HYDRAULICS OF BORDER STRIP IRRIGATION ON LEVEL OR NEARLY LEVEL RICE FIELDS

By

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THESIS

Submitted in partial fulfilment of the
requirements for the degree

Master of Science in Agricultural Engineering

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1983

Dedicated

to

the memory

of

Late Dr. JOSE SAMUEL

former Professor and Head

Department of

AGRICULTURAL ENGINEERING

Kerala Agricultural University

DECLARATION

I hereby declare that this thesis entitled "Hydraulics of Border Strip Irrigation on Level or Nearly Level Rice Fields" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Feb.1983.

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CERTIFICATE

Certified that this thesis entitled "Hydraulics of Border Strip Irrigation on Level or Nearly Level Rice Fields" is a record of research work done independently by Kum. K.P. VISALAKSHI under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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We, the undersigned, members of the Advisory Committee of Kum. K.P. VISALAKSHI, a candidate for the degree of Master of Science in Agricultural Engineering with major in Soil and Water Engineering, agree that the thesis entitled "Hydraulics of Border Strip Irrigation on Level or Nearly Level Rice Fields" may be submitted by Kum. K.P. VISALAKSHI in partial fulfilment of the requirements for the degree.

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(VISALAKSHI. K.P)

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SYMBOLS AND ABBREVIATIONS

Agric.	Agricultural
ASAE	Americal Society of Agricultural Engineers
CC	Cubic centimetre(s)
C.D.	Critical difference
cfs	Cubic feet per second
cm	Centimetre(s)
Co.	Company
Dept.	Department
Divi.	Division
e	Exponential
et-al	and others
FAO	Food and Agriculture Organisation
ft	feet
Fig.	Figure
gm	Gram(s)
ha.	hectare(s)
hr.	hour(s)
ICAR	Indian Council for Agricultural Research
in.	inch(es)
IRRI	International Rice Research Institute
ISAE	Indian Society of Agricultural Engineers
J.	Journal
l	litre(s)
log.	logarithm

Ltd.	Limited
m	metre(s)
mm	millimetre(s)
min.	minute(s)
No.	Number
P	Page
pp.	pages
Proc.	Proceedings
Pvt.	Private
Res.	Research
S.S.	Sum of squares
Sec.	Second(s)
%	Per cent
≤	less than or equal to
≠	Not equal to
≥	More than or equal to
/	per
°	degree(s)
'	minute(s)
"	second(s)
Σ	Sum of

Introduction

INTRODUCTION

Agriculture is the backbone of Indian economy and nearly two-third of the population depends on it for their living. Fifty per cent of the gross national income comes from agriculture and ancillary industries. The production of food in India has to be kept in pace with the needs of the ever-increasing population. Since new areas that can be brought under plough is limited, the only alternative is to increase the productivity of land. Placed in this situation, there is no choice but to make the best possible use of the available natural resources, namely soil and water and to produce maximum from unit area to meet the ever-increasing demand for food.

Man has practised irrigation since time immemorial to produce his food. It has helped to foster large and prosperous civilizations over the centuries. Well planned and efficiently utilised irrigation systems help to keep the food production in pace with the increasing population. In order to achieve these objectives, adoption of modern methods with all possible scientific and technological supports are vital. Hence it is essential to plan and design an efficient low cost economic irrigation system tailored to fit natural conditions and local potential.

A Civil Engineer may define irrigation as the redistribution of rainfall in time and space while an Agricultural Engineer may define irrigation as the application of water to soil, to supply the moisture essential for plant growth. Numerous irrigation methods are adopted the world over. These differ in different places from wild flooding to the very sophisticated methods like drip irrigation. Regardless of their high or low construction cost, irrigation by most methods entail one or several shortcomings like very high labour requirements, very low overall efficiency and low net land utilisation.

Kerala is a land blessed with bountiful rains and elaborate waterways. But experience has shown that our agriculture even today is dependent to a great extent on the rain. More than seventy per cent of the double cropped rice fields lie fallow during summer for want of irrigation facilities. Many large scale river-valley projects are to be commissioned in the near future. Large areas which are now lying fallow can be brought under cultivation after these river-valley projects are commissioned.

At present in the command areas of major irrigation projects and wherever lift irrigation facilities are available, a third crop of rice is taken, during the dry season. The total water requirement of rice in the first and second crop seasons is 10-15 mm per day in loamy sand soils. The percolation loss in these seasons is 6-8 mm per day. But in summer months, rice needs 25-30 mm of water per day in which the percolation loss alone comes to about 20 mm of water per day. Hence if rice is grown during summer months, there is an additional wastage of 12 mm of water due to deep percolation. Growing rice during the summer months in soils with high rate of infiltration should be discouraged because of the very low water use efficiency during this season.

In all other crops, the field is irrigated only upto field capacity and hence the loss due to deep percolation is almost eliminated. The water requirement of field crops like pulses, oil seeds and vegetables is only 6-8 mm per day. Thus, the water needed to raise one hectare of rice can be more profitably used to raise about 4 ha. of any other crop. But now, there is no any satisfactory method of irrigation for the dry land crops in the nearly level rice fallows.

Border strip method of irrigation is hardly practised anywhere in Kerala, eventhough this is a very popular method in the other parts of India for raising cereals, pulses and oil seeds. However, this method is practised there on sloping lands. In Kerala, as the area is under paddy during kharif and rabi seasons, the level of the land cannot be disturbed. For this situation, a technology has to be developed for efficient use of the limited water available in this season for irrigating nearly level rice fallows. The objective of this project is to study the hydraulics of border strip irrigation in nearly level lands and to recommend suitable specifications.

Review of Literature

REVIEW OF LITERATURE

A brief review of literature under the following heads are included in this chapter:

1. Border specifications
2. Intake rate analysis in surface irrigation
3. Water front advance in irrigation borders
4. Recession flow in surface irrigation
5. Hydraulic resistance relationship in irrigation borders
6. Deep percolation losses
7. Irrigation efficiencies
8. Irrigation when and how much

Since nobody has done any work on hydraulics of border irrigation in level fields, the literature pertaining to it is meagre. The literature reviewed is mostly related to border irrigation on sloping lands.

For the border strip flooding method, the field is divided into a series of strips by borders or low flat dikes running down the predominant slope. To irrigate, water is turned on to the head of the border; it advances -confined and guided by two borders- in a thin sheet towards the lower end of the strip. The application of the border method requires skill and can only be applied after a painstaking investigation of soil, topography and water conditions. Otherwise, this method which is one of the most efficient may become a severe liability and create both drainage and salinity problems.

2.1. Border specifications:

Some general suggestions on width, length and slope of borders and the size of irrigation stream are described as follows:

2.1.1. <u>Width of border strip</u>:- The width of border strip usually varies from 3 to 15m, depending on the size of irrigation stream available and the degree of land levelling practicable -Michael (1968). It is not economical to keep the width less than about 3m, as otherwise, too many ridges will have to be formed per unit area of the field surface.

United States Department of Agriculture (1970) recommended the following border strip widths for different grades:

Land grade per cent	Maximum strip width (ft)
0.0 - 0.1	120
0.1 - 0.5	60
0.5 - 1.0	50
1.0 - 2.0	40
2.0 - 4.0	30
4.0 - 6.0	20

2.1.2. <u>Border length</u>:- This depends on the infiltration rate of the soil, the slope of the land and the size of irrigation stream available. For moderate slopes and small to moderate size irrigation streams, the border lengths can be suggested as follows:

Sandy and sandy loam soils	:	60 - 120m
Medium loam soils	:	100 - 180m
Clay loam and clayey soils	:	150 - 300m (Michael-1968)

According to USDA (1970), the maximum length of run for level borders for different depth of flow at inlet are shown in Table No.(1).

2.1.3. Border slope:- The borders should have a uniform longitudinal gradient. Excessive slopes will make the water run to the lower end quickly, causing insufficient irrigation at the upstream end and deep percolation losses at the downstream. They also cause soil erosion in borders.

Recommended safe limits of slopes in borders according to Michael (1968) are as follows:

Sandy loam to sandy soil	:	0.25 - 0.6 per cent
Medium loam soils	:	0.2 - 0.4 per cent
Clay to clay loam soils	:	0.05 - 0.2 per cent

2.1.4. Size of irrigation stream:- The requirement of irrigation stream is expressed in terms of the rate of waterflow per unit width of the border such as in 1/sec/m. The size of irrigation stream needed depends on the infiltration rate of the soil and the width of border strip. The Table No.(2) represents some typical

TABLE -1

Level borders - maximum length of run (ft.)

Unit stream (cfs.)	depth of flow at inlet (ft.)					
	0.8	0.7	0.6	0.5	0.4	0.3
0.0500	450	350	300	225	175	100
0.0400	525	425	350	250	200	125
0.0300	625	500	400	325	225	150
0.0250	700	575	475	350	250	175
0.0200	800	675	525	400	300	200
0.0150	975	825	650	500	375	250
0.0125	1100	925	725	575	400	275
0.0100	1300	1075	850	650	475	325
0.0090	1375	1150	925	700	500	350
0.0080	1500	1250	1000	750	550	375
0.0070	1625	1350	1075	825	600	400
0.0060	1825	1500	1200	925	675	450
0.0050	2050	1700	1350	1050	750	500
0.0040	2400	1975	1575	1225	875	575
0.0035	2600	2150	1725	1325	950	625
0.0030	2640	2350	1875	1450	1050	700
0.0025	2640	2640	2150	1650	1200	775
0.0020	2640	2640	2475	1900	1375	900
0.0015	2640	2640	2640	2350	1700	1125
0.0010	2640	2640	2640	2640	2200	1450

TABLE -2

Typical values of stream sizes for different soil types and slopes.

Soil type with rate of infiltration	Border slope	Flow per metre width l/sec
Sandy soil, 2.5 cm/hr.	0.2 - 0.4 per cent	10 - 15
	0.4 - 0.6 p.c.	7 - 10
Loamy sand, 1.8 - 2.5 cm/hr	0.2 - 0.4 p.c.	7 - 10
	0.4 - 0.6 p.c.	5 - 8
Sandy loam, 1.2 - 1.8 cm/hr.	0.2 - 0.4 p.c.	5 - 7
	0.4 - 0.6 p.c.	4 - 6
Clay loam, 0.6 - 0.8 cm/hr.	0.15-0.3 p.c.	3 - 4
	0.3 - 0.4 p.c.	2 - 3
Clay, 0.2 - 0.6 cm/hr.	0.1 - 0.2 p.c.	2 - 4

values of stream sizes for different soil types and slopes (Michael -1978).

According to USDA (1970), the maximum stream sizes are represented as unit stream which is the flow of water for each 100 feet length of run, one feet wide. The required stream size will be the product of the unit stream, the length of run in hundreds of feet and the width of strip to be irrigated, in feet. The unit stream for level borders for different intake families are given in Table No.(3).

Petrasovits (1969) carried out Border Strip Irrigation tests in the fields at the experimental farm at Billaneh, Euphrates. He did the tests in borders of 50m, 75m and 100m long. The widths tried were 2.5m, 5.0m, 7.5m and 10.0m with the discharge rates of 1 l/sec/m, 1.5 l/sec/m, 2 l/sec/m, 3 l/sec/m and 4 l/sec/m. The slope of the experimental field was 1.0 to 1.2 per cent and 0.1 to 0.2 per cent.

Observations during the tests showed that the 2.5m width of border is not satisfactory because of the difficulties in making ridges at closer spacings with mechanical means, although it was easy to get uniform distribution of water throughout the strip.

On the other hand, it was difficult to assure good quality irrigation in borders of 7.5 and 10m width.

TABLE -3

Level border - Unit stream

Net irrigation (application(in)	Intake family						
	0.1 cfs	0.3 cfs	0.5 cfs	1.0 cfs	1.5 cfs	2.0 cfs	3.0 cfs
1	0.00368	0.01104	0.0184	0.0368	0.0552	0.0736	0.1104
1½	0.00314	0.00942	0.0157	0.0314	0.0471	0.0628	0.0942
2	0.0027	0.0081	0.0135	0.027	0.0405	0.054	0.081
2½	0.00232	0.00696	0.0116	0.0232	0.0348	0.046	0.0696
3	0.002	0.006	0.01	0.02	0.03	0.04	0.06
3½	0.00172	0.00516	0.008	0.0172	0.0258	0.0344	0.0516
4	0.00148	0.00444	0.0074	0.0148	0.0222	0.0296	0.0444
4½	0.00126	0.00378	0.0063	0.0126	0.0189	0.0252	0.0378
5	0.00108	0.00324	0.00540	0.0108	0.0162	0.0216	0.0324
5½	0.00094	0.00282	0.0047	0.0094	0.0141	0.0188	0.0282
6	0.0008	0.0024	0.004	0.008	0.012	0.016	0.024
7	0.0006	0.0018	0.003	0.006	0.009	0.012	0.018
8	0.00044	0.00132	0.0022	0.0044	0.0066	0.0088	0.0132

It was very difficult to regulate the progress of the waterfront, and the high water flow (general flow) required, caused erosion.

In the borders with 1.2 per cent slope, the velocity of the waterfront ranged between 8 m/min. and 15 m/min. With such a velocity, there was the danger of erosion.

He concluded that it was possible to irrigate efficiently borders of 100m length and 5m width with a water flow of 1.5 l/sec/m to 2 l/sec/m (which makes 7.5 to 10 l/sec general flow per border). The time of irrigation would be then 8.5 minutes to 12 minutes. The excess water at the border end was not more then 5 to 10 per cent. It was, however, observed that erosion occured at the head of the borders when the water flow was 2 l/sec/m.

2.2. Intake rate analysis in surface irrigation:

The movement of water from the surface into the soil is called the infiltration. Infiltration rate or the intake rate is the soil characteristic determining the maximum rate at which water can enter the soil under specific conditions. It is one of the major variables in the analysis of surface irrigation systems like furrows, border strips, basins, etc.

Accumulated infiltration or cumulative infiltration is the total quantity of water that enters the soil in a given time.

Field tests conducted under pre-sowing and post-emergence irrigation conditions showed that an equation of the following type would express best the accumulated infiltration - time relationship (Michael - 1968).

$y = at^{\alpha} + b, \quad o \leq a \leq 1;$

$t \neq o$, in which

a, α, and b are the characteristic constants;

y = the accumulated infiltration, cm; and

t = the elapsed time, minutes.

Criddle <u>et al</u> (1956) presented an equation for calculating the contact time necessary, using the intake rate equation

$$\frac{dy}{dt} = At^{n}.$$

Integration with respect to time gives the cumulative intake

$$Y = \frac{At^{n+1}}{n+1}.$$

The required contact time (t_{cr}) necessary to apply the desired depth of irrigation, Y becomes

$$t_{cr} = \left[\frac{Y(n+1)}{A}\right]^{\frac{1}{n+1}}, \text{ where}$$

t_{cr} = required contact time;

Y = total depth of water to be applied; and

n = exponent of t in the intake rate equation.

Christiansen et al (1966) assuming constant normal depth at the upper end and using empirical power functions of water advance and intake rate, related the intake rate to the advance of water in surface irrigation.

Pratap Singh and Chauhan (1973) determined water intake rate from rate of advance, and reported that this method would provide a good estimate of intake in surface irrigation.

Jaswant Singh (1978) obtained the solution for different variable intake rate functions, starting from the continuity equation

Qdt = hDA + I A dt, proposed by Israelsen (1932). The solution to continuity equation for three cases

(i) $I = at^{b}$, (ii) $\bar{I} = \frac{at^{b}}{b+2}$ and (iii) $\bar{I} = a(t-\tau)^{b}$

has been developed, which were

$$\text{(i)} \quad A = \frac{Qt}{h}\left[1 - \frac{2}{3}\frac{a}{h}t^{1/2} + \frac{a^{2}}{h^{2}}t \text{ ------}\right]$$

$$\text{(ii)} \quad A = \frac{Qt}{h}\left[1 - \frac{z_1}{(b+2)} + \frac{z_1^{2}}{(2b+3)(b+2)} \text{ ------}\right]$$

$$\text{(iii)} \quad A = \frac{Qt}{h+a(\Gamma b)\,t^{b}}, \text{ where}$$

$z_1 = \frac{at^{b}}{h(b+2)}$;

Q = rate of flow;

t = time, water has been turned on the land;

h = average surface head;

A = area irrigated; and

I = rate of infiltration.

2.3. Waterfront advance in irrigation borders:

The prediction of the advance of the water sheet is critical. This is attained by applying the hydraulic principles to overland flow. Field trials were often made to observe the combined effect of crop and soil roughness, stream size and cumulative intake on the rate of advance. General solutions of the waterfront advance problem in borders have been developed by earlier workers.

Hall (1956) used a water balance equation and presented a numerical method for estimating the advance of the sheet of water in a border strip during equal time increments. This method, illustrated in fig.1 uses measured cumulative intake as a function of time and assumes a constant depth at the upper end of the border strip based on wide channel flow equations. It also assumes that a ratio or shape factor C_1 of the volume of surface storage to the volume described by D_0x is independent of time, and an additional average depth of water or 'puddle factor' is needed to fill pockets caused by unevenness of the surface of the border strip. The volume of water on the surface of the soil Vi at any time ti is equal to

$$Vi = w\ (C_1 D_0 + \varepsilon)\ xi, \text{ where}$$

V_i = volume of water on the surface at time ti,

w = the width of the border check,

D_o = depth of water at the upper end,

ε = depth correction factor, and

x_i = distance to leading edge in time ti.

As irrigation water flows into a field and progresses down its length, an ever decreasing portion of the total volume of water flows above the ground, while the remainder infiltrates into the soil and forms a part of the subsurface storage. Any rational approach to predict the surface irrigation flows must equate the

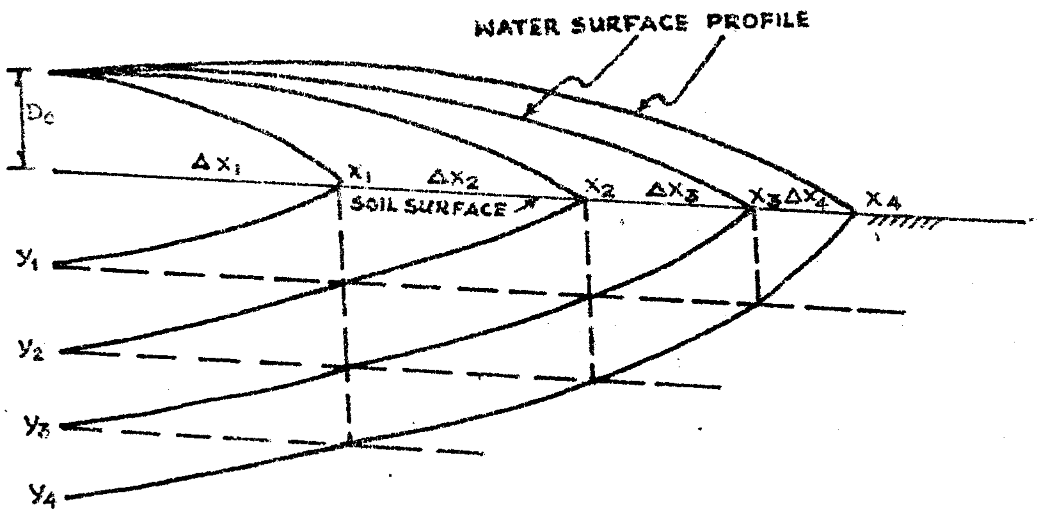


Fig. 1 _ CUMULATIVE INFILTRATION, Y_i, ADVANCE DISTANCE, X_i, AND SURFACE STORAGE AFTER EQUAL TIME INCREMENTS, Δt_i (HALL, 1956) total volume of water discharged at the supply channel to the sum of surface and subsurface storage. Fig.2 is the schematic illustration of the problem (Michael -1978)

Lewis and Milne (1938) proposed the following integral equation to describe the advance of water down a border strip.

$$qt = dx + \int_0^t y(t-ts)\ x^1(ts)\,dts, \text{ in which}$$

q = constant rate of flow per unit width intoduced at the upstream end of the border, cm^2/mm

t = total time for which irrigation water has been applied, minutes

x = distance, the irrigation stream has advanced, cm.

d = average depth of water over the ground surface, cm.

ts = value of t at which x (t) = S, minutes

y(t-ts) = accumulated infiltration at the point x = s at time ts, cm.

s = value of x at t = ts, cm and

$x^1(ts)$ = the value of $\frac{dx}{dt}$ at t = ts.

