專　論

地表灌漑之研究

Study on Surface Irrigation

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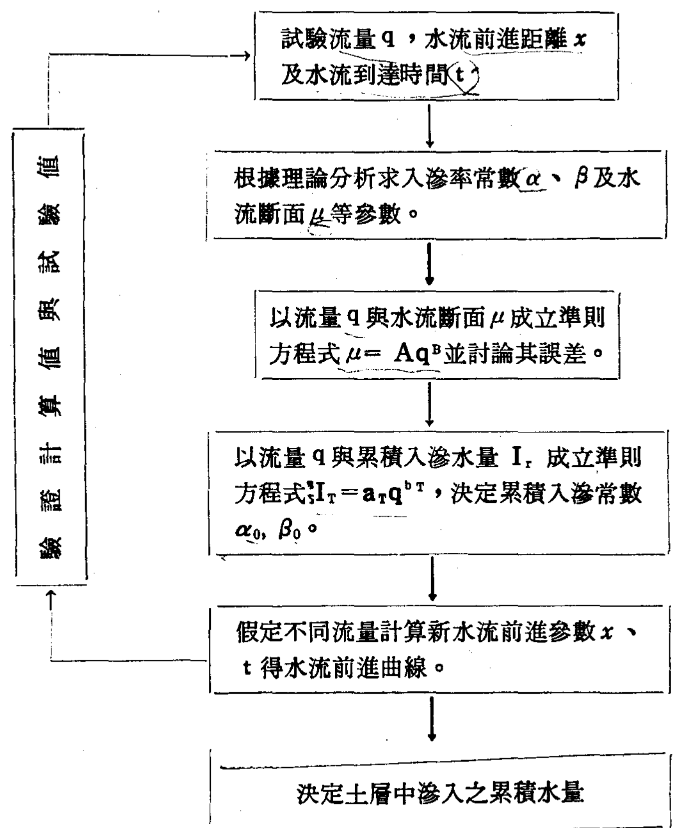
摘　要

本研究過程如下列流程圖。



結論如下：

(1)應用水流前進距離、時間及流量可求得田區內之平均入滲率常數，較以往用圓桶(Cylinder) 及水池(ponding) 等法測定者合理且正確。

(2)畦溝灌漑時，灌漑流量可影響入滲率常數，用圓桶及水池法測定時，未曾考慮此因子，然埂間灌漑時，流量大小不會影響入滲率常數。

(3)水流平均斷面積會受給水流量之影響，但與土質無關。

(4)由此法所分析之資料，可得良好之結果，同時可得到試驗以外各種流量之水流前進因素。

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1. Introduction:

The fluid flow phenomenon of surface irrigation is based on unsteady, non-uniform and open channel flow conditions over a porous bed[11]. It presents a complex problem in theoretical analysis, due to the varying intake rate of the soil and the change of water surface profile on the soil surface. In case that water is turned onto soil surface, it flows in two directions. Because of the pull of gravity, a part of water infiltrates into the soil and the remainder flows along the slope of the soil surface.

Improved design criteria are needed for surface irrigation systems. Criddle et al.[3] gave a clear indication that the length of run will be influenced by application efficiency, intake rate and application time. Bishop[1] and Willardson confirmed this concept. For efficient irrigation, the length of advance with respect to the time curve, application efficiency, distribution efficiency, intake rate and application time..

Two main approaches have been adopted by researchers for the analysis of the fluid flow problem. They are the inflow-outlfow method based on the continuity principle and hydrodynamic analysis.

(1) Continuity principle:

The inflow-outlfow method has been accepted by researchers for many years as a tool for the analysis of this fluid flow problem. Parker[19] and Isaelsen[12] assumed that the intake rate is a constant for their analysis, based on the assumption that the portion of the varying intake rate has been neglected. So the prediction of the advance length at a given time to be longer than the measured length introduced into their results. Lewis and Milne[16] considered that the intake rate is a function of time and assumed that the depth of water on the soil surface is a constant. Their resulted equations for the prediction of the advance curve were checked very well with the field ata. Unfortunately, due to the complexity of the mathematical solutions and of their expressions for intake rate, the method has not widely accepted. Hall[10] applied successive approximations to predict the advance curve for borders by assuming that the water sureface profiles constitute similar curves with the same interception at the normal depth at the upper end of a border. The average depth of water on the soil surface is also assumed to be a constant, which can be estimated by multiplying the normal depth at the upper end of the field by a factor ranging from 0.5 to 1.0. Divis[7] extended this method to the furrow irrigation system. Fok[8,9] made an attempt to predict the advance curve by performing a double integration of the intake rate with respect to time and dividing the result by time to obtain the average depth of water absorbed in the soil for the given time. Kiefer[15] developed an improved correction factor for the computation of the average water depth absorbed in the soil. Christiansen et al.[2] related the intake rate to the advance of water by using a graphical method to determine the intake constants. A procedure similar to that of Christiansen et al. has been followed by Smerdon and Hohn[28] for furrow irrigation method. Chen[4] used a numerical method for integrating the equation of continuity with advance and recession factors to determine advance rate of water front. By Shirai[20,25], an integral equation expressing the advance of water has been developed by using Laplace's transformation. It can calculate intake constants and average flow sectional area by using experimental data from field. It is a pioneer work on surface irrigation by using mathematical computation to get the value of intake rate constants. One part of this study follows Schirai's theory for discussing surface irrigation. Shih[27] used the function of basic intake rate constant in a mathematical equation to predict the relation with advance length and time during irrigation.

(2) Hydrodynamic analysis:

Loo and Hansen[17] did pioneering work on hydrodynamic analysis for problems in suface irrigation. The momentum and continuity principles were applied taking into consideration the water surface profile and the predominant factor. A nonlinear differential equation was developed for their analyses. This was followed by a subsequent development by Su[29]. Su pointed out that this hydrodynamic study was not intended to be practical for extensive field application but could aid in developing an expression on a rational basis. It is believed that there are several researchers working along these lines. Tinney and Basset[33] have made a study of the shape of an advancing front of water in laminar flow and have proceeded to extend their analyses to turbulent flow. As a final step they planned to finish their analyses on flow over a porous bed with varying intake rate.

(3) Research on the field of crops rotated with paddy rice

Because irrigation equipments were rapidly developed in recent years; such as sprinkler, trickle and another garden irrigation equipments, they are convenient to use and can save water during irrigation as comapred with surface irrigation. The researcher for studying suface irrigation was very few in the world during the past decade. However, it is very important to study surface irrigation method in Taiwan right now. The research work was done in the field of upland crops rotated with paddy rice. Many experiments have been done in different soil texture of border and furrow under certain soil moisture. Statistical method was used for analyzing the data by Shih[22,23,24]. Kawano and Sasiprapa[14] studied intake rate and water advance constants in fallow paddy field during dry season. The figures were very low, because soil texture was calyey soil and the soil moisture was high during irrigation. Misunoe et al.[18] made similar study on water advance constants related with discharge and soil moisture in border irrigation.

2. Theoretical Analysis

(1) Basic flow theorem in surface irrigation

When water enters onto field, it flows into two directions. A part of water infiltrates into soil layer and remainder flows along the slope of the soil surface. The flow conditions can be considered with continuity equation[13]. The factors of water cross section, discharge and intake rate related to the time and water advance distance must be included. So that the continuity equation of unsteady flow to develop the parameters on surface irrigation is used:

$$\frac{\partial A}{\partial \tau} + \frac{\partial Q}{\partial \xi} = -i \quad \dots\dots\dots\dots (1)$$

where, A: area of water cross section

Q: discharge

i: intake rate

τ , t : time, when the water advance to the distance ξ and x respectively ($\tau < t$, $\xi < x$)

Integrating the Equation (1) respected to ξ, and assuming average value μ of cross section as constant ($\frac{1}{x}\int_0^x A d\xi = \mu$), it becomes to the Equation (2).

$$q = \int_0^x \phi(t-\tau)\, d\xi + \mu \frac{dx}{dt} \quad \dots\dots\dots\dots (2)$$

where, q: discharge per unit of time

ϕ: intake rate ($\phi = i$)

$(t-\tau)$: intake time at distance ξ when the water advance to x

Making Laplace transform from the Equation (2), it becomes to the Equation (3).

$$V = \frac{q}{\mu p}\left\{1 + \frac{\alpha\Gamma(1+\beta)}{\mu P\,(1+\beta)}\right\}^{-1} \quad \dots\dots\dots\dots (3)$$

where $V = \frac{dx}{dt}$ and α, β are the intake rate constants. Generally, β is in the order of 0 to -1. Putting t = 0 and x = 0 integral in the Equation (3) and inverse transforming; when the water arrives at distance x and the time is t, the Equation becomes:

$$V = V_o F \quad \dots\dots\dots\dots (4)$$

where, $\nu = \frac{x}{t}$, $\nu_0 = q/\mu$, $\zeta = \zeta_0 t^{1+\beta}$, $\zeta = \alpha\Gamma(1+\beta)/\mu$

$$F = 1 - \frac{\zeta}{\Gamma(3+\beta)} + \frac{\zeta^2}{\Gamma(4+2\beta)} \cdots\cdots = \sum_{o}^{\infty} (-1)^n \frac{\zeta^n}{\Gamma(n+2+n\beta)}$$

$$(n = 0, 1, 2, \dots, \infty) \quad \dots\dots\dots\dots (5)$$

when t = 0, $\zeta = 0$; F = 1, $\nu = \nu_o$, Therefore, ν_o may be denoted as initial flow velocity. The Equation (5) is a convergent series. It may be convergent too slowly when t and ζ are large, so that it is difficult to calculate. Therefore, another equation will be derived for calculating F when the value of ζ is large. Putting $d\xi = \frac{d\xi}{d\tau} d\tau$ into the Equation (2), it becomes $qt = \int_o^t \alpha_o (t-\tau)^{\beta_o} \frac{d\xi}{d\tau} d\tau$. Assumed X is Laplace transform from x, therefore PX is the Laplace transform of $\frac{dx}{dt}$, and the Equation (2) becomes:

$$X = \frac{q}{p^2}\left\{\frac{\alpha\Gamma(1+\beta)}{p^{1+\beta}} + \mu\right\}^{-1} \quad \cdots\cdots \quad (6)$$

Spreading powr series with $1/p^m$ (m>0) and inverse transforming every term in the Equation (5), it becomes to the Equation (4). Moreover, spreading power series with p^m and inverse transforming every term, it becomes the Equation (7).

$$F = \frac{\nu}{\nu_0} = \frac{1}{\Gamma(1-\beta)}\cdot\frac{1}{\zeta} - \frac{1}{\Gamma(-2\beta)}\cdot\frac{1}{\zeta^2} + \frac{1}{\Gamma(-1-3\beta)}\cdot\frac{1}{\zeta^3} -$$

$$+ \frac{(-1)^n}{\Gamma(1-n-\beta n-\beta)}\cdot\frac{1}{\zeta^{n+1}} + \cdots\cdots \quad (7)$$

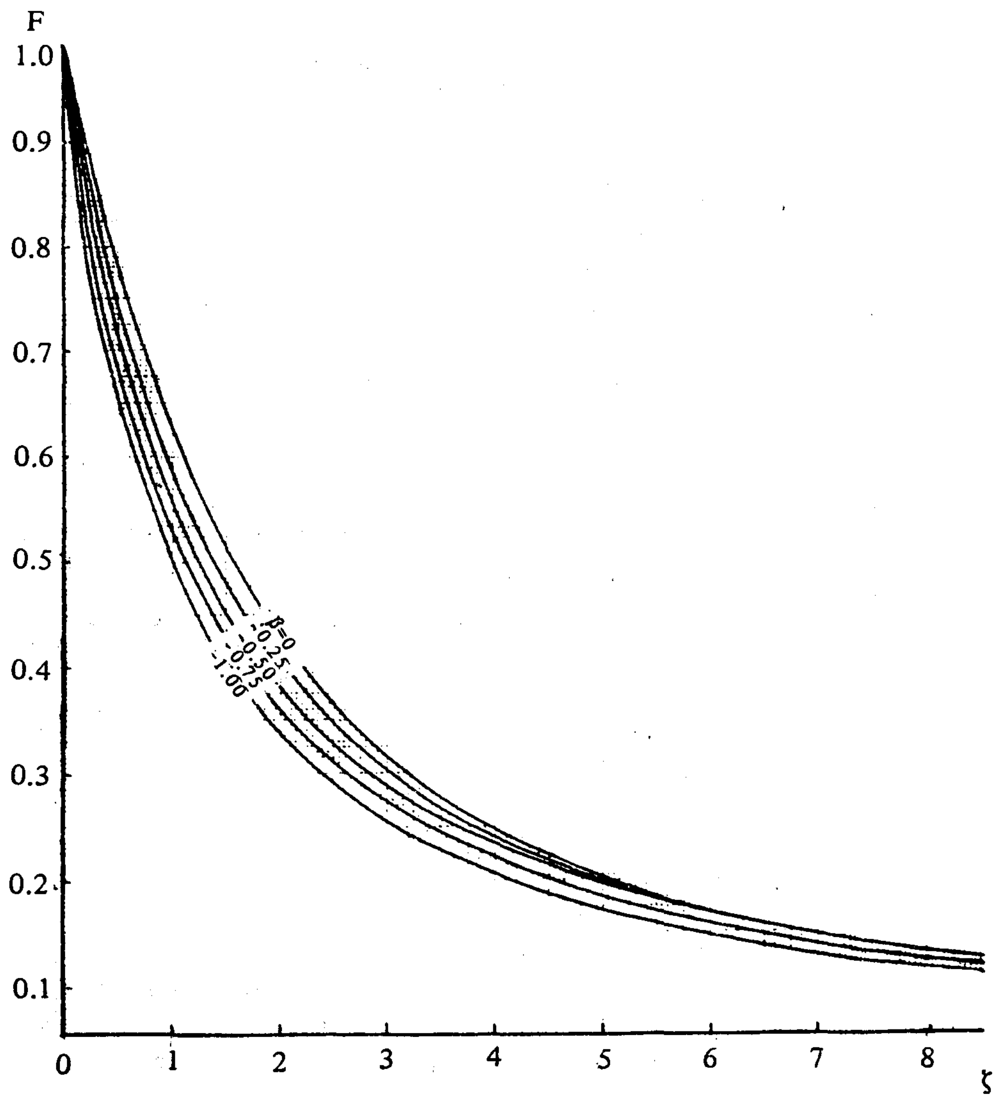


Fig. 1A The relations among F-ζ-β

The Equation (7) is related to theorem of Laplace transform. It can be got an approach spreading and not too much precision, but it is very convenient for calculating the value of ν, if ζ is large.

Based on the above theorem, a chart of the relations among F, β and ζ is shown in Fig. 1.

From Fig. 1, when $\zeta = 0$, F= 1 regardless the value of β, but the value of $-\beta$ increases, F decreases and the values of ξ increases accordingly.

