

EVAPOTRANSPIRATION AND YIELD ANALYSIS ON POTATO UNDER FURROW AND DRIP IRRIGATION METHODS

A Thesis
Submitted to the
Bidhan Chandra Krishi Viswavidyalaya
for the award of the Degree of Doctor of Philosophy
in
AGRICULTURE
(SOIL AND WATER CONSERVATION)

By
Sarat Chandra Behera

DEPARTMENT OF AGRICULTURAL ENGINEERING
FACULTY OF AGRICULTURE
BIDHAN CHANDRA KRISHI VISWAVIDYALAYA
APRIL 1983



Bidhan Chandra Krishi Viswa Vidyalaya

Faculty of Agriculture

Department of Agricultural Engineering

Prof. S.P.Maity, Ph.D.,

KALYANI-741235, NADIA
WEST BENGAL, INDIA
Phone Kln 407

Ref. No.

Dated

197

C E R T I F I C A T E

This is to certify that the work recorded in the thesis entitled "EVAPOTRANSPIRATION AND YIELD ANALYSIS OF POTATO UNDER FURROW AND DRIP IRRIGATION METHODS" submitted by Shri Sarat Chandra Behera for the award of the Degree of Doctor of Philosophy in Soil and Water Conservation of the Bidhan Chandra Krishi Viswavidyalaya, is the faithful presentation of the bonafide research work carried out under my personal supervision and guidance. The results of the investigation reported in the thesis have not so far been submitted for any other Degree or Diploma. The assistance and help received during the course of investigation have been duly acknowledged.

S. Maity 27.4.83

Signature of the Guide.

A C K N O W L E D G E M E N T

With immense pleasure I offer my sincere regards and deepest sense of gratitude and indebtedness to my teacher Dr. S.P.Maity, Professor of Agricultural Engineering, Faculty of Agriculture, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal, for initiating the problem and for planning the work. I also offer my sincere regards for his continuous guidance, keen interest, constant encouragement and valuable advice and help throughout the period of this research work and preparation of the manuscript.

I also express my sincere gratitude to Dr.D.C.Chakraborty, Lecturer and Head, Department of Agricultural Engineering and Shri D. K. Datta, Reader and formerly Head of the Department for providing necessary facilities.

I am indebted to this Viswavidyalaya for providing research scholarship throughout the period of this work.

I am indebted to Dr. T. K. Gupta, Reader, Department of Agricultural Statistics of this Viswavidyalaya and Dr. K.C.Bhuyan, Associate Professor, Department of Statistics, Jahangir Nagar University, Bangla Desh for their valuable suggestions and help.

I take this opportunity to extend my grateful appreciations to all the teachers, staff members of the Department of Agricultural Engineering for their assistance and co-operation.

I deeply appreciate the help received from my dearest friends Dr. K. Sarkar, Dr. S. Samanta, Dr. P. Bhattacharyya, Dr. F. Saha Sikdar, Shri M. Saha, Shri S. Majhi, Shri S. Kisku, Sri S. Karmakar, Shri U. Hati, Shri S. Chakraborty, Shri S. R. Misra, Shri M. Islam and Shri B. Sadhu.

I convey my deepest sense of respect to my parents for their constant inspiration and blessings.

Finally, I am grateful to Dr. N. R. Panigrahi, Director of Agriculture and Food Production, Government of Orissa for his inspiration and for providing me leave to carry out this research work.

Sarat Chandra Behera
27483
(Sarat Chandra Behera)

TABLE OF CONTENTS

Chapter		Page
I	INTRODUCTION ...	1
1.1	Influencing Factors ...	2
1.2	Problem ...	2
1.3	Objectives ...	5
II	REVIEW OF LITERATURE ...	6
2.1	Introductory Remarks ...	6
2.2	Evapotranspiration ...	6
2.2.1	Factors Influencing Evapotranspiration ...	7
2.2.1.1	Climate ...	7
2.2.1.1.1	Temperature ...	8
2.2.1.1.2	Vapour pressure deficit..	8
2.2.1.1.3	Wind velocity ...	9
2.2.1.1.4	Sunshine hours ...	10
2.2.1.1.5	Radiation ...	10
2.2.1.2	Soil moisture tension ...	12
2.2.1.3	Nitrogen ...	13
2.2.1.4	Stages of growth ...	14
2.2.1.5	Irrigation methods ...	15

Chapter		Page
2.3	Evapotranspiration Formulae ...	17
2.3.1	Radiation Method ...	17
2.3.1.1	Penman formula ...	17
2.3.2	Methods Based on Temperature ...	19
2.3.2.1	Blaney-Criddle formula ...	20
2.3.3	Humidity Method ...	21
2.4	Yield ...	21
2.4.1	Factors Influencing Yield ...	21
2.4.1.1	Irrigation in relation to stages at growth ...	21
2.4.1.2	Frequency of irrigation ...	22
2.4.1.3	Soil moisture tension ...	23
2.4.1.4	Nitrogen ...	25
2.4.1.5	Irrigation methods ...	26
2.5	Evapotranspiration of Potato ...	23
2.6	Concluding Remarks ...	28
III	MATERIALS AND METHODS ...	30
3.1	Location and Season ...	30
3.1.1	Location ...	30
3.1.2	Climate ...	30
3.2	Design of Experiment ...	32
3.2.1	Layout ...	32
3.2.2	Soil ...	34
3.2.3	Previous History of the Field ...	35
3.2.4	Treatments ...	35
3.2.4.1	Irrigation methods ...	35

Chapter		Page
	3.2.4.2 Soil moisture tension ...	35
	3.2.4.3 Nitrogen level ...	35
	3.3 Agronomic Practices ...	36
	3.3.1 Manuring ...	36
	3.3.2 Planting ...	36
	3.3.3 Crop Management ...	36
	3.3.4 Harvesting ...	36
	3.4 Techniques of Measurement ...	37
	3.4.1 Soil Moisture Tension ...	37
	3.4.2 Irrigation ...	39
	3.4.2.1 Drip irrigation ...	41
	3.4.3 Evapotranspiration Measurement...	43
	3.4.4 Evapotranspiration Estimates ...	44
	3.4.4.1 Penman formula ...	44
	3.4.4.2 Blaney-Criddle formula ...	46
	3.5 Statistical Analysis ...	47
IV	RESULTS AND DISCUSSION ...	49
	4.1 Evapotranspiration ...	49
	4.1.1 Factors Influencing Evapo- transpiration ...	49
	4.1.1.1 Climate ...	49
	4.1.1.1.1 Temperature ...	49
	4.1.1.1.2 Vapour pressure deficit ...	56
	4.1.1.1.3 Wind velocity ...	62
	4.1.1.1.4 Sunshine hour ...	67

Chapter		Page
4.1.1.2	Soil moisture tension ...	73
4.1.1.3	Nitrogen ...	83
4.1.1.4	Stages of growth ...	91
4.1.1.5	Irrigation methods ...	93
4.1.2	Pan Evaporation and Measured Evapotranspiration ...	98
4.1.3	Comparison of Measured and Estimated Evapotranspiration' ...	100
4.1.3.1	Penman formula ...	100
4.1.3.2	Blaney-Criddle formula ...	103
4.1.4	Development of Equation ...	107
4.2	Yield ...	111
4.2.1	Soil Moisture Tension ...	111
4.2.1.1	Size distribution ...	112
4.2.1.2	Total yield ...	116
4.2.2	Nitrogen ...	119
4.2.2.1	Size distribution ...	119
4.2.2.2	Total yield ...	124
4.2.3	Methods of Irrigation ...	127
4.2.3.1	Size distribution ...	127
4.2.3.2	Total yield ...	129
4.2.4	Interaction ...	132
4.2.4.1	Size distribution ...	132
4.2.4.2	Total yield ...	135
4.3	Evapotranspiration and Yield ...	137
4.4	Water-use Efficiency ...	139

Chapter		Page
4.5	Concluding Remarks	141
V.	SUMMARY AND CONCLUSIONS	144
5.1	Summary	144
5.1.1	Evapotranspiration	145
5.1.2	Yield	149
5.2	Conclusions	151
VI	FUTURE SCOPE OF RESEARCH	154
VII	BIBLIOGRAPHY	(i)

LIST OF FIGURES

3.1	Distribution of climatic variables during three seasons	...	31
3.2	Layout of the field	...	33
3.3	Soil moisture tension and moisture content curve	...	38
3.4	Soil moistures resistance and moisture content curve	...	40
3.5	Layout for drip irrigation (Part field)	...	42
4.1	Relationship between mean air temperature and evapotranspiration	...	50
4.2	Relationship between mean air temperature and evapotranspiration	...	51
4.3	Relationship between mean air temperature and evapotranspiration	...	52
4.4	Relationship between mean air temperature and evapotranspiration during three seasons	...	54
4.5	Relationship between vapour pressure deficit and evapotranspiration	...	57
4.6	Relationship between vapour pressure deficit and evapotranspiration	...	58

4.7	Relationship between vapour pressure deficit and evapotranspiration	...	59
4.8	Relationship between vapour pressure deficit and evapotranspiration during three seasons	...	61
4.9	Relationship between wind velocity and evapotranspiration	...	63
4.10	Relationship between wind velocity and evapotranspiration	...	64
4.11	Relationship between wind velocity and evapotranspiration	...	65
4.12	Relationship between wind velocity and evapotranspiration during three seasons	...	66
4.13	Relationship between sunshine hours and evapotranspiration	...	68
4.14	Relationship between sunshine hours and evapotranspiration	...	69
4.15	Relationship between sunshine hours and evapotranspiration	...	70
4.16	Relationship between sunshine hours and evapotranspiration during three seasons	...	72
4.17	Mean evapotranspiration rate as a function of weeks of growth under soil moisture tensions	...	74
4.18	Mean evapotranspiration rate as a function of weeks of growth under soil moisture tension	...	75
4.19	Mean evapotranspiration rate as a function of weeks of growth under soil moisture tensions	...	76

4.20	Mean evapotranspiration rate as a function of weeks of growth under soil moisture tensions	...	78
4.21	Relationship between total evapotranspiration and soil moisture tension	...	79
4.22	Relationship between total evapotranspiration and soil moisture tension	...	81
4.23	Mean evapotranspiration rate as a function of weeks of growth under four levels of nitrogen	...	84
4.24	Mean evapotranspiration rate as a function of weeks of growth under four levels of nitrogen	...	85
4.25	Mean evapotranspiration rate as a function of weeks of growth under four levels of nitrogen	...	86
4.26	Mean evapotranspiration rate as a function of weeks of growth under four levels of nitrogen during three seasons	...	87
4.27	Relationship between total evapotranspiration and levels of nitrogen	...	89
4.28	Mean evapotranspiration rate as a function of weeks of growth under two methods of irrigation	...	94
4.29	Mean evapotranspiration rate as a function of weeks of growth under two methods of irrigation	...	96
4.30	Relation of pan evaporation rate to measured evapotranspiration rates	...	99
4.31	Relation of daily evapotranspiration rates estimated by the Penman formula to daily measured rates	...	101

4.32	Relation of monthly evapotranspiration rates estimated by the Blaney-Criddle formula to measured rates	...	104
4.33	Relationship between evapotranspiration measured and estimated	...	110
4.34	Relationship between yield of tuber and soil moisture tension	...	117
4.35	Relationship between yield of tuber and levels of nitrogen	...	125
4.36	Relationship between yield of tuber and total evapotranspiration	...	138

LIST OF TABLES

3.1	Distribution of rainfall during three potato seasons	...	32
3.2	Mechanical composition of soil	...	34
3.3	Physical properties of soil	...	34
3.4	Chemical properties of soil	...	34
3.5	Dates of planting, first earthing up and harvesting of potato tuber	...	37
4.1	Variation in total evapotranspiration (cm) with soil moisture tension and irrigation methods	...	80
4.2	Variation in total evapotranspiration (cm) with nitrogen and irrigation methods	...	90
4.3	Variation in evapotranspiration rate (mm/day) with soil moisture tension during different stages of growth	...	92
4.4	Total evapotranspiration (cm) under furrow and drip irrigation	...	95
4.5	Variation in crop-coefficient (k) with soil moisture tension	...	105
4.6	Ratio of measured E_T under three soil moisture tensions to estimated u by the Blaney-Criddle formula	...	106

4.7	Analysis of variance for furrow irrigation	...	109
4.8	Analysis of variance for drip irrigation	...	109
4.9	Variation in size distribution of tuber with soil moisture tension	...	113
4.10	Variation in size distribution of tuber with soil moisture tension and irrigation methods	...	114
4.10a	Variation in size distribution of tuber with soil moisture tension and irrigation methods	...	115
4.11	Variation in total yield (q/ha) with soil moisture tension and irrigation methods	...	116
4.12	Variation in size distribution of tuber with nitrogen	...	120
4.13	Variation in size distribution of tuber with nitrogen and irrigation methods	...	122
4.13a	Variation in size distribution of tuber with nitrogen and irrigation methods	...	123
4.14	Variation in total yield (q/ha) with nitrogen and irrigation methods	...	124
4.15	Variation in size distribution of tuber with irrigation methods	...	128
4.16	Variation in total yield (q/ha) under two methods of irrigation	...	130
4.17	Variation in size distribution of tuber with soil moisture tension and nitrogen	...	133
4.17a	Variation in size distribution of tuber with soil moisture tension and nitrogen	...	134