Philip and Farrel (1964) using Faltung Theorem of the Laplace Transformation, obtained the following general solution for the equation of Lewis and Milne.

$$\frac{x}{q} = L^{-1}\left[\frac{1}{S^3 L(y) + ds^2}\right] \text{ in which}$$

$$L\left[y(t)\right] = \int_0^\infty e^{-st} y(t)\,dt = \psi(s)$$

$$\text{and } L^{-1}\left[\psi(s)\right] = y(t).$$

Michael (1968) concluded that the waterfront advance in vegetated and non-vegetated borders can be

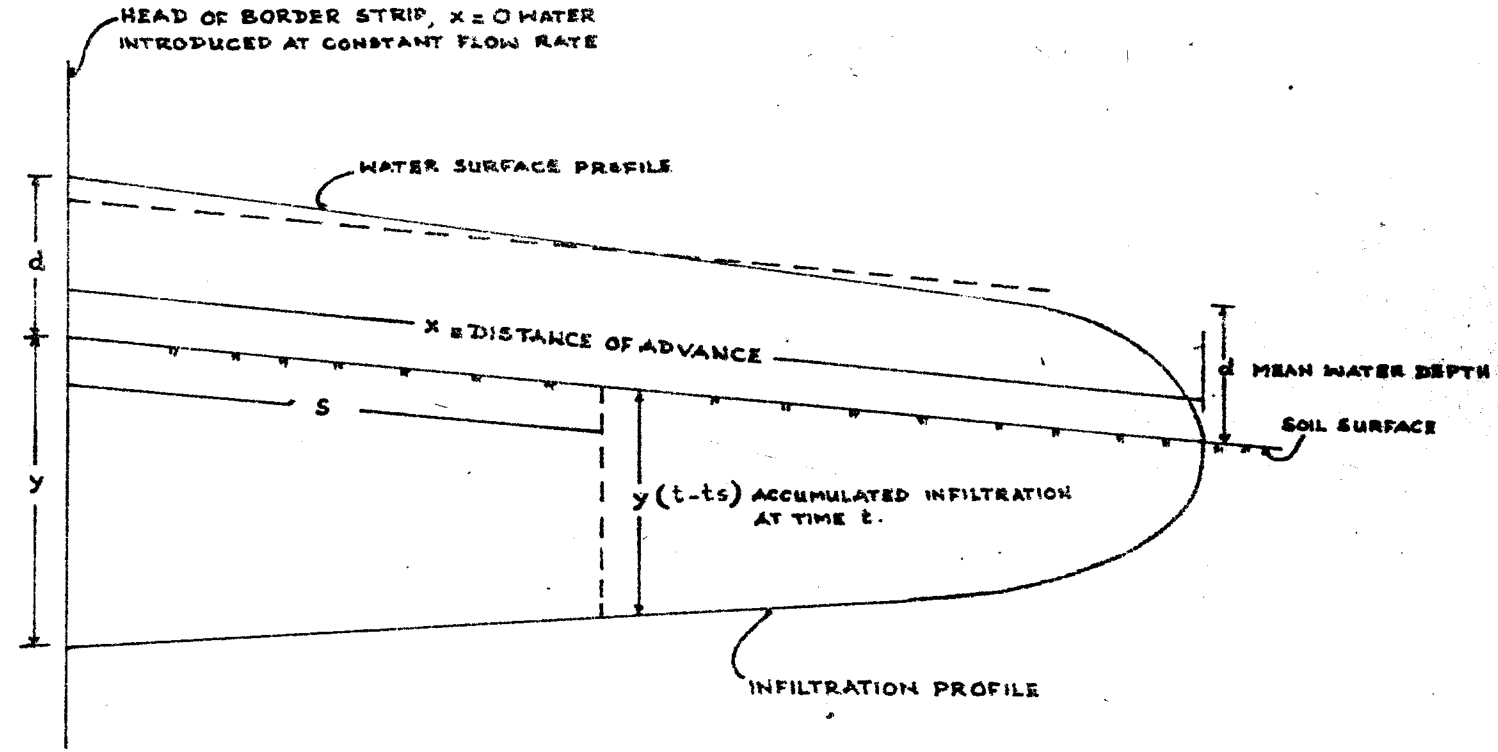


Fig. 2 - DIAGRAM ILLUSTRATING THE INFILTRATION - ADVANCE PROBLEM IN BORDER IRRIGATION.

predicted with reasonable accuracy by the following equations:

$$x = \frac{qt}{b+d}\left[\frac{1}{\Gamma(2)} - \frac{Bt^{\alpha}}{\Gamma(2+\alpha)} + \frac{B^2 t^{2\alpha}}{\Gamma(2+2\alpha)} - \frac{B^3 t^{3\alpha}}{\Gamma(2+3\alpha)} + \cdots\right] \longrightarrow \text{(a)}$$ for small values of t

and $$x = \frac{qt}{b+d}\left[\frac{1}{Bt^{\alpha}\Gamma(2-\alpha)} - \frac{1}{(Bt^{\alpha})^2\,\Gamma(2-2\alpha)} + \frac{1}{(Bt^{\alpha})^3\,\Gamma(2-3\alpha)} \cdots\right] \longrightarrow \text{(b)}$$ for large values of t

where $B = \frac{k}{b+d}r$, in which $k = a\,\Gamma(\alpha+1)$.

Michael (1968) obtained the following limiting conditions for the use of equations (a) and (b). Equation (a) is suitable when $\frac{Bt^{\alpha}}{\Gamma(2+\alpha)} < 1$, and equation (b) is suitable when $\frac{Bt^{\alpha}}{\Gamma(2+\alpha)} > 1$.

Most of the investigators have used the continuity or water balance equation to predict the rate of advance. Bishop et al (1967) justified the following less complex approximations:

$qt = x\bar{D} + x\bar{y} = x\,(C_1 D_o + C_2 Y_o)$, where

q = flow per unit width, l/sec/m

t = total time of flow, sec

x = distance to the leading edge, m

$\bar{D}$ = average water depth on the soil surface, m

$\bar{Y}$ = average cumulative intake over distance x, mm

D_0 = depth of water at the upper end, mm

Y_0 = cumulative intake at upper end, mm

C_1 = Surface storage co-efficient; and

C_2 = intake co-efficient.

The advance distance at any time will be $x = \frac{qt}{C_1 D_o + C_2 Y_o}$. The value of C_1 will vary with the advance distance, slope and hydraulic characteristics of the border strip, but for practical considerations it can be assumed to be independent of time. Its value ranged between 0.67 and 1.0. For steep slopes, large advance distances and small intake rates, C_1 approached the value of 1.0. For flat slopes and small advance distances and for very high intake rates, C_1 approached the value of 0.67.

Mishra and Anjanavelu (1971) derived an empirical equation for water advance in furrows based on experimental results. A nomograph has been presented to reduce the mathematical computation for Karagpur soil.

Sastri and Agrawal (1973) predicted the advance distance for a given set of initial conditions such as slope of land surface, inflow stream per unit width of flow, infiltration characteristics and hydraulic conductivity of soil bed, by evaluating an irrigation number.

2.4. Recession flow in surface irrigation:

Recession flow is considered as the depletion of surface storage. Generally for sloping border strips, the tail water recedes gradually from the upstream end to the downstream end. Information regarding the recession time is essential for design of border or furrow irrigation systems.

Simple expression of recession flow used by Criddle *et al* (1956) for evaluation of infiltration pattern and irrigation efficiency was a power function which showed the empirical relation between the recession flow length and time.

Varma (1981) derived a mathematical relation to determine the recession flow in a check border irrigation system for known advance and infiltration characteristics. The derivation was based upon balancing the volume of water at different stages of the recession phase. Subsurface storage was found from the known infiltration equation and surface storage was approximated by assuming a level surface profile for the ponded water.

2.5. Hydraulic resistance relationships in irrigation borders:

Resistance to flow in borders may be due to the roughness of the ground surface or the retardation offered by vegetation. It is one of the dominant variables that influences the flow characteristics in irrigation borders. The flow conditions in irrigation borders differ from those in open channels in several ways. A review of past work has revealed that Manning's 'n' calculated for uniform flow at a given depth and velocity applies for all practical purposes, to non-uniform flow in a border strip and will adequately represent the composite value of the hydraulic resistance in a vegetated border strip.

The Manning's equation is given by

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$ in which

V = velocity of flow m/sec.,

R = Hydraulic radius, m.,

S = Water surface slope, and

n = Roughness co-efficient of the channel.

Chow (1959) stated that the value of 'n' was dependent, among other things, on the roughness of the channel boundary, characteristics of vegetation, size and shape of flow channel and depth of flow.

Cowan and Palmer (1956) stated that the Manning's 'n' was a suitable parameter to indicate the net effect of all factors, causing retardation of the flow in a channel. Extensive studies on the hydraulic characteristic of vegetation in channels were made during the past 30 years by the United States Soil Conservation Service.

The tests conducted by Michael and Pandya (1971) revealed that

(1) A linear relationship exists between hydraulic resistance and entrance stream size in post-emergence border irrigation after the plants have become established;

(2) There is no substantial difference in the values of the hydraulic resistance obtained during the different post-emergence irrigations on wheat after the plant has become established and under average irrigation conditions;

(3) Irrigation border flows are generally in the turbulent range in vegetated and non-vegetated border strips; and

(4) In border strips having a finely pulverized seed bed and smooth surface, as is commonly obtained during pre-sowing irrigations, the value of the Darcy - Wiesbach resistance co-efficient is 0.025, in the formula,

$$V = \sqrt{\frac{8g\ Rs}{f}},$$ where

g = acceleration due to gravity m/sec^2, and

f = Darcy - Wiesbach roughness co-efficient or friction factor.

2.6. Deep percolation losses

Percolation is the downward movement of water through saturated or nearly saturated soil in response to the force of gravity. Criddle *et al* (1956) calculated the percentage of water that would be lost by deep percolation (in furrow) as 5.3 per cent.

Bishop (1962) showed that deep percolation loss P, expressed as a percentage of the total water absorbed, could be obtained from the equation

$$P = \frac{(R+1)^{n+1} - R^{n+1}}{(R+1)^{n+1} + R^{n+1}} \times 100, \text{ where}$$

P = per cent of water intake which is lost by deep percolation below the root zone; and

R = a time ratio.

$= \frac{t_{cr}}{t_a}$ in which t_{cr} is the required contact time for the desired depth of irrigation water to be absorbed and t_a is the advance time and

n = the exponent of t in the intake equation.

Murthy (1969) derived an expression to estimate the deep percolation losses in check basin system. It was shown that the percolation losses depended upon the time required to cover initially the entire area with water and the lesser this time, the lesser would be the losses.

Chauhan and Pratap Singh (1973) reported an analytical solution to estimate the amount of water loss below the root zone through percolation during surface irrigation.

2.7. Irrigation efficiencies:

Irrigation efficiency indicates how efficiently the available water supply is being used based on different methods of evaluation. After the water reaches the field supply channel, it is important to apply the water as efficiently as possible. A measure of how efficiently this is done is the water application efficiency.

Israelsen (1939) stated that the water application efficiency was clearly a dimensionless physical quantity which was not a direct function of crop response to irrigation.

Israelsen (1962) also stated that the depth of water applied in each irrigation was a dominant factor influencing efficiency of application and that applying excessive water depth in each irrigation caused low efficiency.

Lyman and Willardson (1972) stated that water application efficiencies were known to be primarily affected by uniformity of water distribution and the proportion of water applied that could be stored in the root zone.

A number of research workers including Patil (1970) and Lad and Kolbhar (1976) found that the water use efficiency generally decreased with increase in number of irrigation.

USDA (1970) recommended the design efficiencies for level and graded borders as given in Table(4)and(5).

TABLE -4

Design efficiency for level borders

Intake family	Design efficiency
0.1 and 0.3	75%
0.5	75%
1.0, 1.5 & 2.0	70%
3.0	60%

TABLE -5

Design efficiency for graded borders

Slope range	Intake family			
	0.1 & 0.3	0.5	1.0, 1.5 & 2.0	3.0
0.1 - 0.5%	70%	70%	75%	70%
0.5 - 1.0%	65%	70%	70%	70%
1.0 - 2.0%	60%	65%	70%	65%
2.0 - 3.0%	55%	60%	65%	60%

2.7.1. <u>Distribution efficiency</u>:- Petrasovits (1969) found that the best treatments from the point of view of homogeneous moisture distribution and minimum excess water at the border end were the following:

For a border width of 5m,

Border length	100m	75m
Water flow	2 l/sec/m	1.5 l/sec/m
General flow	10 l/sec	7.5 l/sec
Time of irrigation	13' min	18'min
Dry spots	5 per cent	5 per cent
Excess water	5 per cent	5 per cent
Moistured depth	9-10 cm(±2)	8-10 cm(±2)

Irrigation in ponded borders possesses the problem of ponding in the lower length of the border, resulting in deep percolation if inflow is cut off after the advancing water-front reaches the lower end. High efficiency can be achieved if inflow is terminated at suitable cutoff ratio, earlier than the water-front reaches the lower end of the border.

Studies were conducted by Sewa Ram (1975) to find a suitable cutoff ratio for operations of ponded borders in silt-clay-loam soil. The borders 7.5m in width and 160m in length were laid at 0.45 per cent land slope and sown with wheat crop. Distribution efficiency for 75, 80 and 85 per cent cutoff ratios were found for first, second and third irrigations for an inflow rate of 12 l/sec.

Highest values of distribution efficiency (Ed) were obtained in case of 85 per cent cutoff ratio in first irrigation (Ed = 91.55 per cent), 80 per cent cutoff ratio in second irrigation (Ed = 93.63 per cent) and 75 per cent cutoff ratio in third irrigation (Ed = 93.78 per cent). However, variations in distribution efficiency for 80 and 85 per cent cutoff ratios in first irrigations and 75 and 80 per cent cutoff ratios in second and third irrigations were not appreciable. This study suggested that ponded borders in silt - clay - loam soil irrigated with an inflow rate of 1.6 l/sec/m border width can be efficiently operated at 80 per cent cutoff ratio in first irrigation and 75 per cent cutoff ratio in subsequent irrigations.

2.8. Irrigation - When and how much:

Israelsen and Hansen (1962) stated that maximum production could be obtained in most of the crops, if there is 50 per cent of the available water in the soil, during the vegetative, flowering and wet fruit stages of the growth.

According to Rathore and Singh (1976), water use efficiency was decreased and grain yield was increased with irrigations.

Hukkery and Pandey (1977) stated that the water needs of crops and soil water availability for scheduling of irrigations could not be considered in isolation from that of climatic factors.

Materials and Methods

MATERIALS AND METHODS

Border strip method of irrigation is practised successfully on the lands with a mild slope in one direction. But this method has not been tried in level or nearly level fields to assess its feasibility.

The experiments were done at the Agronomic Research Station, Chalakudy, Trichur District during the year 1981-82. The objects of the experiments were to find out the optimum length, width and stream size of border strips for level or nearly level rice fallows.

An observational trial was conducted prior to the main experiment during 1980-81. The average slope of the field where the experiment was conducted was 0.01 per cent. The widths of 2m, 3m and 4m combined with four discharge rates of 2 l/sec/m, 3 l/sec/m, 4 l/sec/m and 5 l/sec/m were tried. The length of border taken was 50m. The infiltration rate of the soil was 1 cm/hr. and the cumulative infiltration followed the equation

$$y = 0.08002t^{0.7627} - 0.036,$$ where

y = accumulated infiltration, cm; and

t = elapsed time, minutes.

Six irrigations were given and the interval between irrigations was seven days. The time of advance for every 5m advance of the waterfront was observed. The average depth of water was found to be 2 - 2.5 cm. The time of advance for the first irrigation was found to be comparatively more, since some quantity of water was utilised for the initial wetting of the dry soil.

After the first irrigation, cowpea seeds were dibbled in all the strips at a spacing of 15 cm x 25 cm.

For the last two irrigations, the time taken for the advance of the waterfront was more than that for the previous irrigations. This was due to the resistance to flow offered by the fully grown crop and the weeds present in the field. The mean depth of water over the surface during the last two irrigations increased to 4 - 4.5 cm.

Several cutoff lengths were tried to determine the best cutoff length at which the irrigation stream is to be stopped. It was seen that when the stream was cutoff before the waterfront advance reached 66 per cent of the strip length, the water did not reach the downstream end in many cases. When the water was cutoff at 88 per cent, there was excess downstream ponding.

The recession of the tail water was not gradual. Usually for sloping borders, the tail water recedes gradually from the upstream end to the downstream. From the waterfront advance - time relationship (Fig. 3, 4 and 5), it was seen that the higher the discharge rates, the lesser was the time taken for the waterfront to advance and vice-versa.

The actual cutoff time for the stream sizes 2 l/sec/m and 3 l/sec/m were found to be less than the theoretical cutoff time calculated for 5 cm depth of irrigation. For the higher discharges of 4 l/sec/m and 5 l/sec/m, the actual cutoff time was greater than the theoretical cutoff time, which meant that application of more than 5 cm irrigations were required for the water to reach the downstream end of the strip. From this observational trial it was seen that the lesser discharges of 2 l/sec/m and 3 l/sec/m were more efficient than the higher discharges of 4 l/sec/m and 5 l/sec/m.

But, since these were only the results of trials without any replications, it was decided to conduct a detailed experiment to standardise the hydraulics of border strip irrigation on level lands with discharges of 2 l/sec/m and 4 l/sec/m width.