(2) Determination of the relations among intake rate constants, discharge and water cross section

As mentioned in the previous Section, it is complicated to use the Equations to calculate the relations of intake rate constants (α, β), discharge (q) and cross section (μ). If use the relations F $-\zeta-\beta$ in Fig. 1 and cut try method, it can be found the $\alpha-\beta-$q$-\mu$ relations. The procedure of computation is shown below:

A Selecting water advance data of three groups in one advance run, say x_1, t_1; x_2, t_2; and x_3, t_3; those data have to be regular on the water advance curve.

B Calculating the value $\nu_1 = \frac{x_1}{t_1}$ and assuming initial velocity ν_{00}: using the Equation

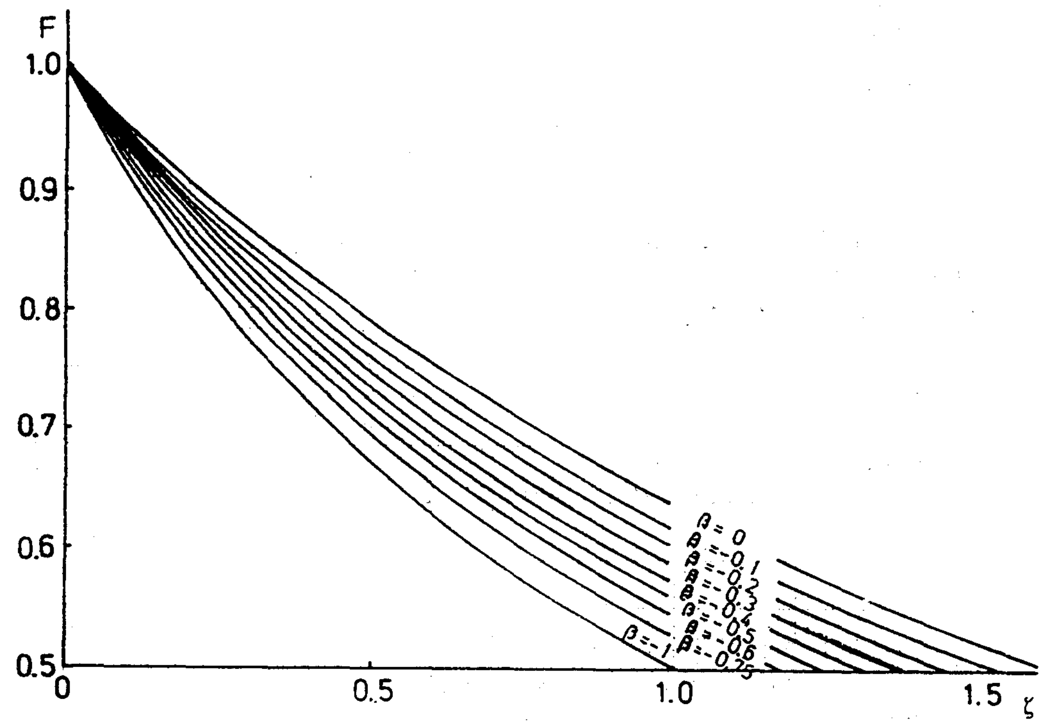


Fig. 1B The relations among F- ζ -β

(4) to calculate Fi $=\nu_i/\nu_o$ and assuming the value of β to find ζ in Fig. 1 or from the Equations (5) or (7).

C Using the Equation (8) to calculate the value of β.

$$1+\beta = \log (\zeta_1/\zeta_2) / \log (t_1/t_2) \quad \text{(8)}$$

D Using the Equation (9A) to calculate the value of ζ.

$$\zeta_o = \zeta_1 / t_1^{(1+\beta)} \quad \text{(9A)}$$

E Using the Equation (9B) to find the correspondent value of ζ_3.

$$\zeta_3 = \zeta_o t_3^{(1+\beta)} \quad \text{(9B)}$$

F Using the value of ζ_3 to find the correspondent value F_3 in Fig. 1 or from Equations (5) and (7).

G Calculating $\nu_{o1} = \zeta_3/F_3$ and comparing the assumed value ν_{oo}, if the error is within the range less than 5%, the result is correct; otherwise, trying it again from the steps (B) to (F) above.

H Using the Equation (10) to calculate the value of α.

$$\alpha = \frac{q}{\Gamma(1+\beta)} \cdot \frac{\zeta_o}{\nu_o} \quad \text{(10)}$$

I Using the Equation (11) to calculate the value of μ.

$$u = \alpha \Gamma(1+\beta) / \xi_o \quad \text{(11)}$$

After calculation following the steps above based on experimental data, many μ, α, β corresponding to q have been got. The equation of cross section μ related to q can be got. The form is shown in the Equation (12).

$$\mu = Aq^B \quad \text{(12)}$$

where, A and B are constants, which can be determined by method of least square. Usually, the intake rate equation is shown in the Equation (13). (β from $0 \sim -1$)

$$i = \alpha t^{\beta} \quad \text{(13)}$$

where, i is intake rate and α, β are calculated from the above. They are related to the discharge q, but it cannot be shown in the Equation. If the Equation (13) is changed into accumulated intake equation, it becomes the Equation (14).

$$I = \int \alpha t^{\beta}\, dt = \frac{\alpha}{1+\beta} t^{1+\beta} = \alpha_o t^{\beta o} \quad \text{(14)}$$

Putting time t as a constant, say 10, 20, 30, 40, 50 minute, then the accumulated intake rate equation (14) can be changed into 1_T related to the discharge q as shown in the Equation (15).

$$I_T = a_T q^{b_T} \quad \cdots\cdots (15)$$

where, I_T: accumulated intake rate in a certain time T, here T = 10, 20, 30, 40, 50 minute

a_T, b_T: constants, to be determined by method of least square or linearization

(3) **Determination of accumulated intake rate constants related to discharge q**

From the equation (15), five groups of T, a_T, b_T values can be got by using method of least square. Next from the Equation (14), the relations among α_o, β_o and q can be obtained. From the Equations (14) and (15), the relation is obtained as below:

$$I = \alpha_o T^{\beta_o} = a_T q^{b_T}$$

$$\log\alpha_o + \beta_o \log T = \log a_T + b_T \log q$$

where, T = 10, 20, 30, 40, 50 minute, and by least square method, the normal equation can be established.

$$\begin{cases} 5 \log \alpha_o + \beta_o [\log T] = [\log a_T] + [b_T \ \log q] \\ [\log T] \log \alpha_o + \beta_o [(\log T)^2] = [\log T \ \log a_T] + [b_T \ \log q] \end{cases}$$

Using matrix, the equations above becomes the Equations (16) and (17).

$$\log \alpha_o = \frac{B}{A} + \frac{C}{A} \log q = 10^{\frac{B}{A}} q^{\frac{C}{A}} \quad \cdots\cdots (16)$$

$$\beta_o = \frac{5 [\log T \log a_T]}{A} - \frac{[\log T] [\log a_T]}{A} + \frac{\{5 [b_T \log T] - \log T] [b_T]\} \log q}{A} \quad \cdots\cdots (17)$$

where, $A = 5\ [(\log T)^2] - [\log T]^2$

$B = [(\log T)^2]\ [\log a_T] - [\log T]\ [\log T \log a_T]$

$C = \log\ [(\log T)^2]\ [b_T] - [b_T \log T]\ [\log T]$

(4) **Calculation of advance run distance x and elapsed time t, based on the analyzed values of μ, α, β, corresponding to discharge q**

A Calculation of α and β, The results from the Equations (16) and (17) are the constants of accumulated intake α_o, β_o, but here α, β are intake rate constants, the relation between the two is:

$\alpha=\alpha_0\beta_0$ and $\beta=\beta_0-1$ ($\beta=0$ to -1)

B Using the Equation (11), $\mu=\alpha\Gamma(1+\beta)\zeta_o$, calculate ζ_o, because α, and β are known in different of q.

C Using the Equation (9A), $\zeta_o=\zeta/t_1^{1+\beta}$, to calculate ζ_o in different irrigation application time t.

D Using the Equation (5) or (7) or Fig. 1, to get the value of F in different value of ζ and β.

E From q/μ, to calculate the initial velocity ν_o.

F From $\nu_o F$, to calculate relative value of ν.

G But $\nu = x/t$, from here to get value of x in different of time t.

From the calculation results above, a set of water advance curves in different q can be obtained.

(5) Computation of accumulated intake in soil layer at the end of irrigation

From the water advance curves in different discharge can be got at the accumulated time, then using the Equation (14), $I=\alpha_o t^{\beta_o}$ accumulated intake in different distance is calculated. After that an accumulated intake curve can be obtained.

3. Irrigation Experiment on Upland Crop

(1) Introduction

In order to carry out the policy of food production, planting area of upland crop will be enlarged by reducing area of paddy rice. In the irrigation phase, nine experiment stations were established in 1963. The most important station is Chia-nan. The irrigation area is about 151,970 ha, it includes Chia-nan and Yun-lin Irrigation Associations with 36% of total irrigation area in Taiwan. Because of shortage of irrigation water, crops rotation in three years is carrying out. It means that crops such as paddy rice, sugar cane and other upland crops are planted within three years. Paddy rice is irrigated with enough water and sugar cane is irrigated 1 to 2 times in growing season. But no irrigation is carried out for upland crops, except when the water is surplus. A new Tseng-Wen reservoir was constructed. During that construction period, how to use the water resource for upland crop irrigation after completion of the reservoir was the main purpose of irrigation experiment. So, Chia-nan Irrigation Association established "Hsueh-chia Upland Crop Irrigation Experiment Station" in 1961[6] and "Hsinkang Irrigation Demonstrateion Station" in 1963[5]. The technical assistance was carried out by the Department of Agricultural Engineering, National Taiwan University, Tainan Agricultural Improvement Station and Taiwan Sugar Research Institute. The field work was carried out by Chianan Irrigation Association itself. These projects were implemented during the 13-year period from 1961 to 1974. The experimental items are described hereunder.

A Crop consumptive use of water[6)]
B surface irrigation and water conveyance loss in irrigation ditches
C Experiment on fertilizer related irrigation factor
D Experiment of improving salty land

The experiment on surface irrigation was done by the author during the 13-year period and details will be described below

(A) Preparation of Experiment

Before experiment on surface irrigation, a working team was organized. The team was composed of about 5 persons. They were assigned to provide the knowledge on hydraulics, irrigation, surveying, crop, soil, etc. The experimental equipments include Parshall flume, surveying level and staff, infiltration meter, soil auger, oven, soil can, stop watch, PVC sheets, etc.

(B) Selection of Experimental Field

Before selection of experimental field, irrigation method on furrow or border, kind of soil texture and crop were decided and pre-selection on the map in a scale of 1/4,800 was made. Then, the field reconnaissance was carried out to observe the details. The conditions observed were described below.

a The experimental plots were selected in the same place, the soil texture and slope were uniform.

b The experimental plots were in regular shape, slope and the length of the plots were more than 100 meter.

(C) Basic Data for Surface Irrigation Experiment

a Soil texture and soil moisture constants

Before carrying out irrigation experiment, soil sample was taken from the experimental field for soil mechanical analysis and soil moisture constants such as field capacity, wilting point, apparent specific gravity were analyzed. The soil samples were taken from five places, in the depth 20 to 100 cm each below field surface in one hectare. The soil data in experimental station of Hsueh-Chia and Hsinkang are shown in Tables 1 to 3, from which the quantity of irrigation water can be estimated from the Equation (18) based on the soil data.

Table 1 Soil texture and soil moisture constants in Hsueh-chia Upland Crop Experiment Station

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil texture	Field capacity (%)	Wilting point (%)	Apparent specific gravity
0– 10	26.82	54.90	18.28	Silty loam	22.60	4.78	1.36
10– 20	26.22	55.10	18.68	Silty loam	20.60	4.66	1.47
20– 40	28.56	53.04	18.40	Silty loam	21.20	4.86	1.44
40– 60	34.82	48.80	16.38	Loam	23.30	6.22	1.34
60– 80	37.96	41.40	20.64	Loam	20.20	5.37	1.46
80–100	55.22	28.60	16.18	Sandy loam	15.68	2.12	1.51
Average				Silty loam	20.60	4.67	1.43

From: Reference (6)

Table 2 Soil texture in Hsinkang Irrigation Demonstration Station

Field No.	Soil depth (cm)	Sand (%)	Clay (%)	Silt (%)	Soil texture
57	10	56.94	13.19	29.87	Sandy loam
57	30	61.07	12.79	26.14	Sandy loam
57	60	51.74	14.19	34.07	Sandy loam
146	10	53.07	15.59	31.34	Sandy loam
146	30	46.07	16.79	37.14	Loam
146	60	61.41	13.93	24.66	Sandy loam
983 –989	0 – 20	48.01	11.71	40.28	Loam
983 –989	20 – 40	46.01	15.03	38.96	Loam
983 – 989	40 – 60	49.76	15.00	35.24	Loam
957 – 965	0 – 20	43.83	17.97	38.20	Loam
957 – 965	20 – 40	42.23	18.25	59.52	loam
957 – 965	40 – 60	42.23	18.05	39.72	Loam
955 – 956	0 – 20	38.04	16.16	45.80	Loam
1001 – 1004	20 – 40	40.24	20.96	38.80	Loam
1001 – 1004	40 – 60	31.64	26.36	42.00	Loam
985 – 990	0 – 20	39.24	14.76	46.00	Loam
985 – 990	20 – 40	27.64	21.16	51.20	Silty loam
985 – 990	40 – 60	38.84	18.76	42.40	Loam
948 – 950	0 – 20	34.85	17.55	47.60	Loam
948 – 950	20 – 40	33.25	21.95	44.80	Loam
948 – 950	40 – 60	28.85	27.95	43.20	Clay loam
948 – 950	60 – 80	27.65	27.15	45.20	Loam
948 – 950	80 – 100	30.45	24.35	45.20	Loam
1003 – 1005	0 – 20	53.84	18.16	38.00	Loam
1003 – 1005	20 – 40	41.91	20.81	73.28	Loam
1003 – 1005	40 – 60	38.64	26.56	34.80	Loam
1003 – 1005	60 – 80	42.14	21.16	31.20	Loam
1003 – 1005	80 – 100	41.44	25.36	33.20	Loam

From: Reference (5) (22)

Table 3 Soil moisture constants in Hsinkang Irrigation Demonstration Station

Soil texture	Field Capacity (%)	Wilting Point (%)	Apparent Specific gravity
Loam	21.00	5.70	1.58
Loam	21.50	4.98	1.58 1.58
Loam	19.46	7.76	1.55
Loam	22.78	8.32	1.53
Loam	18.52	5.74	1.46
Loam	21.84	5.99	1.46
Average	20.85	9.37	1.53
Sandy loam	19.59	5.49	1.39
Sandy loam	19.52	6.47	1.52
Average	19.61	5.98	1.46

From: Reference (5) (22)

$$d = (FC - WP) \times A_s \, s \, D \qquad (18)$$

where, d: depth of water to be irrigated
FC: field capacity of irrigated soil
Wp: wilting point of irrigated soil

As: apparent specific gravity
D: depth of root zone

The suitable irrigation water in Hsueh-chia and Hsinkang stations are shown as below:

Hsueh-chia station: d = (0.206-0.0467) x 1.43 x 40 = 9.11cm

Hsinkang station: d = (0.2085-0.0937) x 1.53 x 40 = 7.03 cm
(for loam)

Hsinkang station: d = (0.1961-0.0598) x 1.46 x 40 = 7.96 cm
(for sandy loam)

The above irrigation water is estimated for the crops with shallow root zone such as corn, peanut, soybean, etc., but for sugar cane, the root zone depth of 60 cm is used.

b Soil moisture before irrigation

Before irrigation experiment, soil samples were taken for determining soil moisture. When the soil moisture is at 50% of available soil moisture, the experiment was carried out.

c Slope surveying

Slope is the important basic data for irrigation, so the data have to be taken before irrigation experiment. In the field of upland crops rotated with paddy rice is very flat and the average slope in Chia-nan irrigation area is shown in Table 4.

