment T1			
	Y	S(m)	CV(%)	CV/Y	Y	S(m)	CV(%)	CV/Y
15	41.0	9.00	21.95	0.54	44.3	10.07	22.72	0.51
30	49.3	8.08	16.40	0.33	66.3	7.57	11.42	0.17
45	58.7	5.51	9.38	0.16	77.0	7.55	9.80	0.13
60	70.7	7.23	10.23	0.14	88.3	6.81	7.71	0.09
75	80.7	7.23	8.96	0.11	94.0	6.08	6.47	0.07
90	85.0	8.66	10.19	0.12	100.7	5.03	5.00	0.05
105	92.0	7.21	7.83	0.09	109.3	8.02	7.34	0.07
120	96.3	8.08	8.39	0.09	115.3	9.50	8.24	0.07
135	98.7	9.61	9.74	0.10	120.0	10.00	8.33	0.07
150	104.7	8.50	8.12	0.08	126.7	13.05	10.30	0.08
165	110.3	9.01	8.18	0.07	131.0	13.11	10.01	0.08
180	112.0	9.54	8.52	0.08	135.3	13.43	9.93	0.07
195	118.3	10.26	8.68	0.07	140.0	11.79	8.42	0.06
210	121.0	10.15	8.39	0.07	150.7	16.17	10.73	0.07
Mean		8.43	10.35	0.14		9.87	9.74	0.11

Y = water advance, m; S(m) = Std. dev. in meters; CV = Coeff. of Var. in percent.

TABLE XXII

STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF WATER ADVANCE DATA OF TREATMENT T2 AND T3, Q = 37.8 L/MIN

	Treatment T2				Treatment T3			
Time,	Y	S(m)	CV(%)	CV/Y	Y	S(m)	CV(%)	CV/Y
15	50.3	4.51	8.96	0.18	36.7	6.81	18.55	0.51
30	64.0	5.29	8.27	0.13	51.3	8.33	16.23	0.32
45	69.7	7.51	10.77	0.15	62.0	12.82	19.82	0.32
60	79.7	8.62	10.82	0.14	71.7	8.50	11.86	0.17
75	91.0	7.94	8.72	0.10	83.3	11.55	13.86	0.17
90	97.0	8.19	8.44	0.09	91.0	12.49	13.73	0.15
105	104.7	13.20	12.61	0.12	98.0	15.13	15.44	0.16
120	107.7	12.06	11.19	0.10	102.7	14.01	13.64	0.13
135	114.0	11.00	9.65	0.08	105.0	13.45	12.81	0.12
150	122.0	11.14	9.13	0.07	112.0	12.00	10.71	0.10
165	131.7	11.93	9.06	0.07	114.0	12.00	10.53	0.08
180	133.0	10.82	8.13	0.06	117.0	11.53	9.86	0.08
195	141.7	10.60	7.48	0.05	124.7	6.66	5.34	0.04
210	142.0	10.15	7.15	0.05	130.7	8.33	6.37	0.05
Mean		9.50	9.31	0.10		10.93	12.77	0.17

Y = water advance, m; S(m) = Std. dev. in meters; CV = Coeff. of Var. in percent.

APPENDIX C

WATER ADVANCE CURVES UNDER SURGE AND CONTINUOUS FLOWS IN FURROWS

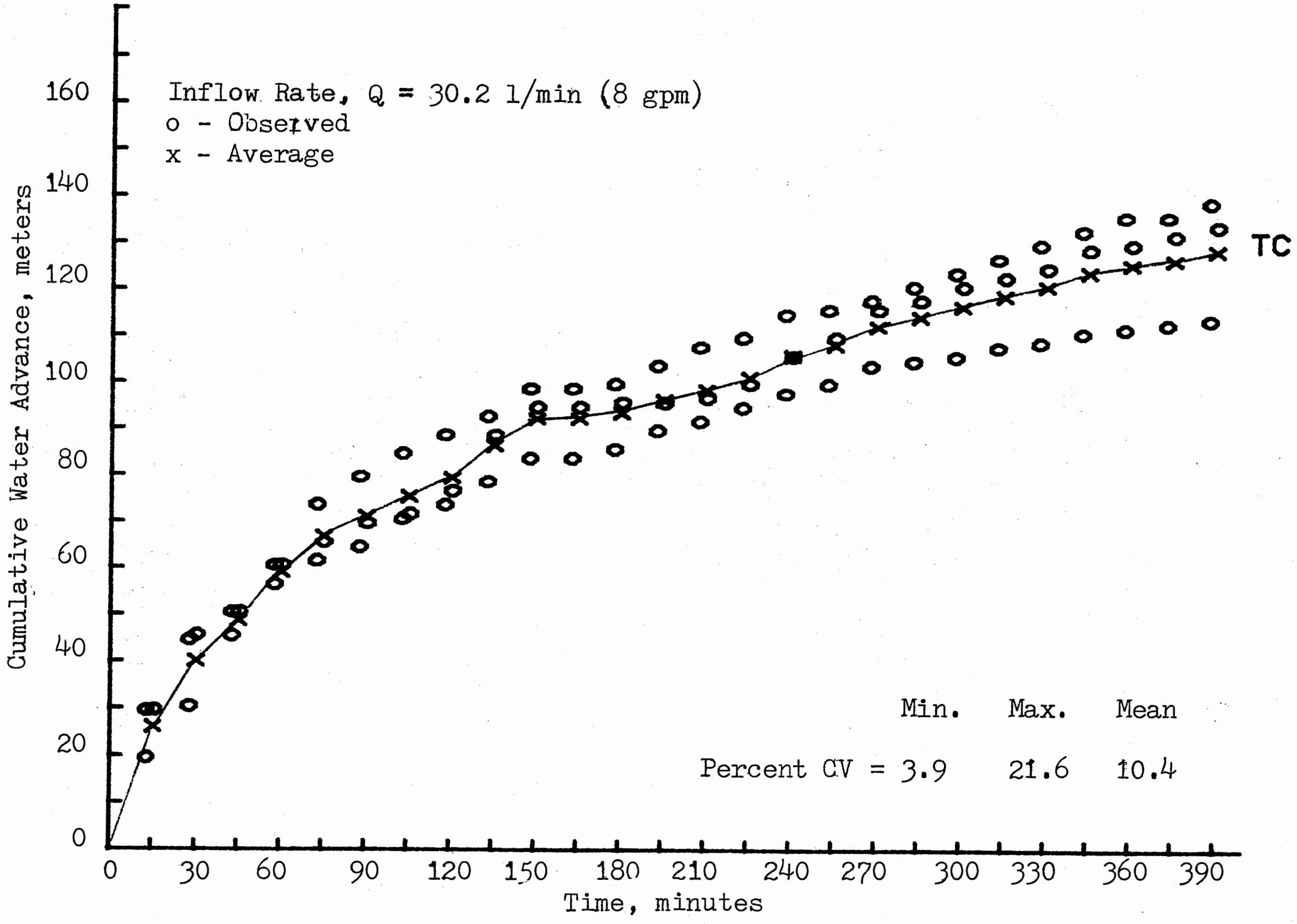

Figure 14. Cumulative Water Advance Along the Furrows Under Treatment TC (Continuous Flow), Q = 30.2 l/min