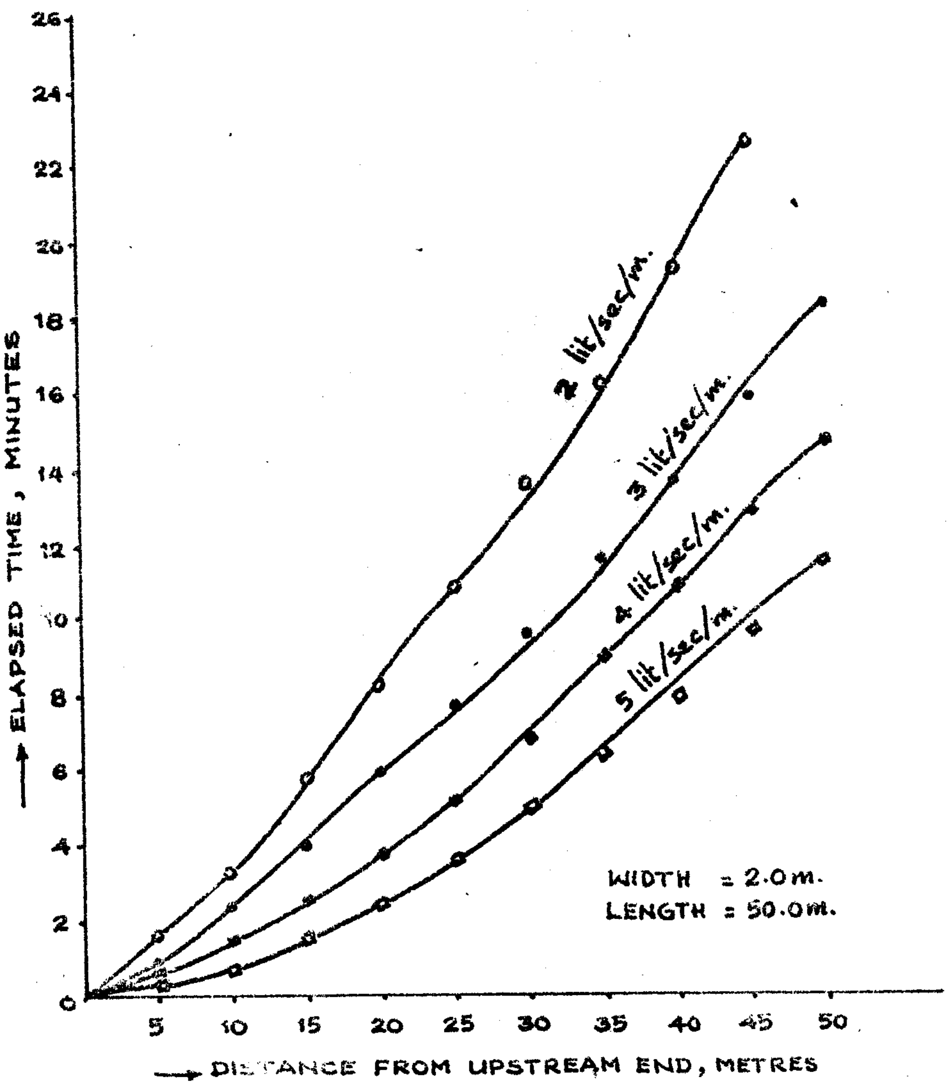


Fig. 3 - MEAN ADVANCE CURVE

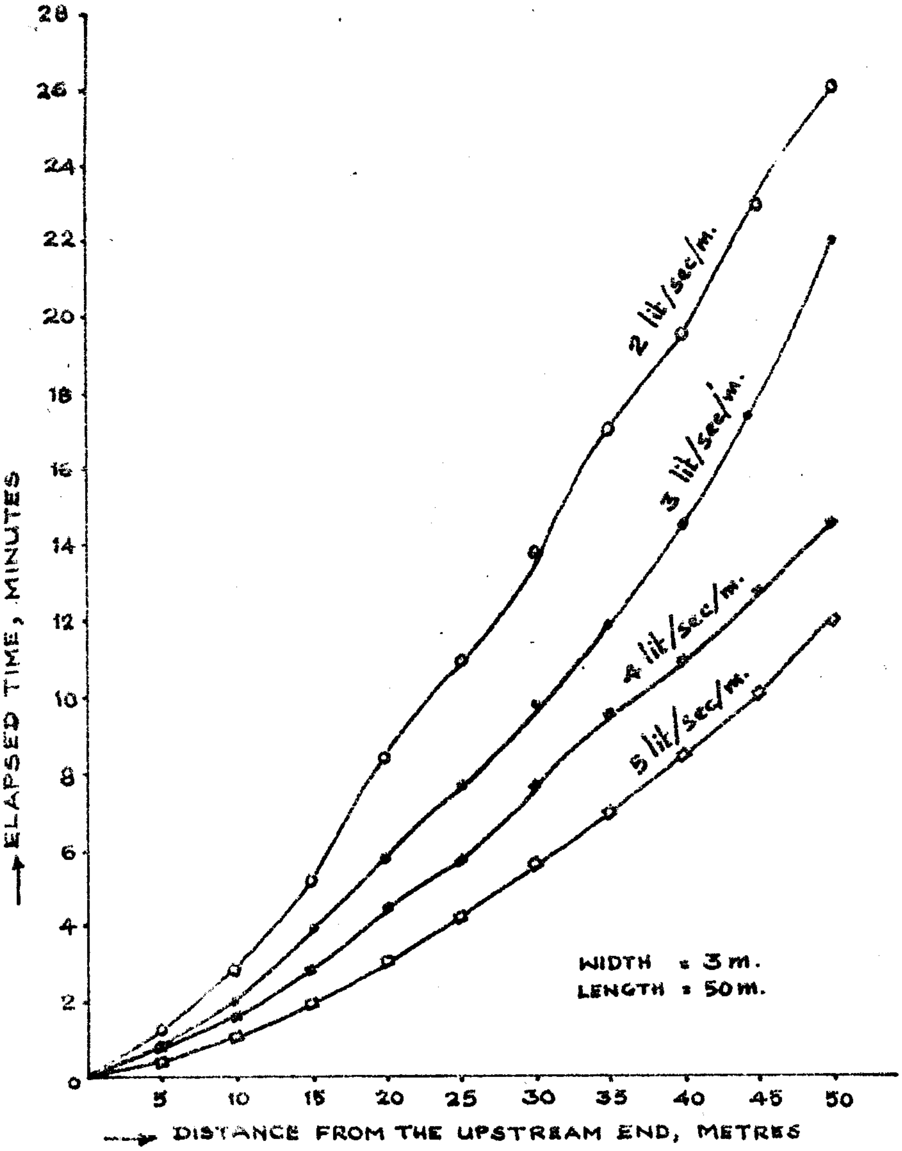


Fig. 4 - MEAN ADVANCE CURVE

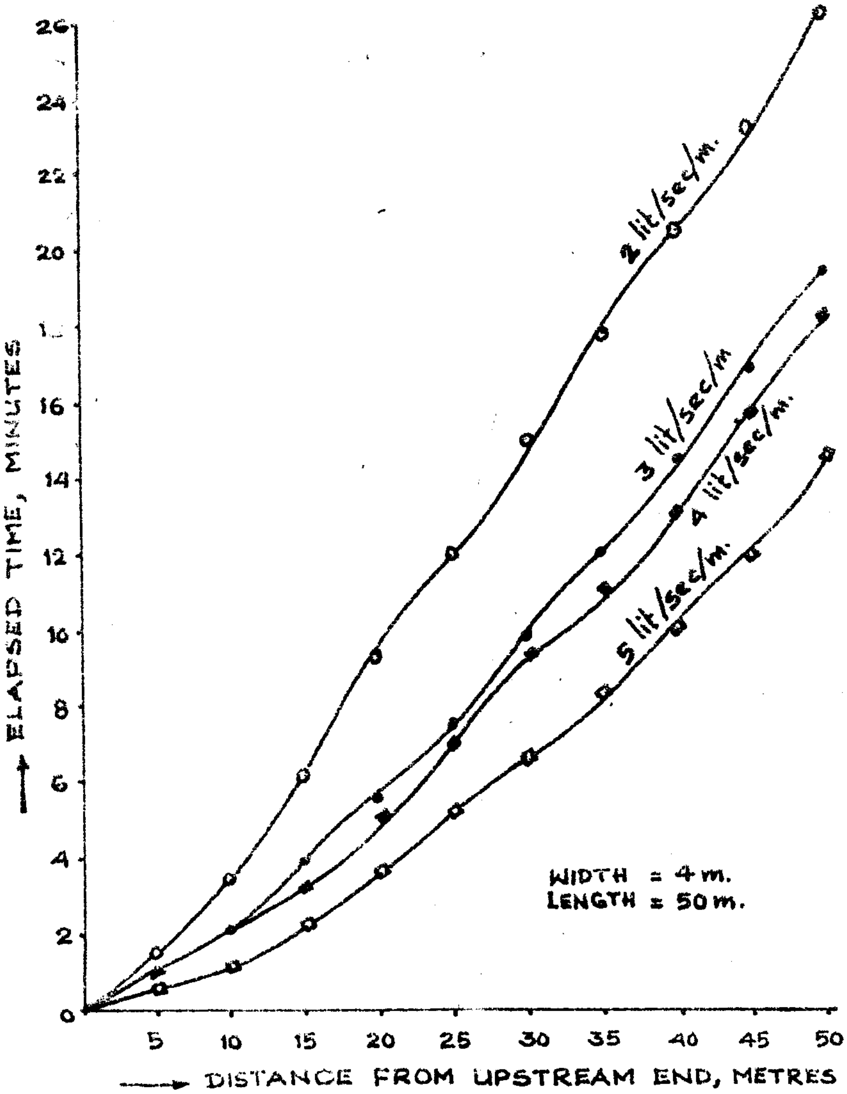


Fig-5. MEAN ADVANCE CURVE

3.1. Brief description of the study area:

3.1.1. Location:- The experimental area is located in the Chalakudy Command Area at 10° 20' North latitude and 76° 20' East longitude and at an elevation of 3.25m above mean sea level.

3.1.2. Climate:- The area is situated in high rainfall region with heavy south-west monsoon and moderate north-east monsoon showers. The amount of rainfall received during the different seasons is presented in Table -6.

The total rainfall received during 1981-82 was 3556.2 mm of which 77.6 per cent, 16.4 per cent and 6 per cent were contributed by the south-west monsoon, north-east monsoon and hot weather rains respectively. The total rainfall showed an increase of 8.4 per cent over the 11 year average. The mean monthly weather data recorded at the station during 1981-82 is presented in Appendix -1.

The 6 per cent rainfall contributed by the hot weather rains is mostly from the rains during December, April and May. January, February and March are the summer months during which not even a single rain is obtained in most of the years. For raising crops

TABLE -6

Amount of rainfall received during different seasons

Season	Rainfall (mm)	
	11 Year mean	81-82
Hot weather period	136.9	212.4
South-west monsoon period	2549.5	2760.0
North-east monsoon period	594.3	583.8

in these periods, border strip method of irrigation is mostly suited if irrigation facilities are there.

3.1.3. Ground Water table:- Periodic ground water flustuations in the experimental area is shown in Table -7 (Annual Report, ARS -1981-82).

3.1.4. Crop rotation followed:- Rice - Rice - Cowpea.

3.2. Physical properties of soil:

3.2.1. The texture of the soil is loamy sand with 74-84 per cent sand, 4 - 12 per cent silt and 7 - 11 per cent clay.

3.2.2. Field capacity and wilting percentage:- Field capacity and wilting percentage were estimated by the pressure plate apparatus available at the College of Horticulture. The apparatus consisted of ceramic pressure plates of high air entry values contained in air tight metallic chambers strong enough to withstand high pressure. The porous plates were saturated first. The saturated soil samples were filled in rubber rings and these were placed on the plates. Then the plates were transferred to the metallic chambers. The plate outlet tube leaving the diaphragm was connected to the outlets of the

TABLE -7

Periodic ground water table

Month	Max.(cm)	Min.(cm)
January, 1982	125	72
February, 1982	150	131
March, 1982	150	150
April, 1982	Below 200	Below 200
May, 1982	Below 200	Below 200

chamber. The chamber was closed with special wrenches to tighten the nuts and bolts with the required torque for sealing it.

Pressure was applied from a compressor through control, which maintained the desired pressures of 1/3 and 15 bars for determining field capacity and wilting point respectively. Water started to flow out from the saturated soil samples through outlet and continued to trickle till equilibrium against the applied pressure was achieved. After that, the soil samples were taken out and oven dried, and the moisture contents were determined.

3.2.3. Bulk density:- The bulk density of the soil was determined by using standard core cutter. The cutting edge of the cylinder of the core sampler was driven into the soil, and an uncompacted core was obtained within the tube. The sample was carefully trimmed at both ends of the core and its weight was taken. The sample was dried in an oven at 105°C until all the moisture was removed and it was again weighed. The volume of the soil core was the same as the inside volume of the core cylinder. The weight of the dry soil divided by the volume of the soil core gave the bulk density of the soil.

3.2.4. <u>Infiltration</u>:- The infiltration rate of the experimental field was determined by using double ring infiltrometer. The experimental set up used for the infiltration measurement is illustrated in Plate -1.

The cylinders were 25 cm deep and were formed of 2 mm rolled steel. The inner cylinder from which the infiltration measurements were taken was 30cm in diameter. The outer cylinder, which was used to form the buffer pond to minimise the lateral spreading of water, was 60 cm in diameter. The cylinders were driven 10 cm deep into the soil. The cylinders were driven into the ground by hammering on a wooden plank placed on top of the cylinder so as to prevent damages to the edges of the cylinders.

The water level in the inner cylinder was read with a hook gauge. Hook gauge measurements were made at frequent intervals in the beginning to determine the initial infiltration rate. The readings were taken till a constant value was attained. Three different tests were conducted & the mean value was used for analysis.

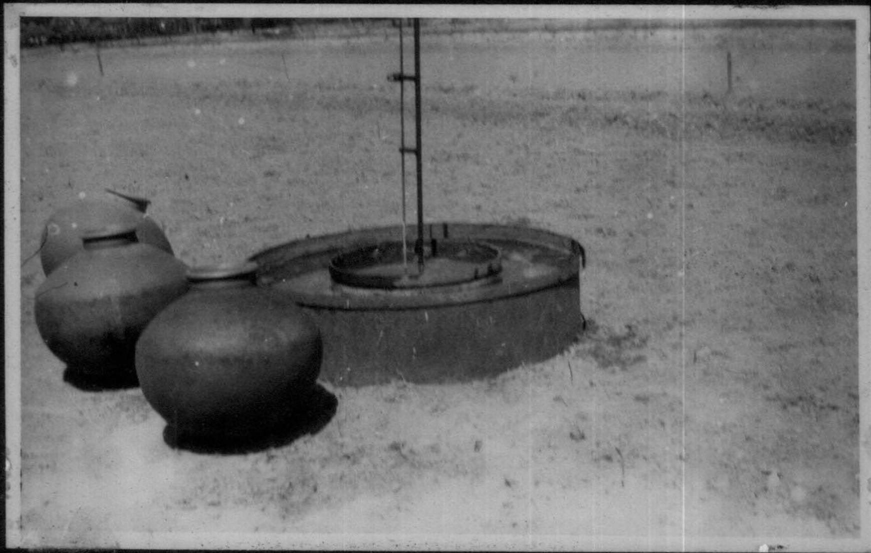


PLATE -1. MEASUREMENT OF INFILTRATION WITH DOUBLE RING INFILTROMETER IN THE FIELD

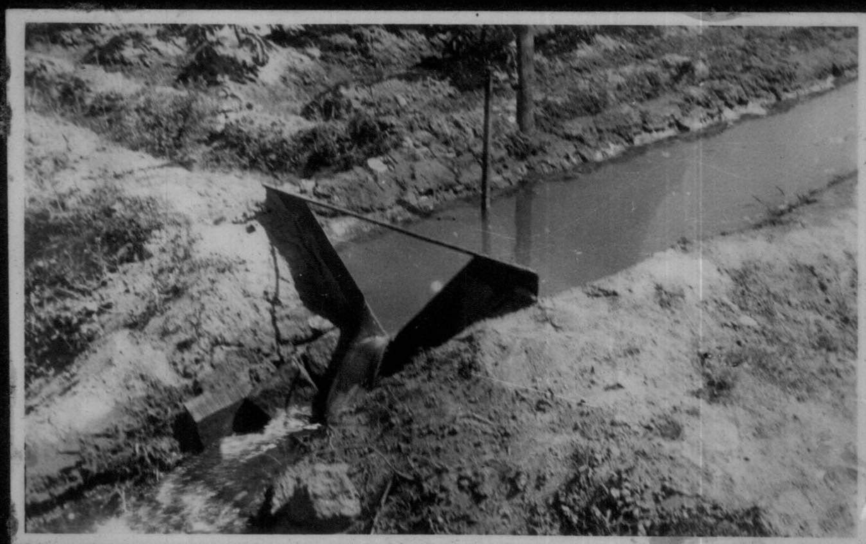


PLATE -2. MEASUREMENT OF IRRIGATION WATER BY V-NOTCH, AT THE EXIT OF THE SUPPLY CHANNEL

3.3. Preparation of field:

The total area of plot where the experiment was conducted was of 6500 sq.m. 4m and 6m wide strips were chosen for the experiment. After every strip, a 45 cm buffer strip was provided to eliminate the effect of lateral seepage on the adjoining plot. The width of boundary ridges of each strip was 30 cm and the height of bunds separating the strips was 20 cm. The length of the strip was 45 m since this was the maximum possible length available. The average length of paddy fields normally will not be more than 45m. The labour requirement for preparing border strips in one hectare of land was about 5 - 7 man-days. The plan of the layout is shown in Fig.6 (a), (b) and (c).

3.4. Land slope:

The magnitude and direction of the slope of the experimental plot were determined using a levelling instrument.