Table 4 The average slope of the field of upland crops rotated with paddy rice in Chia-nan irrigated area

Location	Tung-hou-liao	Hsinkang	Wu-lan	Yaun-zhang	I-zhu	Hsueh-chia	Tai-xi	Average
Slope (%)	0.14	0.15	0.13	0.22	0.19	0.13	0.46	0.20

From: Reference (23) (24)

d Measurement of intake rate

Intake rate is very important for surface irrigation. During irrigation experiment, intake rate was measured. The method of cylinder was used for border irrigation and ponding or inflow-outflow method were used for furrow irrigation. The data of intake rate in every kind of field are shown in Table 5. From the figures in the table, No. 1 to 4 and No. 8[23,24,26] were measured in the field of upland crops rotated with paddy rice when the soil moisture is at 50% of available soil moisture. The basic intake rate are quite low. The data of No. 8 and No. 9[33] were measured in the same field. But No. 8 was measured in the field when upland crop was planted and No. 9 was measured on paddy field when soil moisture was at field capacity. The rest of the intake rate values were measured from ordinary upland field. The figures of basic intake rate are very large as compared with those in the field of upland crop rotated with paddy rice.

(D) Operation of irrigation Experiment

a Staking

Before operation of the experiment, stakes were set at every ten meter in length in the field. When the crop was high, the stakes had have to be shown above the crops. Otherwise, a target was needed to connect with each stake..

Table 5 Intake rate in every kind of field in Taiwan

No.	Location	Soil texture	Intake rate $i = kt^{-n}$ Intake rate constants k*	n	Basic * intake rate	Times of Measurement
1.	Hsueh-chia	Silty loam	211	0.855	1.017	12
2.	Tung-hou-jiao	Silty loam	294	0.719	3.749	4
3.	Chi-li-shin	Sandy loam and loam	246	0.780	2.033	12
4.	Sha-yin	Silty loam to sandy loam	338	0.774	2.916	4
5.	Chi-tin	Sand	1,544	0.265	402.974	
6.	Chang-hun	Sand	145	0.160	69.856	5
7.	I-lan	Sand	224	0.150	114.050	7
8.	Chun-Chi	Loam (upland crop)	198	0.753	1.984	2
9.	Chun-Chi	Loam (paddy field)	7.8	0.796	0.070	30
10.	Shui-shi	Sandy loam	367	0.471	24.381	2
11.	Hsin-yin	Clay	94	0.605	1.752	1
12.	Tai-nan	Sandy loam	28	0.630	0.666	1

* Unit: mm/hr
From: Reference (23) (24) (26) (30) (31) (32)

b Setting of Parshall flume

Setting of Parshall flume at the head of experimental field was made for measuring experimental discharge. The size of the Parshall flume was determined to be six inches for border and three inches for furrow. After setting of the Parshall flume, the ditch from Parshall flume to the entrance of experiment field was paved with PVC sheets to prevent the water seepage from the ditch.

c Water advance run

After all the preparation for experiment was over, the entrance in head ditch was opened and water was supplied into the field. Time keeper observed the water advance run. When the water arrived at some distance from the head of ditch, he recorded the time according to the mark of the stakes as follows:

Distance (m)	10	20	30	40	50	60	70	80	90
Time (min)	0.7	2.0	4.2	7.1	10.5	16.3	23.3	31.1	35.8

In order to help the time keeper in recording the arrived time and get a good accuracy of the experiment, one or two workers were required to regulate the water advance. After finishing the record of the water advance run in the first plot, water was distributed into the next plot and the entrance of first plot was closed at the same time. However, time keeper in the first plot observed water advance run continuously. It was necessary to assign another time keeper to observe the water advance run in the next plot.

During experiment, a discharge keepr was assigned to regulate the díscharge. The discharge keeper had have to watch water flowing in Parshall flume and adjust the discharge to keep a constant.

(E) Distribution of the Members of the Experiment Team

The members of team for the experiment was organized before experiment and the composition of the members was as follows:

– Time keepr for water advance run 2	2 persons
– Discharge keeper and control entrance	1 person
– Measurer of intake rate	2 persons

Other 2 to 3 workers were needed for helping the experiment:

– To regulate water advance run	1 to 2 workers
– To open and close the entrance notch	1 worker occasionally
– To help for intake rate measurement	1 worker occasionally

Therefore, the experimental team was composed of 5 members and 2 to 3 workers during experiment operation.

(F) Taking Soil Sample after Experiment

After all of the irrigation water was infiltrated into soil, soil sample was taken for measuring soil moisture to check how much water was infiltrated into soil root zone. In most type of soil, soil surface may dry up within 24 hours, but in less infiltration soil like clay, it needs 36 to 48 hours.

(G) Results of Water Advance Run

The experimental data of water advance run are shown in Table 6 and 7. In the tables are shown discharge q, total irrigation time t_T, total length of run L_T, water advance distance when the entrance is shut off, D_S, etc. There are the results from 36 advance run in Table 6A for furrow irrigation in sandy loam and 62 advance run on Table 6B for furrow irrigation in silty loam. Tables 7A and 7B show border irrigation 20 and 18 experiments in silty loam and sandy loam respectively.

(H) Discussion on Accuracy of the Irrigation Experiment

The factors influencing accuracy of irrigation experiment are soil moisture before irrigation, discharge, distance and time recorded during water advance run, uniform of slope, roughness of field surface, etc.

a Soil moisture before irrigation

Before experiment, the officers of Hsueh-Chia and Hsinkang Experiment Stations checked soil moisture occasionally. In case that the soil moisture was at 50% of available soil moisture, experiment would be carried out next day. The experiment was continued for two days after taking soil sample, because it needs 24 hours to dry soil in oven.

Table 6A Basic experimental data of water advance run on furrow irrigation (sandy loam)

No.	q (m^3/min)	t_T [1] (min)	L_T [2] (m)	D_S [3] (m)	[4] (%)	Distance (m)/Time (min) when water arrived: 10	20	30	40	50	60	70	80	90	100	110	120
1	.24	40.3	100	100	100	.7	2.0	4.2	7.1	10.5	16.3	23.3	31.1	35.8	40.3		
2	.24	24.0	100	90	90	.7	1.6	3.3	5.3	7.9	10.7	13.3	16.8	20.3			
3	.36	27.3	110	88	80	.7	1.9	3.6	5.5	7.6	10.3	13.0	16.0				
4	.36	29.2	110	77	70	.6	1.5	3.0	4.9	7.2	10.2	13.0					
5	.48	17.8	100	82.5	75	.5	1.3	2.4	5.1	5.2	7.2	9.4	11.9				
6	.48	14.1	90	63	70	.5	1.4	2.5	3.8	5.3	6.9						
7	.24	40.8	120	120	100	.6	1.6	3.4	6.1	9.1	13.7	18.5	22.3	26.9	32.8	38.5	40.8
8	.24	42.7	120	108	90	.5	1.6	3.4	6.0	9.8	14.4	19.2	23.6	34.6			
9	.36	35.9	120	96	80	.5	1.5	3.2	5.3	8.0	11.4	15.2	18.4	22.6			
10	.36	34.9	120	90	75	.6	1.7	3.0	4.6	6.8	9.7	13.0	15.9	20.1			
11	.48	24.6	110	82.5	75	.5	1.6	3.0	4.7	6.7	9.1	11.8	14.5				
12	.48	26.5	110	77	70	.5	1.6	3.0	5.0	7.0	9.5	12.4					
13	.24	26.7	120	120	100	.8	2.1	3.6	5.8	7.8	10.9	12.2	14.7	17.9	20.9	23.6	26.7
14	.24	25.5	120	96	80	.9	2.1	3.7	5.3	7.3	8.8	11.1	13.5	16.3			
15	.18	25.5	80	64	80	1.2	2.9	5.2	8.0	11.1	15.3						
16	.18	19.5	80	72	90	.9	2.4	4.2	6.4	9.2	12.2	16.2					
17	.18	20.8	80	80	100	1.0	2.8	5.2	7.7	10.4	14.6	18.1	20.8				
18	.24	29.5	120	108	90	.8	2.2	3.8	5.8	7.9	10.7	13.8	17.1	19.6	22.9		
19	.30	24.8	120	108	90	.7	1.3	2.9	4.2	5.3	8.5	11.1	13.4	15.7	18.7		
20	.30	22.0	110	88	80	.7	2.3	3.0	4.9	6.5	8.5	10.7	13.4				
21	.30	21.7	120	120	100	.7	1.3	2.4	3.9	5.8	7.2	8.8	10.8	13.0	16.3	18.8	21.7
22	.36	18.6	120	108	90	.6	1.4	2.8	4.3	5.6	7.6	9.3	10.9	12.6	14.4		
23	.36	22.2	120	120	100	.5	1.3	2.9	4.8	6.2	7.8	9.9	11.5	15.0	16.3	19.0	22.2
24	.36	26.0	120	96	80	.8	1.9	3.6	5.9	7.3	9.4	11.8	13.8	16.8			
25	.18	22.3	80	64	80	.9	2.6	4.5	7.1	10.2	13.3						
26	.18	19.6	80	72	90	.9	2.7	4.9	7.3	9.9	13.0	16.3					
27	.18	19.8	80	80	100	.9	2.4	4.4	6.8	9.5	12.9	16.4	19.8				
28	.24	28.9	120	96	80	.7	1.9	3.3	5.1	7.2	9.2	11.3	13.8	16.6			
29	.24	29.6	120	108	90	.8	2.3	3.8	6.2	8.3	10.9	13.9	17.1	19.7	22.5		
30	.24	26.3	120	120	100	.9	2.3	3.7	5.6	7.5	9.8	11.7	14.0	16.6	19.7	24.2	26.3
31	.30	24.8	120	96	80	.7	1.7	2.8	4.7	6.1	8.1	10.4	12.8	15.1			
32	.30	25.4	120	108	90	.7	1.6	3.0	4.6	6.3	9.1	12.2	14.5	15.7	19.8		
33	.30	23.5	120	120	100	.7	1.8	3.0	4.7	6.5	8.6	10.8	12.9	14.8	17.8	20.4	23.5
34	.36	23.9	120	96	80	.7	1.8	3.3	5.1	6.6	8.4	10.9	12.5	15.0			
35	.36	20.5	120	108	90	.7	1.6	2.9	4.5	5.9	7.8	9.5	11.6	13.6			
36	.36	22.0	120	120	100	.7	1.6	3.0	4.5	6.1	8.2	10.2	12.4	14.8	16.8	19.2	22.0
Ave. time when q is .24 m^3/min					(10)	.74	1.97	3.62	5.83	8.33	11.54	14.83	18.40	22.43	26.52		
" " " " .36 "					(10)	.64	1.62	3.13	4.94	6.73	9.08	11.58	13.67	16.31			
" " " " .48 "					(4)	.50	1.48	2.73	4.65	6.05	8.18	11.20	13.20				
" " " " .18 "					(6)	.97	2.63	4.73	7.22	10.05	13.55	16.75	20.30				
" " " " .30 "					(6)	.70	2.28	2.85	4.50	6.08	8.33	10.67	12.97	14.65	17.97		

Note: 1. t_T: total time of irrigation
2. L_T: total length of furrow
3. D_S: water advance distance when the entrance is shut off
4. % : the percentage of water shut off distance to the total length of furrow

From: Reference (22) (23)

Table 6B Basic experimental data of water advance run on furrow irrigation (silty loam)