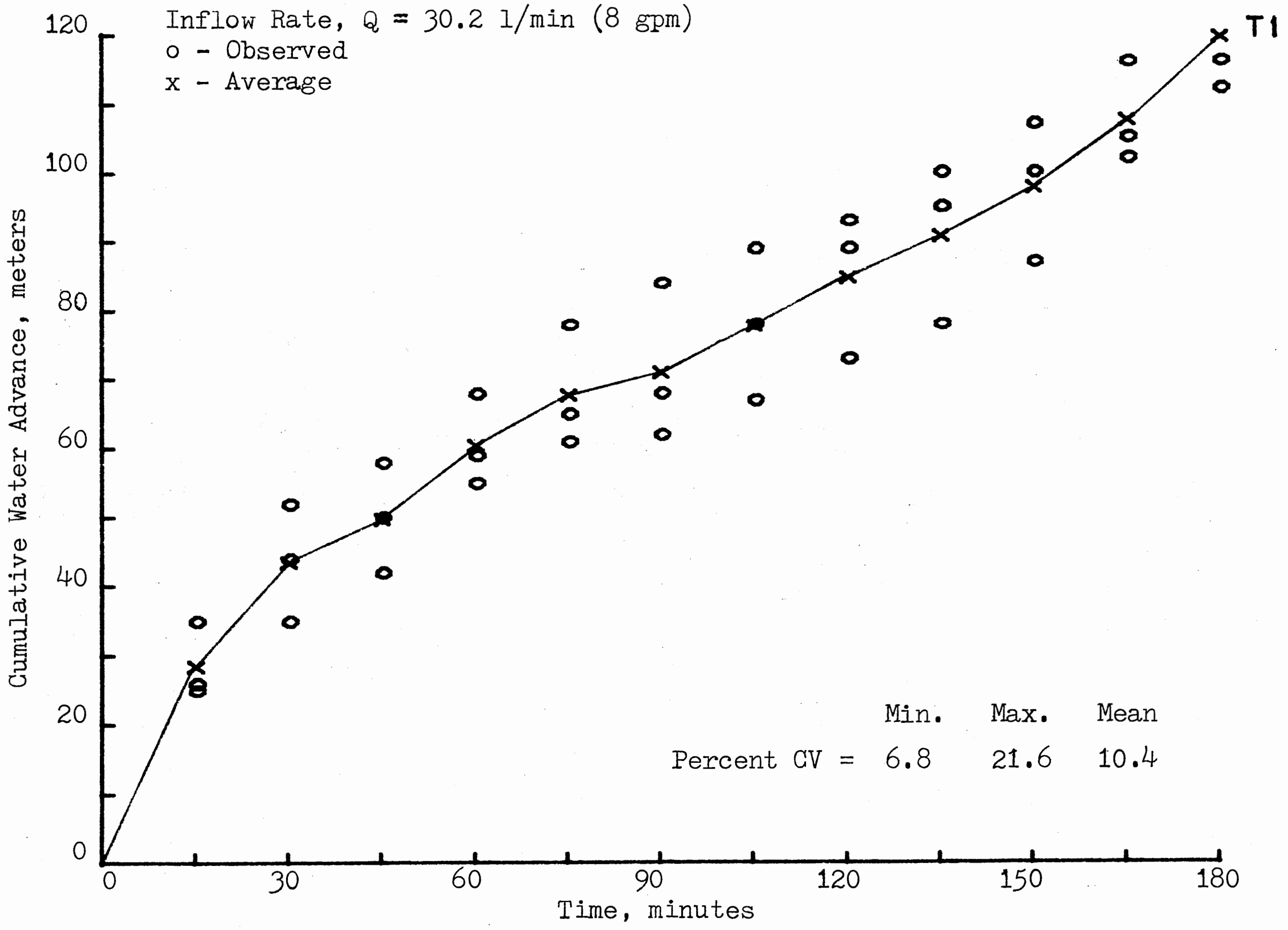

Figure 15. Cumulative Water Advance Along the Furrows Under Treatment T1 (15 min on - 15 min off), Q = 30.2 l/min

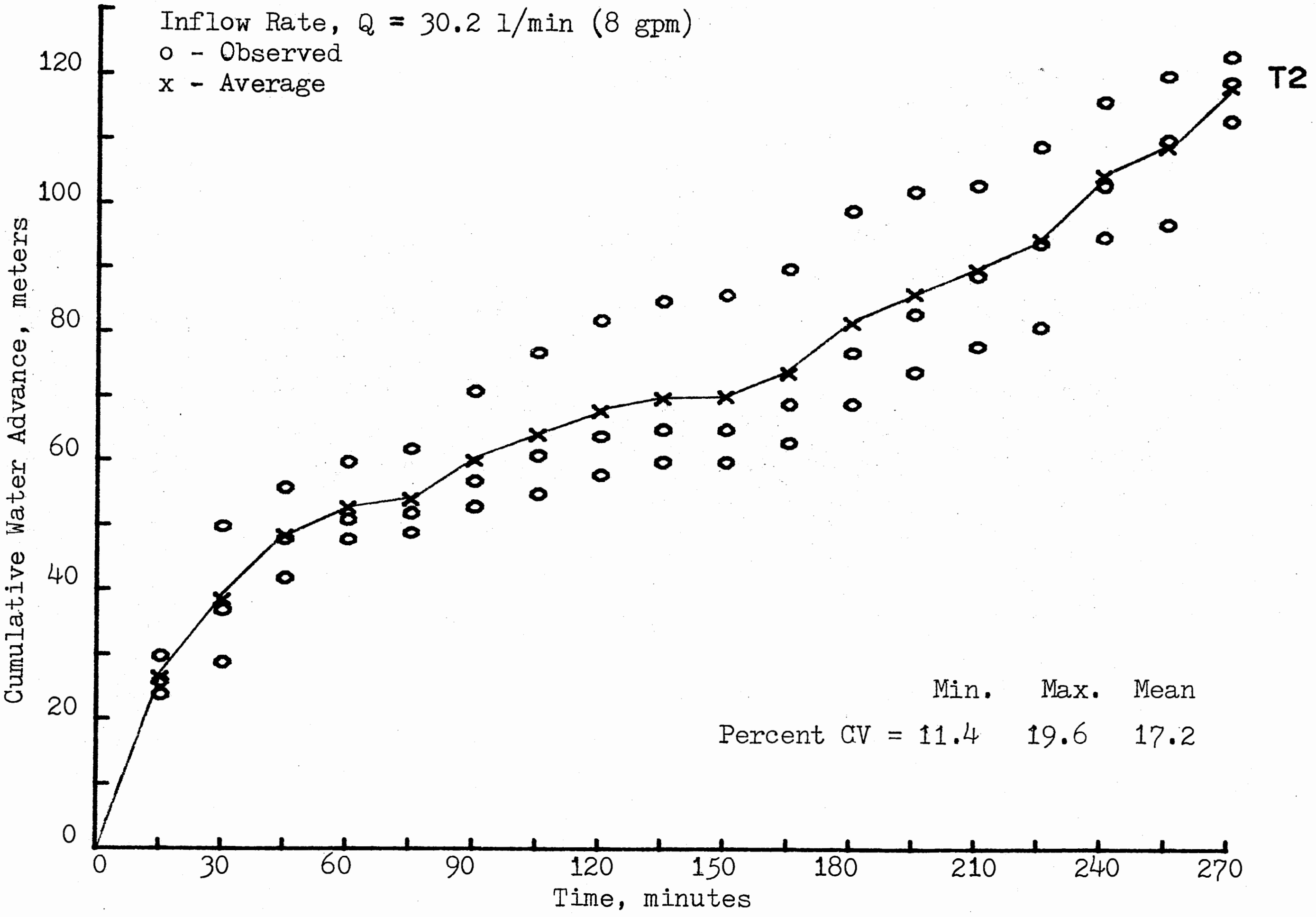

Figure 16. Cumulative Water Advance Along the Furrows Under Treatment T2 (30 min on - 15 min off), Q = 30.2 l/min