The stream sizes selected were 2 l/sec/m width and 4 l/sec/m width. The experiment was laid out with 4 treatments and 5 replications, arranged as by Randomised Block Design. The treatments were,

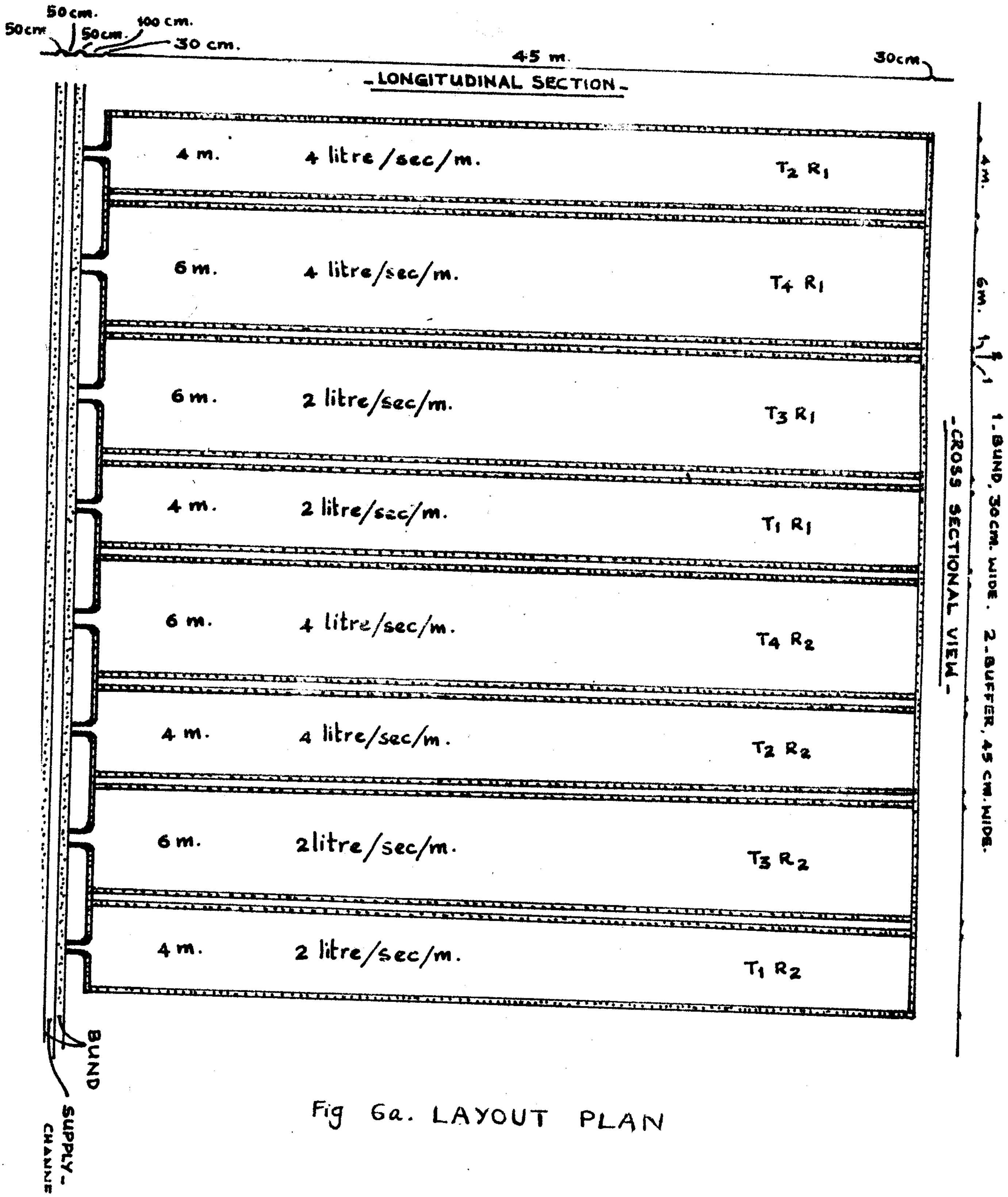


Fig 6a. LAYOUT PLAN

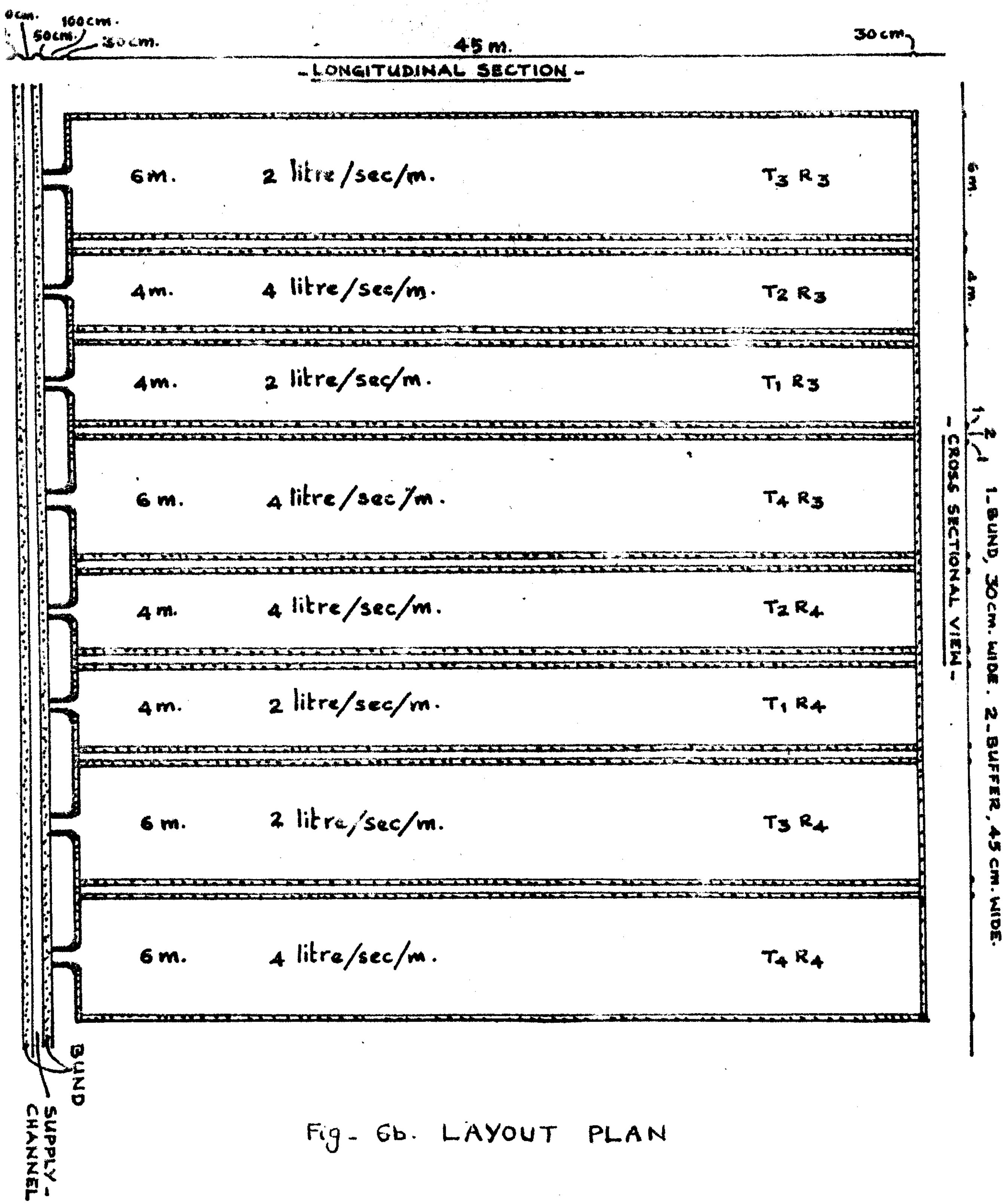


Fig - 6b. LAYOUT PLAN

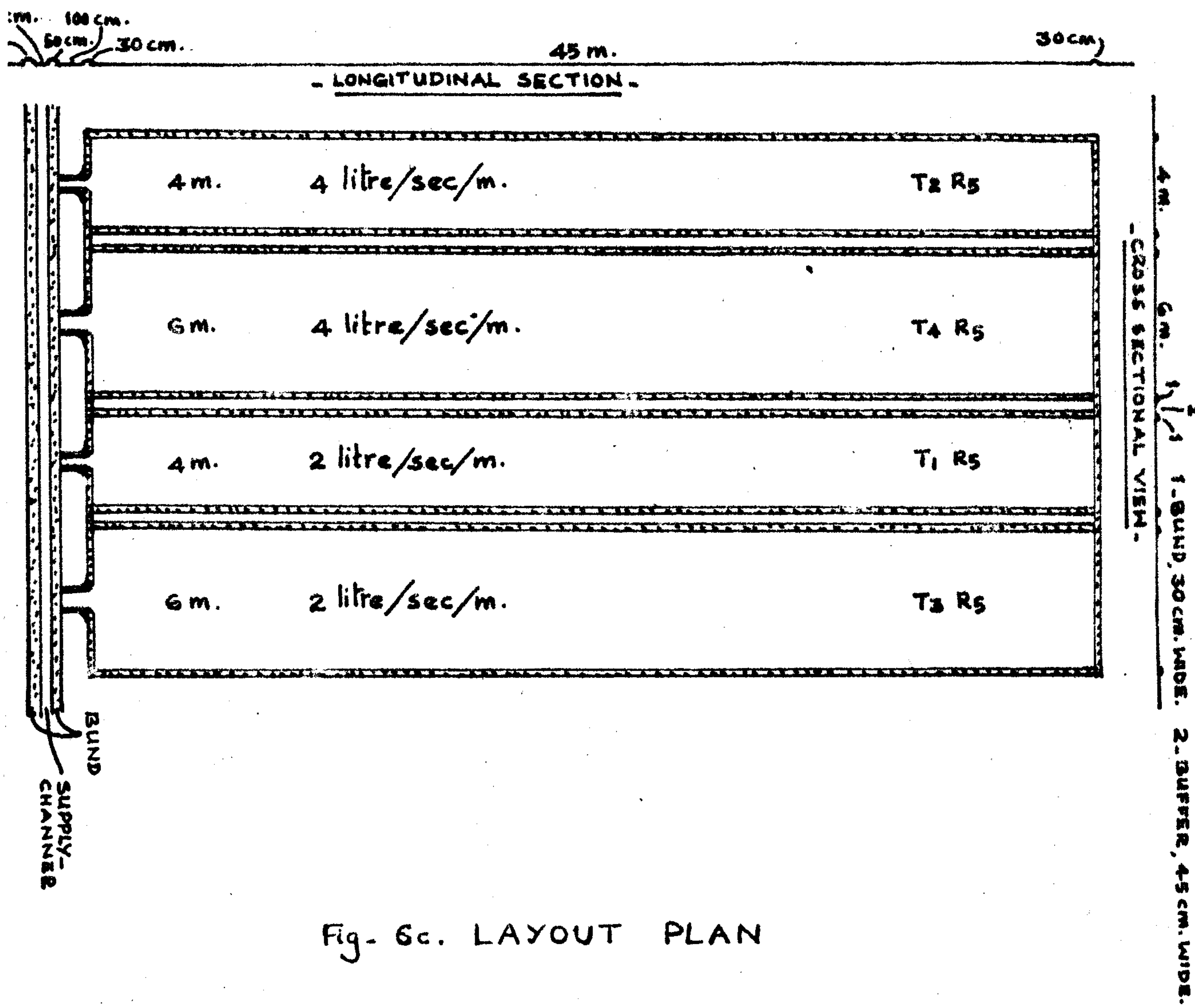


Fig- 6c. LAYOUT PLAN

1) T_1 - 4m width, with 2 l/sec/m

2) T_2 - 4m width, with 4 l/sec/m

3) T_3 - 6m width, with 2 l/sec/m

4) T_4 - 6m width, with 4 l/sec/m

3.5. Source of irrigation water:

The irrigation needs of the experimental field were met both with the canal water from Chalakudy Irrigation Project and the well-water from the farm.

The conductivity and pH of the water ranged between 0.10 and 0.16 mmhos/cm and between 6.3 and 6.8 respectively (Annual Report, ARS -1982).

3.6. Measurement of irrigation water:

The supply channel coming from the source of water was at a higher elevation than the experimental field. To measure the stream sizes, a 90°V-notch was installed at the exit of the supply channel, as in Plate-2.

The V-notch was made up of mild steel sheet, 2 mm thick, 115 cm breadth and 50 cm high. A triangular opening at the top edge constituted the V-notch. The sides of the opening were sharp. Each side was at an angle of 45° to vertical or horizontal, making a total notch angle of 90°.

The V-notch was set at the lower end of the long approach channel, which was sufficiently wide and deep to minimise the velocity of flow. Care was taken to install it exactly vertical. The scale used for measuring the head was located at a distance of about four times the approximate head. The zero of the scale was exactly on the same level as the apex of the V-notch. The channel section immediately downstream from the notch was protected from erosion.

The head corresponding to each discharge rates was maintained by making a temporary by-pass, 5-6m behind the weir pond.

The head of water required for different stream sizes were as shown in Table -8. The relationship between the discharge and the head is given by the following equation:

$Q = 0.0138\ H^{5/2}$ in which

Q = discharge in l/sec; and

H = head, cm.

The water was turned into the strips only after the flow in the supply channel was stabilised.

TABLE -8

Head of water for different discharges
measured on V-notch

Flow rate (lit/sec)	Height of water over V-notch (cm)
8	12.88
16	16.72
12	14.85
24	19.63

3.7. Measurement of depth of flow:

Wooden stakes were driven at intervals of 5m along the length of the border. The stakes were installed inside the border at a distance of about 50 cm from the border ridge. The top level of each stake and the ground level at each point were determined with a dumpy level from which the height of the stake above ground level was established. The difference in elevation between the top of the stake and the water surface was measured at all stations simultaneously, just after the stream was cut off, using scales. The depth of water at each station was estimated by deducting the difference in elevation between the top of the stake and the water surface, from the height of the stake above the ground level.

3.8. Irrigation:

Altogether seven irrigations were given to the strips at an intervals of seven days. After the first irrigation, blackgram seeds were dibbled in all the strips at a spacing of 15 cm x 25 cm. Fertilisers and manures were applied to the crop as recommended in the Package of Practices.

3.9 Cutoff length:

It was observed during the trial conducted that for uniform distribution of water in the entire strip, the best cutoff length was 77 per cent of the total length of the strip, that is 35m from the upstream end for a border strip of 45m long.

3.10. Theoretical cutoff time:

The theoretical cutoff time is the time required to irrigate an area to a desired depth. This can be calculated as follows:

Depth of irrigation	- 5 cm
Width of strip	- 4m
Length of strip	- 45m
Volume of water needed	- 45 x 4 x 0.05m^3
Rate of discharge at the rate of 2 l/sec/m	- 8 l/sec

Therefore, the theoretical cutoff time to irrigate the strip (to a depth of 5 cm) =

$$\frac{45 \times 4 \times 0.05 \times 1000}{8} = 18'45''$$

3.11. Actual cutoff time:

The actual cutoff time is the time taken by the waterfront to reach the designed cutoff length.

During the experiment, in some cases, the inflow had to be stopped before the theoretical cutoff time, because the waterfront reached the cutoff length before that time. In some other cases, the inflow had to be continued even after the theoretical cutoff time, because the waterfront advance did not reach the cutoff length.

3.12. Advance, Recession and Opportunity time:

The time of advance was noted for every 5m distance from the head end of the border, after diverting the inflow into the border. Similarly, the time of recession of water at every 5m distance was noted after the termination of the inflow. The advance and recession time relationships were plotted and opportunity time for every 5m length along the border was obtained from the ordinates between the advance and recession curves.

3.13. Hydraulic resistance:

A commonly used method of estimating the composite value of the hydraulic resistance in vegetated channels employed the Manning's equation. The 'n' values in the equation were defined in relation to depth and velocity of flow, and type and height of vegetation.

The following equations were proposed to describe the hydraulic resistance expressed as Manning's 'n' in vegetated borders:

$n = \frac{d^{5/3} S^{1/2}}{q}$ in which

d = normal depth at the upstream end of border, m.

S = hydraulic gradient, dimensionless

q = entrance stream size in cu.m/sec/unit width of border.

This equation was derived from the original Manning's equation, which is $V = \frac{1}{n} R^{2/3} S^{1/2}$ where V is the velocity of flow m/sec and R is the hydraulic radius, m. In case of border strips, the depth is negligible, considering the width of border, that is

$$R = \frac{A}{P} = \frac{b \times d}{b + 2d} = \frac{b \times d}{b} \quad \text{(since 'd' is negligible)}$$

$$= d$$

Also, $V = \frac{Q}{b \times d} = \frac{q}{d}$

Substituting for R and V in the original equation

$$\frac{q}{d} = \frac{1}{n} d^{2/3} S^{1/2}, \text{ or}$$

$$q = \frac{1}{n} d^{5/3} S^{1/2}, \text{ or}$$

$$n = \frac{d^{5/3} S^{1/2}}{q}$$

PLATE -3. GENERAL VIEW OF A BORDER STRIP

PLATE -4. ADVANCE OF WATERFRONT DURING FIRST IRRIGATION

PLATE -5. UPSTREAM SIDE OF A FLOODED BORDER STRIP

PLATE -6. A VIEW OF THE BORDER STRIP WITH CROP

Results and Discussion

RESULTS AND DISCUSSION

4.1. Initial soil characteristics:

The physical characteristics of the soil were determined.

4.1.1. Bulk density:- The bulk density of the soil was 1.3 gm/cc - Table -9.

4.1.2. Field capacity and wilting point:- The average field capacity and wilting point of the soil in the experimental field were 14.46 per cent and 8.06 per cent respectively. The data are shown in Table -10 (a) and 10 (b).

4.1.3. Infiltration rate:- The basic infiltration rate of the soil was found to be 2.4 cm/hr. The functional relationship between the cumulative infiltration and the elapsed time could be represented by fitting a modified exponential curve of the form $Y = at^{\alpha} + b$. The parameters were estimated by using the method illustrated in Appendix -2.

The equation to the curve was determined as $Y = 0.2152t^{0.7556} + 0.082$. The curve gave a satisfactory fit to the data. The co-efficient of determination R^2 was found to be equal to 99.84 per cent. This

TABLE -9

Estimation of bulk density of soil

Weight of core sampling cylinder (1) kg	Weight of cylinder + moist soil (2) kg	Weight of cylinder + dry soil (3) kg	Weight of dry soil (3)-(1) (4) kg	Volume of cylinder (5) cc	Bulk density (4)/(5) x 1000 (6) gm/cc
1.45	2.65	2.35	0.90	$\frac{\pi}{4}$x7.5^{2}x15	1.358
1.45	2.71	2.17	0.72	= 662 cc	1.086
1.45	2.52	2.42	0.97		1.464
	Mean bulk density			= 1.302 gm/cc	

TABLE -10 (a)

Determination of field capacity

Weight of moisture can (1) gm	Weight of can + wet soil (2) gm	Weight of can + dry soil (3) gm	Weight of dry soil (3)-(1) (4) gm	Weight of moisture (2)-(3) (5) gm	Moisture content (5)/(4)x100 (6) gm
46.33	78.67	74.65	28.32	4.02	14.2
45.97	74.74	71.05	25.08	3.69	14.7
50.57	84.68	80.355	29.785	4.325	14.5
		Mean field capacity = 14.46 per cent			

TABLE -10 (b)

Determination of wilting point

Weight of moisture can (1) gm	Weight of can + wet soil (2) gm	Weight of can + dry soil (3) gm	Weight of dry soil (3)-(1) (4) gm	Weight of moisture (2)-(3) (5) gm	Moisture content (5)/(4)x100 (6) gm
41.535	72.285	72.75	31.215	2.535	8.1
45.46	78.89	76.31	30.85	2.58	8.4
42.03	68.37	66.49	24.46	1.88	7.7
		Mean wilting point = 8.06 per cent			

implied that almost all variations in cumulative infiltration could be explained by the fitted model.

An exponential curve of the form $r = at^b$ was fitted to represent the relationship between the rate of infiltration and the elapsed time. The equation obtained was $r = 15.5t^{-0.342}$. The constants were estimated as shown in Appendix -3. The degree of precision of the curve fitted was examined by estimating the co-efficient of determination and was found to be 97.64 per cent, which meant that the possible errors in prediction was only 2.36 per cent.

The observed values and the predicted values of accumulated infiltration x as well as the rate of infiltration are plotted in Fig.7.

4.2. Land slope:

The benchmark was assumed as 0.000m at the downstream end of each strip. The levels at 5m length and 25m length with respect to the benchmark is given in Table -11 and the slope of each strip was established by dividing the difference in elevation between the first and the last point, by the distance between the first and the last point. The results are given in the last column of Table -11. The mean slope of the experimental field was 0.038125 per cent.