No.	q (m^3/min)	t_T (min)	L_T (m)	D_S (m)	(%)	Distance (m)/Time (min) when water arrived: 10	20	30	40	50	60	70	80	90	100	110	120
1	.12	43.67	100	80	80	1.9	4.2	7.3	10.5	14.3	18.2	22.9	27.9				
2	.12	36.9	100	90	90	1.0	2.7	6.2	9.3	12.6	16.7	20.6	25.8	31.10			
3	.12	45.4	100	100	100	1.9	4.8	8.7	13.5	17.9	22.6	28.0	33.5	39.2	45.4		
4	.24	30.3	100	70	70	1.1	2.5	4.5	6.7	9.3	11.9	14.4					
5	.24	22.9	100	80	80	0.9	2.4	4.1	6.0	8.7	11.2	13.8	16.2				
6	.24	23.9	100	90	90	1.2	2.9	5.1	7.1	9.8	12.5	15.4	18.4	21.2			
7	.36	21.9	100	70	70	0.9	2.3	4.0	5.7	7.6	9.4	12.3					
8	.36	19.9	100	80	80	0.6	1.6	3.2	5.0	6.9	8.8	11.1	13.2				
9	.36	18.9	100	90	90	0.7	1.7	3.7	5.4	7.0	9.3	11.7	14.2	16.4			
10	.12	18.0	100	80	80	1.0	2.3	3.6	5.2	7.0	8.9	10.8	12.7				
11	.12	20.0	100	90	90	0.9	2.4	4.1	5.7	7.6	9.7	11.7	13.9	16.8			
12	.12	18.2	100	100	100	0.9	2.3	3.5	4.9	6.5	8.7	10.7	12.9	15.2	18.2		
13	.24	13.4	100	70	70	0.7	1.6	2.6	3.8	5.1	6.5	7.8					
14	.24	11.7	100	80	80	0.7	1.4	2.3	3.3	4.3	5.6	6.9	8.5				
15	.24	11.4	100	90	90	0.6	1.2	2.0	3.1	4.2	5.6	7.0	8.4	9.8			
16	.36	11.0	100	70	70	0.4	1.1	1.9	2.8	3.9	5.0	6.1					
17	.36	9.9	100	80	80	0.5	1.2	2.0	2.9	3.8	4.9	5.9	6.8				
18	.36	10.0	100	90	90	0.6	1.3	2.1	2.9	3.8	4.9	6.0	7.4	8.7			
19	.12	57.0	110	88	80	1.4	3.1	7.1	12.0	17.5	23.6	30.8	40.7				
20	.12	68.7	90	81	90	2.3	7.0	12.0	19.1	27.8	35.0	43.3	50.5				
21	.12	40.4	90	90	100	1.2	4.0	5.5	9.6	14.3	19.0	26.4	32.7	40.4			
22	.24	19.2	90	63	70	1.0	2.4	5.0	8.3	13.4	17.3						
23	.24	25.2	90	72	80	1.2	3.5	6.6	10.6	14.8	19.8	25.1					
24	.24	25.8	90	81	90	1.2	3.8	6.6	9.8	13.1	17.0	21.0	25.0				
25	.30	13.6	100	70	70	1.0	2.2	3.9	6.3	9.2	12.6	13.6					
26	.30	29.0	90	72	80	0.9	2.6	4.3	6.7	10.1	13.0	18.2					
27	.30	22.3*1	90	81	90	1.5	2.9	5.1	8.0	11.4	14.6	17.7	21.9				
28	.30	21.5	120	84	70	0.6	1.5	2.8	4.3	5.7	7.7	9.4	11.1				
29	.30	17.9	120	108	90	0.5	1.4	2.4	3.9	5.3	7.1	8.9	10.7	12.4	14.0		
30	.30	18.7	120	96	80	0.6	1.5	2.7	4.1	5.6	7.4	9.2	10.9	12.7			
31	.24	22.3	120	84	70	0.8	1.7	2.8	4.0	5.8	7.5	9.5	11.5				
32	.24	18.2	120	108	90	0.5	1.2	2.2	3.5	5.0	6.6	8.5	10.3	12.0	14.2		
33	.24	19.5	120	96	80	0.6	1.5	2.7	4.1	5.7	7.4	9.2	10.9	12.8			
34	.18	23.3	120	96	80	0.7	1.7	3.2	4.5	6.8	8.9	10.9	13.0	14.8			
35	.18	23.2	120	120	100	0.7	1.8	3.5	5.2	6.8	9.4	11.5	13.9	15.9	18.1	20.1	23.2
36	.18	22.2	120	108	90	0.8	2.0	3.3	5.0	7.0	9.1	11.3	13.5	15.4	17.5		
37	.12	42.0	100	80	80	1.5	4.0	4.4	10.0	14.0	18.5	23.2	26.7				
38	.12	32.9	100	100	100	1.1	2.9	5.1	7.7	12.3	15.8	19.9	23.5	28.8	32.9		
39	.12	31.0	100	90	90	1.1	3.4	5.5	8.3	11.7	15.2	18.8	22.1	26.8			
40	.12	33.3	100	100	100	0.9	2.9	5.2	7.8	12.1	16.0	20.6	24.1	29.7	33.3		
41	.12	30.8	100	90	90	0.8	3.8	5.9	8.3	11.3	15.0	18.6	21.3	27.2			
42	.12	41.8	100	80	80	1.6	4.5	7.4	11.5	15.3	20.7	25.6	29.0				
43	.18	21.3	120	120	100	0.6	1.6	3.1	4.4	5.1	8.2	10.2	12.7	14.5	16.6	18.8	21.3
44	.18	20.8	120	108	90	0.8	1.8	3.0	4.5	6.3	8.2	10.2	12.1	14.0	15.9		
45	.18	22.0	120	96	80	0.7	1.8	3.6	4.2	6.9	8.6	10.7	13.0	14.0			
46	.24	17.6	120	108	90	0.5	1.3	2.4	3.6	5.1	6.4	8.3	10.0	11.6	13.3		
47	.24	20.1	120	96	80	0.5	1.5	2.6	4.0	5.6	7.2	9.1	10.7	12.9			
48	.24	21.7	120	84	70	0.7	1.6	2.4	3.5	5.2	6.9	8.7	10.6				
49	.30	17.8	120	108	90	0.6	1.5	2.8	4.3	5.7	7.5	9.3	11.0	12.6	14.1		
50	.30	17.8	120	96	80	0.5	1.4	2.4	3.8	5.3	7.1	8.6	10.3	12.0			
51	.30	22.2	120	84	70	0.5	1.7	3.0	4.4	5.9	7.6	9.2	11.0				
52	.18	28.7	100	80	80	1.5	3.7	6.2	8.7	11.2	14.1	17.6	20.5				
53	.18	27.9	100	90	90	1.6	3.4	5.9	8.3	11.2	13.9	16.6	20.6	23.8			
54	.24	21.3	100	70	70	0.9	2.2	3.7	5.5	7.4	9.6	11.9					
55	.24	19.8	100	80	80	0.7	2.1	3.8	5.6	7.5	9.8	12.3	14.6				
56	.24	18.9	100	90	90	0.8	2.1	3.9	5.6	7.5	9.5	12.0	13.9	16.4			
57	.30	21.9	100	70	70	0.9	2.0	3.6	5.4	7.1	9.7	11.7					
58	.30	23.0	100	80	80	0.7	3.3	4.0	5.9	8.4	11.4	14.5	16.7				
59	.30	21.0	100	90	90	0.9	2.5	4.4	6.5	8.6	10.8	13.1	15.5	18.1			
60	.36	25.1	100	70	70	0.8	2.3	4.0	6.0	8.0	10.5	13.1					
61	.36	22.1	100	80	80	1.0	2.6	4.6	6.7	8.8	11.4	13.5	15.9				
62	.36	21.5	100	90	90	0.7	2.3	4.1	6.6	8.8	11.1	13.7	16.3	19.2			
Ave. time when q is .12 m^3/min					(15)	1.30	3.62	6.10	9.56	13.48	17.57	22.13	26.49				
" " " " .24 "					(18)	.81	2.05	3.63	5.45	7.64	9.91	11.82	13.00				
" " " " .36 "					(9)	.69	1.82	3.29	4.89	6.51	8.37	10.38	12.30	14.77			
" " " " .30 "					(12)	.77	2.04	3.45	5.30	7.36	9.71	11.95	13.23				
" " " " .18 "					(8)	.93	2.23	3.98	5.60	7.66	10.05	12.38	14.91	16.06	17.03		

Note: *1. the time when water arrives at the distance 81 m

From: Reference (22) (23)

Table 7A Basic experimental data of water advance run on border irrigation (sility loam)

No.	q (m^3/min/m)	Width (m)	t_T [1] (min)	L_T [2] (m)	D_S [3] (m)	[4] (%)	Distance (m)/Time arrived (min) 10	20	30	40	50	60	70	80	90	100	Remarks	
1	0.0966		102.2	90			4.0	10.0	18.5	30.2	45.2	59.0	75.5	88.6	102.2		Corn	
2	0.1380		65.1	90			2.3	6.1	11.3	17.4	26.5	36.1	46.5	55.4	65.1		"	
3	0.1212		79.3	90			2.3	7.2	13.1	21.1	32.4	45.2	56.2	69.0	79.3		"	
4	0.0696		82.3	90			3.1	7.9	16.0	24.4	37.4	49.4	60.6	71.0	82.3		"	
5	0.1938		35.1	90			1.8	4.3	7.4	11.4	15.4	20.4	24.7	30.7	35.1		"	
6	0.1452		45.3	90			1.7	4.6	8.2	12.8	18.1	24.1	31.1	37.8	45.3		"	
7	0.0966		65.6	90			2.4	6.3	11.9	18.3	26.3	34.2	43.4	54.0	65.6		"	
8	0.0966		69.1	90			2.8	7.5	13.9	21.6	30.7	41.3	50.8	59.5	69.1		"	
9	0.1380		46.3	90			2.3	5.3	8.5	13.0	18.4	24.8	32.2	39.6	46.3		"	
10	0.0966		44.2	90			2.4	5.6	9.4	13.6	20.0	25.1	31.5	37.8	44.2		"	
11	0.1500		51.5	90			3.7	6.6	10.3	15.8	20.8	26.8	35.8	42.8	51.5		"	
12	0.2100		25.6	70			2.8	4.7	7.8	11.3	15.8	20.2	25.6				"	
13	0.2400		16.3	60			1.6	3.5	5.7	8.3	12.1	16.3					"	
14	0.0696	5	137	100	96	96	8	14	27	38	53	68	82	99	120	137	"	
15	0.0696	5	129	120	104.4	87	3	9	17	27	38	51	61	72	83	97	112	129
16	0.0696	5	126	120	106.8	89	4	10	17	27	40	50	63	72	85	97	111	126
17	0.0696	5	134	120	103.2	86	4	12	21	34	41	50	68	79	95	110	121	134
18	0.0696	5	126	120	104.4	87	4	10	17	28	38	49	57	69	83	98	113	126
19	0.2280	4	70	120			2	4.5	8.5	13.0	19.5	25.0	30.5	36.5	43.5	50.0	59.5	70
20	0.2280	4	98.5	120			2.5	5.5	11.5	17.5	25.5	32.5	43.0	58.0	66.0	74.5	84.5	98.5

Note:
1. t_T: total time of irrigation
2. L_T: total length of the border
3. D_S: water advance distance when the entrance is shut off
4. % : the percentage of water shut off distance to the total length of border

From: Reference (22) (24)

Table 7B Basic experimental data of water advance run on border irrigation (sandy loam)

No.	q (m^3/min/m)	Width (m)	t_T[1] (min)	L_T[2] (m)	D_S[3] (m)	%[4] (%)	Distance, the water arrived (m) / Time, the water arrived (min)											Remarks
1	0.2856	8.4	30	124.3	105.7	85	21.2	31.2	41.5	55.2	74.8	95.4	112.7	124.3				Corn
							3	5	7	10	15	20	25	30				
2	0.2928	8.2	35	137.3	126.7	92	20.6	32.1	43.7	55.3	72.7	85.4	98.9	120.1	137.3			"
							3	5	7	10	15	20	25	30	35			
3	0.3810	6.3	30	127.0	111.8	88	18.0	30.8	37.5	54.2	73.7	81.8	110.7	127.0				"
							3	5	7	10	15	20	25	30				
4	0.2790	8.6	30	127.3	112.0	88	20.5	43.0	56.0	73.3	85.7	102.7	115.3	127.3				"
							3	5	7	10	15	20	25	30				
5	0.3660	7.7	25	141.9	124.9	88	26.5	44.2	57.6	77.3	96.1	114.6	141.9					"
							3	5	7	10	15	20	25					
6	0.2892	8.55	25	82.5	82.5	100	13.2	21.2	28.6	35.6	41.9	50.5	56.0	61.6	69.2	75.5	82.5	
							2	4	6	8	10	13	15	17	20	22	25	
7	0.32[illegible]0	7.7	24	82.4	71.7	87	12.0	21.8	28.8	31.7	43.0	49.5	54.6	59.8	65.8	71.4	82.4	
							2	4	6	8	10	12	14	16	18	20	24	
8	0.3582	6.9	14	63.5	50.8	80	14.6	24.2	32.4	40.7	48.2	56.1	63.5					Corn
							2	4	6	8	10	12	14					
9	0.3689	6.7	16	70.5	62.0	88	13.5	23.8	31.4	41.0	50.3	58.8	65.4	70.5				"
							2	4	6	8	10	12	14	16				
10	0.3800	6.5	14	82.4	53.7	86	21.8	35.5	48.5	54.5	67.0	75.9	82.4					"
							2	4	6	8	10	12	14					
11	0.3482	7.1	14	80.6	67.7	84	16.4	31.9	42.6	53.3	63.5	74.1	80.6					"
							2	4	6	8	10	12	14					
12	0.2588	9.55	9	40.0	35.6	89	18.7	26.9	33.1	40.0								"
							3	5	7	9								
13	0.2760	8.95	9	41.8	35.1	84	14.4	27.8	35.4	41.8								"
							2	5	7	9								
14	0.2856	9.45	35	136.0	129.2	95	20.3	32.7	43.7	59.0	74.7	93.0	107.3	120.5	136.0			"
							3	5	7	10	15	20	25	30	35			
15	0.1800	15.00	40	128.2	115.4	90	20.6	35.5	52.6	67.9	81.4	95.0	107.6	118.1	128.2			"
							3	6	10	15	20	25	30	35	40			
16	0.1392	16.30	35.4	80.0	67.2	84	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0				"
							2.9	5.1	9.0	12.4	17.8	24.2	29.9	35.4				
17	0.1938		50.0	90.0	90.0	100	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0			"
							2.9	4.9	9.1	14.0	20.4	27.2	34.2	42.5	50.0			
18	0.1452		68.0	90.0	90.0	100	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0			"
							2.6	6.7	12.2	19.1	27.1	37.3	47.9	56.5	68.0			

Note: 1. t_T: total time of irrigation
2. L_T: total length of the border
3. D_S: water advance distance when the entrance is shut off
4. % : the percentage of water shut off distance to the total length of border

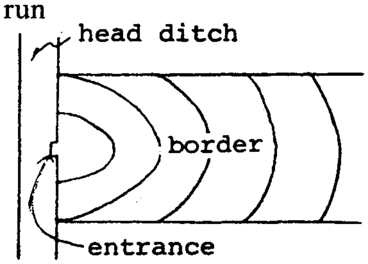
From: Reference (22) (24)

b Discharge

There was enough quantity of water used for experiment. The discharge was controlled at the gate in the upstream of the ditch, but it is controlled again by Parshall flume on head ditch. A discharge keepr checked discharge all the time during experiment.

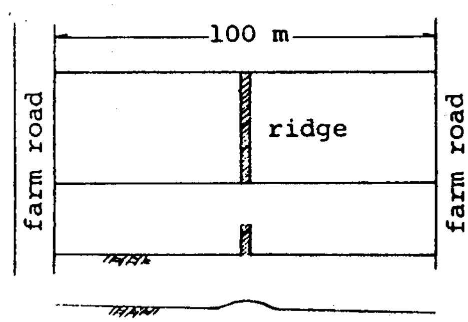
c Distance and time recorded during water advance run

The time keeper read the figures according to the target and the stop watch, but there may be some errors due to water flow condition. When the water was flown into a border, the water flow will be formed as the right figure and some recording errors may occur. In case that the experiment is made in furrow, there may exist some gap holes on furrow ridge such as mouse hold and the water flows out of the measured furrow. It may also be some error in record.



d Slope

Upland crops are rotated with paddy rice in experimental field. When paddy rice is planted, farmers built one or two ridges in one plot, because of uniformity in irrigation for paddy rice. After harvesting paddy rice and planting upland crops, the ridge is destroyed. If the land preparation is not completed, a small stump exists and nonuniform slope is made.



e Roughness of field surface

Since farm size in Taiwan is very small, the selected experimental field is composed of many farmer's areas. There is difference in farming operation custom among their fields and in roughness of each field surface.

The errors mentioned above cannot be avoided. It is only one way that a careful selection of experimental field shall be made before carrying out experiment.

4. Data Analysis

Based on the theoretical analysis mentioned in article 2 and using the experimental data from Tables 6 and 7 to analyze furrow and border irrigation, the procedures include: calculation of intake rate constants α, β; cross section μ from distance x and the elapsed time t corresponding to irrigation discharge q; determination of the normal equation of $\mu = Aq^B$ and discussion of their errors; determination of the normal equation of $I_T = a_T q^{b_T}$ and calculation of accumulated intake constants α_o, β_o; determination of advance distance x and elapsed time t based on the analyzed values of μ, α, β, α_o and β_o, corresponding to the discharge q; calculation of accumulated intake in soil layer at the end of irrigation.n. The details are described below.