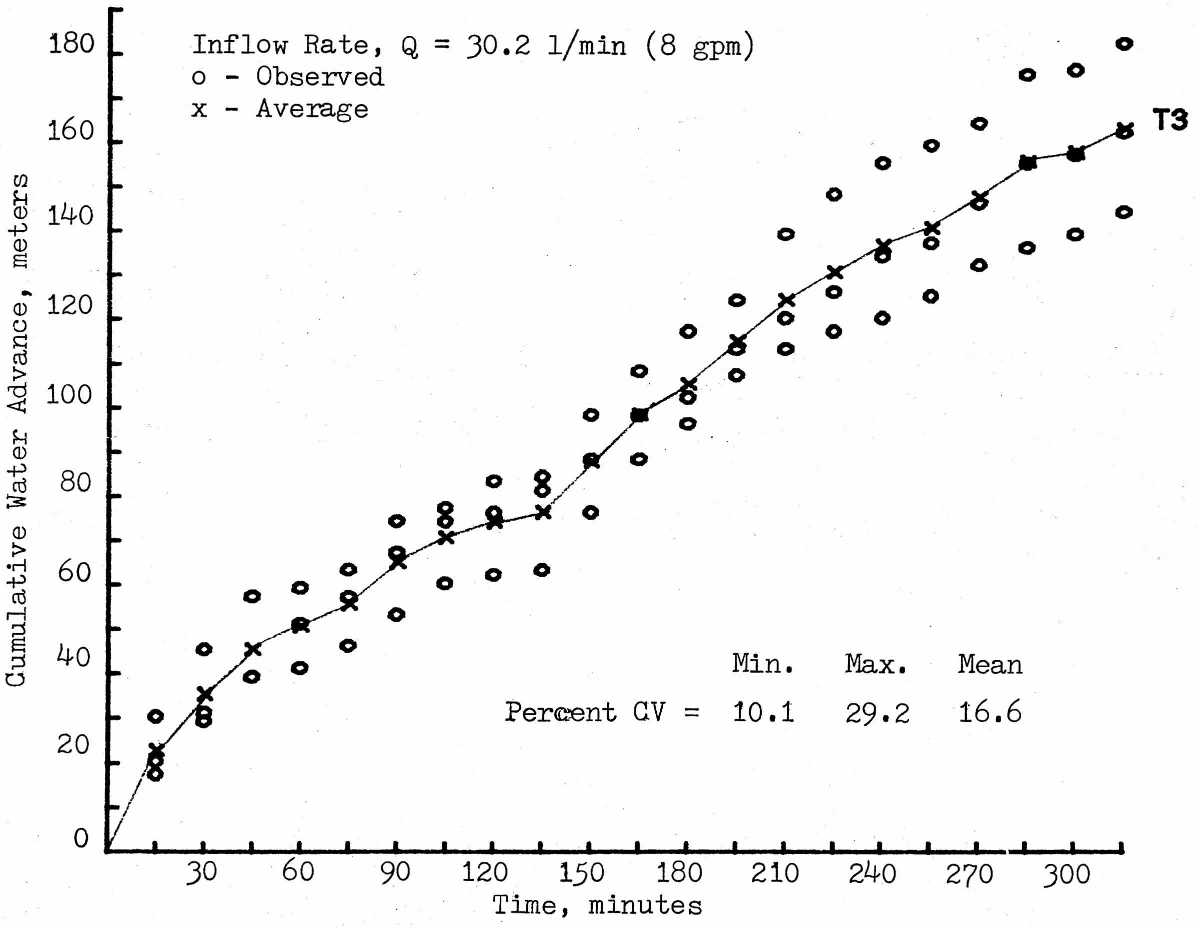

Figure 17. Cumulative Water Advance Along the Furrows Under Treatment T3 (45 min on - 15 min off), Q = 30.2 l/min

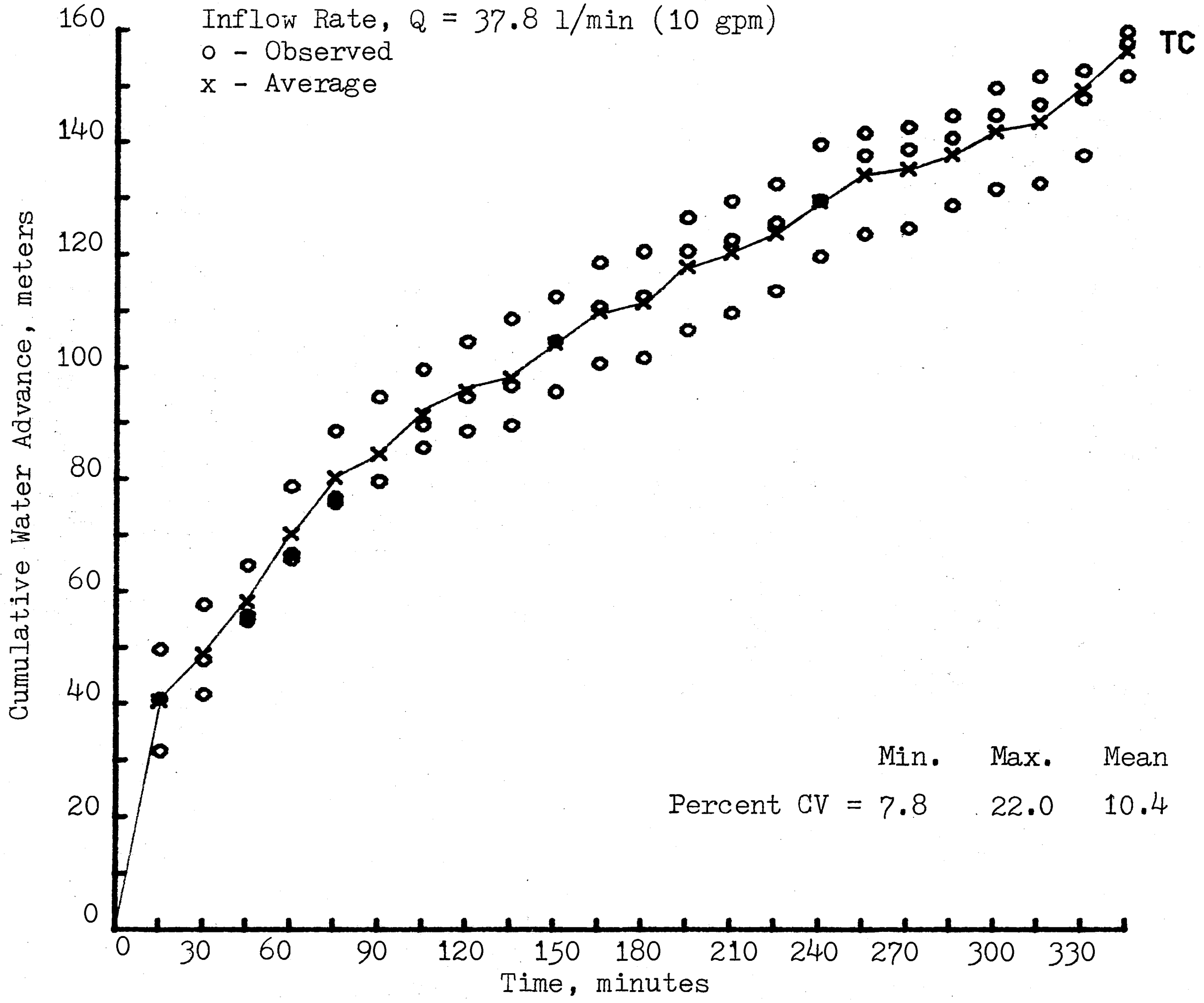

Figure 18. Cumulative Water Advance Along the Furrows Under Treatment TC (Continuous Flow), Q = 37.8 l/min