4.18	Variation in total yield (q/ha) with nitrogen and soil moisture tension	...	136
4.19	Variation in water-use efficiency, (kg/ha)/mm, with soil moisture tension and irrigation methods	...	140
4.20	Variation in water-use efficiency, (kg/ha)/mm with levels of nitrogen and irrigation methods	...	141

LIST OF ABBREVIATION

Abst.	Abstract
Agric.	Agricultural
Agron.	Agronomy
Amer.	American
Ann.	Annual
ASAE	American Society of Agricultural Engineers
ASCE	American Society of Civil Engineers
Aust.	Australian
°C	Degrees centigrade
Can.	Canadian
C.D.	Critical difference
°F	Degrees Farenheit
Fig.	Figure
Hg	Mercury
Hort.	Horticulture
Ind.	Indian
Inst.	Institute
J.	Journal
Kg	Kilogram
Km	Kilometer

LAI	Leaf area index
Meteorol.	Meteorological
Neth.	Netherlands
Physio.	Physiology
Proc.	Proceedings
Res.	Research
Rev.	Review
Sci.	Science
SCS	Soil Conservation Service
S.Em	Standard error of means
Soc.	Society
Sth.	Station
Trans.	Transaction
USWB	United States Weather Bureau
atm.	Atmosphere
Cm	Centimeters
ha	Hectare
hr	Hour
mm	Milimeter
q	Quintal

LIST OF SYMBOLS

B_d	Bulk density, gm/cm ³
E_0	Evaporation rate from free water surface, mm/day
E_T	Measured evapotranspiration rate, mm/day
E_T'	Total measured evapotranspiration, cm/month
$E_T(c)$	Estimated evapotranspiration rate, mm/day
$E_T(s)$	Total evapotranspiration measured, cm/season
E_t	Estimated evapotranspiration by the Penman formula, mm/day
E_{T1}	Evapotranspiration rate at 0.4 atmosphere, mm/day
E_{T2}	Evapotranspiration rate at 0.8 atmosphere, mm/day
E_{T3}	Evapotranspiration rate at 1.2 atmosphere, mm/day
$E_T(N_0)$	Evapotranspiration rate at 0 kg nitrogen, mm/day
$E_T(N_1)$	Evapotranspiration rate at 100 kg nitrogen, mm/day
$E_T(N_2)$	Evapotranspiration rate at 200 kg nitrogen, mm/day
$E_T(N_3)$	Evapotranspiration rate at 300 kg nitrogen, mm/day
F	Sum of monthly consumptive factors
H'	Daily heat budget at the surface in mm of water per day
I_r	Irrigation, mm/day
K	Seasonal empirical crop consumptive-use coefficient
L	Loss of water beyond root zone, mm/day
N	Dose of nitrogen, kg/ha

N_0	0 kg nitrogen/ha
N_1	100 kg nitrogen/ha
N_2	200 kg nitrogen/ha
N_3	300 kg nitrogen/ha
P_w	Moisture content, per cent by weight
R	Extraterrestrial radiation expressed as equivalent depth of evaporation of water, cm/month
R_A	Mean monthly extra-terrestrial radiation, mm of water/day
R_a	Rainfall, mm/day
S	Actual duration of bright sunshine hours
S'	Maximum possible duration of bright sunshine hours
Sr	Runoff, mm/day
T	Soil moisture tension, atmosphere
T_1	Soil moisture tension, 0.1 to 0.4 atmosphere
T_2	Soil moisture tension, 0.1 to 0.8 atmosphere
T_3	Soil moisture tension, 0.1 to 1.2 atmosphere
U	Seasonal consumptive use, cm
U_1	Measured wind speed at height h in feet, miles/day
U_2	Mean wind speed at 2 metres above the ground, miles/day
W	Mean wind speed, km/hour
W_{eff}	Water-use efficiency, (kg/ha)/mm
Y	Yield of tuber, g/ha
b_0	Constant
b_1	Regression coefficient
b_2	Regression coefficient
b_3	Regression coefficient
b_4	Regression coefficient

b_5	Regression coefficient
b_6	Regression coefficient
d	Soil moisture deficit, cm
d_i	Depth of soil of i th layer, cm
e_a	Saturation vapour pressure at mean dew point (i.e. actual vapour pressure in the air), mm Hg
e_s	Saturation vapour pressure at mean air temperature, mm Hg
$(e_s - e_a)$	Vapour pressure deficit, mm Hg
f	Monthly consumptive use factor
k	Monthly empirical crop consumptive-use coefficient
n	Number of soil layer in the root zone
p	Monthly per cent of day time hours of the year
r	Reflection coefficient of surface
t	Daily mean air temperature, $^{\circ}\text{C}$
t'	Monthly mean air temperature, $^{\circ}\text{F}$
t_a	Air temperature o k ($^{\circ}\text{C}$ absolute)
u	Total evapotranspiration estimated by Blaney-Criddle method, cm/month
Δ	Change in soil moisture storage also slope of saturated vapour pressure-temperature curve at mean air temperature
σ	The Stefan-Boltzman constant.

ABSTRACT

Evapotranspiration and yield analysis on potato, irrigated by furrow and drip, was made mainly because its production per hectare is much greater than any other food crop. The study was conducted in the field during three seasons of 1979-80, 1980-81 and 1981-82 on variety Kufri-Chandramukhi under three soil moisture tensions and four levels of nitrogen to examine (a) the inter-relationship amongst measured evapotranspiration, climatic variables, soil moisture tension, nitrogen levels, stages of growth and methods of irrigation (b) the applicability of Penman and Blaney-Criddle formulae in predicting evapotranspiration, (c) the influence of soil moisture tension, nitrogen levels and methods of irrigation on the size distribution and on the total yield of tuber and (d) to develop an equation for estimating evapotranspiration using climatic variables, soil moisture tension and nitrogen levels.

While the rate of evapotranspiration (E_T) increased linearly with the increase of mean air temperature, vapour pressure deficit, sunshine hours, wind velocity, the rate of change in E_T varied with soil moisture tension and levels of nitrogen. The relationship between total evapotranspiration, $E_{T(s)}$, and each of soil

moisture tension and levels of nitrogen was curvilinear. The $E_{T(s)}$ values were significantly higher in furrow irrigation. While E_T varied with the stages of growth, the highest E_T was during the tuber formation stage.

On account of the varying success of the Penman and the Blaney-Criddle formulae, two formulae (one for furrow and the other for drip) involving four climatic variables like mean air temperature, vapour pressure deficit, sunshine hours and wind velocity, soil moisture tension and nitrogen levels, were developed and verified. A good agreement was found to exist between the measured and estimated E_T values.

Higher per cent of large size (45-60 cm and above 60 mm) tuber was under drip irrigation at 0.4 atmosphere soil moisture tension with 100 kg nitrogen. The relationship between the total yield of tuber and each of soil moisture tension and levels of nitrogen was curvilinear. The highest total yield of tuber was at 0.4 atmosphere with 100 kg nitrogen and under drip irrigation.

Apart from saving 10.83 per cent of water, drip irrigation not only produced higher total yield but also higher per cent of large size tuber.

CHAPTER - I

INTRODUCTION

INTRODUCTION

Potato ranks high among food crops. The growing interest in the cultivation of potato is due to the fact that production per hectare is far more than that of any other food crop and that it supplies two and half times more calories per hectare than wheat or rice. Although the total area under potato, in India, is increasing, the average yield is only 85 q/ha. But yield of 250-300 q/ha can be achieved by proper irrigation and crop management. Irrigation is the most important factor influencing potato production (Derco, 1968), other factors being season, variety, nutrient level and plant population. Since the total yield is linearly related to evapotranspiration (Maity and Pandya, 1975) and the yield increases with the water consumption to the point of potential water use (Stegeman and Nelson, 1973) and since the size and quality of potato tubers depend upon maintenance of proper moisture and nutrient level (Tsvetkova, 1972) in the root zone, a scientific system of irrigation should be followed. It may be observed that about 42 per cent of water delivered to the irrigated farms is not beneficially used by the plants and much of this water is an absolute waste that can be avoided by good water management. The rational

use of irrigation, particularly during winter season when there is insufficient water to meet all demands, is essential for good management of water resources. Improvement in the management of water resources can be achieved by either improving the application and distribution efficiencies of the conventional furrow irrigation or by adopting a system of irrigation with higher irrigation efficiencies. Proper management of water implies not only an efficient system of irrigation capable of providing uniform water distribution with higher application efficiency, but also timing of irrigation so as to conform to critical stages of crop growth. Timely application of proper quantity of water, just sufficient to meet the demand of crop, not only saves the wastage, but also assures an increased yield. The frequency and quantity of irrigation water in turn depends on the daily moisture use rate i.e. evapotranspiration rate (E_T). Evapotranspiration and yield analysis on potato, irrigated by furrow and drip methods is, therefore, very important.

1.1 Influencing Factors

The rate of evapotranspiration depends on the combined influence of several factors such as temperature, wind velocity, sunshine hours, vapour pressure deficit, radiation, soil moisture tension, fertility levels of the soil, stage of development of the plant, irrigation methods, soil and crop management. The total yield of tuber, to a large extent, also depends on these factors.

1.2 Problem

The role of soil moisture tension and levels of nitrogen

in regulating evapotranspiration of crops are not entirely clear although it is expected that with the increase of soil moisture tension with time, E_T will decrease. The E_T is also influenced considerably by growth of crops which in turn depends on the fertility status of the soil. It is also expected that a well fertilised crop with its extensive root system will extract soil water from a greater depth (Brown, 1971), but different views exist as to the influence of nitrogen on E_T . It is, therefore, necessary to examine the inter-relationship amongst measured E_T , climatic variables, soil moisture tensions, nitrogen levels and methods of irrigation.

In order to determine the frequency and quantity of water for a particular crop, irrigation studies are required. In the absence of such study recommendation for scheduling of irrigation may be made from the knowledge of soil and root system together with the estimate of evapotranspiration (Erie, 1968). Attempts have been made to develop climatological approach to estimate the water needs of the crop. For estimating evapotranspiration, while Penman (1948) using energy balance and aerodynamic approach developed a formula, Blaney-Criddle (1950) in their formula included temperature and day length terms in addition to an empirical crop co-efficient. These and other formulae have been proposed for estimating E_T and most of them give reliable results when applied to climatic conditions similar to those for which they were developed. Use of formulae for estimating evapotranspiration has been widely accepted. It is, therefore, considered necessary to

examine how far these widely tried formulae can be used in estimating evapotranspiration for the potato crop grown in this locality.

Although much study has been made to determine the relative importance of various components of weather on potential evapotranspiration, the inter-relationship between observed E_T , climate, crop, soil moisture tension and levels of nitrogen does not appear to have been clearly established. Attempts have, therefore, been made to study the functional relationship between observed E_T and soil moisture tensions together with levels of nitrogen and climatic variables.

While different views exist regarding the influence of soil moisture tension and nitrogen on the total yield of tuber, their influence on size distribution is not clearly known. While the total yield of tuber decreases with the increase of soil moisture tension (Struchtemeyer, 1961), maintenance of various levels of soil moisture tension for higher yield (Maity, 1974) has been recommended. The influence of nitrogen on the yield of tuber varies with quantity (Gerasimov, 1970), time of application (Nazir and Gill, 1967) and proper maintenance of soil moisture in the root zone (Misra and Pati, 1970 and Tsvetkova, 1972).

Further, the influence of the methods of irrigation on size distribution and on the total yield is not clearly understood. Attempts have, therefore, been made to analyse the influence of soil moisture tension, nitrogen levels and methods of irrigation

on the size distribution and on the total yield of tuber.

1.3 Objectives

The present investigation was conducted with the following objectives :

- (1) to examine
 - (a) the inter-relationship amongst measured E_T , climatic variables, soil moisture tensions, nitrogen levels, stages of growth and methods of irrigation,
 - (b) the applicability of Penman and Blaney-Criddle formulae in predicting E_T ,
 - (c) the influence of soil moisture tension, nitrogen levels and methods of irrigation on the size distribution and on the total yield of tuber, and
- (2) To develop an equation for estimating evapotranspiration using meteorological variables, soil moisture tensions and nitrogen levels.

CHAPTER - II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1 Introductory Remarks

Evapotranspiration, the water loss to the atmosphere from ground and crop surfaces, has been studied widely. Various attempts have been made to measure evapotranspiration from crops and to correlate the climatic variables with free water surface evaporation and evapotranspiration. The relation between evapotranspiration and production of crop is very important from practical point of view. The variation of soil moisture tension and the application of nitrogen to potato are two important factors which influence the growth and yield of potato. The work reported include factors influencing evapotranspiration, evapotranspiration formulae, the influence of soil moisture tension, nitrogen and methods of irrigation on the total yield of tuber.

2.2 Evapotranspiration

The rate at which water is lost from the soil by evaporation and from the plant by both transpiration and evaporation is termed evapotranspiration rate (E_T). Evaporation of water is a diffusive process by which water vapour is transferred from a given wet surface to the atmosphere. Evaporation only occurs when an energy source exists and when the vapour pressure concentration of the

overlying air is less than that of the evaporating surface.