(1) **Calculation of intake rate constants α, β and water cross section μ from experimental data by cut and try method**

Following the steps to calculate α, β and μ mentioned in subsection (2) of article 2 based on the data of No. 1 experiment in Table 6A, $\sqrt{x}$ and $\log\frac{x}{t}$ are calculated as follows:

x (m)	10	20	30	40	50	60	70	80	90	100
$\sqrt{x}$	3.16	4.47	5.48	6.32	7.07	7.75	8.37	8.94	9.49	10
t (min)	0.7	2.0	4.2	7.1	10.5	16.3	23.3	31.1	35.8	40.3
x/t	14.286	10.000	7.143	5.634	4.762	3.681	3.004	2.572	2.514	2.481
$\log\frac{x}{t}$	1.155	1.000	0.854	0.751	0.678	0.566	0.468	0.410	0.400	0.395

Plotting $\sqrt{x}$ against $\log x/t$ on Fig. 2, it can be got the estimated value $\nu_{oo} = \log\frac{x}{t} = 1.43$ ($\frac{x}{t} = 27$) and it can also be got the other points (0.59, 7.74), (0.68, 7.07), and (0.75, 6.32) on Fig. 2

After solving the log (x/t) and nn points, three couples of x and t can be got as follows:

$x_1 = 60$m	$x_2 = 50$m	$x_3 = 40$m
$t_1 = 15.424$ min.	$t_2 = 10.5$ min.	$t_3 = 7.1$ min.

Using the Equation (4) to get F values from ν_{oo} and x_i/t_i, then estimation of β is made to get the value of from Fig. 1.

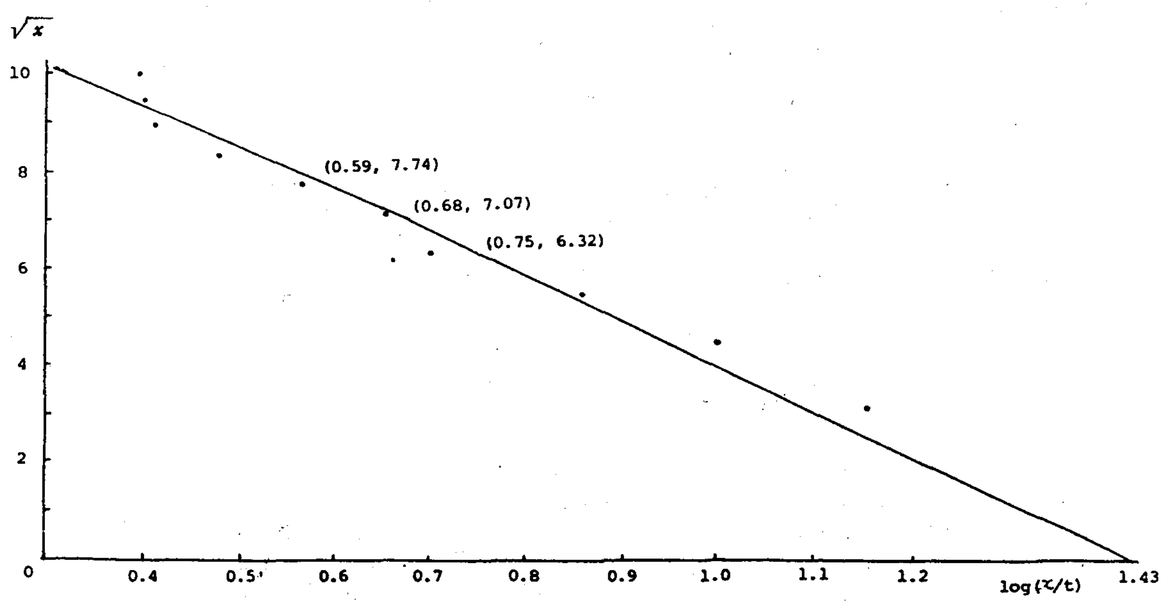


Fig. 2 Method of estimating ν_{oo}, x_i and t_i values

v_{oo}	x_1/t_1	F	ζ
27.00	3.890	0.144	7.240
	4.762	0.176	5.760
	5.634	0.214	4.564

From the Equation (8), the value of β is calculated.

$$1+\beta = \log(\zeta_1/\zeta_2)/\log(t_1/t_2)$$

$$= \log(7.24/5.76)/\log(15.424/10.5) = 0.595$$

$$\therefore \beta = -0.405$$

Using the Equation (9A), ζ_o is calculated.

$$\zeta_o = \zeta_1/t_1^{(1+\beta)} = 7.24/15.424^{0.595} = 1.4228$$

Using the Equation (9B), ξ_3 is calculated.

$$\zeta_3 = \zeta_o t_3^{(1+\beta)} = 1.4228 \times 7.1^{0.595} = 4.567$$

From Fig. 1, $F_3 = 0.214$ is got.

$$\nu_{o1} = \nu_3/F_3 = 5.634/0.214 = 26.327$$

Check: $(27 - 26.327)/27 = 0.025 = 2.5\% < 5\%$ O.K.

If there is much error when estimation of ν_{oo} and points $(\log\frac{x}{t}, \sqrt{x})$ on Fig. 2 calculation has to be made again.

From the Equation (10), ($q = 0.24$ m^3/min),

$$\alpha = \frac{q}{\Gamma(1+\beta)} \cdot \frac{\xi_o}{\nu_o} = \frac{q}{\Gamma\, 0.595} \cdot \frac{1.4228}{26.327}$$

$$= \frac{0.24}{1.501} \times \frac{1.4228}{26.327} = 0.00864 \text{ m}^2$$

From the Equation (11),

$$\mu = \alpha\Gamma(1+\beta/\zeta_o = 0.00864 \times 1.501/1.4228$$

$$= 0.00912 \text{ m}^2 \text{ or } 91.2 \text{ cm}^2$$

The computations of α, β and μ are done by computer. The total experimental data are 136; 36 for furrow irrigation in sandy loam soil texture, 62 for furrow irrigation in silty loam, 20 for border irrigation in silty loam and 18 for border irrigation in sandy loam. The values of α, β, μ and q are summarized in Table 8 and 9.

Table 8A Calculated data of α,β and μ based on water advance run on furrow irrigation (sandy loam)

No.	Discharge (m^3/min)	Intake rate constants α	Intake rate constants −β	Cross section area μ (cm^2)
1	.240	.00864	0.405	91.20
2	.240	.00708	0.554	81.36
3	.360	.00911	0.518	168.84
4	.360	.01060	0.551	104.40
5	.480	.01080	0.441	158.40
6	.480	.00940	0.511	182.40
7	.240	.00802	0.501	76.80
8	.240	.00795	0.460	83.20
9	.360	.01110	0.576	104.04
10	.360	.00993	0.451	119.88
11	.480	.01208	0.519	182.40
12	.480	.01240	0.553	177.60
13	.240	.00528	0.615	126.96
14	.240	.00522	0.552	125.76
15	.180	.00554	0.408	144.72
16	.180	.00477	0.435	121.50
17	.180	.00416	0.398	187.20
18	.240	.00559	0.579	138.24
19	.300	.00678	0.520	118.80
20	.300	.00666	0.569	115.20
21	.300	.00564	0.457	147.90
22	.360	.00652	0.654	142.56
23	.360	.00828	0.674	78.12
24	.360	.00842	0.575	165.96
25	.180	.00560	0.442	109.98
26	.180	.00484	0.510	138.60
27	.180	.00547	0.499	100.08
28	.240	.00557	0.628	89.52
29	.240	.00576	0.571	131.52
30	.240	.00460	0.603	165.65
31	.300	.00634	0.567	125.70
32	.300	.00714	0.566	109.50
33	.300	.00648	0.609	120.60
34	.360	.00748	0.534	186.48
35	.360	.00712	0.596	140.76
36	.360	.00776	0.620	132.12

Description

α, β, and μ in the table are calculated from the equations below:

$$i = \alpha q t^{\beta}$$

$$\mu = \alpha \Gamma(1+\beta)/\zeta_o = \frac{q}{v_o}$$

where,

α: intake rate coefficient

β: intake rate power

q: discharge (m^3/min)

V_o: velocity (m/min)

μ: average water cross section (cm^2)

$$\zeta = \alpha \Gamma(1+\beta)/\mu$$

Table 8B Calculated data of α, β and μ based on water advance run of furrow of furrow irrigation (silty loam)

No.	Discharge (m^3/min)	Intake rate constants α	-β	Cross section area μ (cm^2)	No.	Discharge (m^3/min)	Intake rate constants α	-β	Cross section area μ (cm^2)
1	.120	.00400	0.501	136.80	32	.240	.00439	0.628	83.04
2	.120	.00383	0.537	105.60	33	.240	.00427	0.601	130.80
3	.120	.00446	0.633	121.20	34	.180	.00392	0.592	80.46
4	.240	.00648	0.531	150.72	35	.180	.00367	0.693	98.28
5	.240	.00571	0.503	165.12	36	.180	.00360	0.571	95.76
6	.240	.00353	0.833	116.64	37	.120	.00385	0.536	129.60
7	.360	.00762	0.631	197.28	38	.120	.00409	0.596	71.16
8	.360	.00782	0.563	169.92	39	.120	.00359	0.666	99.00
9	.360	.00695	0.507	255.24	40	.120	.00436	0.545	64.92
10	.120	.00186	0.579	89.40	41	.120	.00144	0.320	160.80
11	.120	.00207	0.561	102.00	42	.120	.00436	0.525	124.80
12	.120	.00215	0.447	81.24	43	.180	.00376	0.623	77.22
13	.240	.00354	0.572	121.44	44	.180	.00306	0.742	82.80
14	.240	.00270	0.316	144.24	45	.180	.00292	0.598	136.26
15	.240	.00337	0.593	92.88	46	.240	.00454	0.609	69.60
16	.360	.00504	0.576	113.76	47	.240	.00461	0.570	92.88
17	.360	.00464	0.566	113.92	48	.240	.00490	0.571	78.48
18	.360	.00340	0.597	168.12	49	.300	.00456	0.758	126.30
19	.120	.00529	0.534	93.84	50	.300	.00531	0.649	111.60
20	.120	.00732	0.759	103.32	51	.300	.00570	0.712	96.00
21	.120	.00490	0.515	67.32	52	.180	.00396	0.563	221.40
22	.240	.00880	0.402	139.68	53	.180	.00378	0.675	216.00
23	.240	.00958	0.544	152.40	54	.240	.00523	0.544	144.00
24	.240	.00838	0.647	168.00	55	.240	.00502	0.630	144.00
25	.300	.00696	0.250	226.20	56	.240	.00506	0.645	119.28
26	.300	.00855	0.375	198.60	57	.300	.00639	0.569	170.10
27	.300	.00918	0.559	192.30	58	.300	.00792	0.599	171.00
28	.300	.00501	0.686	134.70	59	.300	.00660	0.706	166.80
29	.300	.00528	0.631	119.10	60	.360	.00853	0.529	223.92
30	.300	.00555	0.646	115.80	61	.360	.00781	0.716	216.00
31	.240	.00432	0.597	116.88	62	.360	.00868	0.668	196.00

Description: The same with Table 8 A

Table 9A Calculated data of α, β and μ based on water advance run on border irrigation (Sandy loam)

No.	Discharge (m^3/min/m)	Intake rate constants α	$-\beta$	Water depth (m)	Description
1	0.2856	0.0047	0.570	0.0303	The same with Table 8 but discharge unit is m^3/min/m and water cross section area is the same water depth in border irrigation.
2	0.2928	0.0070	0.683	0.0203	
3	0.3810	0.0063	0.656	0.0414	
4	0.2790	0.0061	0.442	0.0156	
5	0.3660	0.0053	0.376	0.0266	
6	0.2892	0.0078	0.616	0.0327	
7	0.3210	0.0084	0.699	0.0338	
8	0.3582	0.0093	0.620	0.0275	
9	0.3689	0.0055	0.777	0.0363	
10	0.3800	0.0070	0.370	0.0251	
11	0.3482	0.0056	0.679	0.0243	
12	0.2588	0.0080	0.636	0.0181	
13	0.2760	0.0091	0.428	0.0221	
14	0.2856	0.0053	0.569	0.0260	
15	0.1800	0.0043	0.580	0.0149	
16	0.1392	0.0058	0.654	0.0149	
17	0.1938	0.0084	0.506	0.0216	
18	0.1452	0.0080	0.634	0.0198	
Ave.		0.00677	0.583		

Table 9B Calculated data of α, β and μ based on water advance run on border irrigation (Silty loam)

No.	Discharge (m^3/min/m)	Intake rate constants α	$-\beta$	Water depth (m)	Description
1	0.0966	0.0067	0.495	0.0174	The same with Table 8 but discharge unit is m^3/min/m and water cross section area is the same water depth in border irrigation.
2	0.1380	0.0071	0.547	0.0169	
3	0.1212	0.0075	0.510	0.0138	
4	0.0696	0.0045	0.541	0.0108	
5	0.1938	0.0066	0.563	0.0218	
6	0.1452	0.0057	0.483	0.0155	
7	0.0966	0.0052	0.621	0.0125	
8	0.0966	0.0059	0.673	0.0154	
9	0.1380	0.0061	0.619	0.0150	
10	0.0966	0.0037	0.602	0.0142	
11	0.1500	0.0063	0.578	0.0232	
12	0.2100	0.0064	0.544	0.0289	
13	0.2400	0.0054	0.311	0.0300	
14	0.0696	0.0051	0.586	0.0235	
15	0.0696	0.0047	0.628	0.0142	
16	0.0696	0.0045	0.626	0.0155	
17	0.0696	0.0047	0.633	0.0186	
18	0.0696	0.0042	0.649	0.0188	
19	0.2280	0.0140	0.652	0.0199	
20	0.2280	0.0126	0.578	0.0274	
Ave.		0.0063	0.572		

(2) Determination of the Normal Equation $\mu = Aq^B$

The value of μ calculated from Tables 8 and 9 is related to the factors of α, β and q. If it is related todischarge only, the form of $\mu = Aq^B$ is designed. Then, the normal equation is established and the errors of this equation is assessed with the methods of least square and linearization. In the course of calculation, the errors of residuals, standard errors of the coefficients A and B, and 95% confidence limit are considered. The values of A, B and standard errors in the normal equations are listed as below.

Item	$A \pm \sigma A$	$B \pm \sigma B$
Furrow irrigation Sandy loam	179 ± 13	0.27 ± 0.06
Furrow irrigation Silty loam	260 ± 40	0.47 ± 0.10
Border irrigation Sandy loam	0.035 ± 0.006	0.30 ± 0.13
Border irrigation Silty loam	0.132 ± 0.036	0.95 ± 0.13

Because of simplification, two kinds of soil texture in furrow and border irrigations are combined in one equation respectively. The constants of A and B are shown as below.

Item	$A \pm \sigma A$	$B \pm \sigma B$
Furrow irrigation	215 ±22	0.37 ±0.07
Border irrigation	0.062 ±0.008	0.645 ±0.065

If linearization method is used to calculate, the constants are shown as below.