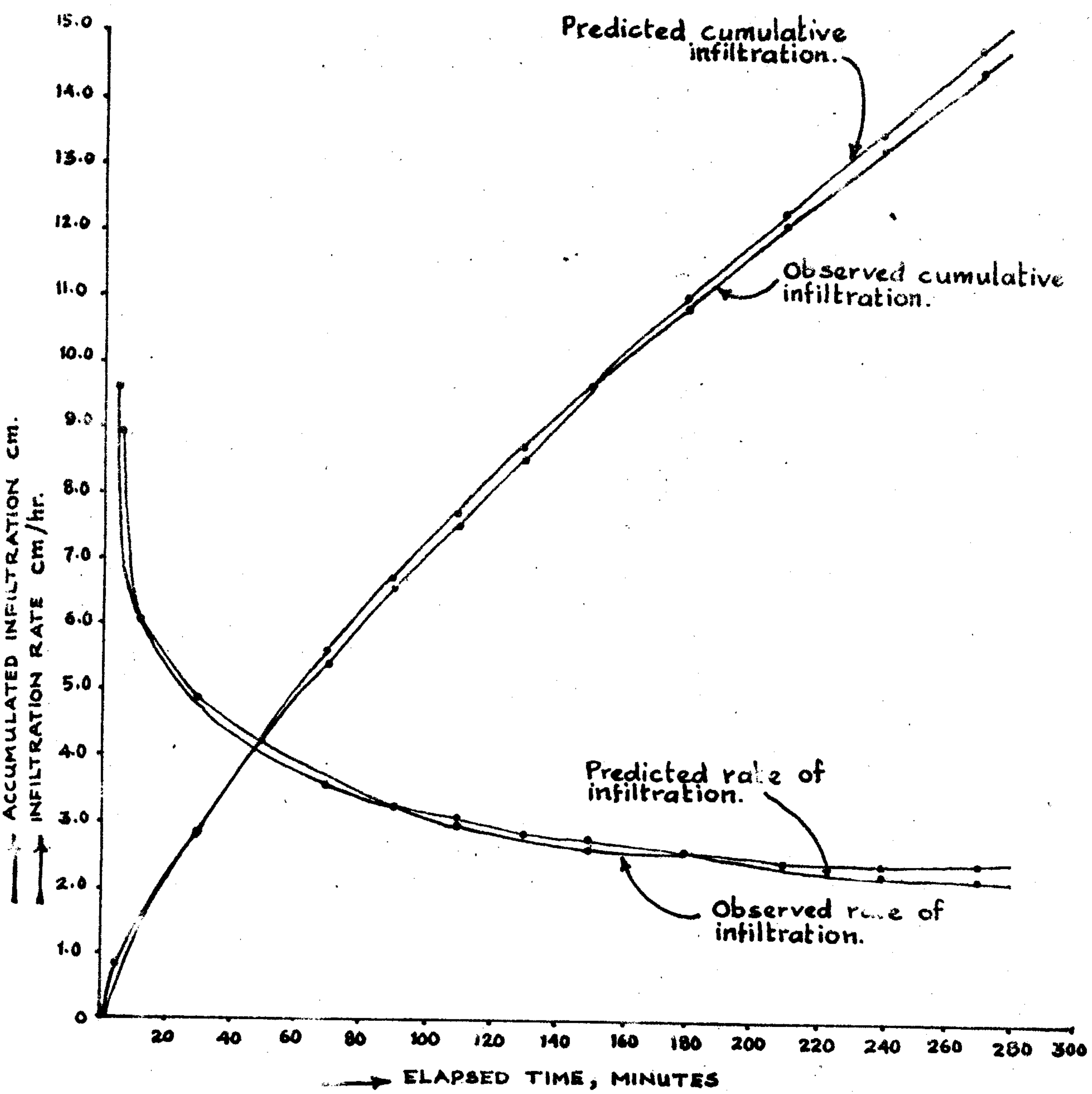


Fig.7- PLOT OF ACCUMULATED INFILTRATION AND AVERAGE INFILTRATION RATE.

TABLE -11

Elevation with respect to Bench mark

Treatments/ Advance length		5.0m	25m	45m	Land slope (per cent)
T_1	R_1	0.010	0.005	0.00	0.025
	R_2	0.015	0.005	0.00	0.0375
	R_3	0.015	0.010	0.00	0.0375
	R_4	0.015	0.010	0.00	0.0375
	R_5	0.015	0.010	0.00	0.0375
T_2	R_1	0.010	0.010	0.00	0.025
	R_2	0.020	0.005	0.00	0.050
	R_3	0.015	0.005	0.00	0.0375
	R_4	0.015	0.005	0.00	0.0375
	R_5	0.015	0.010	0.00	0.0375
T_3	R_1	0.015	0.010	0.00	0.0375
	R_2	0.015	0.005	0.00	0.0375
	R_3	0.030	0.020	0.00	0.075
	R_4	0.015	0.005	0.00	0.0375
	R_5	0.015	0.010	0.00	0.0375
T_4	R_1	0.015	0.005	0.00	0.0375
	R_2	0.020	0.020	0.00	0.050
	R_3	0.010	0.005	0.00	0.025
	R_4	0.015	0.005	0.00	0.0375
	R_5	0.015	0.005	0.00	0.0375

Sample calculation:

$$\left(\frac{0.010 - 0.005}{20} + \frac{0.005 - 0.000}{20}\right) \div 2 \times 100$$

$$= 0.025 \text{ per cent}$$

4.3. Advance of waterfront:

The time of advance for every 5m interval was noted with a stop watch and the mean values obtained are presented in Fig.8 to 14. The results revealed that out of seven irrigations, the waterfront of the first irrigation took maximum time to cover 97 per cent length of the strip. The reason for this was that a major portion of the water was utilised for wetting the dry soil during the first irrigation. Also it was seen that the rate of advance was faster with increasing the discharge rate and vice-versa.

4.4. Depth of flow:

The depth of flow over the surface measured just after the cutoff is tabulated in the Table -12. The readings obtained, ranged between 1.6 and 6.1 cm.

4.5. Depth of application:

The usual depth of irrigation application for field crops is 5 cm in the sandy loam soil of the Agronomic Research Station, Chalakudy. This depth has been arrived at after taking into consideration the moisture holding capacity of the soil and the