Water is lost from plant in the form of vapour, primarily through the stomatal openings by a process known as transpiration. Water moves from the soil into the plant only if the potential energy of water in the leaf is lower than that in the soil (Gardner, 1965). The transpiration rate depends on the vapour pressure gradient between the saturated cell wall and free air above the plant and is regulated by the diffusion resistance in the substomatal, stomatal and boundary layer regions of the diffusion path. The combined effects of evaporation and transpiration occurring from plant and soil is also termed as potential evapotranspiration (Thorntwaite, 1948). Penman (1956) prefers to call this as evaporation and points out that in both cases, the process involved is the same.

2.2.1 Factors Influencing Evapotranspiration

The rate of evapotranspiration (E_T) of different crops varies greatly under the same condition (Hanks et al., 1968). Even the E_T of the same crop varies according to the stage of growth and the period of the year in which it is grown. Of the various factors affecting E_T , climate, crop, soil moisture tension, fertility level and methods of irrigation are important.

2.2.1.1 Climate

The E_T depends on the evaporative power of the atmosphere as determined by temperature, vapour pressure deficit, wind

velocity, bright sunshine hours and radiation.

2.2.1.1.1 Temperature

Both evaporation (E_0) and evapotranspiration rate (E_T) increased proportionately as temperature was varied approximately from 60° to 105°F when humidity was held constant at 50 per cent (Jensen, 1967). As air temperature increases, the saturated vapour pressure increases in a non-linear manner. Thus a larger vapour pressure gradient above the crop is expected with higher air temperature, resulting in more rapid removal of water vapour (Jensen and Haise, 1963). A linear relationship between the temperature and the ratio of latent heat of evaporation to short wave radiation was reported by Jensen and Haise (1963) and Linacre (1967). While Wilcox (1963) considered temperature as the best single weather element for estimating E_T , Pruitt (1964) explained that the correlation between the air temperature and E_T was due to the direct relationship of both parameters to radiation and not to an actual direct effect of air temperature on E_T . With the increase of air temperature up to a certain limit, increased E_T was observed on potato (Maity and Pandya, 1975), on wheat (Ghosh, 1974) and on paddy (Sarkar, 1975). Temperature difference between leaf and air can be used in determining water stress for all crops that exhibit stomatal control of water loss (Elwynn Taylor, 1980).

2.2.1.1.2 Vapour pressure deficit

Evapotranspiration rate (E_T) is proportional to the vapour pressure gradient between the evaporating surface and the

surrounding air. It is the relative dryness of the air which counts for E_T , rather than the absolute dryness of the air (Slatyer and McIlroy, 1961). When the temperature was held constant at 70°F, both E_0 and E_T of red kidney beans decreased proportionately as humidity varied from 20 to 90 per cent [Woerner (quoted by Jensen, 1967)]. Pruitt (1964) concluded from a number of studies that under near constant conditions, E_0 is closely related to the difference in vapour pressure ($e_s - e_a$) between the surface and some height above. He suggested a linear relationship between these two parameters and that line should pass through the origin. Monteith (1959) observed that for E_0 to take place, there should be a vapour pressure difference between evaporating surface and air. Since the vapour pressure deficit generally reaches a peak by 14.00 hours, E_T losses are usually highest at midday decreasing rapidly with the decrease of vapour pressure deficit (Frost and Schwalen, 1960, and Maity, 1972). Considering the importance of vapour pressure deficit on E_T , this parameter was included in estimating E_T from paddy crop (Maity and Sarkar, 1982).

2.2.1.1.3 Wind velocity

According to the theory of turbulence, the upward flow of water vapour is equal to the product of vertical gradient of vapour pressure and the rate of mixing. The latter depends on the rate of change of wind speed with the height (Chang, 1968). While E_T from beans, sugarbeet and grass sward increased with the increase of wind velocity (Pruitt, 1960), E_T from sugarbeet exceeded that of a grass sward, apparently because of turbulence induced by

the greater roughness of the sugarbeet crop (Pruitt, 1960). It was observed by Frost and Schvalen (1960) that evapotranspiration losses from clover, bermuda grass and sudan grass reach a peak near midday, increasing with vapour pressure deficit and wind velocity. Higher E_T due to higher wind velocity over paddy crop was reported by Sarkar (1975).

2.2.1.1.4 Sunshine hours

The E_T is much higher during the light period than during the darkness period. Hani (1966) measured E_T of beans and E_0 from pan under different light periods, holding the other climatic components constant. While the change in diurnal light period had little influence on E_0 , it had a marked influence on daily E_T for the 6-hour and 24-hour periods (continuous light). Influence of sky condition on E_T is much greater than that of irrigation (Burman and Loudon, 1968). Burman and Loudon (1968) reported that when bright sunshine occurred, all energy balance components (including E_T) were high. The passage of clouds almost immediately reduced the magnitude of energy balance components. The source of energy for E_T may be solar energy and its interception by row crops is a function of their orientation with respect to the sun (Michael, 1978).

2.2.1.1.5 Radiation

Solar radiation is the principal source of energy for E_T . In the absence of advected energy, a close relationship between the potential evapotranspiration and net radiation usually exists

(Michael, 1978). Much of the net radiation may be converted directly to latent heat and often accounts for as much as 80 per cent of the water evaporative loss (Pelton, 1964). Mukammal and Bruce (1960) found that relative importance of radiation, humidity, and wind velocity in determining pan evaporation were in the ratio 80:6:14 respectively. Pruitt (1964) observed a quick response of evapotranspiration to radiation change while comparing potential evapotranspiration for rye grass with net incoming radiation, on a calm clear day in spring. When E_T was compared with net radiation, air temperature and saturation deficit, the air temperature and saturation deficit were more out of phase with E_T than net radiation (Pruitt, 1964). However, the fraction of the net radiation used in the E_T varied during the course of the day.

Evapotranspiration/net radiation ratios ranged from 0.4 to 0.7 until around noon, reaching a value of 1.0 between 16.00 to 17.00 hrs. Thereafter, the evapotranspiration exceeded the net radiation. Tanner and Pelton (1960) presented some hourly and daily comparisons of evapotranspiration and net radiation, showing a strikingly close relationship between the two phenomena. Daily net radiation was found (Ritchie, 1971) to be divided primarily between evaporative flux and sensible heat flux. He observed that when crop canopies covered at least 45 per cent of the ground surface and the plant evaporation is not limited by soil water, daily net radiation was approximately equal to the daily measured evaporation. Measurement of energy budget in Ontario (Grahm and King, 1961), Hawaii (Chang, 1961), and England (House et al., 1960)

indicated that in the tropics and during the warm season in the middle latitudes, 80 to 90 per cent of the net radiation was responsible for evapotranspiration.

2.2.1.2 Soil moisture tension

Evapotranspiration rate (E_T), the water loss to the atmosphere from ground and vegetative surface to the air, is governed by the concurrently meteorological condition and soil moisture tension (Maity, 1975). Since the drying rate of bare soil is proportional to the water content and is inversely proportional to the time (Wiegand, 1962), E_T has been observed to decrease with time. If plant factors are constant, this decrease must result from the increased soil moisture tension, with which water is held by the soil or from the relatively slower rate of conductivity of water through the soil and into the plant tissue as compared to the greater evaporative power of the atmosphere (Eagleman and Decker, 1965).

In annual row crops covering only a small fraction of ground surface, potential evapotranspiration rates occur only for a brief period when soil moisture tension is low after rain or irrigation. During such periods the resistance to the water loss in the plant and soil pathways is small (Ritchie, 1971). As the soil moisture tension increases, the resistance of the soil pathways increases rapidly, causing decrease in E_T (Thornton, 1961, and Hanks et al., 1968; Black et al., 1969; Ritchie, 1971 and Maity, 1975). Moreover, when the soil surface is moist, the thermal contact coefficient

of the soil is relatively large and more of the net radiation enters the soil as the reflectance of wet soil is less (Montieth, 1959). Since water is available, a large part of this heat is used in evaporation rather than heating the soil (Ekern et al., 1967). The E_T decreases rapidly with the increase of soil moisture tension in an exponential manner (Holmes and Robertson, 1963; Eagleman and Decker, 1965, and Maity, 1975).

2.2.1.3 Nitrogen

Although different views exist as to the influence of nitrogen (N) on E_T , a large number of workers are of the view that E_T increases with the addition of N fertilizer. E_T is regulated to a large degree by evaporative demand of the atmosphere when soil water is not limiting, and crop covers the land completely. Even when the water is limiting, a well fertilized crop with its extensive root system can extract soil water under higher tension and from deeper depth to contribute a significant increase in water use (Viets, 1962). On dry land grain culture, E_T was increased with the addition of N (Luebs and Laag, 1967). Luebs and Laag (1969) further observed that E_T was 14 and 40 per cent higher with 45 and 90 kg N/ha respectively for a period of 18 days before and during tillering. During a subsequent 26 days dry period, available soil water was depleted first at the highest N level. Extraction of soil water from a greater depth can be largely influenced by the increase of N fertiliser resulting in increase of total E_T (Brown, 1971). He pointed out that the winter wheat under no nitrogen treatment extracted water from upper 91 cm, while wheat from

fertilised plot extended its depth of extraction to 183 cm. Application of nitrogen helps in decreasing stomatal resistance. Withholding nitrogen from tea plants growing in sand culture increased stomatal resistance and reduced transpiration (Nagarjah, 1981). He further observed that the capacity of the stomata to open fully in the morning was not impaired and leaf water potential and probably root resistance were unaffected. The sensitivity of transpiration on stomatal resistance to soil water stress was increased by N deficiency. Increase of E_T with the addition of N was reported by Olson et al. (1964) on corn, grain sorghum; Willatt (1969) on maize; Jaeger (1966) on oat; Singh and Bains (1971) on sorghum; Bond et al. (1971) and Ghosh (1974) on winter wheat and Sarkar (1975) on paddy.

2.2.1.4 Stages of growth

The influence of degree of crop cover and stage of growth is very important factor on E_T (Gates and Hanks, 1967). Two principal factors associated with degree of cover are (i) related to reflection (ii) related to the relative ease with which water is evaporated from bare soil compared with the transpiration. While reflection from bare wet soil is usually lower than that from the dense crop, evaporation from most bare soils decreases rapidly one or two days after irrigation or a rain. Under the same conditions, transpiration continues even for 15 days. Thus, soil water content may be sufficient to maintain transpiration but not evaporation from soil and, consequently, transpiration will increase as the per cent of cover increases. Of the two

factors, second factor is most important and therefore, E_T increases with the increase of per cent of cover. Penman et al. (1967) reported that for annual crops, plant evaporation is proportional to plant leaf area before plant leaves begin to shade one another. When plants begin to intercept most of the incoming radiation, plant factors begin to have an increasing influence on the fraction of the potential evaporation as long as water is freely available to plant roots (Mamken et al., 1968, and Nagawiecka and Boron, 1974). In an adequate supply of water in the root zone, plant factors influence E_T during most of the first half of growing season until a threshold canopy leaf area index (LAI) was obtained (Ritchie and Burnett, 1971). When the percentage of cover was > 50 , E_T from mowed orchard grass planted in rows of varying widths, was either equal to or slightly greater than E_T at full cover (Marlatt, 1961). Similar results in respect of irrigated snap beans and potatoes were made by Tanner (1963). Varying E_T , 1.6 to 2.7 mm/day during sowing to jointing and 2.7 to 3.5 mm/day during earing phase of wheat was reported by Rathore and Singh (1976).

2.2.1.5 Irrigation Methods

The evapotranspiration rate is influenced by the amount of water applied and extent of surface wetness by any method of irrigation.

Though in principle, amount of water to be applied by any method of irrigation is equal to the amount depleted by the crops,

in practice, usually a higher quantity of water is applied depending on the application efficiency. Drip irrigation can easily achieve 90 per cent or more application efficiency which can hardly be achieved by surface irrigation (Wu and Gitlin, 1975). It was reported that water consumption in furrow irrigation was 15.6 m^3 higher over sprinkler irrigation for production of 100 kg seed cotton (Shuravilin, 1977).

Experiments to compare the drip irrigation with conventional surface irrigation showed that the former can save 80 per cent of water (Sivanappan, 1977-78). Since in drip irrigation, the gross amount of water applied to the sugarcane was found to be less than the furrow irrigation or sprinkler, Hawaii is rapidly converting the sugarcane land to drip irrigation (Gibson, 1976). Even eucalyptus plants under drip irrigation used only one quarter of the amount of the water used by basin irrigation during the period January to June 1972 (Ram and Singh, 1976). Whether the tubes were placed underground or to a depth of 5 to 10 cm or on the surface, in general, drip irrigation saved 50 to 75 per cent water (Joyce, 1976 and Sourell et al., 1981) and in particular, 49.5 per cent water on tomato (Channappa, 1979).

Apart from saving of water, trickle irrigation was effective in controlling the volume of return flow (Wierenga, 1977) and the wetting pattern under each emitter of a drip irrigation system was a narrow cone (Goode et al., 1978 and Koren and Shlevin, 1977).