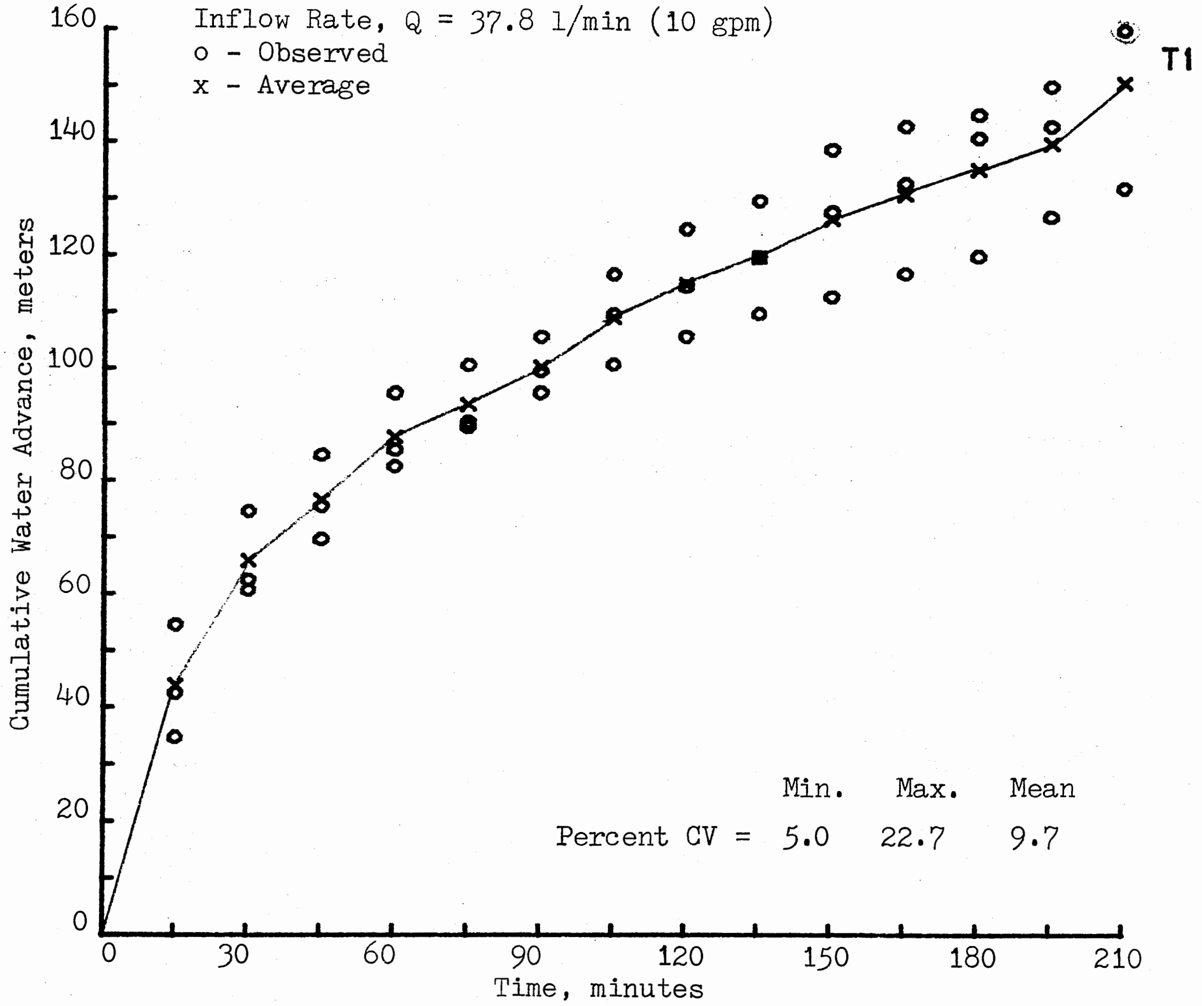

Figure 19. Cumulative Water Advance Along the Furrows Under Treatment T1 (15 min on - 15 min off), Q = 37.8 l/min

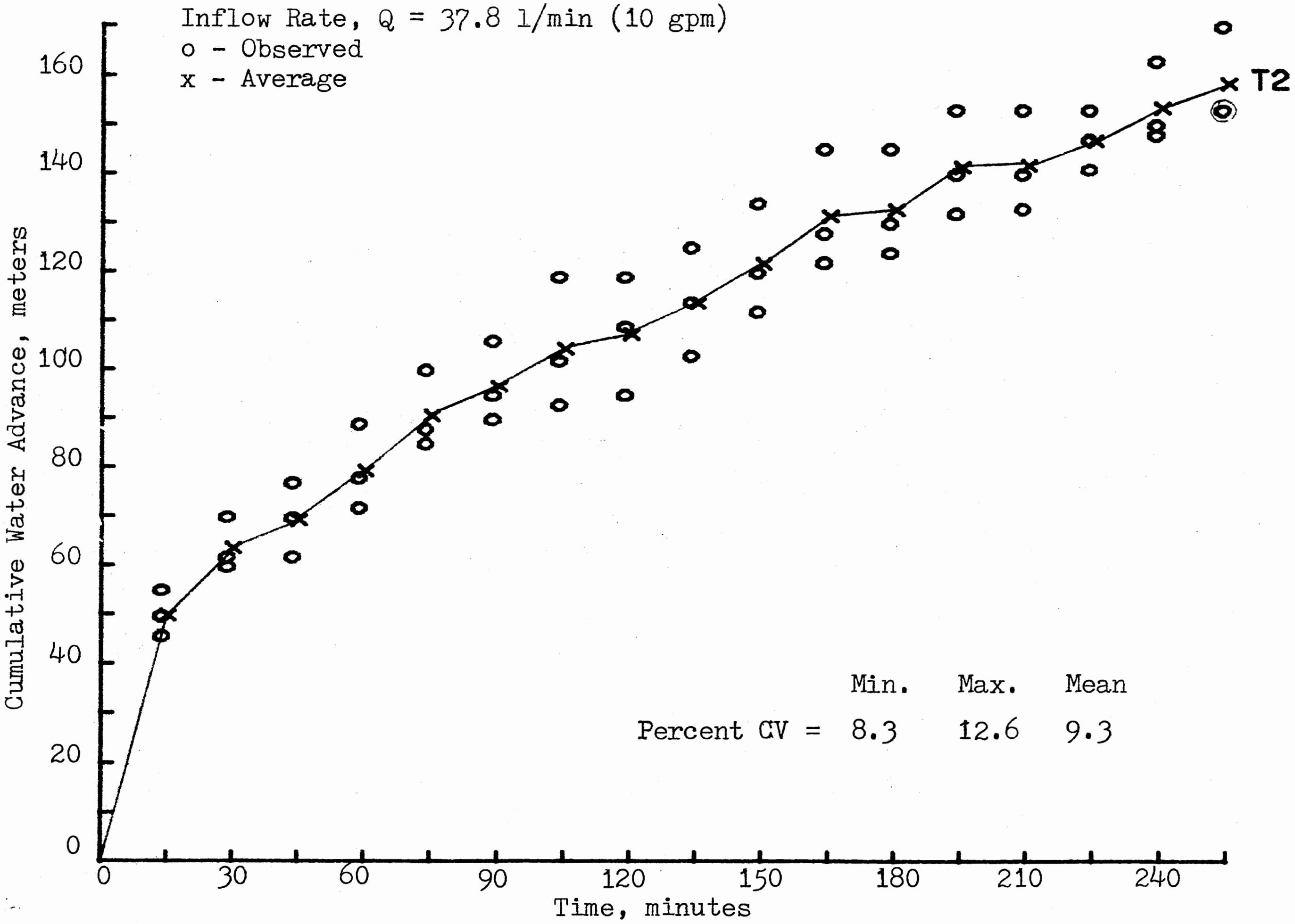

Figure 20. Cumulative Water Advance Along the Furrows Under Treatment T2 (30 min on - 15 min off), Q = 37.8 l/min