Fig 8 ADVANCE CURVE
IRRIGATION No. 1

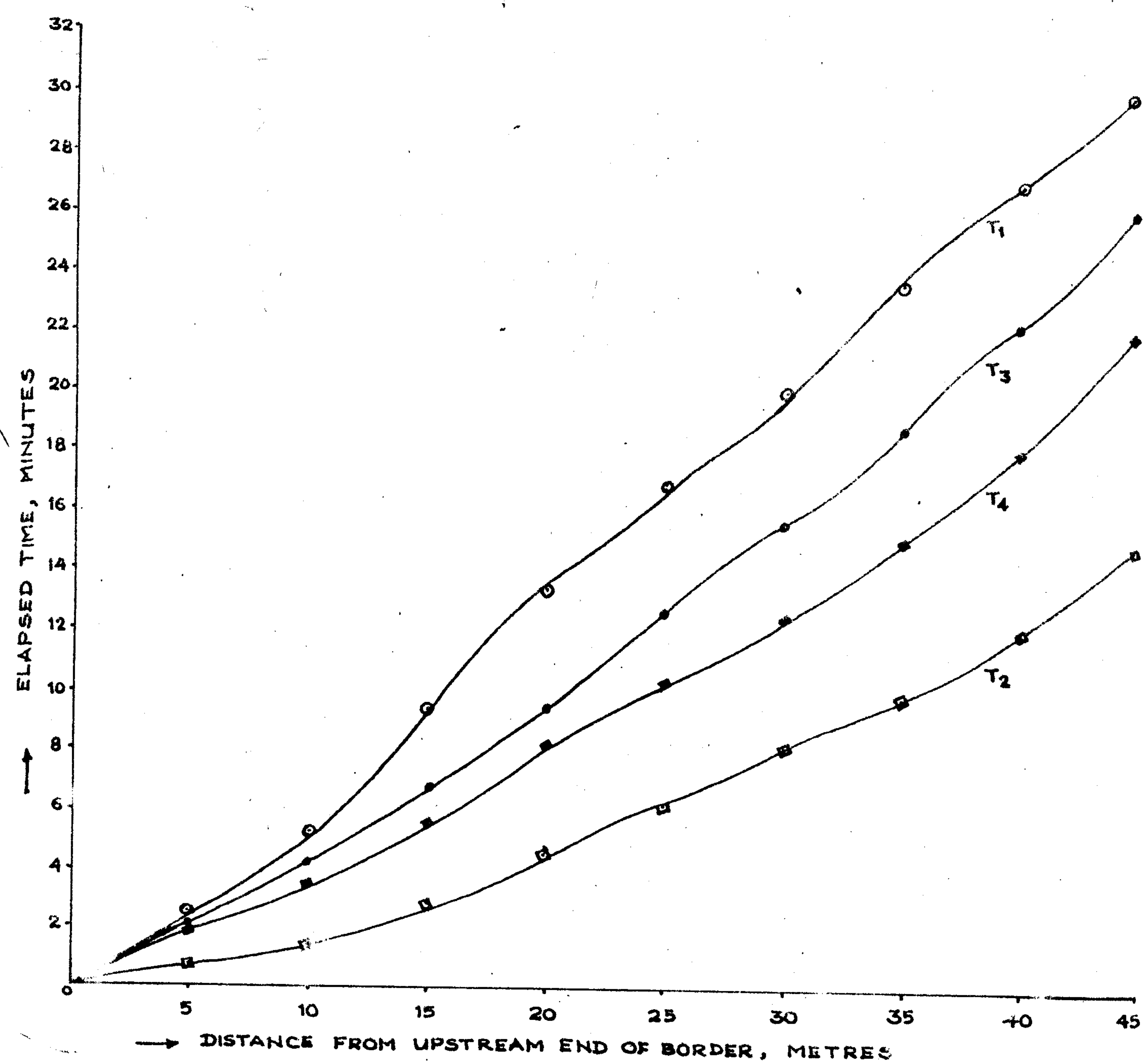


Fig. 9. ADVANCE CURVE
IRRIGATION No. 2

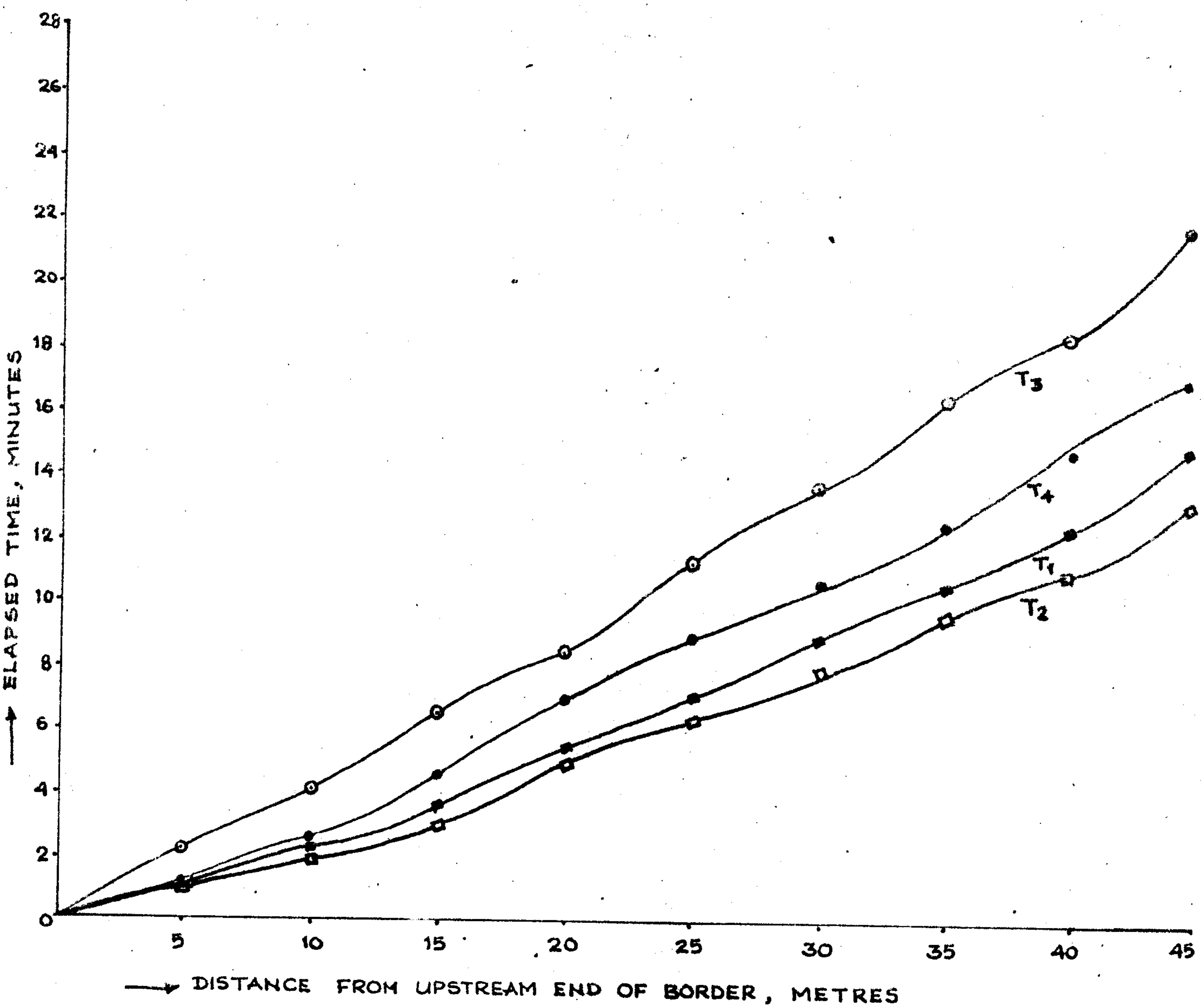


Fig. 10 ADVANCE CURVE
IRRIGATION No. 3

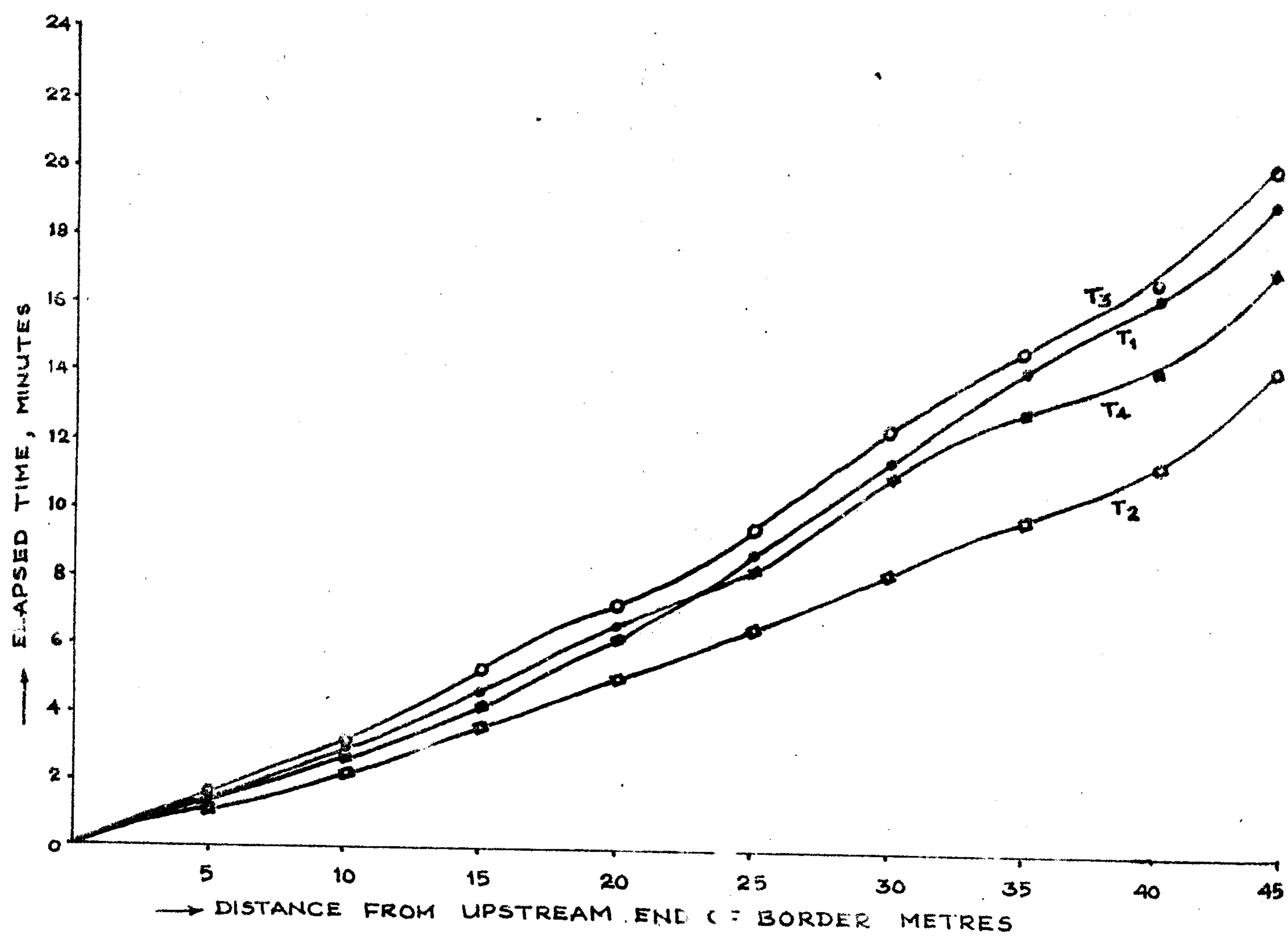


Fig. 11 ADVANCE CURVE
IRRIGATION No. 4

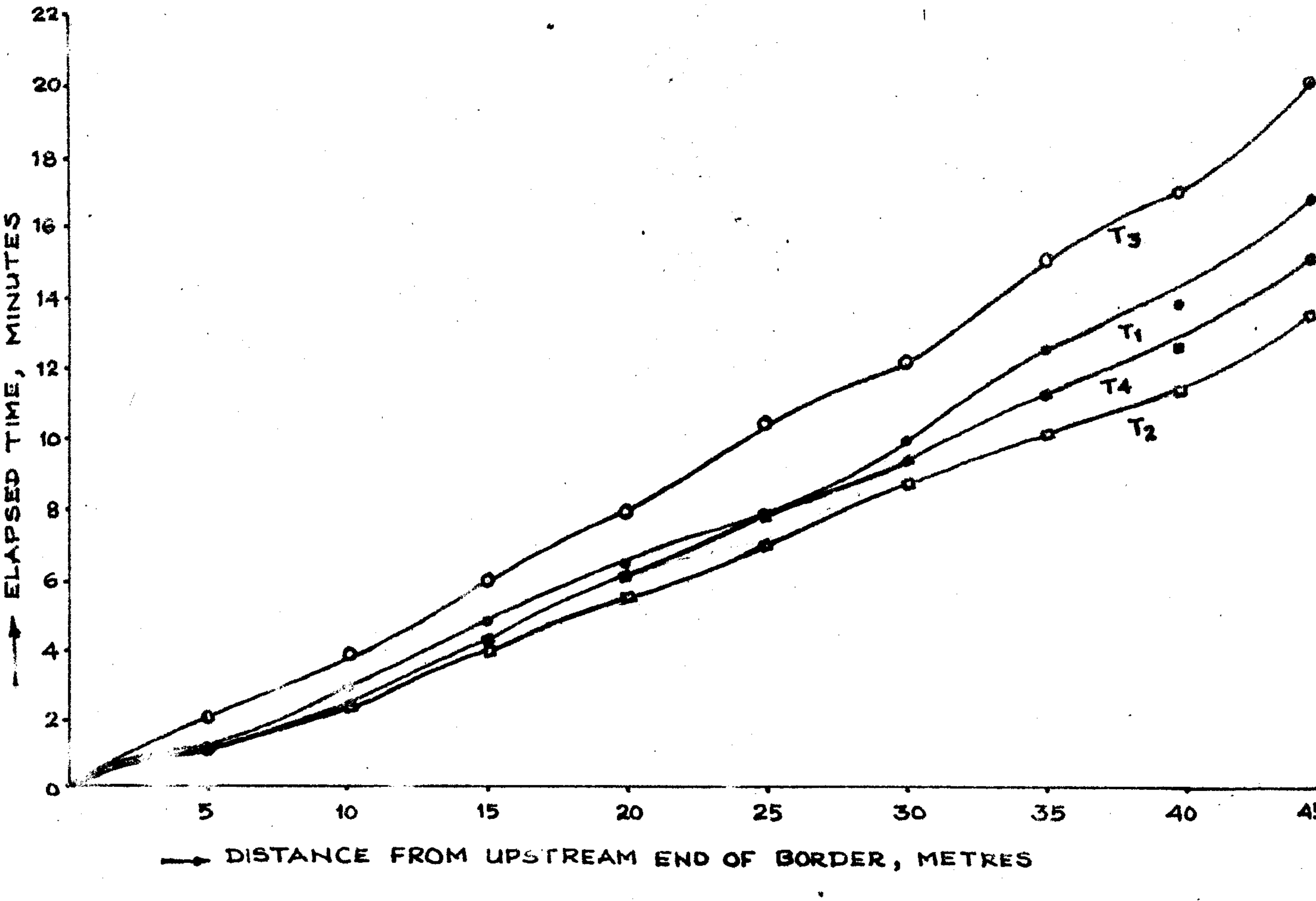


Fig 12 ADVANCE CURVE
IRRIGATION No. 5

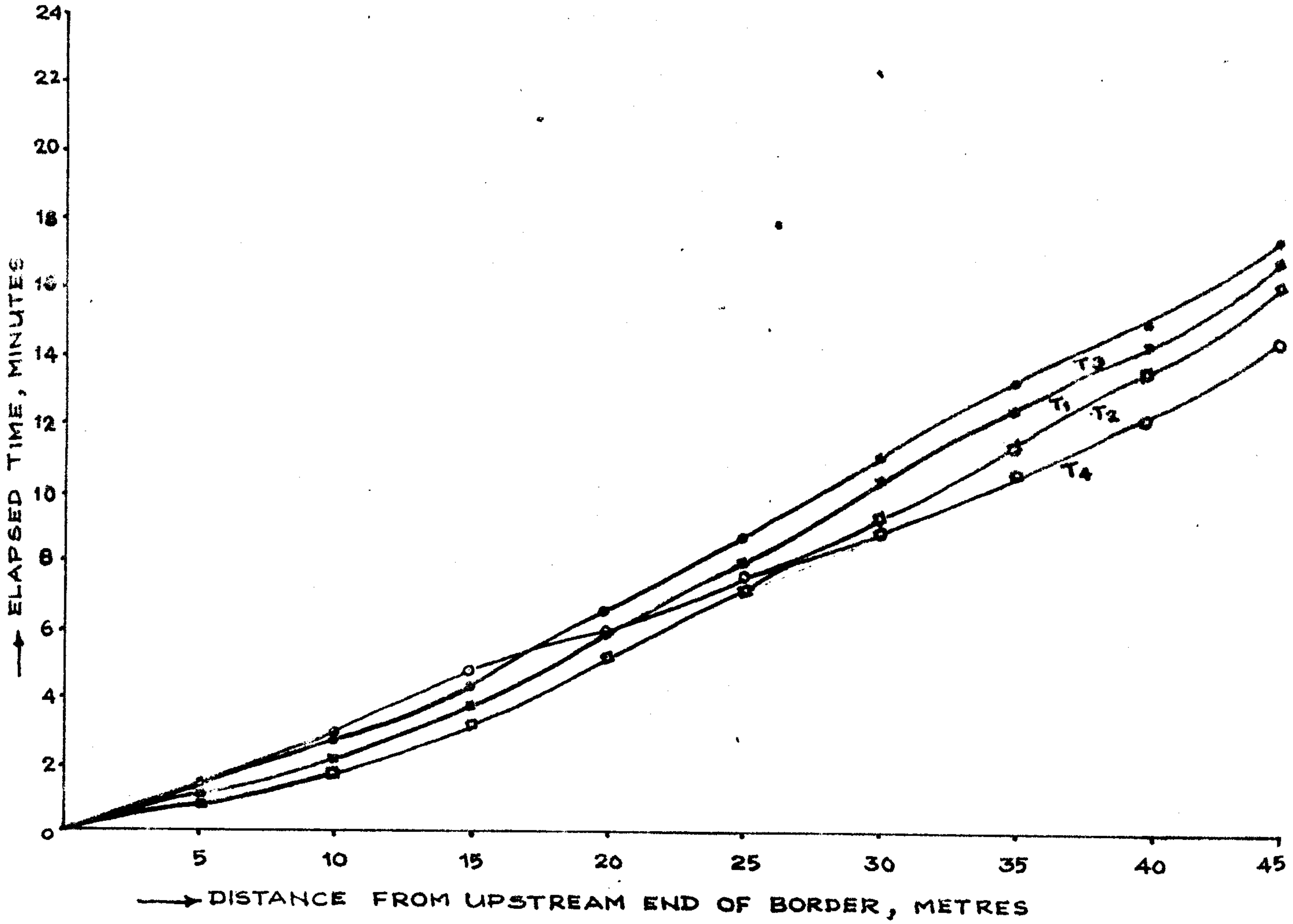


Fig. 13 ADVANCE CURVE
IRRIGATION No. 6

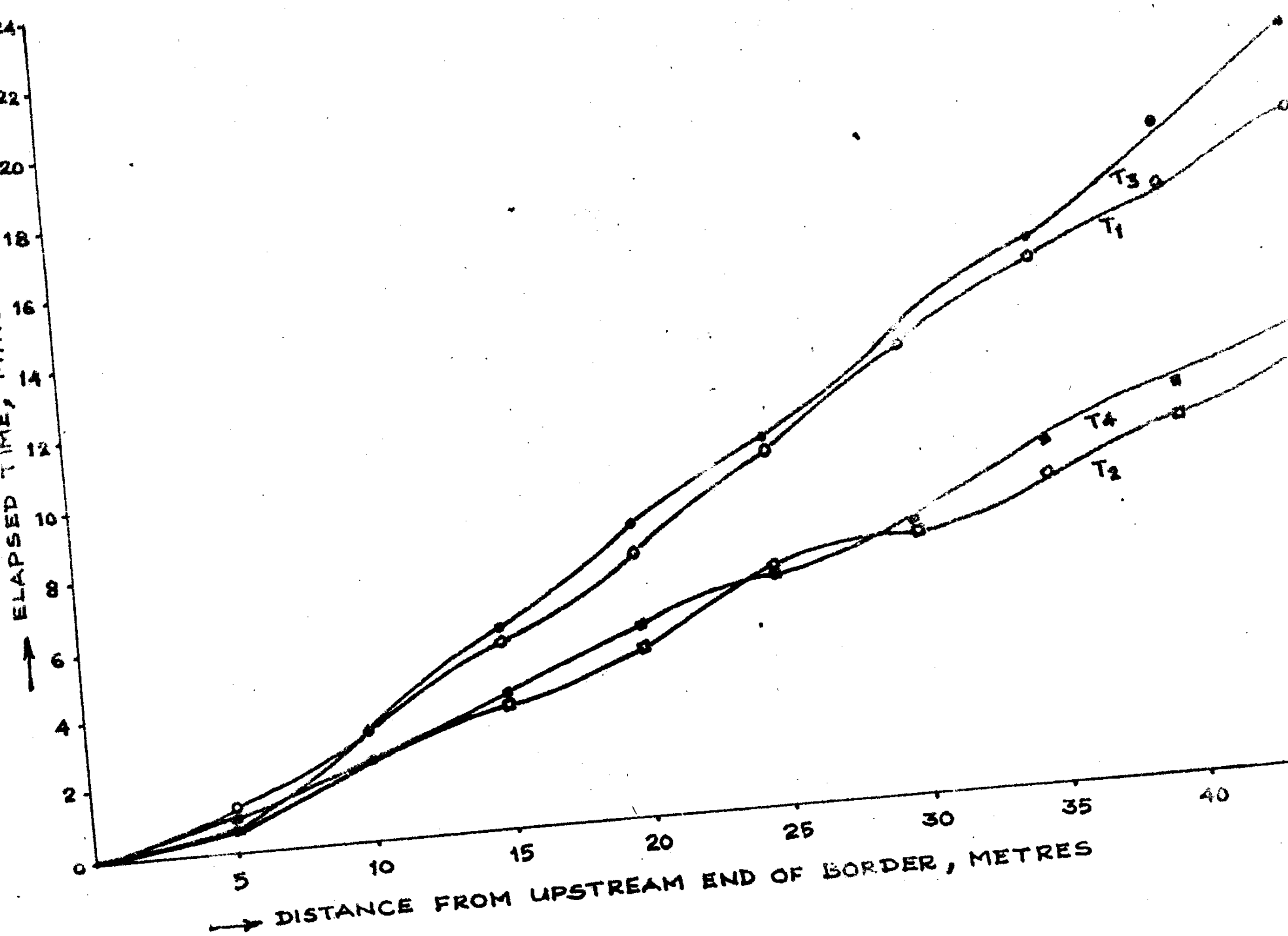
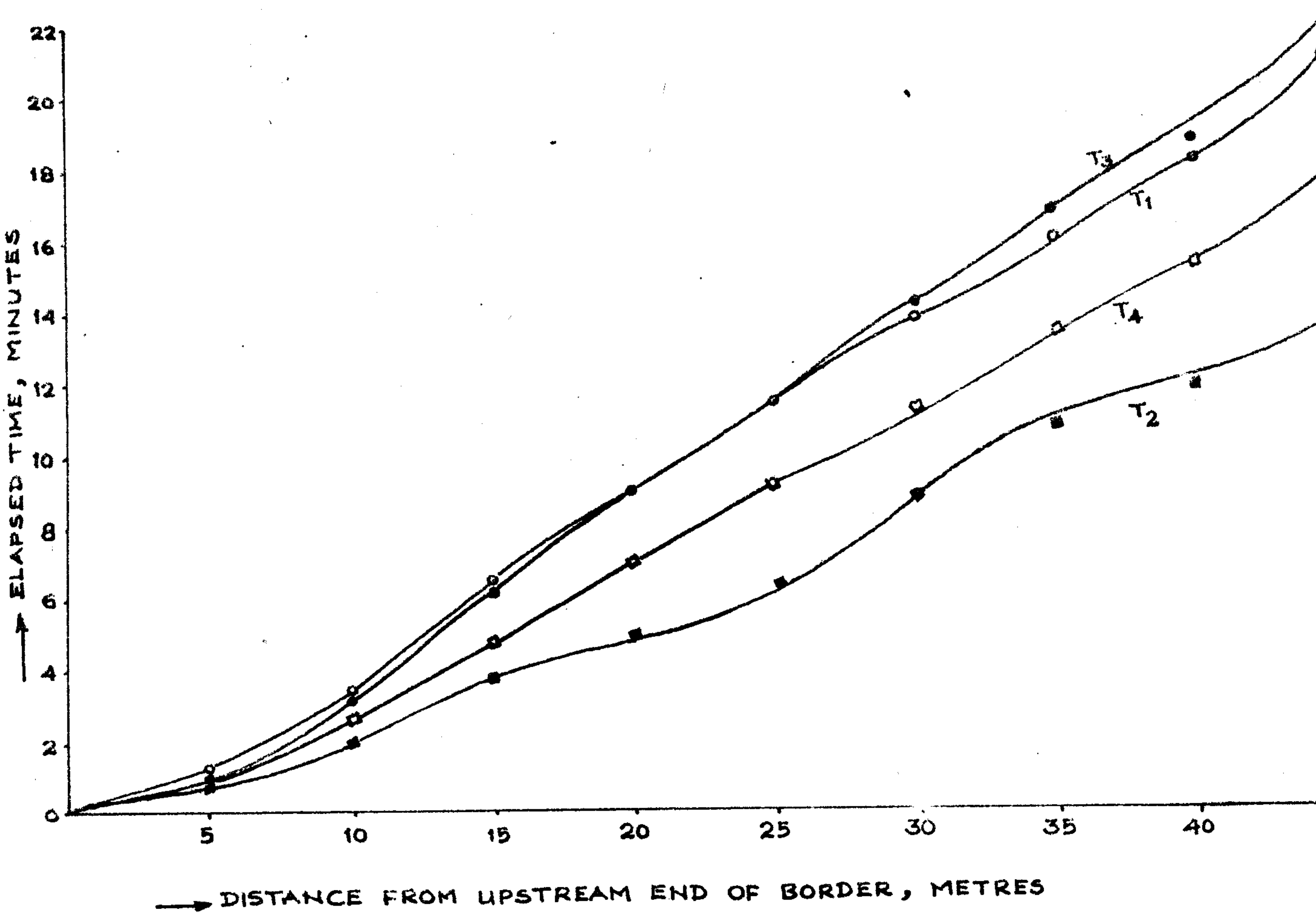


Fig 14. ADVANCE CURVE
IRRIGATION No. 7



effective root zone of the field crops. If more than 5 cm of water is applied, the excess over 5 cm will go beyond the root zone and the crop will not be able to utilise this water. Hence it is very important to limit the depth of application of water to 5 cm.

4.6. Cutoff:

66, 77 and 88 per cent (corresponding to 30, 35 and 40m advance length) cutoff ratios were tried during the observational trial. It was observed that in the case of the cutoff ratio of 66 per cent, water did not reach the downstream end while in the case of 88 per cent cutoff raio, there was excess ponding at the downstream end. For 77 per cent cutoff ratio, almost uniform distribution was observed in most of the cases. Hence it was decided to adopt 77 per cent as the cutoff ratio during the main experiment.

The time required to apply 5 cm depth of irrigation for both the discharge rates were theoretically calculated. They were 18'45" and 9'22" for the discharge rates of 2 l/sec/m and 4 l/sec/m respectively.

During the experiment, water was cutoff when the waterfront advance reached 35m from the upstream end corresponding to 77 per cent cutoff ratio.

Time required for this in each case was noted. The data are presented in Table -13.

The actual cutoff time in the field and the estimated theoretical time were compared. From this, it was seen that the actual cutoff time exceeded the theoretical cutoff time, 4 times in T_1; 3 times in T_3; 21 times in T_2 and 31 times in T_4, out of a total of 35 irrigations. Chisquare test applied (Appendix -4) to this data revealed that the overall effects of treatments influenced highly the cutoff time. The treatments T_1 and T_3 were found to be significantly superior to the treatments T_2 and T_4. In other words, the lesser discharge of 2 l/sec/m took less time than the theoretical time, to reach the cutoff length in most of the cases, while the higher discharge of 4 l/sec/m exceeded the theoretical time in majority of the cases.

When the actual cutoff time is less than the theoretical time, it meant that the depth of irrigation applied is less than 5 cm. Hence in such cases, it is easy to apply the desired depth, by extending the cutoff time. But if the cutoff time is more than the estimated theoretical time, it is not possible to limit the depth of application to 5 cm and spread the water in the entire field uniformly. In these cases,

TABLE -13

Actual cutoff time at 77 per cent advance length

Treatment/order of irrigation		1.	2.	3.	4.	5.	6.	7.
T_1	R_1	28'00"	12'30"	15'10"	12'5"	10'30"	17'50"	17'50"
	R_2	28'0"	13'5"	13'10"	12'0"	11'10"	15'50"	17'5"
	R_3	18'40"	[illegible]	14'35"	11'40"	14'40"	14'55"	16'0"
	R_4	26'10"	13'0"	12'40"	13'50"	13'45"	[illegible]	14'5"
	R_5	22'5"	12'15"	17'0"	12'55"	12'10"	13'5"	16'10"
T_2	R_1	9'50"	9'50"	10'5"	9'55"	12'15"	8'50"	10'0"
	R_2	9'15"	11'0"	9'50"	11'10"	14'15"	9'0"	9'50"
	R_3	10'5"	9'22"	9'15"	11'40"	6'30"	8'50"	8'45"
	R_4	9'20"	9'35"	10'15"	9'30"	8'0"	9'5"	13'5"
	R_5	10'5"	9'0"	10'25"	9'10"	8'50"	9'15"	12'20"
T_3	R_1	18'0"	18'5"	14'25"	16'50"	13'30"	17'35"	17'40"
	R_2	21'30"	20'5"	16'20"	16'40"	12'0"	16'0"	18'10"
	R_3	23'0"	18'20"	14'0"	14'45"	14'45"	15'5"	17'20"
	R_4	18'40"	18'0"	13'20"	14'0"	13'55"	15'20"	15'0"
	R_5	18'10"	17'50"	14'25"	15'10"	12'50"	14'40"	16'20"
T_4	R_1	18'10"	12'50"	12'5"	11'45"	12'25"	10'0"	12'15"
	R_2	17'20"	12'5"	18'5"	13'10"	11'45"	9'25"	12'0"
	R_3	18'5"	11'25"	13'10"	12'10"	8'30"	10'15"	13'0"
	R_4	19'10"	14'5"	14'40"	10'20"	9'15"	10'10"	16'10"
	R_5	18'10"	12'20"	13'20"	8'55"	11'5"	8'55"	13'15"

Note: The values underlined, represent the cutoff times that exceeded the theoretical cutoff time.

more than 5 cm of water have to be applied for uniform distribution of water in the field.

In treatment T_1, all the four cases in which cutoff time exceeded the theoretical cutoff time were during the first irrigation and in treatment T_3, two out of three times this happened during the first irrigation.

Results of the experiment revealed that the depth could be limited to 5 cm, when the rate of application was 2 l/sec/m, excepting during the first irrigation. This result coincides with the result obtained by Sewa Ram (1975). He concluded that for the first irrigation, the best cutoff ratio was 85 per cent and for the second and third irrigations the cutoff ratios were 80 and 75 per cent respectively.

Among the treatments T_2 and T_4, T_2 was found to have marginal superiority though both the treatments were not satisfactory. The actual cutoff time in T_2 exceeded the theoretical cutoff time 21 times out of 35 irrigations. This implied that except for a few cases, the depth of irrigation could not be limited to 5 cm. With 2 l/sec/m discharge rate, the widths of 4m and 6m were on par. The variation observed in these treatments might be due to chance.

4.7. Recession:

The average recession time observed for the discharges of 2 l/sec/m and 4 l/sec/m in 4m width strips are shown in Table -14; and the graphs showing advance and recession curves are given in Fig.15 and 16.

The recession curve was found almost parallel to the advance curve, upto the first 30m length for the discharge of 2 l/sec/m. That is, from 0 to 30m length, the infiltration opportunity time was almost the same. The mean opportunity time was 33 minutes, 47 seconds. From 30 to 35m, the opportunity time was gradually increasing. That is, from 30m onwards, there was excess infiltration opportunity time, which contributed to wastage of water at the downstream end. Petrasovits (1969) also observed excess water of 5 - 10 per cent at the downstream end during his experiments on borders of 1.2 per cent slope.