2.3 Evapotranspiration Formulae

Several empirical and semiempirical formulae have been proposed to estimate evapotranspiration of crops and to develop water balance method. Each of these usually applies to a given locality, vegetation, stage of growth of crop and season, and in many cases these are not widely adaptable. Tanner (1967) grouped the empirical methods into following classes :

- (i) those depending primarily on the relation of E_T to radiation,
- (ii) methods based on temperature, and
- (iii) humidity methods.

2.3.1 Radiation Method

Formulae based on radiation method include those of Penman (1948), Oliver (1961) and Christiansen (1968). These formulae, in principle, are not empirical and became so only when one or more of the terms are estimated from empirical formulae (Tanner, 1967). Only Penman (1948) formula is reviewed here.

2.3.1.1 Penman formula

The equation consists of two terms, the energy term and the aerodynamic term. Although the Penman's equation is based on sound physical principle and hence is universally applicable (Milthrope, 1960), various criticisms have been raised against this equation. One of these is its dependance on radiation values which are estimated (Tanner and Pelton, 1960). Penman used the Brunt formula,

a crude method to estimate net radiation from sunshine duration, humidity and temperature. Where net radiation is measured or a relationship between incoming and net radiation is determined, such data should be used. Penman assumed the constant reflectivity values, whereas the reflectivity of water varies with the sun angle (Linacre, 1963). The effect of wind speed on evaporation can be assessed accurately only by determining gradient using measurements at least at two heights (Halstead and Covey, 1957). In the Penman's formula, the available energy is assumed to be apportioned between heat transfer to the surrounding air and evaporation in the same ratio as that of temperature gradient. This assumes equality of heat and water vapour which is realised only under neutral conditions. The ratio of this coefficient may be as great as two with moderate instability and increases with strong insolation, high winds and height above the surface (Swinbank, 1958). Penman used the mean values instead of instantaneous values (Halstead and Covey, 1957). The Penman equation does not give accurate daily estimates and is usually accurate only for a period of five days and longer (Gilbert and van Bavel, 1954). The ratio between the potential evapotranspiration and Penman's estimate of open water evaporation varies with the height of vegetation and the climate, particularly the advected energy of the area. Penman (1952) argued, from a theoretical ground, that it is possible for tall vegetation to have higher evapotranspiration rate. In areas of strong advection, the Penman equation may greatly underestimate the potential maximum evapotranspiration.

Chang (1961) reported that potential maximum evapotranspiration of a tall sugarcane crop exceeded the Penman estimate by some ten per cent. Penman formula over estimated the measured E_T from onion crop during the colder period and hotter season (Warang and Dastane, 1971).

However, Pruitt in California (1960) and Washington (1960), Stanhill in Israel (1961), Chang in Hawaii (1961) indicated that the Penman equation is more accurate than the Thornthwaite formula.

2.3.2 Methods Based on Temperature

Tanner (1967) listed the following points from what has been discussed by vanWijk and deVries (1954) and Pelton et al. (1960), regarding the basis of temperature methods and their limitations.

(i) These methods rely on mutual correlation of evapotranspiration and air temperature with radiation.

(ii) Temperature methods are best suited to monthly estimates and are not reliable for short period estimates.

(iii) In the region with large annual temperature range, the air temperature lags behind radiation much more than evapotranspiration, causing the methods to underestimate during warming months and overestimate during cooling months.

(iv) These methods require calibration for a given region and adjustment.

In spite of the limitations, temperature methods are widely used mainly because these methods are simple and temperature records are readily available.

Since the Blaney-Criddle (1950) formula has been used widely and with varying success, this method will be reviewed.

2.3.2.1 Blaney-Criddle formula

Blaney-Criddle (1950) developed a simplified formula using temperature and day time hours for the arid western portion of the United States. This formula has been used extensively by the Soil Conservation Service of the United States Department of Agriculture. Outside the semi-arid climate of the Western United States, the performance of the Blaney-Criddle method is usually poor (Jackson, 1960 and Stanhill, 1961). One disadvantage is that the coefficient K must be determined empirically for each different crop in the area in which it is desired to use the formula. Though the Blaney-Criddle formula suffers from drawbacks, yet one unique feature of this method is the inclusion of a crop coefficient. They recognised that in arid climate, the consumptive use of crop may vary greatly with the condition of its physical stand. Pruitt (1960) observed considerable deviation of Blaney-Criddle estimates from measured consumptive use with K factors. He suggested that the estimates of consumptive use be made with variable K factor. In general, the value of K increases with the height of vegetation and completeness of ground cover. This agrees well with the theoretical consideration

of surface roughness (Chang, 1968).

2.3.3 Humidity Methods

Most of the humidity methods are the modification of the Dalton's equation. Because of the difficulty of measuring the value of vapour pressure at the plant surface, this formula has not been used for estimating evapotranspiration. Relative humidity at the surface of freely transpiring leaves commonly assumed to be 100 per cent may indeed be much lower (Inoue, 1963). Wind speed at one height can not give an adequate measurement of turbulence as the wind gradient varies with roughness of the surface.

2.4 Yield

2.4.1 Factors Influencing Yield

The effect of varying levels of nitrogen and soil moisture tension on the growth and yield of potato have been studied and it has been reported that high yield and good quality of potato could be obtained by maintaining proper quantity of fertilizer and water in the root zone, particularly during certain periods of its life cycle.

2.4.1.1 Irrigation in relation to stages of growth

The potato has the following three phases of development (Steineck, 1959). The first phase of stolon formation begins about 3 weeks after emergence. The second phase of tuber setting (4-5 weeks after emergence) needs presence of adequate moisture in the soil to set tuber. The third phase of tuber growth is

much longer and is a decisive period for single tuber weight. Irrigation during this stage increases the weight of individual tuber, while irrigation before flowering increases the number of tubers per plant (Supersperg, 1967). Since yield is linearly related to E_T (Maity and Pandya, 1975) and yield increases with water consumption to the point of potential water use (Stegman and Nelson, 1973) a regular supply of moisture from the beginning of stolon formation to maturity should, therefore, be maintained for higher yield (Hansen, 1963 and Delis et al., 1964). However, irrigation at tuber formation gave higher yield than irrigation at stolon formation or during early bulking period (Llewelyn, 1963). While Bradley and Pratt (1955) and Dashevskii (1971) realised the importance of maintaining high moisture level during early growth and development of potato, Hansen (1963) recommended the maintenance of adequate moisture during the entire growth period. Decrease in soil moisture during the mature phase reduces potato yield (Kuzniar, 1968). Even a reduction of yield by 20 per cent was observed by Stockton (1962) when last irrigation was given 21 days before harvest. Loon (1981) opined that the tuber yields were greater with draught at the tuber bulking stage than at any other growth stage.

2.4.1.2 Frequency of irrigation

High yield of potato was obtained with the increased frequency (Perez et al., 1961 and Hukkeri and Moolani, 1965) and quantity of water (Haddock, 1961, and Chandani et al., 1962). While one inch of water every 7 days on light soils and 1.5 inch

every 10 days on heavier soils was an effective plan (Fulton, 1958), irrigating once in 10 to 15 days was sufficient to produce good crop in Arizona (Oebker, 1962). However, 25 to 37.5 mm of water per irrigation at 3 day interval on sandy loam soil was recommended by Misra and Pati, 1970. While no significant improvement in yield was observed by giving 10 to 14 applications of water (Nazir and Gill, 1967). Greasley and Lather (1971) observed that the total amount of water applied was more important than the frequency in determining the tuber yield. However, experiments conducted at Patna (Bihar) in which irrigation intervals of 6, 12, 18 and 24 days were tried during tuber formation showed that the yield increased with the increase in frequency of irrigation. In similar experiments at Jullundar (Punjab) and Babugarh (Uttar Pradesh) conducted over wide agro-ecological conditions, irrigation frequencies of 10-14 days respectively were found to be optimum (Singh, 1969). In West Bengal, application of 2 inches of water per irrigation applied frequently to prevent excessive drying, was adequate (Choudhuri and Ray, 1964). Yield of potato can be increased by most frequent irrigations (Till, 1963; Wellings, 1969 and Maity, 1974).

2.4.1.3 Soil moisture tension

High yield and good quality of potato could be obtained by maintaining available soil moisture at the root zone between 75 to 50 per cent (Bradley and Pratt, 1955; Haddock, 1961; Struchtemeyer, 1961; Dunton, 1968; Renea and Berindei, 1969 and Drewitt, 1970). Maintenance of soil moisture either at 75 per

cent (Tsvetkova, 1972) or at 80 per cent (Giovanardi, 1980) is the best for higher production. Irrigating at (a) 75 per cent, (b) 50 per cent, (c) 25 per cent and (d) 0 per cent available soil moisture showed that yield from (a) was 17 per cent higher than (b) and (c) and 72 per cent higher than (d) (Bravo et al., 1968).

The range of available soil moisture has also been expressed in terms of energy concept of soil moisture tension. While the yield of tuber decreases with the increase of soil moisture tension (Struchtemeyer, 1961), maintenance of soil moisture tension between 0.1 to 0.3 atmosphere for higher yield is recommended (Myhre, 1958; Jones and Johnson, 1958 and Maity, 1974). On the other hand, higher yields and better quality of tubers were produced by irrigation at 0.5 atmosphere soil moisture tension (Flocker and Timm, 1966) which provides the most efficient use of water and fertilizer. Irrigations at tensions above (Grewal and Singh, 1978) or below the range of 40-60 centibars may be harmful to yield and quality (Stockton, 1962), although the optimum moisture level may vary from year to year (Jacob et al., 1952).

Irrigation at lower soil moisture tension (0.20 atm) maintains an optimum hydrothermal regime for better growth and yield of potato by lowering the maximum soil temperature and raising minimum soil temperature (Grewal and Singh, 1978).

Yield of potato is also influenced by the leaf water potential, tuber water potential and water saturation deficit. Although tuber yield was affected with the lower availability of water, it

did not decrease for values of leaf water potential lower than 9.8 bars (Sanchez et al., 1974). However, tuber expansion ceases at tuber water potential of about -4 to -5 bars (Gandar, 1975). Transpiration started to decline at 79-80 per cent relative water content of leaf samples (Stegman and Nelson, 1973). Water stress decrease potato yields by reducing leaf area and/or photosynthesis/unit leaf area (Loon, 1981). Increase in draught periods from 2 to 4 to 6 weeks decreased the yield of potato by 19, 25 and 69 per cent respectively (Jones and Johnson, 1958).

2.4.1.4 Nitrogen

The influence of nitrogen on yield of potato has been recognised (Hukkeri and Moolani; 1965 ; Nazir and Gill, 1967; Munster, 1969 and Misra and Pati, 1970). The influence of N on yield of potato varies with quantity (Choudhury and Ray, 1964 and Gerasimov, 1970) time of application (Nazir and Gill, 1967) and proper maintenance of soil moisture in the root zone (Misra and Pati, 1970 and Tsvetkova, 1972). While application of irrigation at 3-day intervals to depths of 25-37.5 mm with 135 kg N + 180 kg P_2O_5 + 180 kg K_2O per hectare (other doses are 90 + 90 + 90 and 180 + 270 + 270) gave the highest yield of tuber (Misra and Pati, 1970), considerable increase in total and ware yields of tubers were obtained by applying 36 kg P_2O_5 and 18 kg K_2O in addition to 54 kg N per acre at frequent irrigation to keep the soil moisture tension at about 0.3 atmosphere (Hukkeri and Moolani, 1965). While irrigation helps in increasing the yield over rainfed condition, application of 60 kg

N + 60 kg P_2O_5 /ha gave average yields of 16.13 and 18.57 t/ha respectively under (a) rainfed and (b) irrigated condition (Gerasimov, 1970). At soil moisture content of 80 per cent field capacity, application of 60 kg N + 60 kg P_2O_5 + 90 kg K_2O /ha not only increased the yield by 30 per cent, the proportion of marketable tubers increased to 96.1 per cent and tuber weight increased to 84.4 gm (Tsvetkova, 1972). Twelve irrigation (each 2 inches) with 120 lbs N/acre helped to produce the highest yield (Chandani et al., 1962).

2.4.1.5 Irrigation methods

Potato is irrigated mostly by furrow irrigation and irrigation by sprinkler (Supersperg, 1967 and Tsvetkova, 1972), spray and trickle methods are increasing (Wilson, 1953). Because of improved crop yields, quality, savings in water and operational cost, area under drip irrigation has expanded remarkably in Great Britain (Wolf, 1976).

In drip irrigation, small and precise quantity of water is delivered to individual plants and the system is considered to reduce water stress (Shoji, 1977). Accumulation of drops of water in drip irrigation should last at least 50 to 200 times longer than the time taken for their discharge for better maintenance of water (Nosenko and Koryagin, 1975).

Peach trees fertilized through drip irrigation at 1/2 surface application rate responded equally as well as those

fertilized at full rate (Chesness and Couvillon, 1976). The yield and quality of different crops increased by drip irrigation. The yields of tomato, melon and cucumber were increased by 5 to 16 kg/m³ of irrigation water (Grainer et al., 1976). In trials with the melon cv. Valenciano Amarelo, standard furrow irrigation applied at 2 soil water level (0.4 to 0.7 atm) was compared with drip irrigation using 1, 2 or 4 emitters/planting hole (2 plants) applied at similar soil water levels. The highest average yield (13817 kg/ha) was obtained from drip irrigation with 2 emitters/planting hole applied at 0.7 atm (Abreu et al., 1978). Yield of tomato (Goldberg et al., 1976) carrot, and onion were more under drip irrigation than sprinkler when equal gross amount of water used (Melstad and Deboer, 1978). While 1.25 t/feddon of pea was obtained by hand watering, in drip irrigation the yield was 2.5 t/feddon or 0.42 ha (El.Awady et al., 1976). Yield of drip irrigated tomato was 27.8 per cent more than that of furrow irrigated crop (Channappa, 1979).