Item	$A \pm \sigma A$	$B \pm \sigma B$
Furrow irrigation	226 ±0.35	0.38 ±0.11
Border irrigation	0.046 ±0.011	0.46 ±0.13

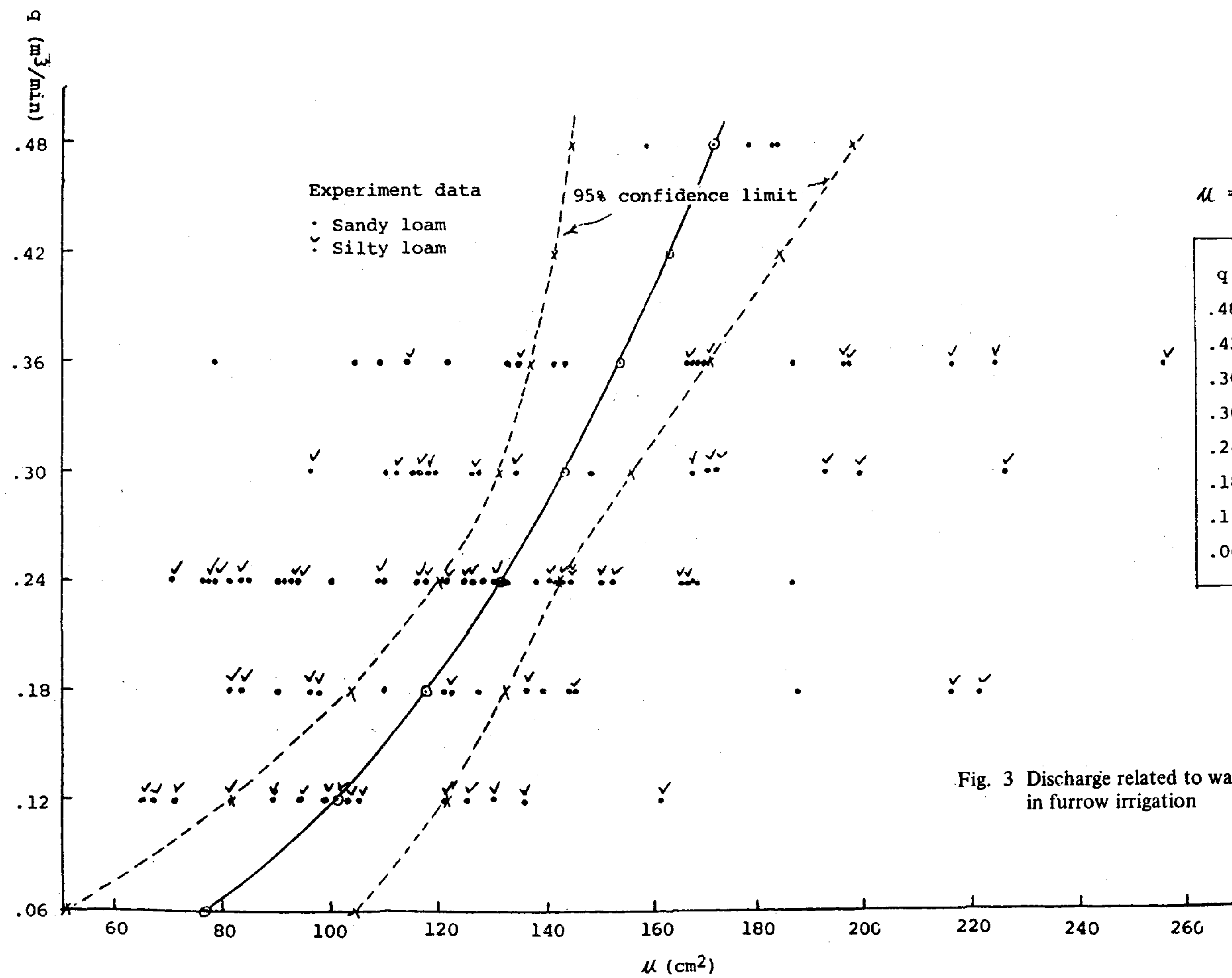
So, the equation of μ related to q are:

Furrow irrigation; $\mu f = 0.226g^{0.38}$ .... (18)

Border irrigation; $\mu b = 0.046q^{0.46}$ .... (19)

The unit of μ is square meter in furrow and meter in border, and the unit of q is m^3/min in furrow and m^3/min/m in border.

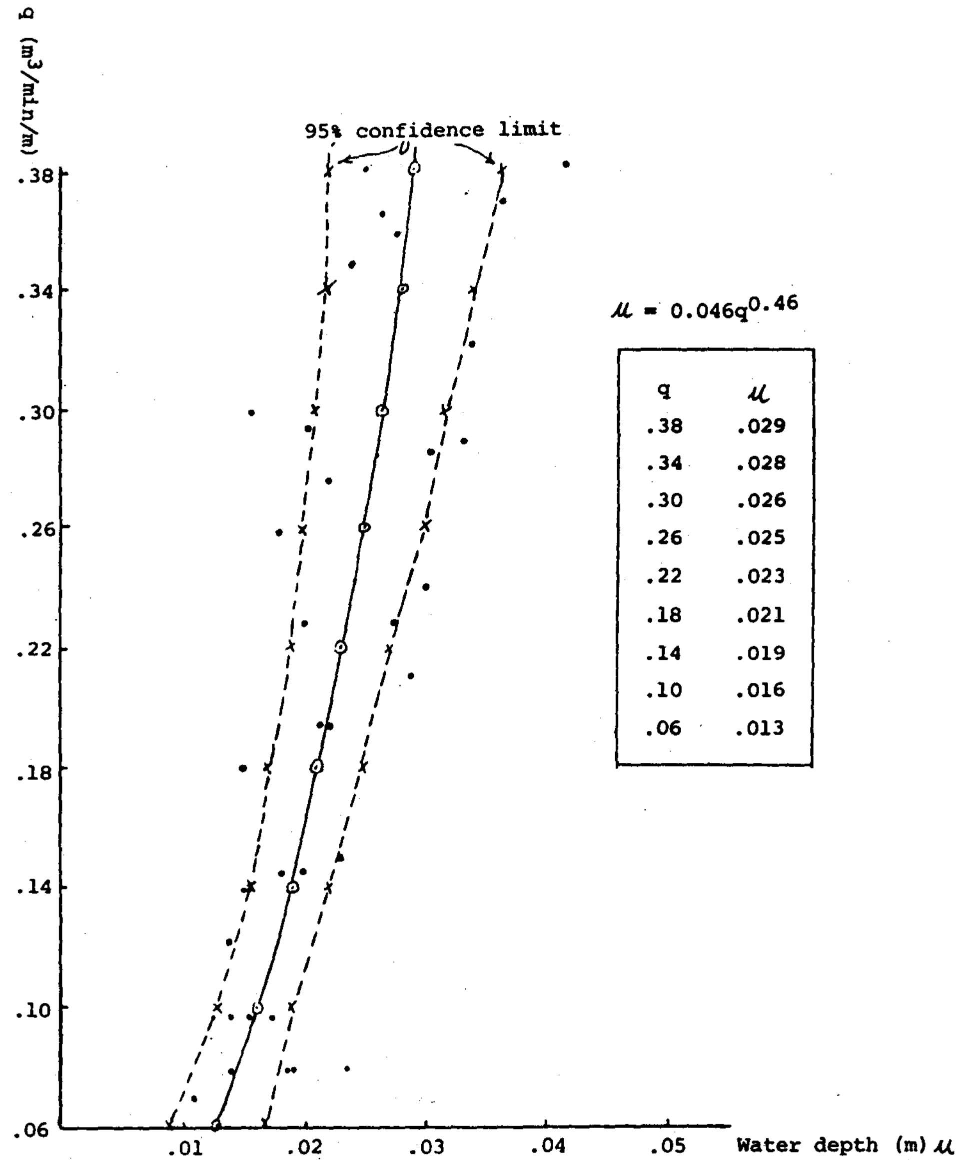
If the actual figures from the function of discharge q are computated by the different method, the results are shown as below.



$A = 226q^{.38}$

q	A
.48	170.99
.42	162.53
.36	153.29
.30	143.03
.24	131.40
.18	117.79
.12	100.97
.06	77.59

Fig. 3 Discharge related to water cross section in furrow irrigation



q	u
.38	.029
.34	.028
.30	.026
.26	.025
.22	.023
.18	.021
.14	.019
.10	.016
.06	.013

Fig. 4 Discharge related to water cross section in border irrigation

Furrow irrigation

Item	Equation	Discharge 0.1	0.3	0.5
Sandy loam	$179q^{0.27}$	96.128	129.323	148.448
Silty loam	$260q^{0.47}$	88.099	147.646	187.711
Combined (least square	$215q^{0.37}$	91.715	137.712	166.363
Combined (Linearization)	$226q^{0.38}$	94.212	143.026	173.666

Border irrigation

Item	Equation	Discharge 0.1	0.3	0.5
Sandy loam	$0.035q^{0.3}$	0.0175	0.0244	0.0284
Silty loam	$0.132q^{0.95}$	0.0148	0.0421	0.0683
Combined (Least square)	$0.062q^{0.645}$	0.0140	0.0285	0.0296
Combined (Linearization)	$0.046q^{0.46}$	0.0159	0.0264	0.0334

From the figures above, the combined calculation with the method of linearization seems to be the most suitable one.

(3) Determination of Normal Equation $I_T = a_T q^{b_T}$ and Accumulated Intake Constants α_o and β_o

In the Equation (13) $i = \alpha t^{\beta}$, α and β are intake rate constants, which are calculated from Tables 8 and 9. Integrating this equation, it becomes an accumulated intake equation and the constants nn and nn can be calculated as $\alpha_o = \frac{\alpha}{1+\beta}$ and $\beta_o = 1 + \beta$.

From the coefficients α and β above and putting time t, say 10, 20, 30, 40 and 50 minutes, as the function of q, the value of accumulated intake can be got. Using linearization method, the constants a_T and b_T in the normal equation $I_T = a_T q^{b_T}$ are established as follows:

Furrow irrigation

Soil texture	I_{fT}*	$a_T \pm \sigma a_T$	$b_T \pm \sigma b_T$
Sandy loam	I_f10	0.12 ± 0.02	0.81 ± 0.14
	I_f20	0.16 ± 0.03	0.77 ± 0.17
	I_f30	0.20 ± 0.04	0.78 ± 0.18
	I_f40	0.223± 0.046	0.76 ± 0.19
	I_f50	0.248± 0.057	0.754± 0.198
Silty loam	I_f10	0.082± 0.020	0.61 ± 0.18
	I_f20	0.11 ± 0.03	0.61 ± 0.19
	I_f30	0.13 ± 0.04	0.61 ± 0.21
	I_f40	0.15 ± 0.04	0.60 ± 0.21
	I_f50	0.16 ± 0.05	0.60 ± 0.23

*I_{fT}; Accumulated intake in furrow at certain time

Border irrigation

I_{bT}*	$a_T \pm \sigma a_T$	$b_T \pm \sigma b_T$
I_b10	0.045 ±0.08	0.032± 0.123
I_b20	0.060 ±0.011	0.041± 0.13
I_b30	0.072 ±0.014	0.046± 0.138
I_b40	0.0815 ±0.016	0.049± 0.15
I_b50	0.09 ±0.02	0.053± 0.16

*I_{bT}; Accumulated intake in border at certain time

Using the principle of matrix, 5 equations in different soil texture of furrow irrigation the results are solved as shown below.

Sandy loam:

$$\alpha_o = 0.0418 q^{0.879} \quad \text{(20)}$$

$$\beta_o = 0.4550 - 0.0737 \log q \quad \text{(21)}$$

$$\beta = 1 - \beta_o = -(0.5450 + 0.0737 \log q) \quad \text{(22)}$$

$$\alpha = \alpha_o (1 - \beta) = 0.031 (1 + \beta) q^{0.879} \quad \text{(23)}$$

Silty loam

$$\alpha_o = 0.031 q^{0.628} \quad \text{(24)}$$

$$\beta_o = 0.4223 - 0.0154 \log q \quad \text{(25)}$$

$$\beta = 1 - \beta_o = -(0.5777 + 0.0154 \log q) \quad \text{(26)}$$

$$\alpha = \alpha_o (1 - \beta) = 0.031 (1 + \beta) q^{0.628} \quad \text{(27)}$$

For border irrigation, it is shown that in the normal equations above the errors of index are larger than the value of index itself. It means that intake rate constants are independent and it is not rleated with discharge q. Therefore, the values of α and β are taken as an average from Table 9; $\alpha = 0.0065$, $\beta = 0.5775$ and $\alpha_o = 0.0152$, $\beta_o = 0.4225$.

(4) Determination of New Water Advance Distance x and Elapsed Time t

According to the theorem mentioned in article 2 in order to calculate the new water advance distance x and elapsed time t, the basic figures of μ, α and β corresponding to discharge q, have to be provided. From the Equations (18), (22), (23), (26) and (27), the values of μ, α and β are calculated in Table 10 for furrow irrigation. For border irrigation, the values of α and β are averaged from Table 9 and μ is taken from the Equation (19). They are listed in Table 13.

From the data above, computer is used to calculate ζ_0. Then assuming t to calculate ζ_0 and F, at last the water advance distance values are obtained. The results of furrow irrigation in sandy loam and silty loam are shown in Figs. 5A and 5B respectively. For border irrigation, the results are shown in Fig. 6.

Table 10 Discharge q related to accumulate intake when time is constant in furrow irrigation (Sandy loam)

No.	q	I_{f10}	I_{f20}	I_{f30}	I_{f40}	I_{f50}
1	.24	0.0572	0.0863	0.110	0.1304	0.1489
2	.24	0.0443	0.0604	0.0724	0.0823	0.0909
3	.36	0.0573	0.0801	0.0974	0.1119	0.1246
4	.36	0.0664	0.0906	0.1087	0.1237	0.1367
5	.48	0.0700	0.1031	0.1293	0.1519	0.1721
6	.48	0.0593	0.0832	0.1014	0.1167	0.1302
7	.24	0.0507	0.0717	0.0873	0.1013	0.1132
8	.24	0.0510	0.0742	0.0924	0.1079	0.1217
9	.36	0.0695	0.0932	0.1107	0.1251	0.1375
10	.36	0.0640	0.0937	0.1170	0.1371	0.1549
11	.48	0.0760	0.1061	0.1289	0.1481	0.1649
12	.48	0.0776	0.1058	0.1269	0.1443	0.1594
13	.24	0.0333	0.0435	0.0508	0.0568	0.0618
14	.24	0.0327	0.0446	0.0535	0.0608	0.0672
15	.18	0.0366	0.0551	0.0701	0.0831	0.0948
16	.18	0.0310	0.0459	0.0577	0.0679	0.0770
17	.18	0.0276	0.0419	0.0535	0.0637	0.0728
18	.24	0.0350	0.0469	0.0556	0.0627	0.0689
19	.30	0.0427	0.0595	0.0723	0.0830	0.0924
20	.30	0.0417	0.0565	0.0669	0.0758	0.0834
21	.30	0.0363	0.0528	0.0659	0.0770	0.0869
22	.36	0.0418	0.0531	0.0611	0.0675	0.0729
23	.36	0.0538	0.0674	0.0770	0.0845	0.0909
24	.36	0.0527	0.0708	0.0841	0.0950	0.1045
25	.18	0.0363	0.0634	0.0670	0.0786	0.0890
26	.18	0.0305	0.0429	0.0523	0.0602	0.0672
27	.18	0.0346	0.0490	0.0600	0.0693	0.0775
28	.24	0.0353	0.0456	0.0531	0.0591	0.0642
29	.24	0.0361	0.0485	0.0578	0.0654	0.0719
30	.24	0.0289	0.0381	0.0447	0.0501	0.0548
31	.30	0.0397	0.0536	0.0639	0.0723	0.0800
32	.30	0.0447	0.0604	0.0720	0.0816	0.0899
33	.30	0.0408	0.0535	0.0627	0.0701	0.0765
34	.36	0.0469	0.0648	0.0783	0.0896	0.0994
35	.36	0.0446	0.0592	0.0699	0.0782	0.0856
36	.36	0.0490	0.0637	0.0744	0.0830	0.0903

Note: q : discharge (m^3/min)

I_f: accumulated intake in furrow (m^2)
10, 20, 30 ... are intake time (min).