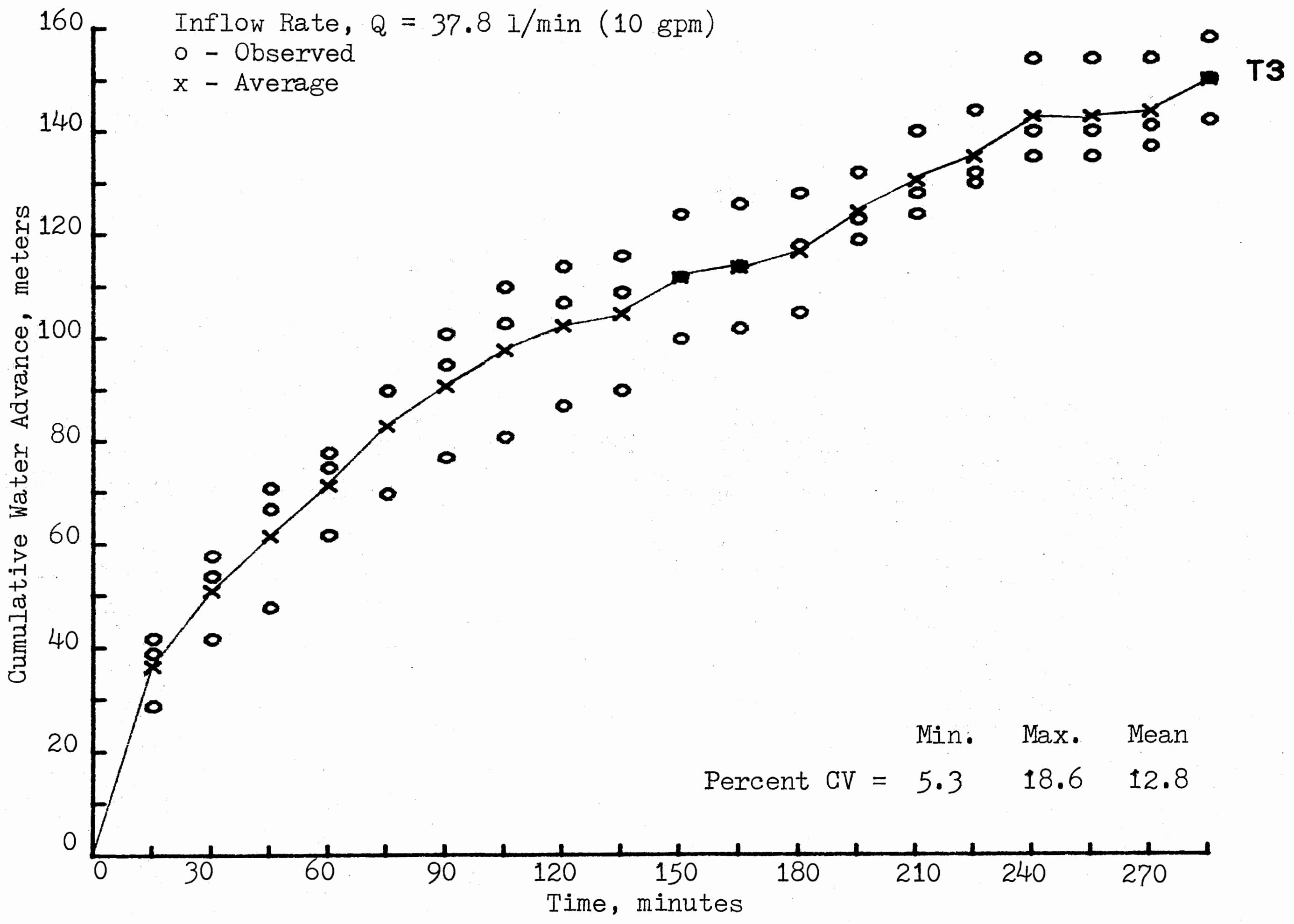

Figure 21. Cumulative Water Advance Along the Furrow Under Treatment T3 (45 min on - 15 min off), Q = 37.8 l/min

APPENDIX D

ANALYSIS OF VARIANCE AND COMPARISON AMONG MEANS ON THE AVERAGE RATE OF WATER ADVANCE

TABLE XXIII

ANALYSIS OF VARIANCE TABLE - AVERAGE RATE OF WATER ADVANCE IN M/MIN, Q = 30.2 L/MIN

Sources of Variation	DF	SS	MS	$F_{.05}$	Fc
Treatment	3	0.0728	0.0243	3.59	5.85*
Error	8	0.0332	0.0042		
Total	11	0.106			

*Significant at 5% level.

TABLE XXIV

ANALYSIS OF VARIANCE TABLE - AVERAGE RATE OF WATER ADVANCE IN M/MIN, Q = 37.8 L/MIN

Sources of Variation	DF	SS	MS	$F_{.05}$	Fc
Treatment	3	0.0894	0.0298	3.59	5.84*
Error	8	0.0408	0.0051		
Total	11	0.1302			

*Significant at 5% level.

TABLE XXV

COMPARISON AMONG MEANS TABLE - AVERAGE RATE OF WATER ADVANCE IN M/MIN, Q = 30.2 L/MIN

Treatment	Mean*
T1	0.66
T3	0.59
TC	0.52
T2	0.45

$$LSD = t_{.05} \times S_d$$

$$S_d = \sqrt{\frac{2S^{2**}}{r}} = \sqrt{\frac{2(0.004)}{3}}$$

$$= 0.0526$$

$$LSD = 2.306 \times 0.0526$$

$$= 0.12$$

TABLE XXVI

COMPARISON AMONG MEANS TABLE - AVERAGE RATE OF WATER ADVANCE IN M/MIN, Q = 37.8 L/MIN

Treatment	Mean*
T1	0.84
T2	0.79
T3	0.73
TC	0.61

$$LSD = t_{.05} \times S_d$$

$$S_d = \sqrt{\frac{2S^{2**}}{r}} = \sqrt{\frac{2(0.005)}{3}}$$

$$= 0.0825$$

$$LSD = 2.306 \times 0.0825$$

$$= 0.19$$

* Treatment means underscored by the same line have no significant differences at 5% level.

** S^2 = error mean square.

APPENDIX E

ANALYSIS OF VARIANCE AND COMPARISON AMONG MEANS ON THE AVERAGE DEPTH OF WATER APPLICATION

TABLE XXVII

ANALYSIS OF VARIANCE TABLE - AVERAGE DEPTH OF WATER APPLIED IN 100 METERS OF IRRIGATED FURROW IN CM, Q = 30.2 L/MIN

Sources of Variation	DF	SS	MS	$F_{.05}$	Fc
Treatment	3	11.56	3.85	3.59	4.88*
Error	8	6.36	0.79		
Total	11	17.92			

*Significant.

TABLE XXVIII

ANALYSIS OF VARIANCE TABLE - AVERAGE DEPTH OF WATER APPLIED IN 100 METERS OF IRRIGATED FURROW IN CM, Q = 37.8 L/MIN

Sources of Variation	DF	SS	MS	$F_{.05}$	Fc
Treatment	3	2.06	0.69	3.59	1.06^{ns}
Error	8	5.16	0.65		
Total	11				

ns = not significant.

TABLE XXIX

COMPARISON AMONG MEANS TABLE - AVERAGE DEPTH OF WATER APPLIED IN CM, Q = 30.2 L/MIN

Treatment	Mean*			
T2	6.78	│		
TC	6.65	│	│	
T3	5.07		│	│
T1	4.51			│

$$LSD = t_{.05} \times S_d$$

$$S_d = \sqrt{\frac{2S^{2**}}{r}} = \sqrt{\frac{2(0.79)}{3}}$$

$$= 0.726$$

$$LSD = 2.306 \times 0.726$$

$$= 1.67$$

---

* Treatment means underscored by the same line have no significant differences at 5% level.

** S^2 = error mean square.

APPENDIX F

FURROW INTAKE RATE DATA

TABLE XXX

FURROW INTAKE RATE DATA FOR TREATMENT SC (CONTINUOUS FLOW)

Intake Opport. Time, min	Furrow Intake Rate, mm/min Blocks 1	2	3	Mean
10	6.06	6.99	7.18	6.74
15	4.33	2.68	2.75	3.25
20	2.60	1.99	2.57	2.39
25	1.54	1.76	2.38	1.89
30	1.77	1.65	2.17	1.86
35	2.01	1.53	2.00	1.85
40	2.05	1.46	1.86	1.79
45	1.68	1.39	1.78	1.62
50	1.32	1.22	1.72	1.42

TABLE XXXI

FURROW INTAKE RATE DATA FOR TREATMENT S1 (10 MIN ON - 15 MIN OFF)

Intake Opport. Time, min	Furrow Intake Rate, mm/min Blocks 1	2	3	Mean
10	7.38	6.33	5.60	6.44
15	2.50	5.48	2.47	3.48
20	2.51	3.79	1.93	2.74
25	2.47	2.51	1.40	2.13
30	2.34	2.52	1.51	2.12
35	2.29	2.54	1.64	2.16
40	2.38	2.57	1.52	2.16

TABLE XXXII

FURROW INTAKE RATE DATA FOR TREATMENT S2 (15 MIN ON - 15 MIN OFF)

Intake Opport. Time, min	Furrow Intake Rate, mm/min			Mean
	Blocks			
	1	2	3	
10	6.06	5.31	7.36	6.24
15	4.33	4.33	5.67	4.78
20	2.60	3.34	3.98	3.31
25	1.54	2.35	2.92	2.27
30	1.77	1.35	2.37	1.83
35	2.01	1.34	1.82	1.72
40	2.05	1.35	1.61	1.67
45	1.68	1.35	1.63	1.55
50	1.32	1.36	1.67	1.45
55	1.07	1.24	1.64	1.32
60	1.09	1.11	1.60	1.27