While there was no significant difference in yield of grain Sorghum under drip and sprinkler irrigation (Ravelo et al., 1977), fruit yields of strawberries increased by 34 per cent with overhead irrigation and 37 per cent with trickle irrigation (Locascio et al., 1977). With heavy cropping Cox's orange Pippin apple trees, fruit size was greatly increased with trickle irrigation over no irrigation (Delver, 1977). Similar type of results i.e. greater fruit yields/tree larger individual fruit, more trunk growth and more fruit buds/peach tree was observed by Reeder et al. (1976) compared to dryland control and with sprinkler

irrigation.

Sugarcane was irrigated by both furrow and drip systems. The total increase with drip irrigation amounted to 8.1 tons cane/acre and 1.63 tons raw sugar-acre (Hill, 1977). In the ratoon crop the corresponding increase amounted to 19.0 and 2.52 tons/acre respectively.

2.5 Evapotranspiration of Potato

The daily rate of extraction from the entire root zone gradually increased from 0.05 inch (after first irrigation) to 0.213 inch (31 days before harvest) and dropped gradually to 0.136 inch till last irrigation was given (Maity, 1964-65). The rate of extraction gradually increased with the decrease in soil moisture tension or increased frequency of irrigation (Bradley and Pratt, 1955; Blake et al., 1955; Mech, 1969, and Maity, 1972). Jacob et al. (1952) observed an increase of average of weekly evapotranspiration rate from 1.19 to 1.29 inches when frequency of irrigation increased from three to eleven. A further increase in rate from 1.29 to 1.44 inches was also due to increased frequency of irrigation from 11 to 26.

2.6 Concluding Remarks

The influence of climatic factors including radiation, temperature, vapour pressure deficit, wind velocity and sunshine hours has been reviewed. Amongst these factors radiation has been found to play an important role. While a close relationship between evapotranspiration and net radiation exists, the influence

of other climatic factors cannot be ignored. The degree of crop cover and stage of growth is important in intercepting the incoming radiation. With the increase of per cent of cover the evapotranspiration increases. Soil moisture tension is very important in controlling the evapotranspiration rate. With the decrease in soil moisture tension the evapotranspiration increases as the resistance to flow of water decreases. Application of nitrogen helps in the increase of vegetative growth together with the depth and spread of root system. Higher evapotranspiration from higher dose of nitrogen has been reported. Of the several method of irrigation, drip irrigation can save much more water. Several formulae for estimating evapotranspiration have been proposed.

The potato crop is very sensitive to change in soil moisture tension and nitrogen. At 60 kg N/ha, maintenance of soil moisture tension between 0.1 to 0.4 atmosphere starting from stolon formation to maturity has been observed to increase the yield.

CHAPTER - III

MATERIALS AND METHODS

MATERIALS AND METHODS

3.1 Location and Season

3.1.1 Location

Evapotranspiration and yield analysis on potato, irrigated by furrow and drip methods, were conducted on the Research Farm, Department of Agricultural Engineering, Faculty of Agriculture, Bidhan Chandra Krishi Viswavidyalaya at the Kalyani Campus, District Nadia, West Bengal, during the three potato growing seasons of 1979-80, 1980-81 and 1981-82. The Research Farm is situated at 22.53°N latitude and 89.0°E longitude at an elevation of 6.00 metres above the mean sea level.

3.1.2 Climate

This region receives a long term average annual rainfall of 1500 mm, mostly concentrated during the months of June to October. The winter rainfall is scanty and seldom exceeds 116 mm. The maximum summer temperature of this area is about 40°C during April-May and the minimum temperature is as low as 10°C during December-January. Monthly distribution of rainfall, weekly average data of mean air temperature, vapour pressure deficit, duration of bright sunshine hours, wind velocity and humidity throughout the

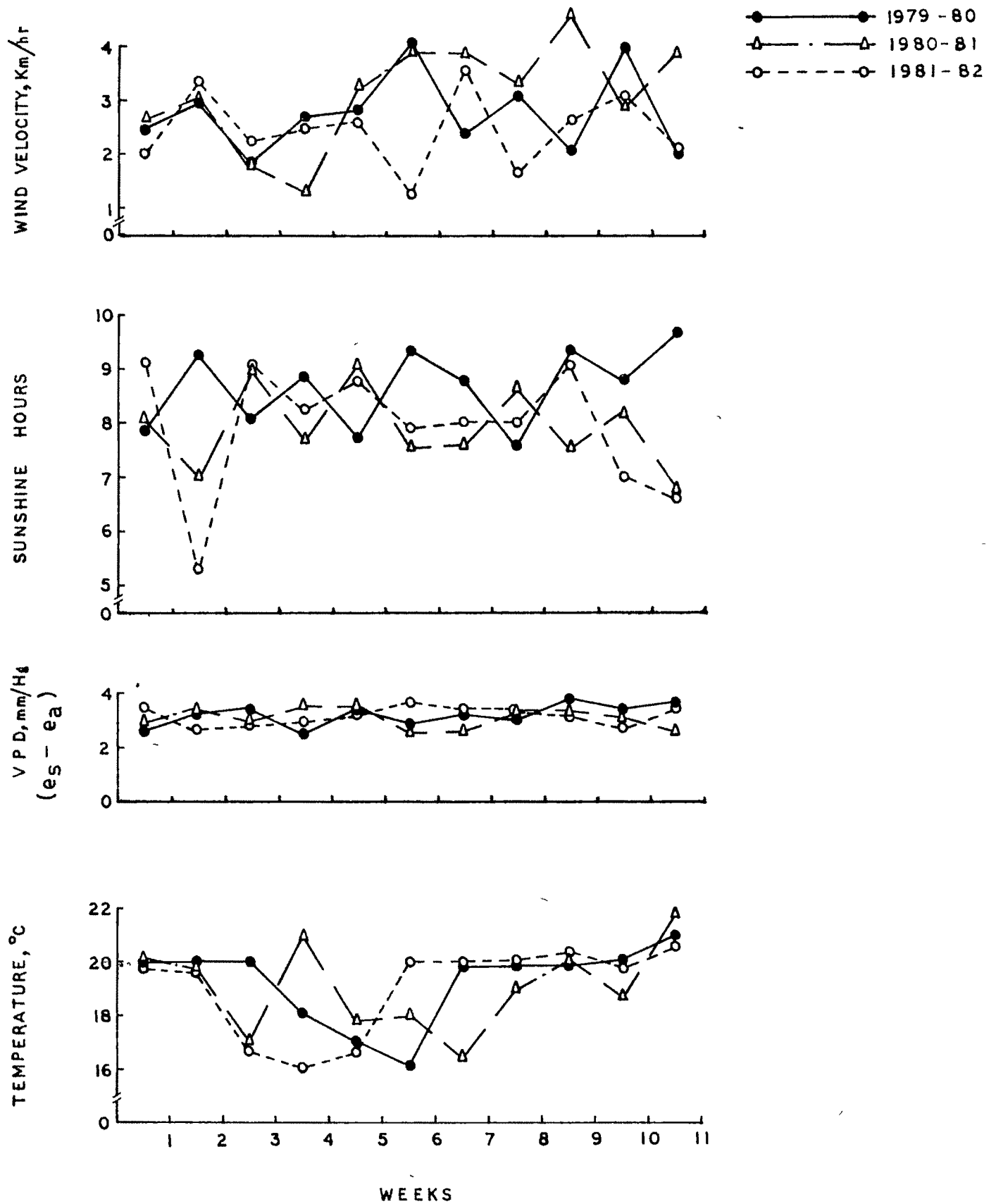


FIG 3 1 DISTRIBUTION OF CLIMATIC VARIABLES DURING THREE SEASONS

growing period of potato during all the three seasons, are illustrated in Figure 3.1 and presented in Table 3.1. Daily, maximum and minimum temperatures, wind velocity, bright sunshine hours, humidity, vapour pressure and rainfall readings were recorded from the Meteorological Observatory, Rice Research Station, Chinsura, Government of West Bengal. The free water surface evaporation rates were measured on the USWB Class A pan evaporimeter placed near the experimental site.

Table 3.1 Distribution of rainfall during three potato seasons

Season	Date	Rainfall (mm)	Season	Date	Rainfall (mm)
1979-80	Dec.19	2.0	1980-81	Feb. 8	1.3
	Dec. 20	2.5		Feb. 9	22.8
	Jan. 1	6.8		Feb. 10	5.08
	Jan. 23	Trace	1981-82	Dec. 9	3.3
	Feb. 2	1.9		Dec. 10	7.5
1980-81	Jan. 1	9.6		Dec. 11	7.6
	Jan. 31	9.3		Feb. 3	12.2
	Feb. 1	5.1			

3.2 Design of Experiment

3.2.1 Layout

The field experiment was laid out in split-split design with three replications. The size of each individual plot was

REPLICATION - I

DT ₂ N ₀	DT ₁ N ₃	DT ₃ N ₁	FT ₂ N ₁	FT ₁ N ₂	FT ₃ N ₃
DT ₂ N ₂	DT ₁ N ₂	DT ₃ N ₂	FT ₂ N ₃	FT ₁ N ₃	FT ₃ N ₁
DT ₂ N ₃	DT ₁ N ₀	DT ₃ N ₀	FT ₂ N ₂	FT ₁ N ₀	FT ₃ N ₂
DT ₂ N ₁	DT ₁ N ₁	DT ₃ N ₃	FT ₂ N ₀	FT ₁ N ₁	FT ₃ N ₀



REPLICATION - II

DT ₁ N ₃	DT ₂ N ₁	DT ₃ N ₂	FT ₂ N ₂	FT ₁ N ₀	FT ₃ N ₀
DT ₁ N ₁	DT ₂ N ₃	DT ₃ N ₃	FT ₂ N ₀	FT ₁ N ₁	FT ₃ N ₂
DT ₁ N ₂	DT ₂ N ₂	DT ₃ N ₁	FT ₂ N ₁	FT ₁ N ₂	FT ₃ N ₁
DT ₁ N ₀	DT ₂ N ₀	DT ₃ N ₀	FT ₂ N ₃	FT ₁ N ₃	FT ₃ N ₃

F = FURROW IRRIGATION

D = DRIP IRRIGATION

T₁ = 0.4 atmT₂ = 0.8 atmT₃ = 1.2 atmN₀ = 0 Kg N/haN₁ = 100 Kg N/haN₂ = 200 Kg N/haN₃ = 300 Kg N/ha

REPLICATION - III

FT ₂ N ₀	FT ₁ N ₀	FT ₃ N ₀	DT ₃ N ₁	DT ₂ N ₃	DT ₁ N ₁
FT ₂ N ₁	FT ₁ N ₂	FT ₃ N ₃	DT ₃ N ₀	DT ₂ N ₁	DT ₁ N ₃
FT ₂ N ₂	FT ₁ N ₃	FT ₃ N ₁	DT ₃ N ₃	DT ₂ N ₂	DT ₁ N ₂
FT ₂ N ₃	FT ₁ N ₁	FT ₃ N ₂	DT ₃ N ₂	DT ₂ N ₀	DT ₁ N ₀

3m

4m

FIG 3 2 LAYOUT OF THE FIELD

4m x 3 m (Figure 3.2).

3.2.2 Soil

The soil of the experiment plot is clay loam in texture and not subjected to drainage problem. The physico-chemical properties of the soil upto a depth of 30 cm have been presented in Tables 3.2, 3.3 and 3.4.

Table 3-2 Mechanical composition of soil

Particle size distribution		
Sand %	Silt %	Clay %
28	30	40

Table 3.3 Physical properties of soil

Bulk density gm/cm ³	Particle density gm/cm ³	Moisture content, per cent by weight			Hydraulic conductivity cm/hr
		Water holding capacity	Field capacity	Permanent wilting point	
1.35	2.65	56.75	24.0	8.25	0.785

Table 3.4 Chemical properties of soil

Organic matter %	Organic carbon %	Nitrogen %	P ₂ O ₅ in ppm	K ₂ O in ppm	pH
3.424	1.986	0.1039	289	386	6.74

3.2.3 Previous History of the Field

The land remained fallow for about five years before the experiment was laid out.

3.2.4 Treatments

The evapotranspiration and yield analysis was made on variety Kufri Chandramukhi with two irrigation methods under three soil moisture tension and four nitrogen levels. The treatments were replicated three times in all the three seasons at the same plot.

3.2.4.1 Irrigation methods

Two irrigation methods i.e. conventional furrow and drip irrigation were considered in the main plots.

3.2.4.2 Soil moisture tension

The following three soil moisture tensions were maintained at the root zone of the crop on sub-plot treatments.

T₁, 0.1 to 0.4 atmosphere

T₂, 0.1 to 0.8 atmosphere

T₃, 0.1 to 1.2 atmosphere

3.2.4.3 Nitrogen level

The sub sub-plot treatments included the following levels of nitrogen.