Table 10 Discharge q related to accumulate intake when time is constant in furrow irrigation (Silty loam)

No.	q	I_{f10}	I_{f20}	I_{f30}	I_{f40}	I_{f50}
1	.12	0.0253	0.0357	0.0438	0.0505	0.0565
2	.12	0.0240	0.0331	0.0400	0.0456	0.0506
3	.12	0.0283	0.0365	0.0423	0.0471	0.0511
4	.24	0.0407	0.0563	0.0681	0.0779	0.0865
5	.24	0.0361	0.0509	0.0623	0.0719	0.0803
6	.24	0.0310	0.0349	0.0373	0.0391	0.0406
7	.36	0.0483	0.0624	0.0724	0.0806	0.0875
8	.36	0.0489	0.0663	0.0791	0.0897	0.0989
9	.36	0.0438	0.06173	0.0754	0.0869	0.0970
10	.12	0.0116	0.0156	0.0185	0.0209	0.0229
11	.12	0.0130	0.0176	0.0210	0.0238	0.0263
12	.12	0.0139	0.0204	0.0255	0.0299	0.0338
13	.24	0.0221	0.0298	0.0355	0.0401	0.0441
14	.24	0.0191	0.0306	0.0404	0.0492	0.0573
15	.24	0.0211	0.0280	0.0331	0.0372	0.0407
16	.36	0.0316	0.0423	0.0503	0.0568	0.0624
17	.36	0.0290	0.0392	0.0468	0.0530	0.0584
18	.36	0.0213	0.0282	0.0332	0.0373	0.0408
19	.12	0.0332	0.0459	0.0554	0.0633	0.0703
20	.12	0.0529	0.0625	0.0689	0.0739	0.0780
21	.12	0.0309	0.0432	0.0526	0.0605	0.0674
22	.24	0.0583	0.0883	0.1125	0.1336	0.1527
23	.24	0.0600	0.0824	0.0991	0.1129	0.1251
24	.24	0.0535	0.0683	0.0789	0.0873	0.0945
25	.30	0.0522	0.0878	0.1170	0.1476	0.1745
26	.30	0.0577	0.0890	0.1146	0.1372	0.1577
27	.30	0.0575	0.0780	0.0933	0.1059	0.1169
28	.30	0.0329	0.0408	0.0464	0.0508	0.0545
29	.30	0.0335	0.0432	0.0502	0.0558	0.0606
30	.30	0.0354	0.0453	0.0522	0.0579	0.0626
31	.24	0.0271	0.0359	0.0422	0.0474	0.0519
32	.24	0.0278	0.0360	0.0418	0.0465	0.0506
33	.24	0.0268	0.0354	0.0416	0.0466	0.0510
34	.18	0.0245	0.0326	0.0385	0.0433	0.0474
35	.18	0.0242	0.0300	0.0340	0.0371	0.0397
36	.18	0.0225	0.0303	0.0361	0.0408	0.0449
37	.12	0.0242	0.0333	0.0402	0.0460	0.0510
38	.12	0.0257	0.0340	0.0400	0.0449	0.0492
39	.12	0.0232	0.0292	0.0330	0.0368	0.0397
40	.12	0.0273	0.0374	0.0450	0.0513	0.0568
41	.12	0.0101	0.0162	0.0213	0.0260	0.0303
42	.12	0.0274	0.0381	0.0461	0.0529	0.0589
43	.18	0.0238	0.0309	0.0360	0.0404	0.0439
44	.18	0.0222	0.0265	0.0294	0.0326	0.0354
45	.18	0.0183	0.0242	0.0285	0.0320	0.0350
46	.24	0.0286	0.0375	0.0439	0.0491	0.0536
47	.24	0.0289	0.0389	0.0463	0.0524	0.0576
48	.24	0.0307	0.0413	0.0491	0.0556	0.0612
49	.30	0.0328	0.0389	0.0429	0.0460	0.0486
50	.30	0.0339	0.0433	0.0499	0.0552	0.0597
51	.30	0.0384	0.0469	0.0527	0.0573	0.0611
52	.18	0.0248	0.0335	0.0400	0.0454	0.0501
53	.18	0.0246	0.0308	0.0351	0.0386	0.0415
54	.24	0.0328	0.0450	0.0541	0.0617	0.0683
55	.24	0.0318	0.0411	0.0478	0.0531	0.0577
56	.24	0.0322	0.0413	0.0477	0.0528	0.0572
57	.30	0.0400	0.0539	0.0642	0.0727	0.0800
58	.30	0.0497	0.0657	0.0773	0.0867	0.0948
59	.30	0.0442	0.0542	0.0610	0.0664	0.0709
60	.36	0.0536	0.0742	0.0899	0.1029	0.1143
61	.36	0.0529	0.0644	0.0722	0.0784	0.0835
62	.36	0.0562	0.0707	0.0809	0.0890	0.0958

Note: q : discharge (m^3/min), I_f: accumulated intake in furrow (m^2). 10, 20, 30 ... are intake time (min).

Table 11 Discharge q related to accumulate intake when time is constant in border irrigation

No.	q	Ib10	Ib20	Ib30	Ib40	Ib50
1	0.2856	0.0294	0.0396	0.0472	0.0534	0.0588
2	0.2928	0.0458	0.0571	0.0649	0.0711	0.0763
3	0.3810	0.0404	0.0513	0.0590	0.0651	0.0703
4	0.2790	0.0395	0.0582	0.0729	0.0856	0.0970
5	0.3660	0.0357	0.0551	0.0709	0.0849	0.0976
6	0.2892	0.0492	0.0642	0.0750	0.0837	0.0912
7	0.3210	0.0558	0.0688	0.0777	0.0847	0.0906
8	0.3582	0.0587	0.0764	0.0891	0.0994	0.1082
9	0.3689	0.0412	0.0481	0.0527	0.0561	0.0590
10	0.3800	0.0474	0.0734	0.0947	0.1135	0.1306
11	0.3482	0.0365	0.0456	0.0520	0.0570	0.0612
12	0.2588	0.0508	0.0654	0.0758	0.0842	0.0913
13	0.2760	0.0594	0.0883	0.1113	0.1312	0.1491
14	0.2856	0.0332	0.0447	0.0533	0.0603	0.0664
15	0.1800	0.0269	0.0360	0.0427	0.0482	0.0529
16	0.1392	0.0372	0.0473	0.0544	0.0601	0.0649
17	0.1938	0.0530	0.0747	0.0913	0.1052	0.1174
18	0.1452	0.0508	0.0654	0.0759	0.0843	0.0915

Table 12 Basic data for calculating water advance run distance and time in furrow irrigation

q (m^3/min)	μ (m^2)	Sandy loam		Silty loam	
		α	$-\beta$	α	$-\beta$
0.10	0.0094	0.0029	0.471	0.0032	0.562
0.12	0.0101	0.0034	0.477	0.0036	0.564
0.18	0.0118	0.0047	0.490	0.0046	0.566
0.20	0.0123	0.0051	0.493	0.0049	0.567
0.24	0.0131	0.0060	0.499	0.0055	0.568
0.30	0.0143	0.0072	0.506	0.0063	0.570
0.36	0.0153	0.0083	0.512	0.0070	0.571
0.40	0.0160	0.0090	0.516	0.0075	0.572
0.48	0.0171	0.0105	0.521	0.0083	0.573
0.50	0.0173	0.0108	0.523	0.0086	0.573

Table 13 Basic data for calculating water advance run distance and time in border irrigation

q (m^3/min/m)	μ (m)	α	$-\beta$
0.05	0.0116	0.0065	0.5775
0.07	0.0135	0.0065	0.5775
0.10	0.0159	0.0065	0.5775
0.15	0.0192	0.0065	0.5775
0.20	0.0219	0.0065	0.5775
0.25	0.0243	0.0065	0.5775
0.30	0.0264	0.0065	0.5775
0.35	0.0284	0.0065	0.5775
0.40	0.0302	0.0065	0.5775
0.45	0.0319	0.0065	0.5775
0.50	0.0334	0.0065	0.5775

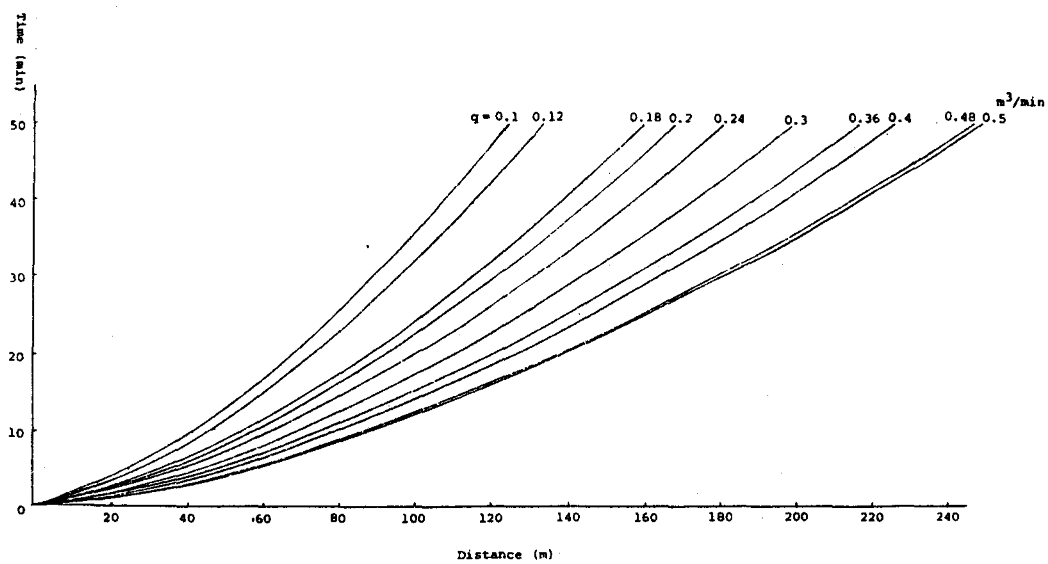


Fig. 5A Water advance curves in furrow irrigation (Sandy loam)

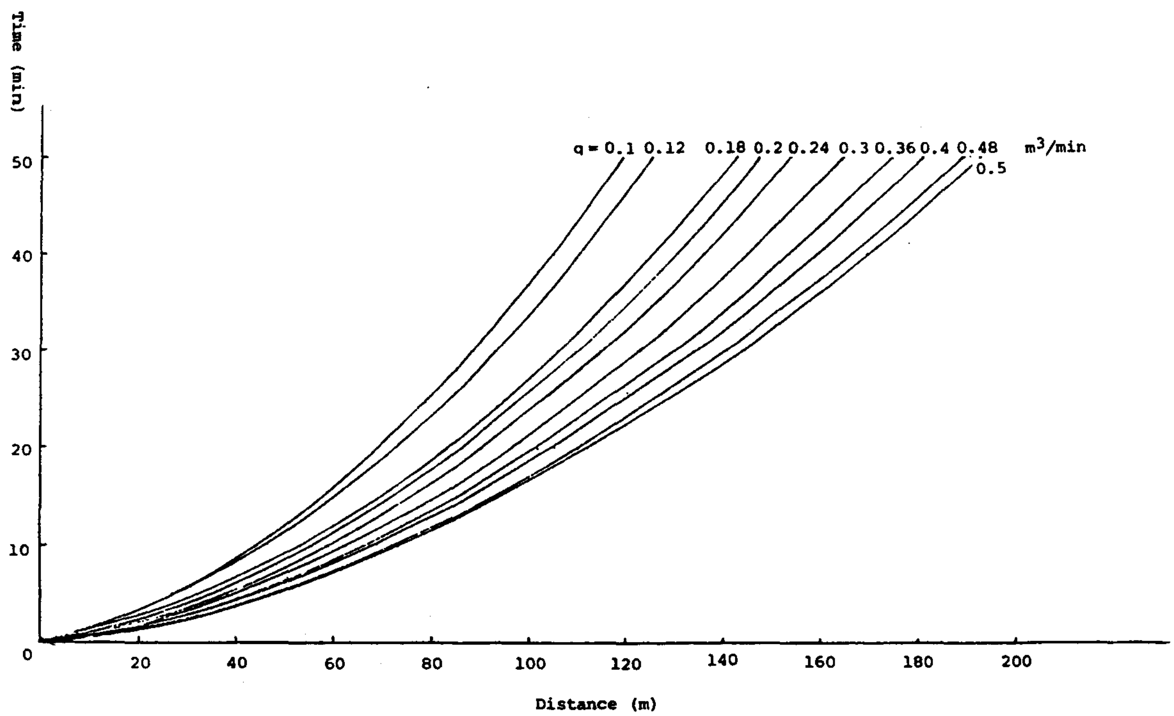


Fig. 5B Water advance curves in furrow irrigation (Silty loam)

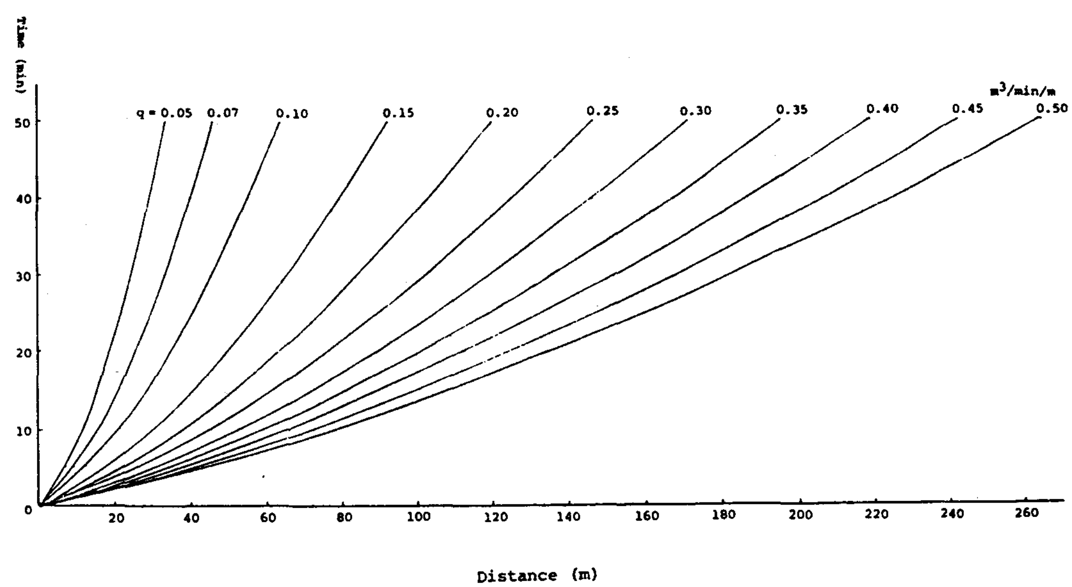


Fig. 6 Water advance curves in border irrigation

In case that the calculated data of water advance run are plotted into experimental data, the examples of furrow irrigation in sandy loam and silty loam are shown in Figs. 7A and 7B respectively. They show a very good result. For border irrigation, the calculated results are not exact discharge as compared with experimental data. An approximate discharge is compared in Fig. 8.