TABLE XXXIII

FURROW INTAKE RATE DATA FOR TREATMENT S3 (20 MIN ON - 15 MIN OFF)

Intake Opport. Time, min	Furrow Intake Rate, mm/min			Mean
	Blocks			
	1	2	3	
10	7.48	5.31	6.11	6.30
15	4.72	4.33	5.05	4.70
20	3.00	3.34	3.99	3.44
25	1.83	2.35	2.93	2.37
30	1.76	1.36	2.39	1.84
35	1.70	1.34	2.08	1.71
40	1.63	1.34	1.76	1.58
45	1.52	1.35	1.57	1.48
50	1.33	1.36	1.61	1.43
55	1.15	1.24	1.64	1.34
60	0.95	1.11	1.68	1.25

APPENDIX G

SAMPLE STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION OF FURROW INTAKE RATE DATA

TABLE XXXIV

STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF FURROW INTAKE RATE DATA OF TREATMENTS SC (CONTINUOUS FLOW) AND S1 (10 MIN ON - 15 MIN OFF)

Intake Opport. Time, min	Trt. SC (Continuous Flow)			Trt. S1 (10 min on - 15 min off)		
	Mean mm/min	Std. Dev. mm/min	CV Percent	Mean mm/min	Std. Dev. mm/min	CV Percent
10	6.74	0.85	8.89	6.44	0.89	13.89
15	3.25	0.93	28.71	3.48	1.73	49.97
20	2.39	0.34	14.39	2.74	0.95	34.72
25	1.89	0.44	23.04	2.13	0.63	29.57
30	1.86	0.27	14.64	2.12	0.54	25.45
35	1.85	0.27	14.83	2.16	0.46	21.41
40	1.79	0.30	16.82	2.16	0.56	25.90
45	1.62	0.20	12.50			
50	1.42	0.26	18.63			
Mean		0.43	16.94		0.82	28.70

TABLE XXXV

STANDARD DEVIATION AND COEFFICIENT OF VARIATION OF FURROW INTAKE RATE DATA OF TREATMENTS S2 (15 MIN ON - 15 MIN OFF) AND S3 (20 MIN ON - 15 MIN OFF)

Intake Opport. Time, min	Trt. S2 (15 min on - 15 min off)			Trt. S3 (20 min on - 15 min off)		
	Mean mm/min	Std. Dev. mm/min	CV Percent	Mean mm/min	Std. Dev. mm/min	CV Percent
10	6.24	1.04	16.62	6.30	1.10	17.42
15	4.78	0.77	16.19	4.70	0.36	7.67
20	3.31	0.69	20.86	3.44	0.50	14.62
25	2.27	0.69	30.55	2.37	0.55	23.22
30	1.83	0.51	28.01	1.84	0.52	28.22
35	1.72	0.35	20.08	1.71	0.37	21.64
40	1.67	0.36	21.32	1.58	0.22	13.61
45	1.55	0.18	11.47	1.48	0.12	7.79
50	1.45	0.19	13.21	1.43	0.15	10.75
55	1.32	0.29	22.17	1.34	0.26	19.47
60	1.27	0.29	22.74	1.25	0.38	30.70
Mean		0.51	20.11		0.41	17.74

APPENDIX H

FURROW INTAKE RATE CURVES UNDER SURGE AND CONTINUOUS FLOW

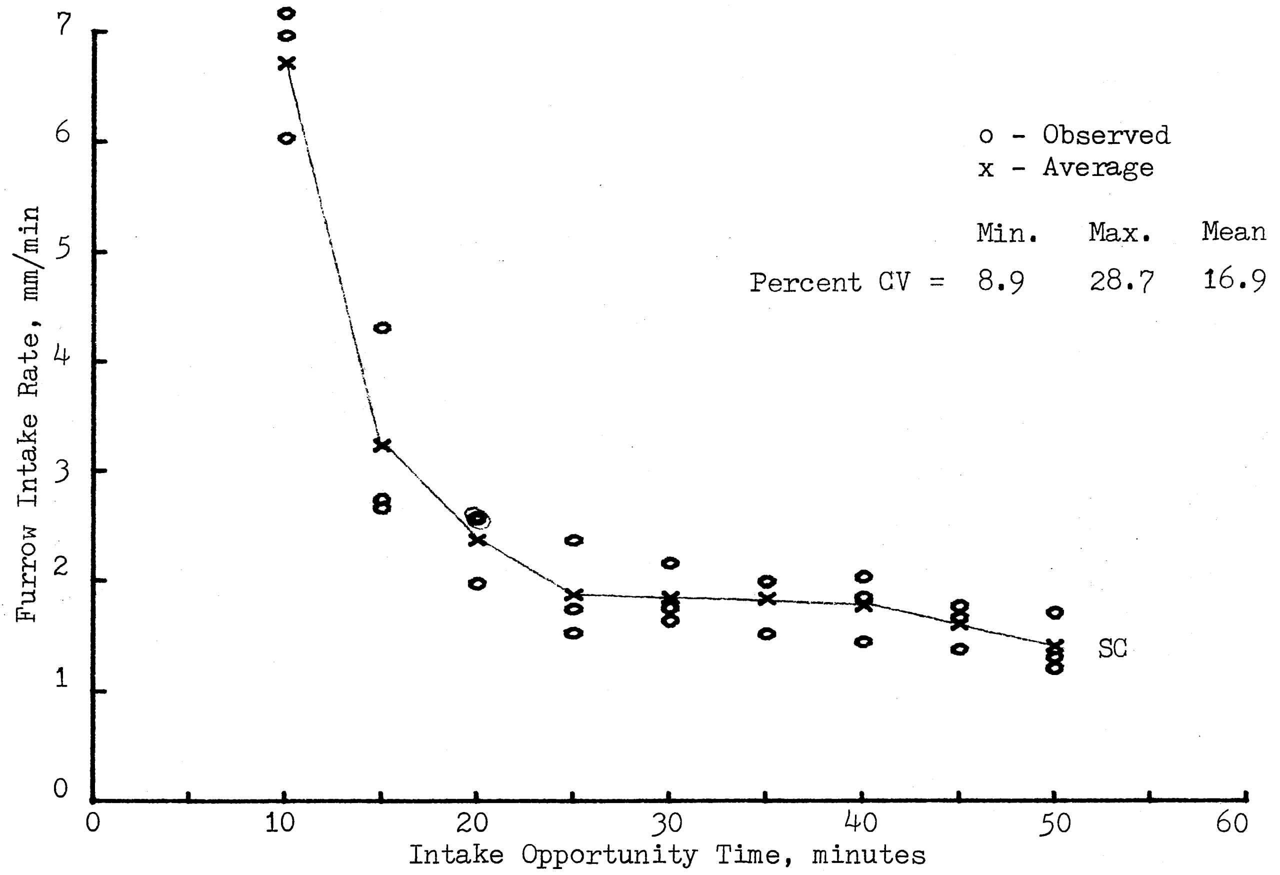

Figure 22. Intake Rate Curve of Treatment SC (Continuous Flow) in Irrigated Furrow.