N₀, no application

N₁, 100 kg/ha

N₂, 200 kg/ha

N₃, 300 kg/ha

3.3 Agronomic Practices

3.3.1 Manuring

In each season, before planting of tubers, Farm Yard Manure was added to the soil, at the rate of 10 tonnes/ha, 20 days prior to planting and was mixed thoroughly up to a depth of 25-30 cm. The entire 90 kg of single-superphosphate and 90 kg of murate of potash plus half the nitrogen dose of the respective nitrogen (N) treatments were applied at the planting. The remaining half N was applied at the time of first earthing up.

3.3.2 Planting

Small healthy well sprouted tubers, 18-20 grams each, were selected and were treated with agallol before planting. The soil was treated with aldrin to protect the tubers from whiteant attack. The tubers were planted carefully in furrows maintaining a spacing of 22.5 cm and 50 cm between tubers and rows respectively.

3.3.3 Crop Management

The soil crust, if any, was broken one week after the planting of tubers to enhance quick emergence and the earthing up was done at 21st day after planting. Dithane-M-45 was sprayed 2 to 3 times to control the attack of blight.

3.3.4 Harvesting

At the end of each season, potato was harvested using hand tools, cleaned and weighed separately. The size distribution for each treatment was made 4 to 5 days after harvest.

The dates of planting, first earthing up and date of harvesting are given in Table 3.5.

Table 3.5 Dates of planting, first earthing up and harvesting of potato tuber

Particulars	Season		
	1979-80	1980-81	1981-82
Planting	Nov. 17	Nov. 20	Nov. 18
First earthing up	Dec. 8	Dec. 10	Dec. 9
Harvesting	Feb. 14	Feb. 22	Feb. 16
No. of days between planting and harvesting	89	94	90

3.4 Techniques of Measurement

3.4.1 Soil Moisture Tension

The soil moisture tension of 0.4 atmosphere was measured by means of mercury manometer tensiometers (Lark type). The moisture tensions of 0.8 and 1.2 atmosphere were measured by specially constructed gypsum blocks (Pereira, 1951). Both tensiometers and gypsum blocks were buried at a depth of 25-30 cm for different soil moisture tension measurements. Twentyfour hours after the application of sufficient quantity of water, moisture content of the soil was determined gravimetrically and the corresponding soil moisture tension and resistance readings were recorded daily at about 11 A.M. Moisture content of soil against tension up to 0.8 atmosphere and corresponding resistance values were plotted.

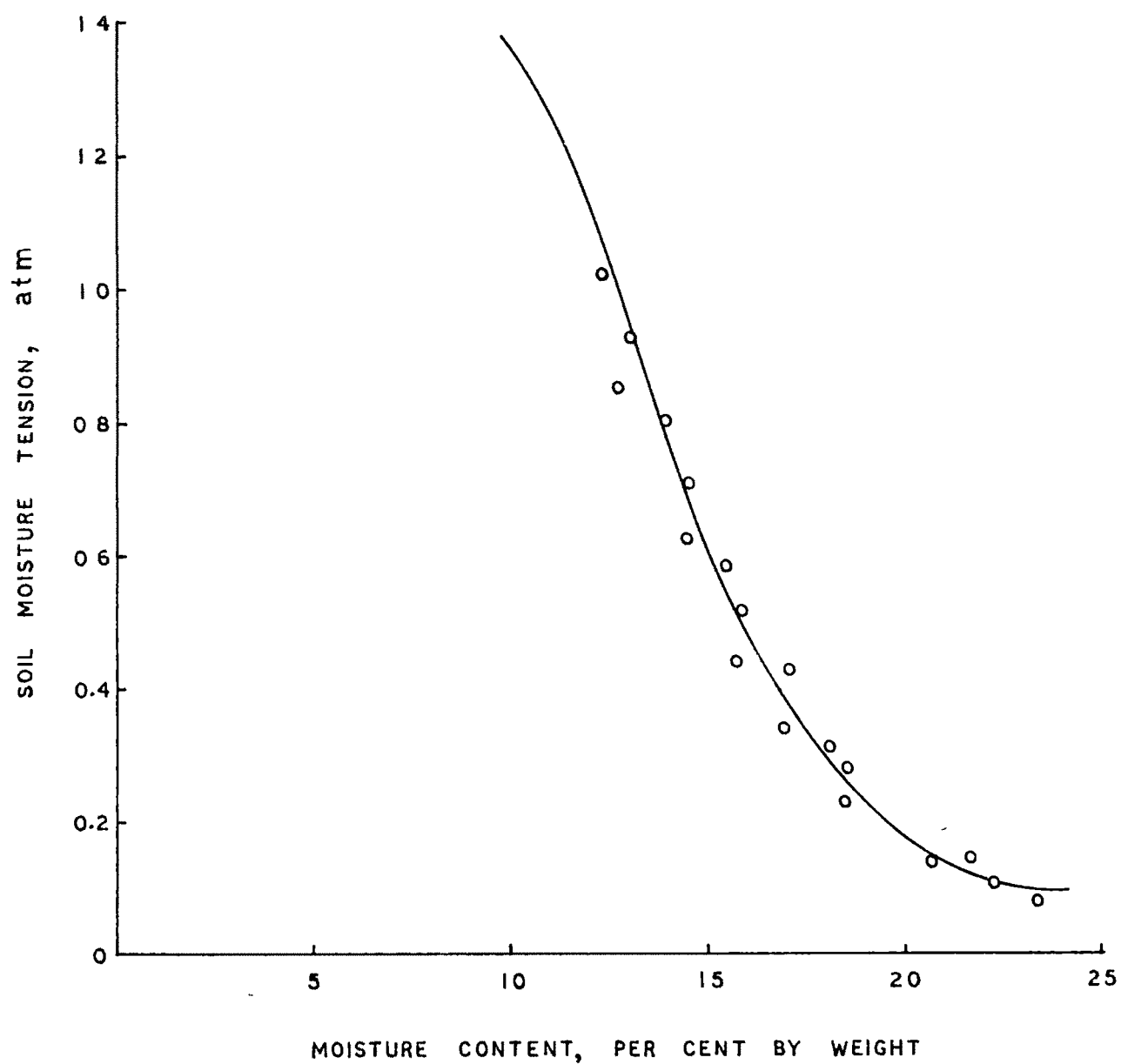


FIG 3 3 SOIL MOISTURE TENSION AND MOISTURE CONTENT CURVE

Beyond the tensiometer range, moisture tension, moisture content and resistance values were determined using pressure plate apparatus (Michael, 1978).

The curves, moisture content, per cent by weight, moisture tension in atmosphere, and resistance in Ohms, were fitted (Figures 3.3 and 3.4). Gypsum blocks were standardised. These moisture-tension and moisture-resistance curves were prepared before planting of tuber.

3.4.2 Irrigation

During the planting of tuber the moisture content of the soil, in all the plots, was almost equal. The actual irrigation treatment began after the first earthing up i.e. 21 days after planting and a common irrigation of 2.91 cm was applied to all the treatments. The moisture tension and moisture resistance values were recorded daily at about 11 A.M. When the soil moisture tension of 0-30 cm depth reached the predetermined values, the corresponding moisture present was determined from the moisture-tension and moisture-resistance curves (Figures 3.3 and 3.4). Since the lower limit of tension was fixed at 0.1 atmosphere (field capacity) and since the corresponding moisture present per cent by weight was known, calculated amount of water just sufficient to meet the deficit for 0 to 25 cm layer, was applied uniformly with extreme care in each plot. The soil moisture deficit was calculated by the following equation.

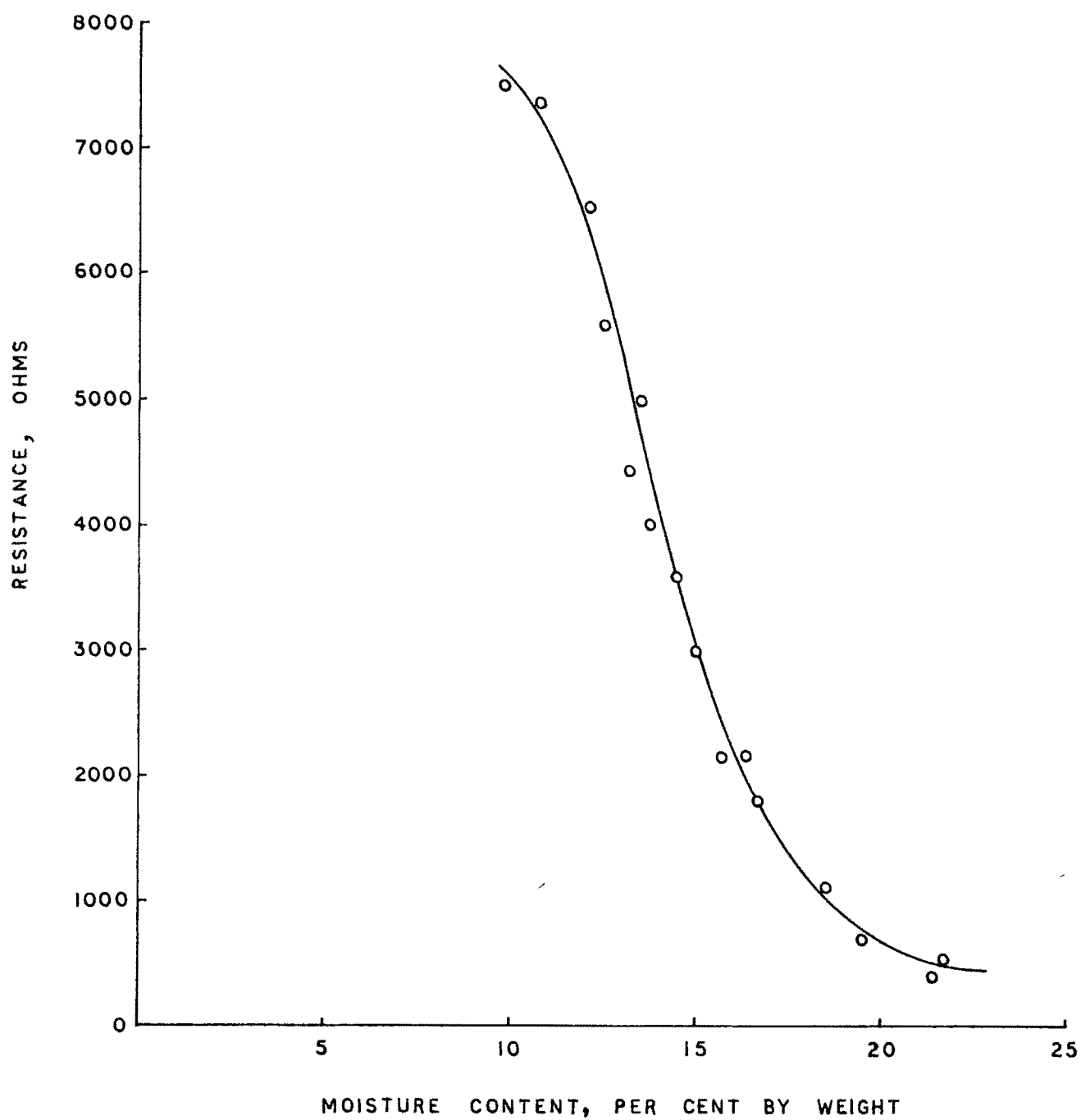


FIG 3 4 SOIL MOISTURE RESISTANCE AND MOISTURE CONTENT CURVE

$$d = \sum_{i=1}^n \frac{P_w}{100} \times B_d \times D_i \quad (3.1)$$

where, d = Soil moisture deficit, cm

P_w = Moisture deficit in i th layer, per cent by weight

B_d = Bulk density, gm/cm³

D_i = Depth of soil, cm of i th layer

n = Number of soil layers in the root zone.

Application of irrigation was stopped 10 days before harvest.

3.4.2.1 Drip irrigation

The basic equipment for drip irrigation consists of (a) water-supply head, (b) mains and sub mains (c) laterals, and (d) drip emitters.

Head

The head consists of G.I. sheet water supply tank (56 cm in diameter X 110 cm in height) was placed on a cast iron stand of 150 cm high. The supply tank had an arrangement for maintenance of constant head of water and regulated outflow at its bottom.

Main, sub-mains and laterals

Flexible polythene pipes of 1.9 cm diameter of desired length were used. The pipes were connected to the submains and the laterals by P.V.C. 'T', bends and elbows (Figure 3.5). The open ends were closed with greese and rubber stopper. One lateral was placed in furrow for two rows of plants. Both mains, submains and laterals were fixed firmly to the ground by necessary 'U' hooks.