For the discharge of 4 l/sec/m, the first 0 - 15m receded within 32 minutes after cutoff. Then from 15 to 30m, the curve obtained was almost parallel to the advance curve in that range. That is, the time of ponding was almost the same in that range, which was about 32 minutes. From 30m onwards, the tail water receded more slowly, giving more opportunity time. The

TABLE -14

Average recession and opportunity times obtained with the discharge rates of 4 l/sec/m and 2 l/sec/m

4 l/sec/m				2 l/sec/m			
Length of advance	Time of advance	Time of recession	Opportunity time	Length of advance	Time of advance	Time of recession	Opportunity time
0	0	16'40"	16'40"	0	0	31'0"	31'0"
5	0'45"	22'0"	21'15"	5	0'45"	34'25"	33'40"
10	1'30"	27'0"	25'30"	10	2'0"	36'45"	34'45"
15	2'35"	32'10"	29'35"	15	4'15"	39'45"	35'30"
20	4'10"	35'10"	31'0"	20	7'40"	41'45"	34'5"
25	5'50"	37'20"	31'30"	25	9'20"	43'35"	34'15"
30	7'20"	41'20"	34'0"	30	11'30"	44'45"	33'15"
35	9'22"	48'20"	39'0"	35	14'15"	49'45"	35'30"
40	10'35"	56'10"	45'35"	40	16'45"	56'45"	40'0"
45	12'5"	64'0"	51'55"	45	19'35"	65'0"	45'25"

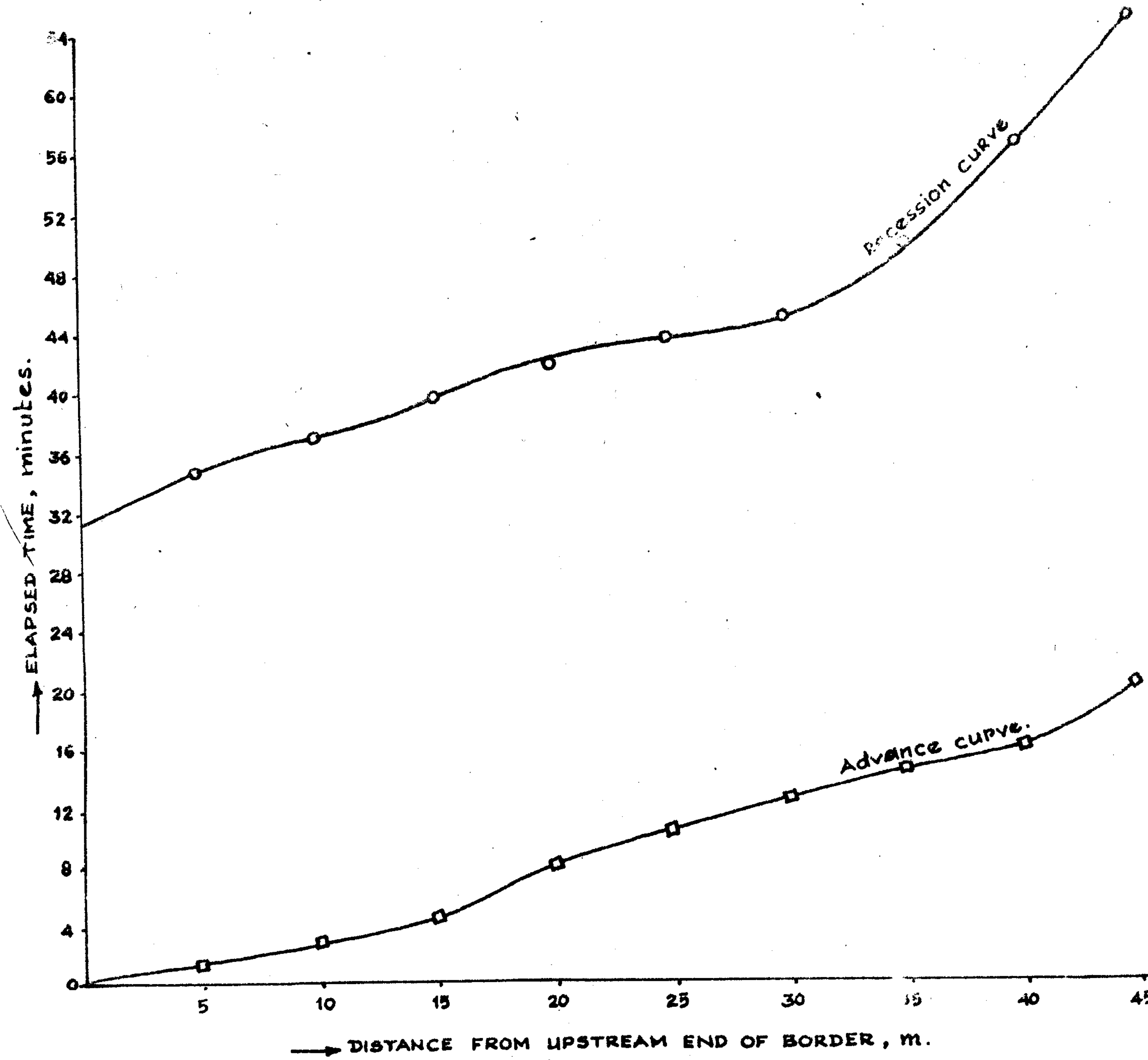


Fig. 15 - ADVANCE AND RECESSION CURVES FOR THE DISCHARGE RATE OF 2 LITRES/sec/m.

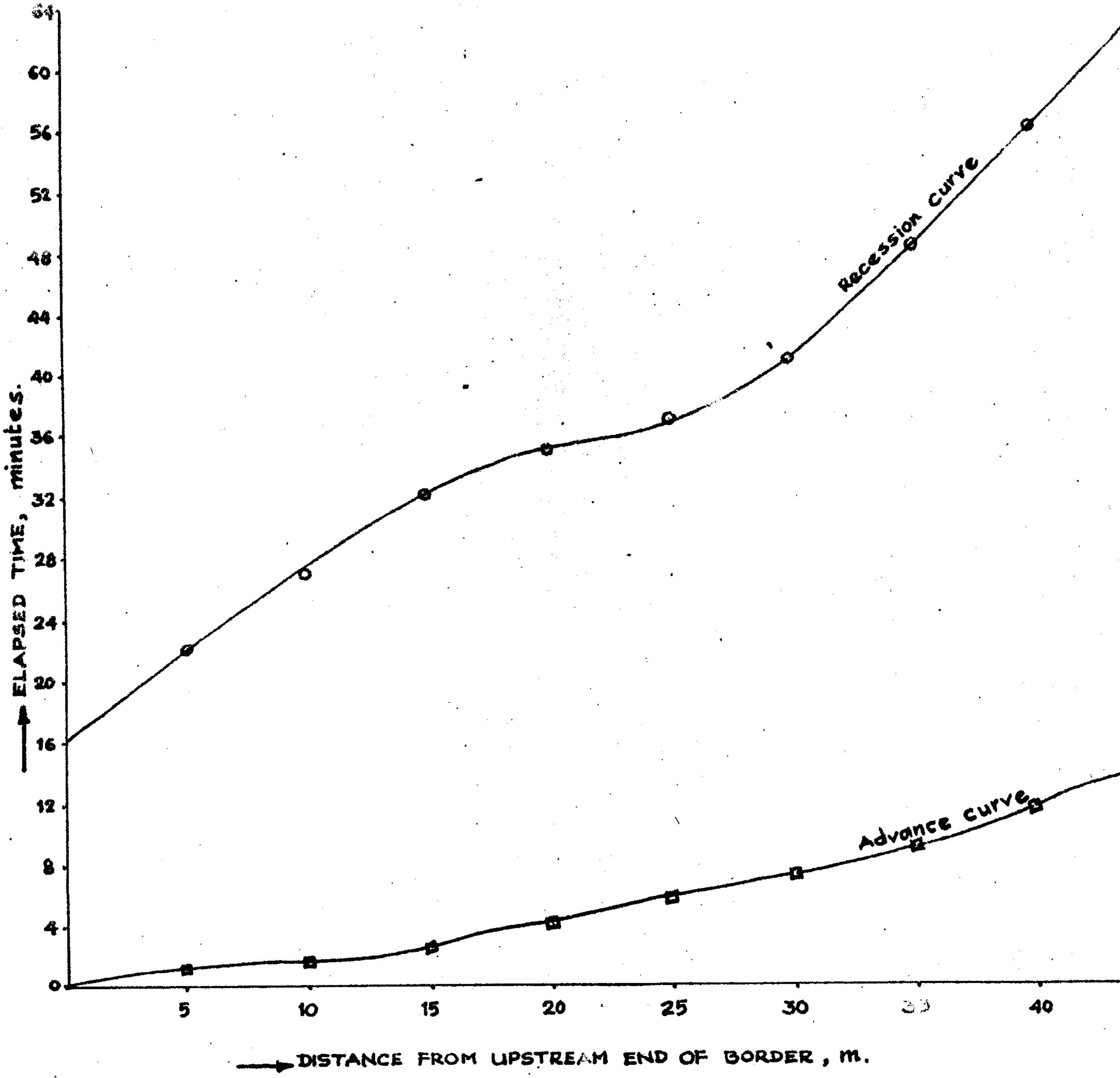


Fig. 16 - ADVANCE AND RECESSION CURVES FOR THE DISCHARGE RATE OF 4 LITRES/sec/m.

opportunity time varied from 39' at 35m to 51'55" at 45m. This resulted in deep percolation at the downstream end. In other words, with this discharge rate, the opportunity time varied from 16'40" at the upstream end to 51'55" at the downstream end which resulted in very low water distribution efficiency.

From these observations, the discharge of 2 l/sec/m was found to be the best. This treatment gave almost the same time of ponding upto 66 per cent of the advance length.

4.8. Velocity of flow:

The velocity of flowing water was determined by dividing the length of advance by the time of advance. The values obtained are shown in Table -15. The analysis of variance table is shown in Appendix -5. From this, it was seen that the velocity was highly influenced by the treatments, the order of irrigation and the interaction of order with treatments. The higher the discharge rates, the higher was the velocity and vice-versa. Considering the order of irrigation, the velocity of flow was less for the first irrigation due to the higher initial infiltration. Velocity of flow increased for the second irrigation. No significant differences were observed between the second, third and fourth

TABLE -15

Velocity of flowing water (m/sec)

Treatments/ Order of irrigation		1	2	3	4	5	6	7
T_1	R_1	0.036	0.058	0.038	0.048	0.055	0.033	0.033
	R_2	0.021	0.051	0.044	0.049	0.052	0.037	0.034
	R_3	0.031	0.056	0.043	0.05	0.039	0.042	0.036
	R_4	0.022	0.051	0.046	0.043	0.042	0.045	0.045
	R_5	0.026	0.054	0.034	0.045	0.048	0.045	0.036
T_2	R_1	0.059	0.067	0.058	0.067	0.048	0.066	0.058
	R_2	0.063	0.061	0.059	0.052	0.044	0.065	0.059
	R_3	0.058	0.065	0.063	0.05	0.089	0.067	0.067
	R_4	0.063	0.052	0.057	0.061	0.073	0.064	0.045
	R_5	0.058	0.056	0.056	0.064	0.067	0.063	0.047
T_3	R_1	0.037	0.037	0.043	0.039	0.043	0.033	0.033
	R_2	0.036	0.033	0.036	0.035	0.049	0.036	0.032
	R_3	0.027	0.036	0.045	0.039	0.039	0.039	0.034
	R_4	0.025	0.037	0.044	0.045	0.042	0.038	0.039
	R_5	0.032	0.037	0.043	0.038	0.045	0.043	0.036
T_4	R_1	0.037	0.045	0.048	0.049	0.047	0.058	0.048
	R_2	0.038	0.048	0.037	0.044	0.05	0.062	0.049
	R_3	0.037	0.051	0.051	0.048	0.069	0.057	0.045
	R_4	0.035	0.048	0.049	0.057	0.063	0.057	0.036
	R_5	0.037	0.047	0.05	0.065	0.053	0.065	0.044

irrigations. Weeding was done after the fourth irrigation. Since the resistance to flow offered by the weeds was reduced, the velocity increased slightly, for the fifth irrigation. It was not significantly different from the sixth irrigation. For the last, the seventh irrigation, the velocity again decreased due to the flow resistance offered by the weeds and the fallen dead leaves.

Petrasovits (1969) observed that erosion was caused when the velocity exceeded 8 m/min. The velocity was maximum in the treatment T_2 and this velocity was only 3.6 m/min. Hence the velocity was very much within the safe limit.

4.9. Hydraulic gradient:

The hydraulic gradients for all irrigations were estimated from the observed depth of flow and the known surface gradient, and are tabulated in Table -16. The values obtained, ranged between 0.00011 and 0.00165.

4.10. Hydraulic resistance:

The hydraulic resistance expressed as Manning's 'n' were computed from the equation

$$n = \frac{d^{5/3} s^{1/2}}{q} .$$

The values are shown in Table -17. The analysis of variance table is shown in Appendix -6. It showed that the treatments and the order of irrigations influenced the hydraulic resistance. The 'n' values were found to be significantly higher in the treatments T_3 and T_1. In these treatments, n value ranged between 0.02 and 0.185.

The present study revealed that a discharge rate of 2 l/sec/m is the best for irrigating nearly level borders of 4m and 6m widths for the following reasons:

1) The depth of irrigation can be limited to 5 cm even in soils having high rate of infiltration. The present study was conducted in loamy sand soil having a basic infiltration rate of 2.4 cm per hour.

2) The lower discharge rate of 2 l/sec/m reduces the time of ponding at the downstream end and this minimise the wastage due to deep percolation at the downstream end.

3) This discharge rate gives almost equal opportunity time throughout the entire length of the strip, excepting at the downstream end, thus giving better distribution efficiency.

4) Soil erosion in the strip is minimum at this rate of discharge.

5) Long strips upto 45m length in loamy sand can be irrigated with high degree of efficiency.

6) As only a low rate of discharge is required to practise this method, even in areas having

limited availability of water, an additional crop can be profitably raised.

At present, in the command areas of major irrigation projects and wherever lift irrigation facilities are available, a third crop of rice is taken during the dry season. The total water requirement of rice in the first and second crop seasons is 10 - 15 mm per day in loamy sand soils. The percolation loss in these seasons, is 6 - 8 mm per day. But, in summer months the rice needs 25 - 30 mm of water per day in which the percolation loss comes to about 20 mm of water per day. Hence if rice is grown during summer months, there is an additional wastage of 12 mm of water due to deep percolation. Growing rice during the summer months in soils with high rate of infiltration should be discouraged because of the very low water use efficiency.during this season. Since in all other crops, no standing water is kept in the field and the field is irrigated only upto field capacity, the loss due to deep percolation is almost eliminated. The water requirement of other field crops like pulses, oilseeds and vegetables is 6 - 8 mm per day. In other words, the water needed to raise one hectare of rice in summer months can be more profitably used to raise about 4 ha. of any other crop.

So far the policy of the Government of Kerala has been to provide water from irrigation schemes only for rice crop. Now there is a shift in the policy of the Government. It has been decided to provide water for other seasonal crops also during the summer season. But the extension workers are not in a position to suggest any satisfactory method of irrigation for the dryland crops in the rice fallows. Border strip method of irrigation is hardly practised anywhere in Kerala, eventhough this is a very popular method in the other parts of India for raising cereals, pulses and oilseeds. However, this method is practised there on sloping lands. This method has got the following advantages:

1. Minimum land preparation is needed.
2. Distribution and high water application efficiencies are possible.
3. The strip bunds being small, is removed during the land preparation for the next crop without incurring any additional expenditure.
4. Labour requirement in irrigation is greatly reduced.
5. Operation of the system is simple, easy and can be practised by ordinary farmer without any difficulty.

The present study revealed that this method can be practised efficiently on level or nearly level fields, also Since the method can be practised successfully on nearly level fields, this is best suited for raising a successful crop in the rice fallows during the dry season. Most of the paddy fields have a mild natural slope in one of the directions. This slope can be used to advantage by laying the strips in the direction of the natural slope. This method can be recommended to the cultivators for raising a crop in the rice fallows.

The specifications of border strips for nearly level fields, as obtained from the present study are given below:

Length of border	: Upto 45m
Width of border	: 4 - 6m
Rate of flow	: 2 l/sec/m
Slope	: should be laid in the direction of natural slope
Height of strip bunds	: 20 cm
Base width of bunds	: 30 cm

Summary

SUMMARY

In Kerala, more than 70 per cent of the double cropped rice fields lie fallow during summer months. Rice cannot be grown during this season because of the limited availability of water and the very low water use efficiency that can be attained during this season. The development of a technology for efficient use of limited water available during summer is necessary to make use of these rice fallows for cultivating crops other than rice. As most of the area is under paddy during first and second crop seasons, the level of the land cannot be disturbed. Hence an efficient method of irrigation which can be practised on nearly level fields has to be developed for raising a successful crop in these fields during the dry season. The border strip method of irrigation, practised on sloping lands requires the minimum land preparation. The objective of this project was to study the hydraulics of border strip irrigation in nearly level lands and to recommend suitable specifications.

The experiment was done at the Agronomic Research Station, Chalakudy during 1981-82 after conducting a preliminary trial during 1980-81. The sources of water for irrigation were the well water and the canal water from the Chalakudy Irrigation Project.

The basic soil characteristics were measured. The field capacity and wilting point were estimated to be 14.46 per cent and 8.02 per cent respectively. The surface gradient was 0.03815 per cent. The infiltration rate of the soil was found to be 2.4 cm/hr. The curve fitted for cumulative infiltration of the form $y = at^{\alpha} + b$ was, $y = 0.2152t^{0.2556} + 0.082$. The equation obtained for the rate of infiltration was $r = 15.5t^{-0.342}$. The analysis showed that these curves gave a satisfactory fit to the data.

The experiment consisted of five replications of four treatments. The treatments were two widths of 4m and 6m combined with two discharge rates of 2 l/sec/m and 4 l/sec/m, the length of strip in all the cases being 45m. Altogether seven irrigations were given at an intervals of seven days. Blackgram seeds were dibbled in the field after the first irrigation and cultural practices as recommended in the Package of Practices were followed.

The stream sizes were measured by using a V-notch installed at the exit of the supply channel. The time of advance of waterfront, the depth of flow and the time of recession of tail water were observed at every 5m length for each strip. Based on the preliminary tests, cutoff point was fixed at 35m from the upstream end - 77 per cent of the strip length. The hydraulic gradient, hydraulic resistance and the velocity of flow for each irrigation were determined. The advance and recession curves were drawn.

The results of the experiment showed that a discharge rate of 2 l/sec/m is the best for irrigating nearly level borders of 4m and 6m widths for the following reasons:

1) The depth of irrigation could be limited to 5 cm even in soils having high rate of infiltration;

2) The lower discharge rate of 2 l/sec/m reduced the time of ponding at the downstream end and this minimised the wastage due to deep percolation at the downstream end;

3) This discharge rate gave almost equal opportunity time throughout the entire length of the strip, excepting at the downstream end, thus giving better distribution efficiency;

4) Soil erosion in the strip was minimum at this rate of discharge;

5) Long strips upto 45m length in loamy sand could be irrigated with high degree of efficiency; and

6) As only a low rate of discharge was required to practise this method, even in areas having limited availability of water, an additional crop can be profitably raised.

At present, in the command areas of major irrigation projects and wherever lift irrigation facilities are available, a third crop of rice is taken, during the dry season. The total water requirement of rice in the first and second crop seasons is 10-15 mm per day in loamy sand. The percolation loss in these seasons, is 6-8 mm per day. But, in summer months, rice needs 25-30 mm of water per day in which the percolation loss alone comes to about 20 mm of water per day. Hence if rice is grown during summer months, there is an additional wastage of 12 mm of water due to deep percolation. Growing rice during the summer months in soils with high rate of infiltration should be discouraged because of the very low water use efficiency during this season. Since in all other crops, no standing water is kept in the field and the field is irrigated only upto field capacity, the loss due to deep percolation is almost eliminated. The water requirement of other field crops like pulses, oilseeds and vegetables is only 6-8 mm per day. In other words, the water needed to raise one hectare of rice in summer months can be more profitably used to raise about 4 ha. of any other crop.

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The present study revealed that this method can be practised efficiently on level or nearly level fields also. Since the method can be practised successfully on nearly level fields, this is best suited for the rice fallows during the dry season. Most of the paddy fields have a mild natural slope in one of the directions. This slope can be used to advantage by laying the strips in the direction of natural slope. This method can be recommended to the cultivators for raising a crop in the rice fallows.

The specifications of border strips for nearly level fields, as obtained from the results of the present study are given below:

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Width of border	- 4 - 6m
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Slope	- should be laid in the direction of natural slope
Height of bunds separating the strips	- 20 cm
Base width of bunds	- 30 cm

References

REFERENCES

Annual Report 1982, Agronomic Research Station, Chalakudy.