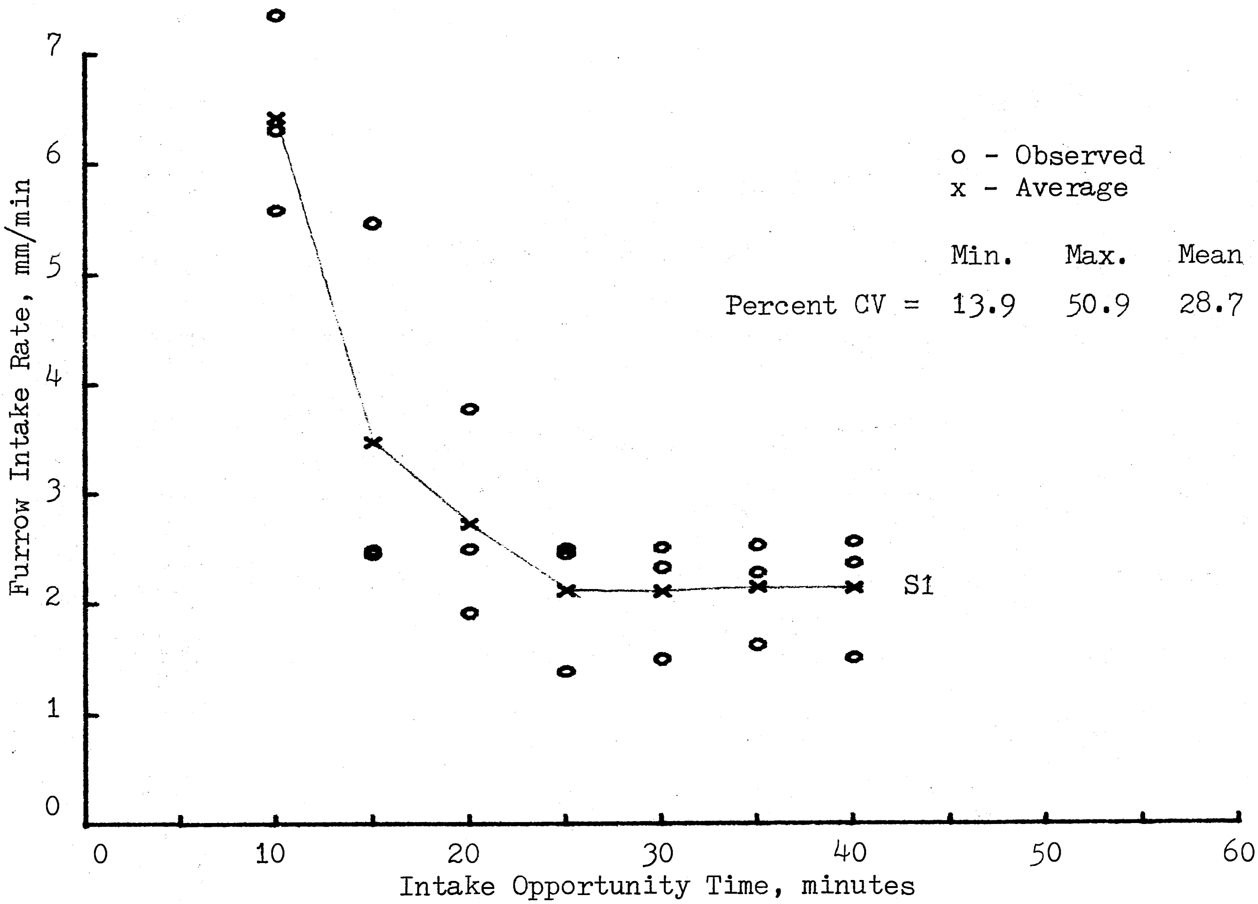

Figure 23. Intake Rate Curve of Treatment (10 min on - 15 min off) in Surge Irrigated Furrow

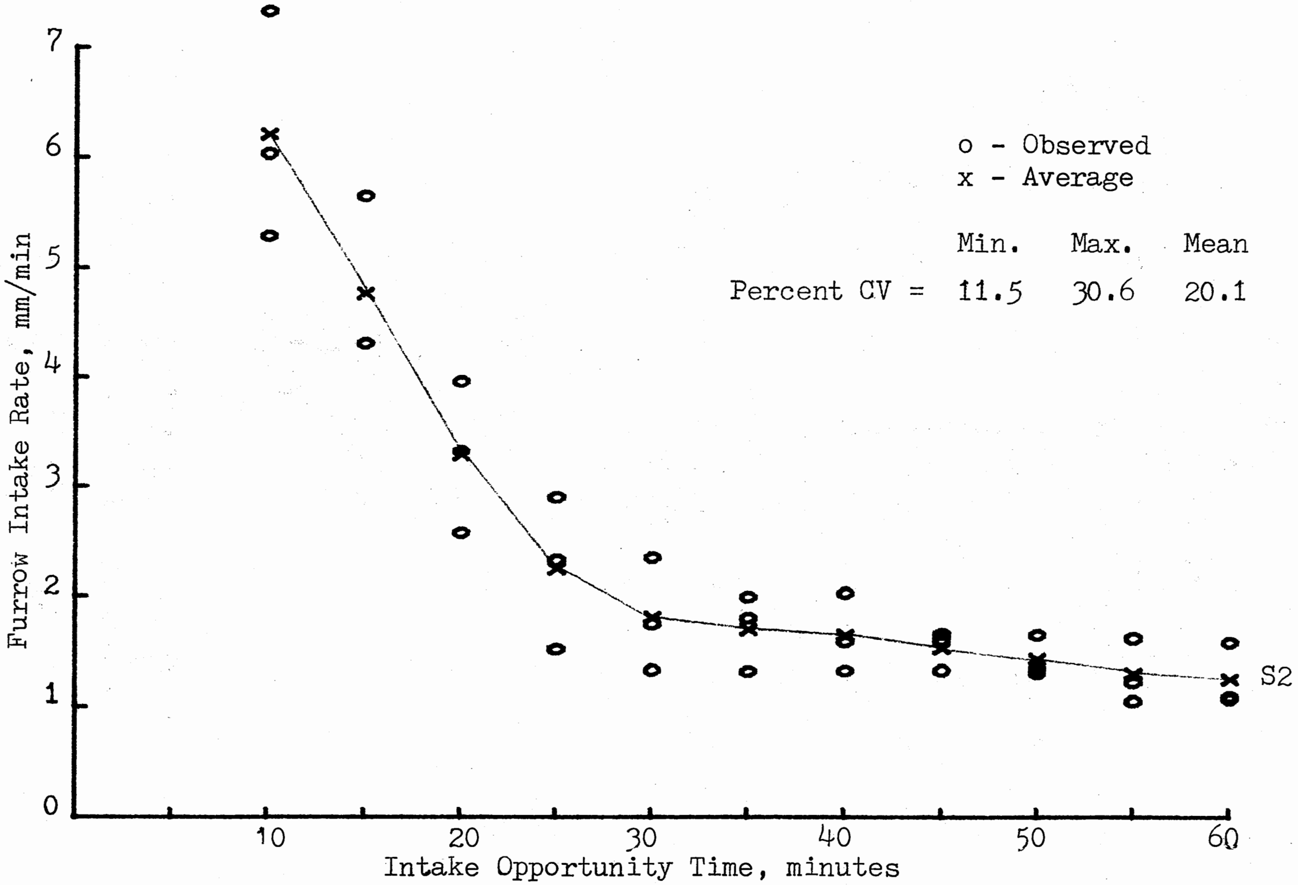

Figure 24. Intake Rate Curve of Treatment (15 min on - 15 min off) in Surge Irrigated Furrow