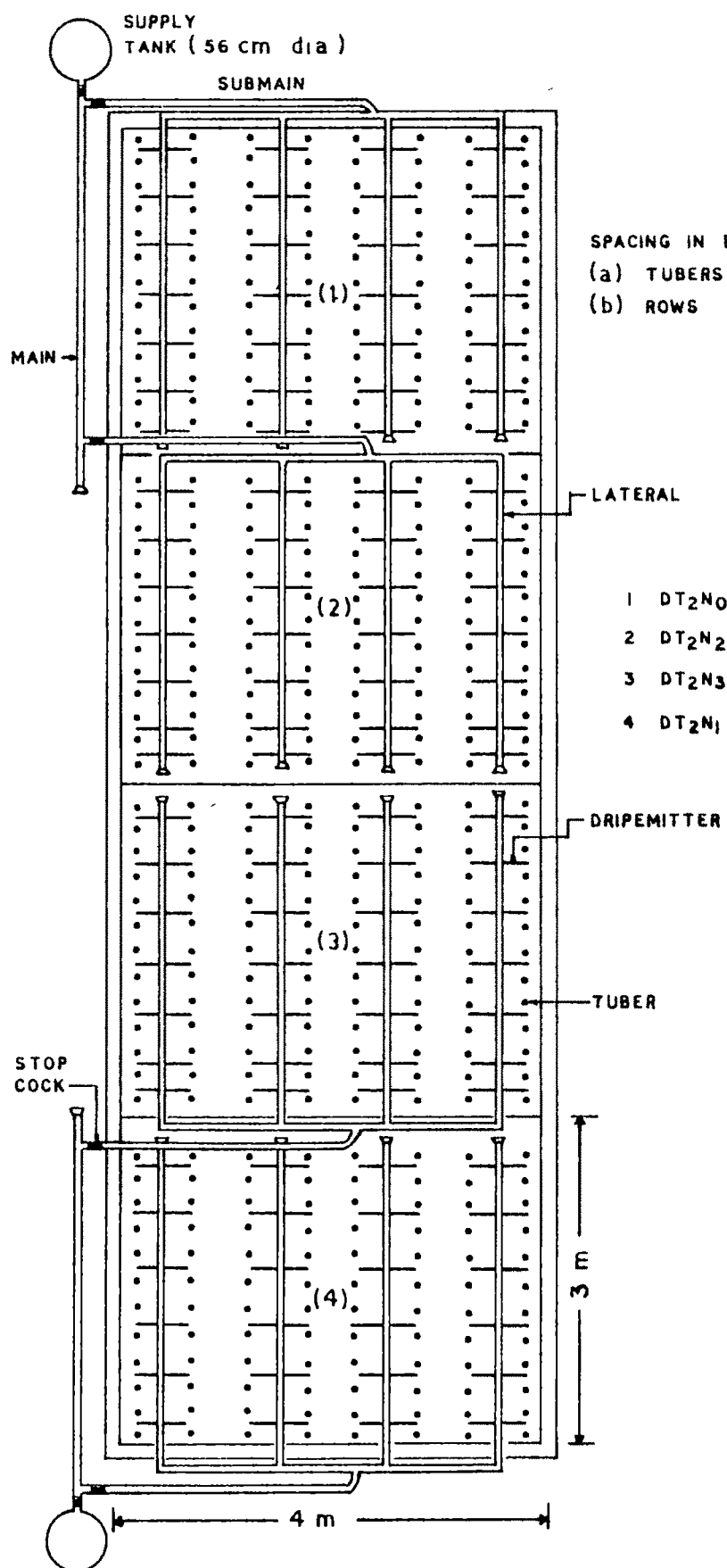


FIG 3 5 LAYOUT FOR DRIP IRRIGATION (PART FIELD)

Drip emitters

For uniform and slow (dropwise) application of water about 30-40 cm length of polythene pipes (one mm dia) were connected to the laterals by means of adhesive (Araldite) at the rate of one emitter per two plants. At each open end of the emitter, a small galvanised wire was inserted. Each emitter was placed within a small tube placed in the root zone to prevent clogging. All joints were tested against leakage and the rate of discharge from each emitter was calibrated before placing them in the experimental field.

3.4.3 Evapotranspiration Measurement

The daily rate of evapotranspiration (E_T) of the potato crop under different treatments was measured by water-balance method (Slatyer, 1967). The water balance in the soil is given by :

$$E_T = R_a + I_r - S_r - L + \Delta W$$

where,

E_T = Evapotranspiration rate, mm/day

R_a = Rainfall, mm/day

I_r = Irrigation, mm/day

S_r = Run off, mm/day

L = Loss of water beyond root zone, mm/day

ΔW = Change in mean soil moisture storage (initial minus final) during the period under study, mm/day.

As the major portion of the roots of potato was concentrated

within 25 cm depth of soil, the moisture content of this layer of soil was determined daily by tensiometers and gypsum blocks and curves (Figures 3.3 and 3.4). The amount of moisture lost beyond the effective root zone in most cases was negligible, because the calculated quantity of water just sufficient to increase the moisture in the root zone to a pre-determined value (0.1 atmosphere) was applied very carefully to achieve uniform wetting. However, the loss below the root zone, if any, was measured daily by different sets of tensiometer buried at a depth of 60 cm. Since the plots were separated by ridges, the surface run-off between the plots could not take place.

Knowing daily, the amount of rainfall, irrigation and the moisture loss below the root zone, if any, and also knowing the moisture present in the root zone, E_T was calculated for each day.

3.4.4 Evapotranspiration Estimates

Since the measurement of evapotranspiration for any crop is time consuming, two empirical formulae were used to estimate evapotranspiration. For these purpose, the measured evapotranspiration rates at three soil moisture tensions under two methods of irrigation were compared with the values estimated by (a) Penman formula (1948), and (b) Blaney-Criddle formula (1950).

3.4.4.1 Penman formula

For evaluation of the various factors in this formula, different tables, figures (Criddle, 1958) and climatic data

are used. The reflectance for the potato crop varied between 0.17 to 0.27 m/u (Montieth, 1959)

$$E_t = \frac{\Delta H + 0.27 E_o}{\Delta + 0.27}$$

where,

E_t = Potential evapotranspiration of water, mm/day

Δ = Slope of the curve of vapour pressure at saturation versus air temperature, t_a , mm Hg/°F

H = Daily heat budget at the surface, mm of water/day
and is given by -

$$RA (1-r) (0.18 + 0.55 S/S') - T_a^4 (0.56 - 0.092 ea) (0.10 + 0.90 S/S')$$

RA = Mean monthly extra terrestrial radiation, mm water per day (obtainable from Smithsonian Meteorological Table No. 132, 1951)

r = Reflection coefficient of crop surface

S = Actual duration of bright sunshine hour

S' = Maximum possible duration of bright sunshine hour (obtainable from Smithsonian Meteorological Table No. 171, 1951).

σ = Stefan-Boltzman constant = 2.01×10^{-9} mm/day

t_a = Air temperature °K (°C absolute)

ea = Saturation vapour pressure at mean dew point (i.e. actual vapour pressure in the air), mm of mercury

= e_s X relative humidity

e_s = Saturation vapour pressure at mean air temperature,
mm of mercury

E_0 = Evaporation of water, mm/day. E_0 is given by
 $E_0 = 0.35 (e_s - e_a) (1 + 0.0098 U_2)$. E_0 is an
aerodynamic component.

U_2 = Mean wind speed at 2 metres above the ground, miles/day.
Wind measurements taken at other heights can be corrected to 2 metre elevation by the use of formula.

$$U_2 = U_1 \frac{\log 6.6}{\log h}$$

U_1 = Measured wind speed, miles/day at height h in feet.

On the basis of Lake Hefner studies, Penman (1956) changed the wind velocity term to $(0.5 + U_2/100)$. This affects the results slightly.

3.4.4.2 Blaney-Criddle formula

Consumptive use was computed by multiplying mean monthly temperature by monthly per cent of annual day time hours and crop coefficient. The consumptive use factors were determined from climatic data. Crop coefficient K was estimated for different stages of growth for three seasons and for three moisture tension regimes from the measured E_T . The consumptive use of the potato crop for a particular month was estimated using the value of k averaged over three seasons for that month.

The Blaney-Criddle formula reads as

$u = kf$ and $U = \text{sum of } kf = Kf$ where,

- t' = Mean monthly temperature in degrees Fahrenheit
 P = Monthly per cent of day time hours of the year.
 f = $\frac{t' \times P}{100}$ = Monthly consumptive-use factor,
 u = Monthly consumptive-use, inches
 U = Seasonal consumptive-use (or evapotranspiration)
in inches
 F = Sum of the monthly consumptive-use factors for the
period (sum of the products of mean monthly temperature and monthly per cent of day time hours of the year)
 K = Empirical crop consumptive-use coefficient for
irrigation season or growing period.
 k = Monthly empirical crop consumptive-use coefficient.

In metric units -

- u = $kp \frac{45.7 t + 813}{100}$ monthly consumptive use, mm.
 t = Mean monthly temperature, °C.

3.5 Statistical Analysis

The analysis of variance (Cochran and Cox, 1955 and Gomez and Gomez, 1976) was made to analyse the data statistically. The significance of different sources of variation was tested. In the summary tables of results, the standard error of means (S. Em $\pm$) and values of critical differences (C.D.) to compare the differences between means were presented. The per cent of the total yield in respect of size distribution of tuber, was

transferred to angular values.

Coefficients of correlation and regression (simple and multiple) equations, polynomial equations were developed following the method as described by Little (1966). The validity of equations were tested.

CHAPTER - IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

4.1 Evapotranspiration

4.1.1 Factors Influencing Evapotranspiration

Amongst the various factors influencing evapotranspiration climate, soil moisture tension, nitrogen level, stages of growth and irrigation methods have been studied for three potato growing seasons of 1979-80, 1980-81 and 1981-82.

4.1.1.1 Climate

The influence of climatic variable on evapotranspiration was studied. Since it was not possible to measure radiation on the crop surface and since sunshine hours has a relation with the radiation, the influence of sunshine hours on the daily measured rate of evapotranspiration (E_T) is considered. In addition to sunshine hours, temperature, vapour pressure deficit and wind velocity are included in this study. The relationships between E_T and each of these four climatic parameters are obtained statistically.

4.1.1.1.1 Temperature

The influence of mean air-temperature ($^{\circ}\text{C}$) on E_T from potato crop (weekly average data), irrigated by furrow and drip, was

1979 - 80

50

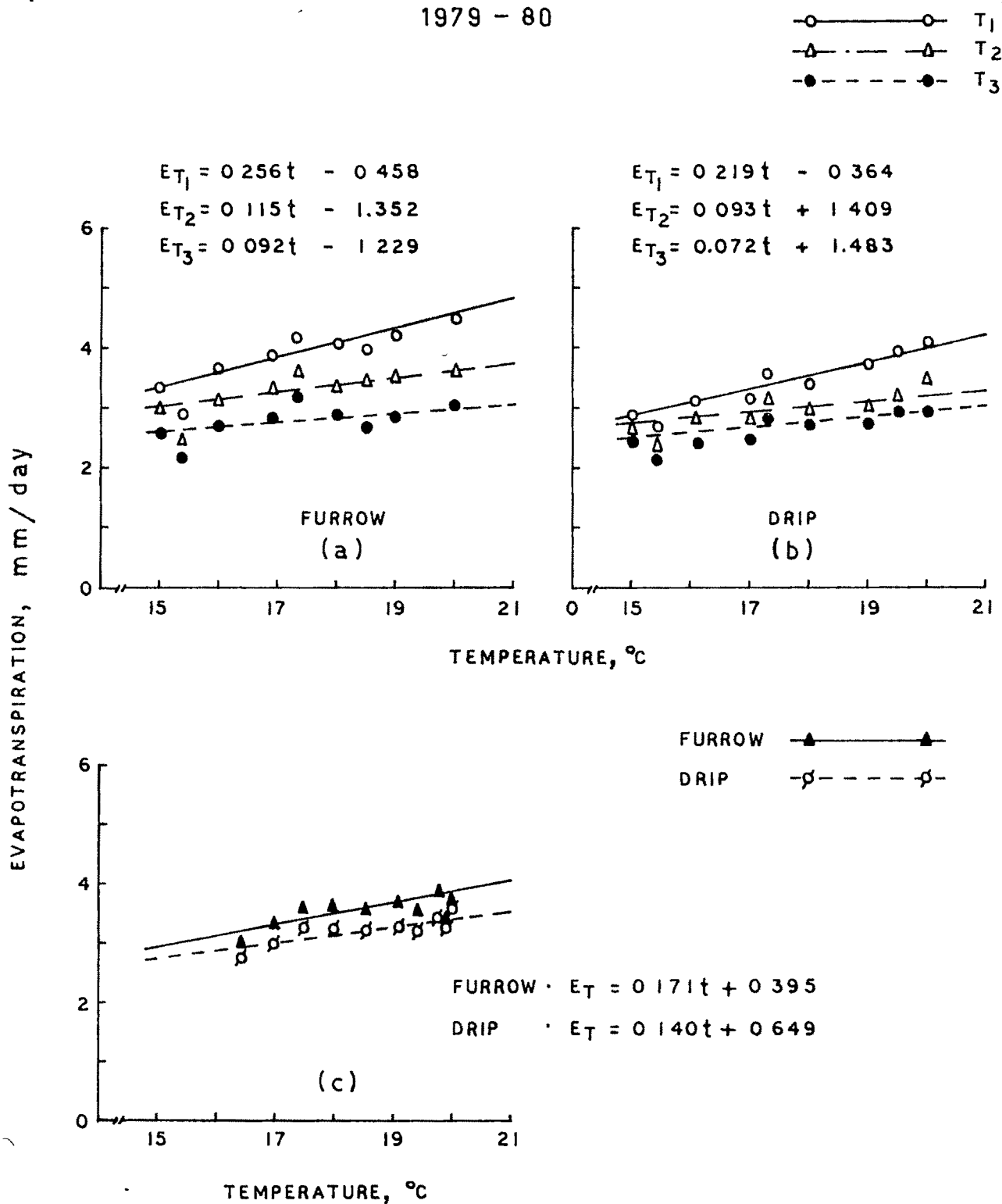


FIG 4.1 RELATIONSHIP BETWEEN MEAN AIR TEMPERATURE AND EVAPOTRANSPIRATION

1980 - 81

$\circ$ — $\circ$ T_1
 $\triangle$ — $\triangle$ T_2
 $\bullet$ - - $\bullet$ T_3