Bishop, A.A. 1967. Surface Irrigation Methods and Practices. Water Use Seminar Damascus. *Irrigation and Drainage Paper*. FAO, United Nations, Rome.

Bishop. A.A. and Fok. Y.S. 1965. Analysis of Water Advance in Surface Irrigation. *J. of Irrign. and Drain. Div. Proc. of ASAE*. **9** : 99-116.

Chow. Ven te. 1959. *Open channel Hydraulics*. Mc Graw-Hill Book Co., Inc., New York. P.680.

Christiansen, J.E., Bishop, A.A. and Fok, Y.S. 1966. Evaluation of Intake Rate Constants as Related to Advance of Water in Surface Irrigation. *Transactions of ASAE* **9** : 671-674.

Cowan, W.L. and Palmer. 1956. Estimating Hydraulic Roughness Coefficients. *Agricultural Engineering*. St. Joseph. Mich. pp. 473-475.

Criddle, W.D., Davis, S., Pair, C.H. and Shockley, D.G. 1956. Methods of Evaluating Irrigation Systems. *Agricultural Handbook*. No. **82**. Soil Conservation Service. USDA, Washington. P.24.

Hall, W.A. 1956. Estimating Irrigation Border Flow. *Agricultural Engineering*. **17** (4) : 263-265.

Mukkery, S.B. and Pandey. 1977. Water Requirements and Irrigation Management of Crops in India. *IARI Monograph No*. **4**. Water Technology Centre, New Delhi.

Israelsen, O.W. and Hansen, V.E. 1962. Irrigation Principles and Practices. John Wiley and Sons, Inc., New York. 3rd edn.

*Lad, S.L. and Kelbar, P.N. 1976. Effects of Irrigation Scheduled according to water use factors on soil moisture use pattern and water use efficiency of wheat. Coll. of Agric. Pune. 1. pp.747-749.

Lewis, M.R and Milne, W.E. 1938. Analysis of Border Irrigation. Agricultural Engineering 19. pp.267-272.

Lyman, S. and Willardson. 1972. Attainable Irrigation Efficiencies. J. of Irrign. and Drain. Divi. 98 (IR-2). P.239.

*Michael, A.M. 1968. Evaluation of Hydraulic Characteristics Influencing Border Irrigation Design. Ph.D. Thesis, Dept. of Agric.Engg. Indian Institute of Technology, Karagpur.

Michael, A.M. 1978. Irrigation Theory and Practice. Vikas Publishing House, Pvt.Ltd., New Delhi 1st edn.

*Michael, A.M. and Pandey, S.L. 1970. Time Your Irrigation for top yields. Intensive Agriculture. May, 1970.

Michael, A.M. and Pandya, A.C. 1971. Water front Advance in Irrigation Borders. J of Agricultural Engineering Res. 16 (1) : 62-71.

Michael, A.M. and Pandya, A.C. 1971. Hydraulic Resistance Relationships in Irrigation Borders. J. of Agricultural Engineering Res. 16 (1) : 72-80

Michael, A.M., Shri Mohan and Swaminathan, K.R. 1972. Design and Evaluation of Irrigation Methods. IARI. Monograph No.1 (New series), Water Technology Centre. IARI, New Delhi.

Mishra, A.P. and Anjanavelu, B. 1971. Analysis of Water Advance in Irrigation Furrows. The Harvester. 13 pp.20-22.

Murthy, V.V.N. and Agarwal, M.S. 1970. A Rational Approach to the Design of Check System of Irrigation. *J. of Agricultural Engineering Res.* 15 (2) : 163-170.

Petrasovits. 1971. Investigations on Surface Irrigation Methods in the Euphrates Basin. Water Use Seminar Damascus. *Report of the FAO/UNDP. Regional Seminar on Effective Use of Irrigation Water at the Farm level.* Damascus, Syria.

*Philip, J.R. and Farrrel, D.A. 1964. General Solution of the infiltration - advance problem in irrigation hydraulics. *J. of Geophysical Research.* 69. No.4 : 621-631.

Ram, Sewa. 1975. Inflow cutoff Ratio for Irrigation in ponded Border Strips. *Proc. of the Second World Congress on Water Resources.* New Delhi. Water for Human Needs. Vol.1.

Rathore, S.S. and Singh, R.M. 1976. Consumptive use of water by dwarf wheat and its relationship with climatological parameters. *Indian J. of Agron.* 2.

Sastri, G. and Agarwal, S.C. 1973. Irrigation number - A new technique to evaluate Irrigation Advance Distance. *J. of Agricultural Engineering Res.* 18. pp. 189-195.

Singh, Jaswant, 1975. Some Aspects of Advance of Water in Border Irrigation. *Proc. of the Second World Congress on Water Resources.* New Delhi. Water for Human Needs, Vol.1. P.387.

Singh, Pratap and Chauhan, H.S. 1973. Determination of Water Intake Ratio of Advance front. *Transactions of ASAE.* 16 (6) : 1081-1084.

United States Department of Agriculture.1970. Irrigation guide for Southern and Southe-eastern Idaho. USDA And SCS.

Verma, S.C. 1981. Predicting Recession in a Check Border Irrigation System. *J. of Agricultural Engineering Res.26*. pp.379-386.

* = Originals not seen.

Appendices

Appendix - 1

Mean monthly weather data during the period of experiment recorded at Agronomic Research Station, Chalakudy

Month	Rainfall			Mean temperature (°c)		Mean relative humidity (%)		Mean open pan evaporation (mm/day)	Mean wind speed (km/hr)
	Total (mm)	Mean (mm/day)	Number of rainy days	Maximum	Minimum	Morning (8 AM)	Afternoon (2 PM)		
Jan 82	-	-	-	35.19	20.13	78.77	33.61	4.18	2.20
Feb 82	-	-	-	35.55	22.29	80.64	37.26	4.72	2.90
Mar 82	11.5	0.37	1	36.10	24.40	79.42	42.23	5.49	3.70
Apr 82	67.2	2.24	2	35.47	25.83	78.33	56.85	5.42	3.73
May 82	133.7	4.31	7	34.35	25.45	83.84	55.14	4.38	3.08
Jun 82	911.3	30.40	22	29.50	23.80	91.90	77.70	3.67	3.10

Appendix - 2

INFILTRATION ANALYSIS

Construction of the mathematical model for cumulative infiltration:

Let $y = at^{\alpha} + b$

For $t_1 = 5'$, $y_1 = 0.8$ cm

For $t_2 = 270'$, $y_2 = 14.5$ cm

$t_3 = \sqrt{t_1 t_2} = \sqrt{5 \times 270} = 36.75'$

y_3 corresponding to 36.75' (from graph) = 3.3 cm.

Therefore, the value of $b = \dfrac{y_1 y_2 - y_3^2}{y_1 + y_2 - 2y_3}$

$$= \frac{0.8 \times 14.5 - 3.3^2}{0.8 + 14.5 - 2 \times 3.3} = 0.082$$

that is, $b = 0.082$

$y = at^{\alpha} + 0.082$

$y - 0.082 = at^{\alpha}$

Taking logarithms,

$\log (y - 0.082) = \log a + \alpha \log t.$

or, $Y = A + Bx$ where

$Y = \log (y - 0.082)$

$A = \log a$

$B = \alpha$

$X = \log t$

The normal equations are,

$$\Sigma Y = nA + B\Sigma X \longrightarrow (1)$$

$$\Sigma XY = A\Sigma X + B\Sigma X^2 \longrightarrow (2)$$

Here, n = 13 = Number of observations

$$\Sigma Y = 13\,A + B\Sigma X$$

$$\Sigma XY = A\Sigma X + B\Sigma X^2$$

Y (log (y-0.082))	X (log t)	XY	X^2
-0.1439	0.6990	-0.1006	0.4886
0.2089	1.1761	0.2457	1.3832
0.4499	1.4771	0.6645	2.1818
0.6251	1.6990	1.0621	2.8866
0.7418	1.8451	1.3687	3.4044
0.8207	1.9542	1.6038	3.8189
0.8819	2.0414	1.8003	4.1673
0.9354	2.1139	1.9773	4.4686
0.9781	2.1761	2.1284	4.7354
1.0342	2.2553	2.3324	5.0864
1.0799	2.3222	2.5077	5.3926
1.1212	2.3802	2.6687	5.6654
1.1590	2.4314	2.8179	5.9117
Σ= 9.8922	Σ=24.571	Σ= 21.0769	Σ=49.5909

Substituting the values in the normal equations,

$$9.8922 = 13 A + 24.571 B \longrightarrow (1)$$

$$21.0769 = 24.571 A + 49.5909 B \longrightarrow (2)$$

From these equations, the value of B is 0.7556, and the value of A is − 0.6672.

that is, $\underline{\alpha = 0.7556}$.

and log $a = -0.6672 = \bar{1}.3328$.

Therefore, a = 0.2152

Hence, the equation is,

$$y = \underline{\underline{0.2152\, t^{0.7556} + 0.082}}$$

Time elapsed min. t	Observed cu. infiltration cm. Y	Predicted cu. infiltration cm. $\hat{Y}$	$(Y-\hat{Y})$	$(Y-\hat{Y})^2$	Y^2
5	0.8	0.81	−0.01	0.0001	0.64
15	1.7	1.75	−0.05	0.0025	2.89
30	2.9	2.89	0.01	0.0001	8.41
50	4.3	4.22	0.08	0.0064	18.49
70	5.6	5.42	0.18	0.0324	31.36
90	6.7	6.53	0.17	0.0289	44.89
110	7.7	7.59	0.11	0.0121	59.29
130	8.7	8.60	0.1	0.01	75.69
150	9.6	9.57	0.03	0.0009	92.16
180	10.9	10.97	−0.07	0.0049	118.81
210	12.1	12.31	−0.21	0.0441	146.41
240	13.3	13.61	−0.31	0.0961	176.89
270	14.5	14.87	−0.37	0.1369	210.25
	Σ=98.8			Σ=0.3754	Σ=986.18

$$R^2 = \frac{\text{S.S. due to regression}}{\text{Total S.S.}}$$

$$\text{Total S.S.} = Y^2 - \frac{(\Sigma y)^2}{n}$$

$$= 986.18 - \frac{98.8^2}{13}$$

$$= \underline{235.3}$$

S.S. due to regression = Total S.S.

− S.S. due to error

= 235.3 — 0.3754

= 234.925

$R^2 = \frac{234.925}{235.3} =$ 99.84 per cent.

Appendix - 3

Construction of the Mathematical Model for Rate of Infiltration

Let $r = at^b$, in which r = rate of infiltration

$\log r = \log a + b \log t$, or,

$R = A + bX$, where

$R = \log r$

$A = \log a$

$X = \log t$

The normal equations are,

$$\Sigma R = nA + b\Sigma X \longrightarrow (1)$$

$$\Sigma RX = A\Sigma X + b\Sigma X^2 \longrightarrow (2)$$

R (log r)	X (log t)	RX	X^2
0.9823	0.6990	0.6866	0.4886
0.7324	1.1761	0.8614	1.3832
0.6812	1.4771	1.0062	2.1818
0.6232	1.6990	1.0588	2.8866
0.5911	1.8451	1.0906	3.4044
0.5185	1.9542	1.0133	3.8189
0.4771	2.0414	0.9739	4.1673
0.4771	2.1139	1.0085	4.4686
0.4314	2.1761	0.9388	4.7354
0.4150	2.2553	0.9359	5.0864
0.3802	2.3222	0.8829	5.3926
0.3802	2.3802	0.9049	5.6654
0.3802	2.4314	0.9244	5.9117
Σ=7.0699	Σ=24.571	Σ= 12.2862	Σ=49.5909

Substituting the values in the normal equations,

$$7.0699 = 13\,A + 24.571\,b \longrightarrow (1)$$

$$2.2862 = 24.571\,A + 49.5909\,b \longrightarrow (2)$$

Solving these two equations, the value of

$b = -0.342$, and

$A = 1.1902$

that is, $\log a = 1.1902$

Therefore, $a = 15.5$.

Hence, the equation is $r = \underline{\underline{15.5t^{-0.342}}}$

Elapsed time t (min)	Observed rate, r cm/hr	Predicted rate, $\hat{r}$ cm/hr	$r-\hat{r}$	$(r-\hat{r})^2$	r^2
5	9.6	8.94	0.66	0.4356	92.16
15	5.4	6.14	−0.74	0.5476	29.16
30	4.8	4.84	−0.04	0.0016	23.04
50	4.2	4.07	0.13	0.0169	17.64
70	3.9	3.63	0.27	0.0729	15.21
90	3.3	3.33	−0.03	0.0009	10.89
110	3.0	3.11	−0.11	0.0121	9.00
130	3.0	2.93	0.07	0.0049	9.00
150	2.7	2.79	−0.09	0.0081	7.29
180	2.6	2.62	−0.02	0.0004	6.76
210	2.4	2.49	−0.09	0.0081	5.76
240	2.4	2.38	0.02	0.0004	5.76
270	2.4	2.30	0.1	0.01	5.76
	49.7			Σ=1.1195	237.43

$$R^2 = \frac{\text{S.S. due regression}}{\text{Total S.S.}}$$

Total S.S. $= \Sigma r^2 - \frac{(\Sigma r)^2}{n} = 237.43 - \frac{(49.7)^2}{13}$

$= \underline{47.423}$

S.S. due to regression = Total S.S. − S.S. due to error = 47.423 − 1.1195 = 46.3035

R^2 = ~~97.64~~ = $\frac{46.3035}{47.423}$ = 97.64 per cent

Appendix - 4

Chisquare analysis of cutoff time

Comparisons	Chisquare value
Overall effects of treatments	65.236**
T_1 and T_2	17.982**
T_1 and T_3	0.158
T_1 and T_4	42.0**
T_2 and T_3	21.0**
T_2 and T_4	7.0**
T_3 and T_4	45.0**

Note: ** - Significant at 1 per cent level ($P < 0.01$)

Appendix - 5

Analysis of variance table for velocity of flow

Source	S.S.	d.f.	M.S.	F
Total	0.0198	139	-	-
Replication	0.0001706	4	0.0000427	1.122
Treatments	0.010294	3	0.003431	90.261**
Order of irrigation	0.003079	6	0.0005133	13.5025**
Treatment x order of irrigation	0.002195	18	0.0001219	3.2071**
Error	0.004106	108	0.00003801	-

Note : ** - Significant at 1 per cent level.

Order/ Treat-ments	1	2	3	4	5	6	7	Mean
T_1	0.0272	0.053	0.041	0.047	0.0472	0.0404	0.0368	0.0418
T_2	0.0602	0.062	0.0586	0.0588	0.0642	0.065	0.0552	0.0603
T_3	0.0314	0.036	0.0422	0.0392	0.0436	0.0378	0.0368	0.0379
T_4	0.0368	0.0457	0.047	0.0526	0.061	0.0598	0.0444	0.0496
Mean	0.0389	0.0487	0047	0.049	0.054	0.0508	0.0428	-

C.D. for comparing treatments = 0.00295
-Do- order = 0.003899
-Do- Treat x order = 0.00779.

Appendix - 6

Analysis of variance table for Hydraulic resistance

Source	S.S.	df	M.S	F
Total	0.138361	139	-	-
Replications	0.0041171	4	0.0010293	1.6395
Treatments	0.020551	3	0.00685	10.9117**
Order of irrigations	0.024969	6	0.004162	6.6288**
Treat. x order	0.020923	18	0.001162	1.8515
Error	0.067802	108	0.000628	-

Note: ** - Significant at 1 per cent level

Order/ Treat- ments	1.	2	3	4	5	6	7	Mean
T_1	0.0253	0.0505	0.0628	0.0674	0.0576	0.0505	0.0915	0.0579
T_2	0.0199	0.0483	0.0375	0.0439	0.0445	0.0667	0.0690	0.0471
T_3	0.0675	0.0829	0.0274	0.0559	0.0653	0.1045	0.0999	0.0719
T_4	0.0323	0.0246	0.0384	0.0327	0.0541	0.0406	0.0552	0.0397
Mean	0.0363	0.0516	0.0415	0.0499	0.0554	0.0656	0.0789	-

C.D. for comparing the treatments = 0.01198
-Do- order of irrigation = 0.01585
Interaction of order x treat… = 0.03169

HYDRAULICS OF BORDER STRIP IRRIGATION ON LEVEL OR NEARLY LEVEL RICE FIELDS

By

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ABSTRACT OF THESIS

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ABSTRACT

In Kerala, more than seventy per cent of the double cropped rice fields lie fallow during summer months. Rice cannot be grown during this season because of the limited availability of water and the very low water use efficiency that can be attained during this season. The development of a technology for efficient use of limited water available during summer is necessary to make use of these rice fallows for cultivating crops other than rice. As most of the area is under paddy during first and second crop seasons, the level of the land cannot be disturbed. But now, there is no any satisfactory method of irrigation suitable for irrigating nearly level rice fallows. The objective of this project was to study the hydraulics of border strip irrigation in nearly level lands and to recommend suitable specifications.

The experiment was done at the Agronomic Research Station, Chalakudy during 1981-82. It consisted of five replications of four treatments. The treatments were two widths of 4m and 6m combined with two discharge rates of 2 l/sec/m and 4 l/sec/m, the length of strip in all cases being 45m. The surface gradient was 0.03815 per cent in the direction of natural slope,

Altogether seven irrigations were given at an interval of seven days. Blackgram seeds were dibbled in the field after the first irrigation and cultural practices as recommended in the Package of Practices were followed.

The time of advance of waterfront, the depth of flow and the time of recession of tail water were observed at every 5m length for each strip. The cutoff length was chosen as 77 per cent from the upstream end. The hydraulic gradient, hydraulic resistance and velocity of flow for each irrigation were determined. The advance and recession curves were drawn.

The results of the experiment revealed that a discharge rate of 2 l/sec/m is the best for irrigating nearly level borders of 4m and 6m widths. The depth of irrigation could be limited to 5 cm even in soils having high rate of infiltration. The lower discharge rate of 2 l/sec/m reduced the time of ponding at the downstream end and this minimised the wastage due to deep percolation at the downstream end. Soil erosion in the strip was minimum at this rate of discharge, and long strips upto 45m length in loamy sand could be irrigated with high degree of efficiency. As only a low rate of discharge is required to practise this method, even in areas having limited availability of water, an additional crop can be profitably raised.

It is estimated that the water needed to raise one hectare of rice in summer months can be more profitably used to raise about 4 ha. of any other crop. Hence, growing rice during summer season should be discouraged and the land should be utilised to raise other remunerative crops like pulses, oilseeds and vegetables. Now the Government has decided to provide water not only for rice but also for other seasonal crops during the summer months. But now, there is no any satisfactory method of irrigation for nearly level fields. Border strip method of irrigation is hardly practised anywhere in Kerala, even though this is a very popular method in the other parts of India for raising cereals, pulses and oilseeds. However, this method is practised there on sloping lands.

Since the present study revealed that this method can be practised efficiently on level or nearly level fields, this is best suited for the rice fallows during the dry season. Most of the paddy fields have a mild natural slope in one of the directions. This slope can be used to advantage by laying the strips in the direction of natural slope. This method can be recommended to the farmers for raising a crop in the rice fallows.

The specifications of border strips for nearly level lands are as follows:

Length of border	- Upto 45m
Width of border	- 4 - 6m
Rate of flow	- 2 l/sec/m
Slope	- should be laid in the direction of natural slope
Height of bunds separating the strips	- 20 cm
Base width of bunds	- 30 cm