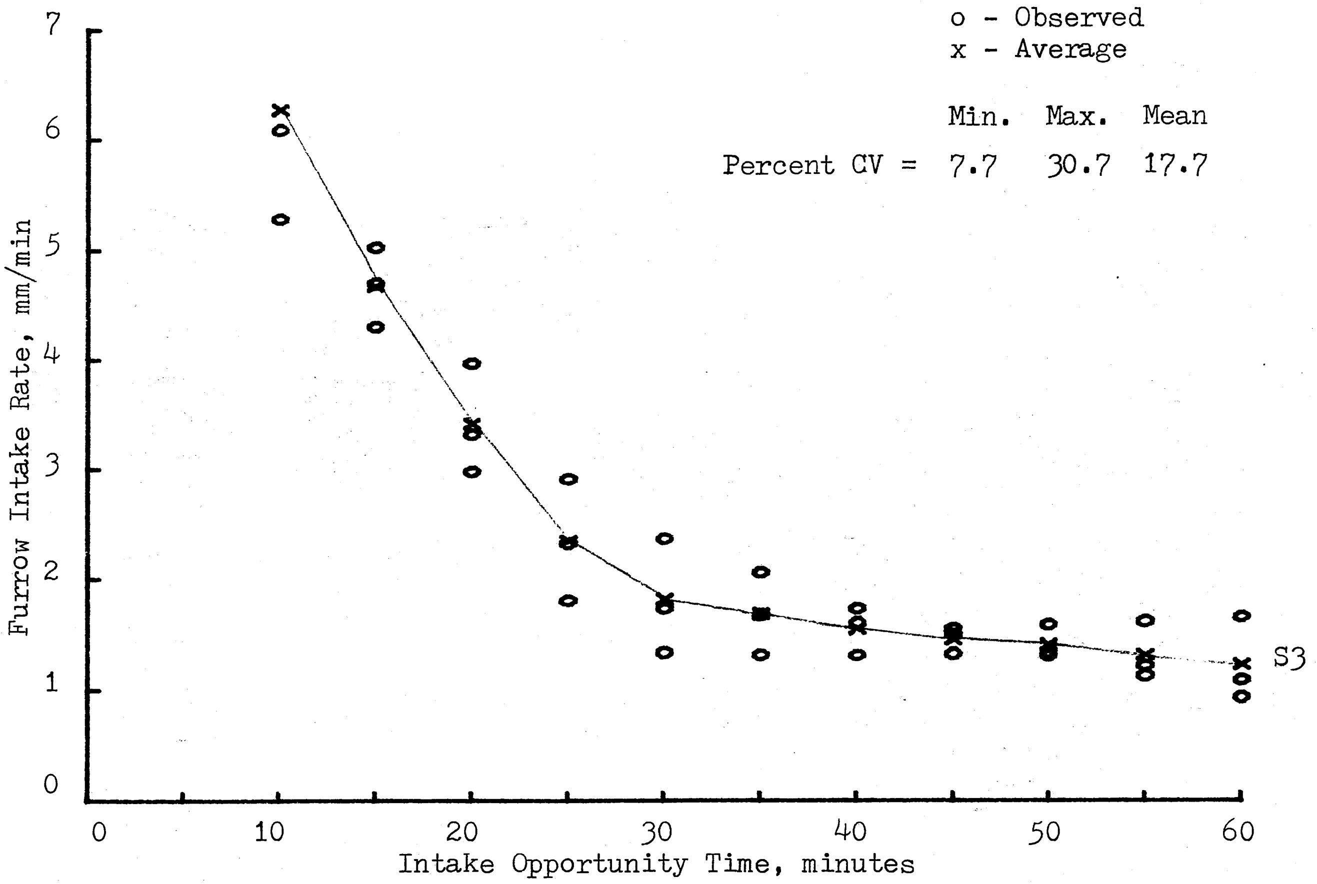

Figure 25. Intake Rate Curve of Treatment (20 min - 15 min off) in Surge Irrigated Furrow

APPENDIX I

ANALYSIS OF VARIANCE OF OBSERVED FURROW INTAKE RATES AT 10-MINUTE AND 40-MINUTE INTAKE OPPORTUNITY TIMES

TABLE XXXVI

ANALYSIS OF VARIANCE TABLE - FURROW INTAKE RATES AT 10 MINUTES INTAKE OPPORTUNITY TIME

Sources of Variation	DF	SS	MS	$F_{.05}$	Fc
Blocks	2	1.2592	0.6296		
Treatments	3	0.4499	0.1500	4.76	0.16^{ns}
Error	6	5.6208	0.9368		
Total	11	7.3299			

ns = not significant

TABLE XXXVII

ANALYSIS OF VARIANCE TABLE - FURROW INTAKE RATES AT 40 MINUTES INTAKE OPPORTUNITY TIME

Sources of Variation	DF	SS	MS	$F_{.05}$	Fc
Blocks	2	0.3152	0.1576		
Treatments	3	0.5822	0.1941	4.76	1.39^{ns}
Error	6	0.8352	0.1392		
Total	11	1.7326			

ns = not significant.

APPENDIX J

TYPICAL FURROW CROSS SECTIONS

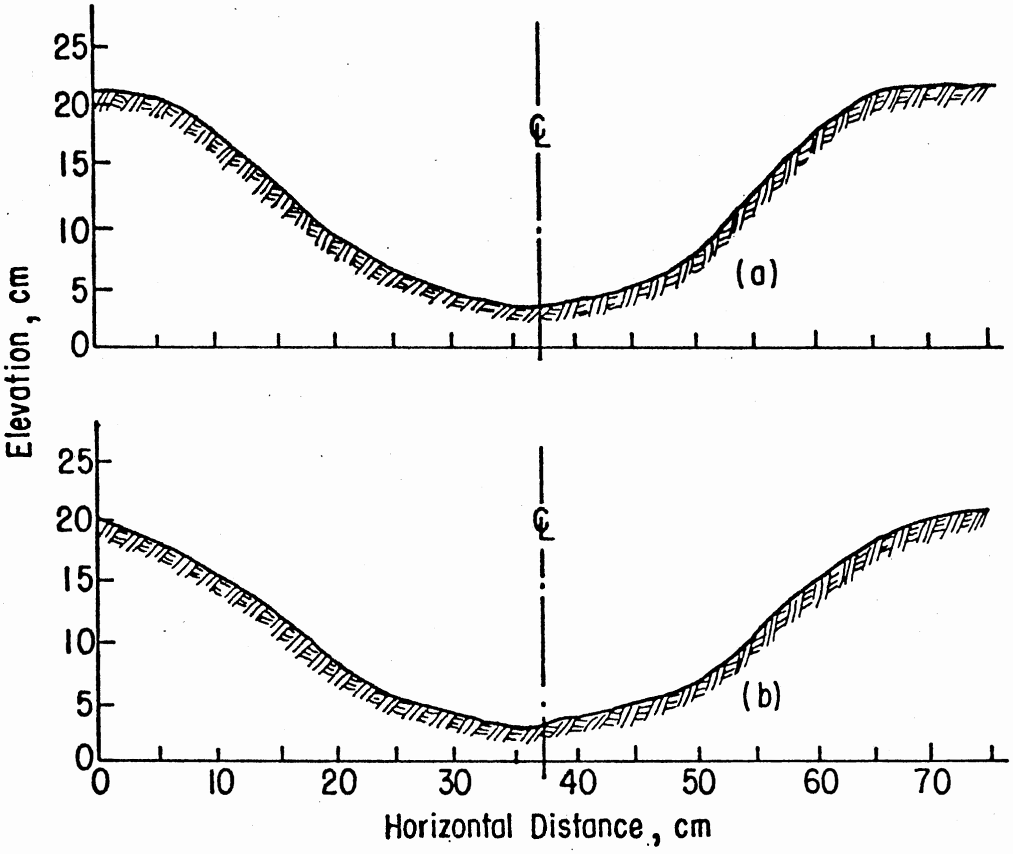

Figure 26. Typical Furrow Cross Sections.

VITA

JOSE LAZARO TABAGO

Candidate for the Degree of

Doctor of Philosophy

Thesis: ADAPTATION AND EVALUATION OF SURGE IRRIGATION UNDER PHILIPPINE CONDITIONS

Major Field: Agricultural Engineering

Biographical;

Personal Data: Born in Laur, Nueva Ecija, Philippines, March 19, 1940, the son of Marcos G. Tabago and Ma. Salome R. Lazaro. Married to Alicia S.I. Morelos on November 9, 1969.

Education: Graduated high school from the Central Luzon Agricultural College, Nueva Ecija, Philippines, in April, 1960; received Bachelor of Science in Agricultural Engineering from the Central Luzon State University in April, 1966; received Master of Engineering degree from the Asian Institute of Technology, Thailand in May, 1973; completed the requirements for the Doctor of Philosophy degree at Oklahoma State University in December, 1983.

Professional Experience: Project Evaluator, Irrigation Service Unit (defunct), Department of Public Works & Communications, September, 1966 to June, 1967; Training Officer, Philippine Army, 1974 - 1975; Chairman, Department of Agricultural Engineering, Central Luzon State University, June, 1979 to November, 1979; Research Project Leader in water management, Philippine Council for Agricultural Resources Research and Development, 1975 - 1978; Instructor and Assistant Professor, Central Luzon State University, July, 1967 to present.