(5) Calculation of Accumulated Intake in Soil Layer and Water Surface Profile at the End of Irrigation

After getting the data of water advance run on x and t, the intake time t_i at the certain distance can be calculated from the advance curves in Figs. 5 and 6.Then using the Equation $I = \alpha_o t_i^{\beta_o}$ to calculate the accumulated intake at certain distance of furrow and border irrigation, the calculation is shown in Table 14. When q = 0.3, the accumulated intake curve are shown in Figs. 9 and 10.

5. Discussion and Conclusion

As for the theory of this study, the principle of continuity equation is adopted to set the equations for analysis.

The basic data are taken from 136 field experiments in sandy loam and silty loam soils in this study; 98 experiments in furrow irrigation and 38 in border irrigation. The soil moistures are controlled at 50% of available moisture before carrying out experiments. Experimental fields are planted with sweet potato (furrow) or corn (border) and rotated with paddy rice. The average slope is about 0.2%. The data of water advance run and discharge are observed during the experiment.

Based on the theorem and the experimental data, intake rate constants α,β and water cross section μ are calculated by cut and try method. Then the relation of water cross section μ corresponding to discharge q are set up, and a normal equation as the form $\mu = Aq^B$ is established such as A= 226±35, B= 0.38±0.11 for furrow irrigation and A= 0.046±0.011, B= 0.46±0.13 for border. Putting intake time as constant, say 10, 20, 30, 40 and 50 minute, in order to calculate accumulated intake related to discharge, a set of normal equation $I_T = a_T q^{b_T}$ are established. Matrix principal is used to solve a set of normal equations in different irrigation method and soil texture. The constants of α_o and β_o in furrow irrigation is established.

Sandy loam; $\alpha_o = 0.0418q^{0.879}$
$\beta_o = 0.4550 - 0.0737 \log q$

Silty loam; $\alpha_o = 0.031q^{0.628}$
$\beta_o = 0.4223 - 0.0154 \log q$

However, in border irrigation the error is very large. It means that the intake rate constants are independent and not related with discharge. The intake rate can be calculated from the initial α and β such as $\alpha_o = 0.0514$ and $\beta_o = 0.4225$.

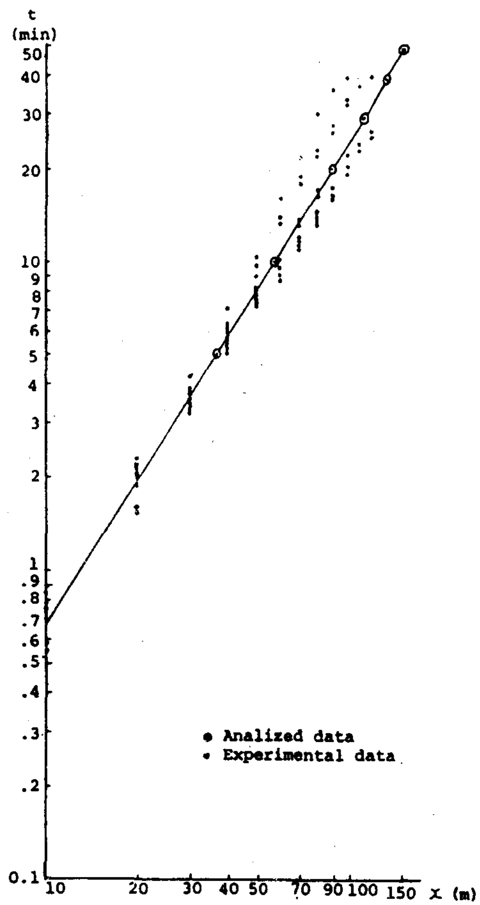


Fig. 7A Furrow q=0.24 m³/min SaL

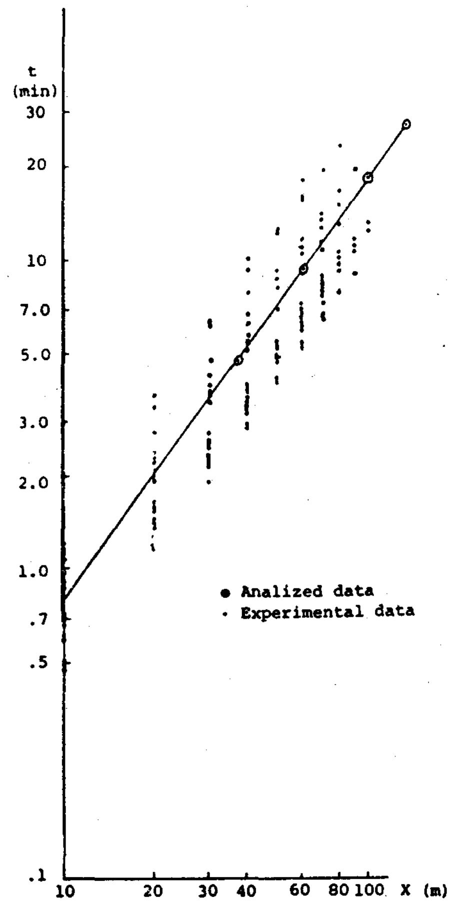


Fig. 7B Furrow q=0.24 m³/min SiL

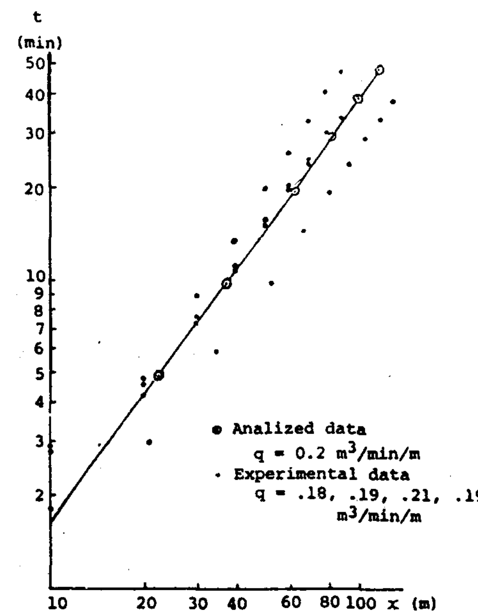


Fig. 8 Border

Table 14 Accumulated intake calculation when q=0.3

χ	Furrow						Border		
	SaL, α_o = 0.0146, β_o = 0.494			SiL, α_o = 0.0147, β_o = 0.430			α_o = 0.0154, β_o = 0.4225		
(m)	t (min)	t_i (min)	If (cm^2)	t (min)	ti (min)	If (cm^2)	t (min)	ti (min)	Ib (m)
10	1.0	49.0	0.0998	1.0	48.7	0.0782	1.5	48.0	0.0790
20	1.5	48.5	0.0993	1.8	47.9	0.0776	3.5	46.0	0.0776
30	3.0	47.0	0.0978	3.8	45.9	0.0762	5.0	44.0	0.0762
40	5.0	45.0	0.0957	4.7	45.0	0.0755	7.0	42.5	0.0751
50	7.0	43.0	0.0936	6.7	43.0	0.0741	8.4	41.1	0.0740
60	9.3	40.7	0.0911	8.3	41.4	0.0729	12.0	37.5	0.0712
70	12.0	38.0	0.0881	10.5	39.2	0.0712	14.5	35.0	0.0692
80	14.7	35.3	0.0849	12.7	37.0	0.0694	17.4	32.1	0.0667
90	17.7	32.3	0.0813	15.0	34.7	0.0676	20.3	29.2	0.0641
100	21.3	28.7	0.0767	17.5	32.2	0.0654	23.5	26.0	0.0610
110	25.0	25.0	0.0716	20.3	29.4	0.0629	26.8	22.7	0.0576
120	29.0	21.0	0.0657	23.0	26.7	0.0604	30.5	19.0	0.0534
130	33.0	17.0	0.0592	26.0	23.7	0.0573	34.0	15.5	0.0490
140	37.5	12.5	0.0508	29.0	20.7	0.0541	37.5	12.0	0.0440
150	42.3	7.7	0.0400	32.3	17.4	0.0502	41.5	8.0	0.0371
160	47.7	2.3	0.0220	35.5	14.2	0.0460	45.5	4.0	0.0277
165	50.0	0	0	-	-	-	-	-	-
170				39.0	10.7	0.041	49.5	0	0
180				42.5	7.2	0.034			
190				46.0	3.7	0.026			
200				49.7	0	0			

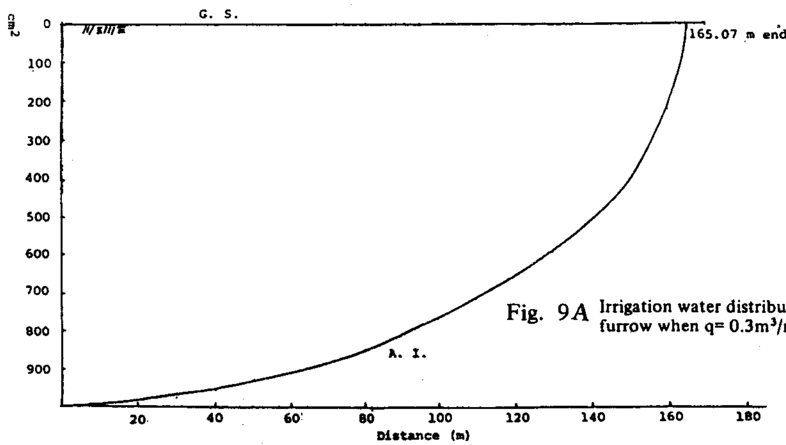


Fig. 9A Irrigation water distribution at the end of irrigation furrow when q= 0.3m³/min (Sandy loam)

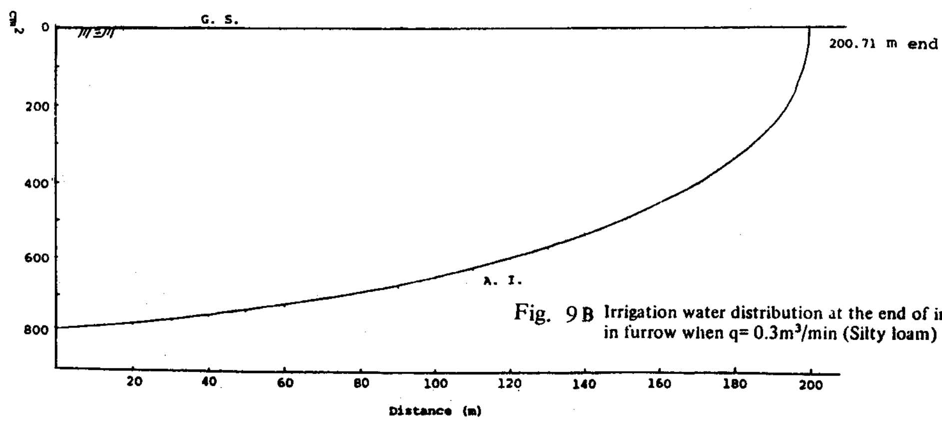


Fig. 9B Irrigation water distribution at the end of irrigation in furrow when q= 0.3m³/min (Silty loam)

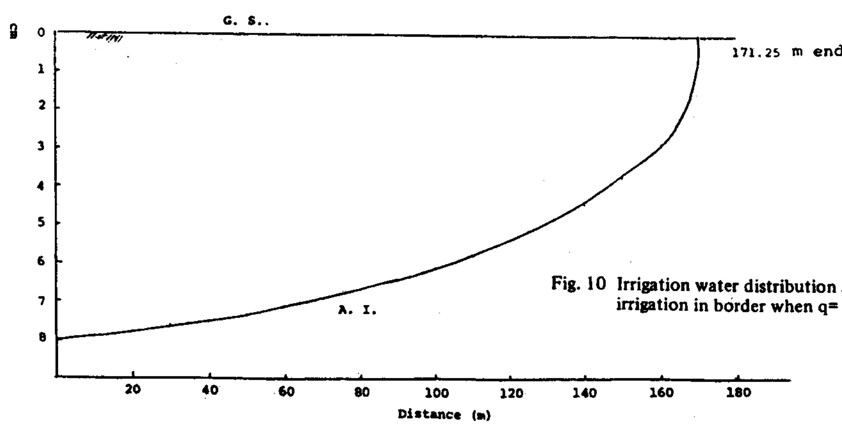


Fig. 10 Irrigation water distribution at the end of irrigation in border when q= 0.3m³/min/m

During the data analysis, the errors of residuals, standard error and 95% confidence limit are assessed by using the method of least square.

Using the analyzed data above, water advance distance x and elapsed time t are calculated with discharges from 0.1 m^3/min to 0.5m^3/min both in furrow and border irrigation as shwon in Figs. 5 and 6 respectively. Plotting x and t together with experimental data, they show the reasonable results.

From the advance curves, accumulated time t_i can be found. Using the Equation $I= \alpha_0 t_i^{\beta_0}$ to calculate accumulated intake the results are plotted on Figs. 9 and 10.

The discussion on the conclusion of this study is described as follows:

(1) The intake rate is a very important factor for surface irrigation. Irrigators usually use cylinder or ponding or inflow-outflow method for measuring intake rate, which is spot measurement. If the method introduced in this study is used to calculate intake rate constants from water advance data, the results can be applied to the field. It is sure that the accuracy is much higher than that of the existing methods.

(2) If the original data taken from field experiment in this study are accurate, the reasonable results can be got through this analysis, because this calculation is very accurate from the field operation point of view.

(3) The original data of this study seems to be fairly good, because the experimental worker had done the experiments very carefully for making the discharge measurement. For example, one discharge keeper checked the Parshall flume discharge all the time during experiment. But the natural conditions on roughness of ground surface, nonuniform slope, narrow water entrance of border, etc. might cause some errors during experiment.

(4) The experiments were done in the field of upland crops rotated with paddy rice, so the results will be used in this kind of field only, because there are some special characteristics in this kind of field.

(5) Since modern irrigation equipments such as sprinkler and drip are developed in recent years, surface irrigation method seems to be out of date. Most of countries do not use the surface irrigation method and the researcher is also very few in the world. The surface irrigation method is still used especially in the field of upland crops rotated with paddy rice. So, the author emphasizes that the research work on surface irrigation is still very important in the future.

(6) Following this study, the author hopes that more detailed study will be made putting emphasis on the following points in the future.

(A) Soil moisture movement phenomenon in soil layer after irrigation.

(B) Discussion on irrigation efficiencies after irrigation.

(C) Cut back methods can be studied in different conditions of fields or soils.

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