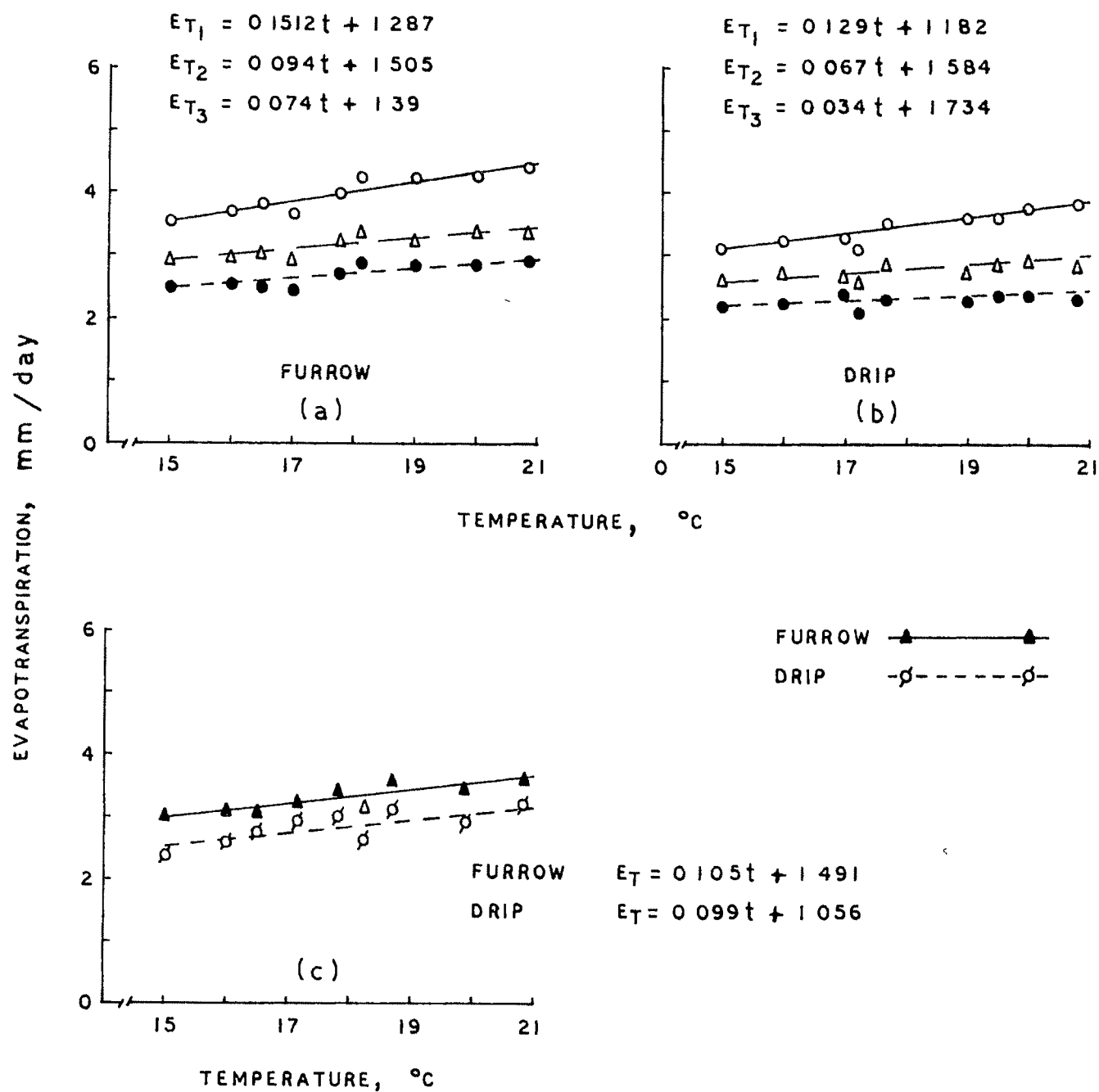


FIG 4 2 RELATIONSHIP BETWEEN MEAN AIR TEMPERATURE AND EVAPOTRANSPIRATION

1981 - 82

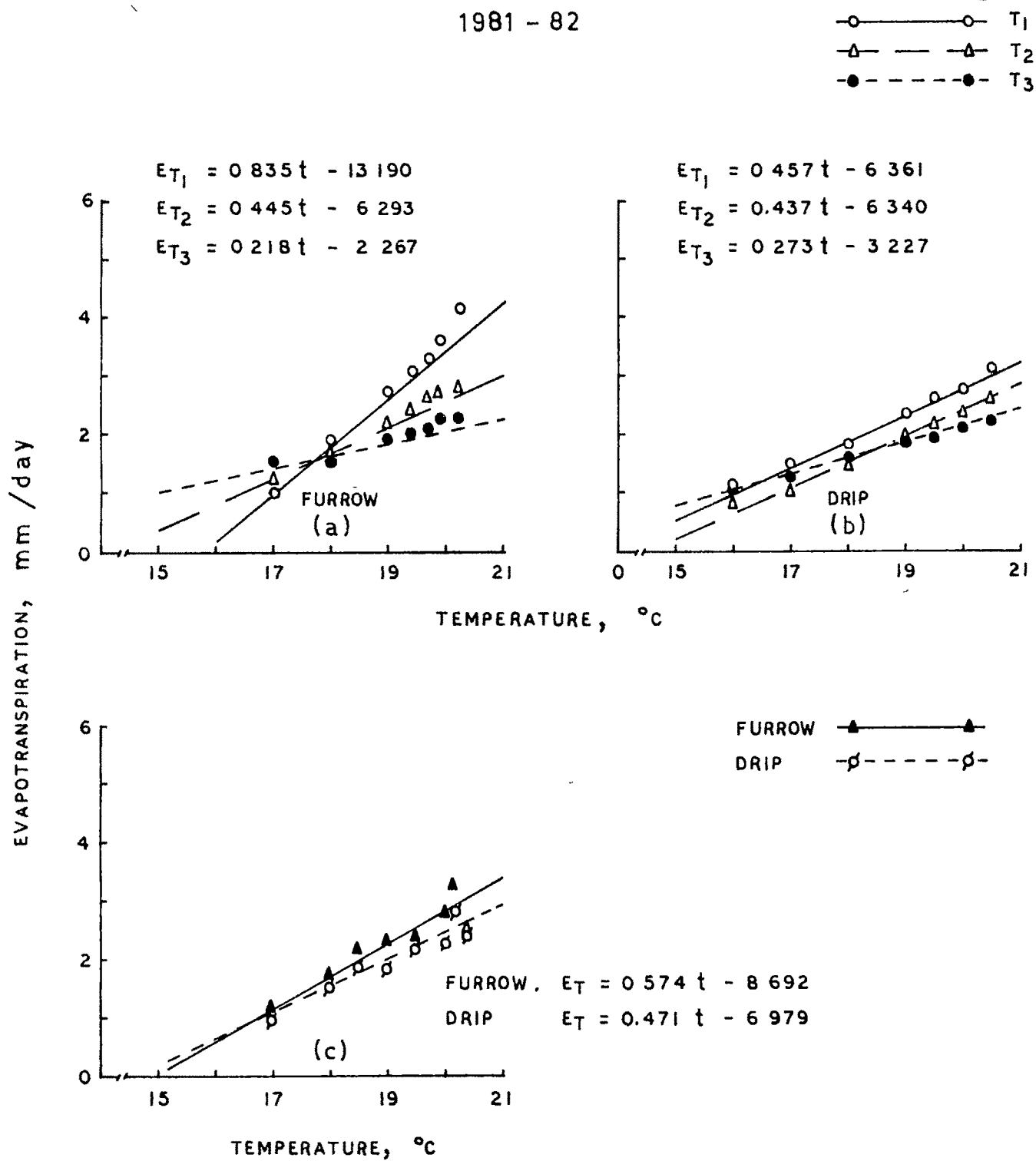


FIG 4 3 RELATIONSHIP BETWEEN MEAN AIR TEMPERATURE AND EVAPOTRANSPIRATION

studied. The values of mean air temperature (t) and E_T are plotted and best fit lines are drawn statistically to represent their relationship (Figures 4.1, 4.2 and 4.3).

The relationship (Figures 4.1, 4.2 and 4.3) indicates that the increase in E_T is associated with the increase of air temperature. The rate of change of E_T with t varies with soil moisture tension and season. While the rate of increase is maximum under 0.4 atmosphere, it gradually decreases with the increase of soil moisture tension irrespective of the methods of irrigation.

When the average data of E_T and t for three seasons are considered together (Figure 4.4) the following equations are obtained :

$$\text{Furrow : } E_{T_1} = 0.351 t - 2.975, \quad r = 0.954 \quad (4.1)$$

$$E_{T_2} = 0.209 t - 1.024, \quad r = 0.931 \quad (4.2)$$

$$E_{T_3} = 0.122 t - 0.191, \quad r = 0.974 \quad (4.3)$$

$$\text{Drip : } E_{T_1} = 0.265 t - 1.801, \quad r = 0.999 \quad (4.4)$$

$$E_{T_2} = 0.201 t - 1.166, \quad r = 0.999 \quad (4.5)$$

$$E_{T_3} = 0.138 t - 0.240, \quad r = 0.997 \quad (4.6)$$

where, E_T = Evapotranspiration rate, mm/day and subscripts 1, 2 and 3 indicate soil moisture tension, atmosphere.

t = Mean air temperature, °C.

These equations (4.1 to 4.6) are applicable only in the range

1979 - 1982

54

○ — T₁
 △ — T₂
 ● - - - T₃

$$\begin{aligned} E_{T_1} &= 0.351t - 2.975, & r &= 0.954 \\ E_{T_2} &= 0.209t - 1.024, & r &= 0.931 \\ E_{T_3} &= 0.122t - 0.191, & r &= 0.974 \end{aligned}$$

$$\begin{aligned} E_{T_1} &= 0.265t - 1.801, & r &= 0.999 \\ E_{T_2} &= 0.201t - 1.166, & r &= 0.998 \\ E_{T_3} &= 0.138t - 0.240, & r &= 0.997 \end{aligned}$$

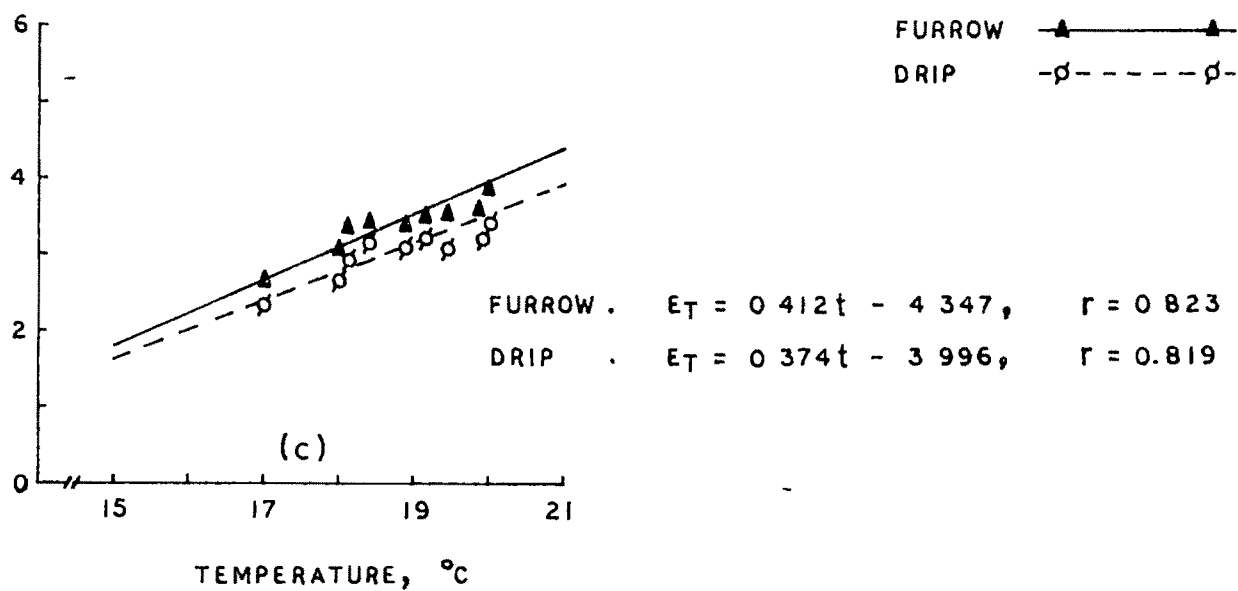
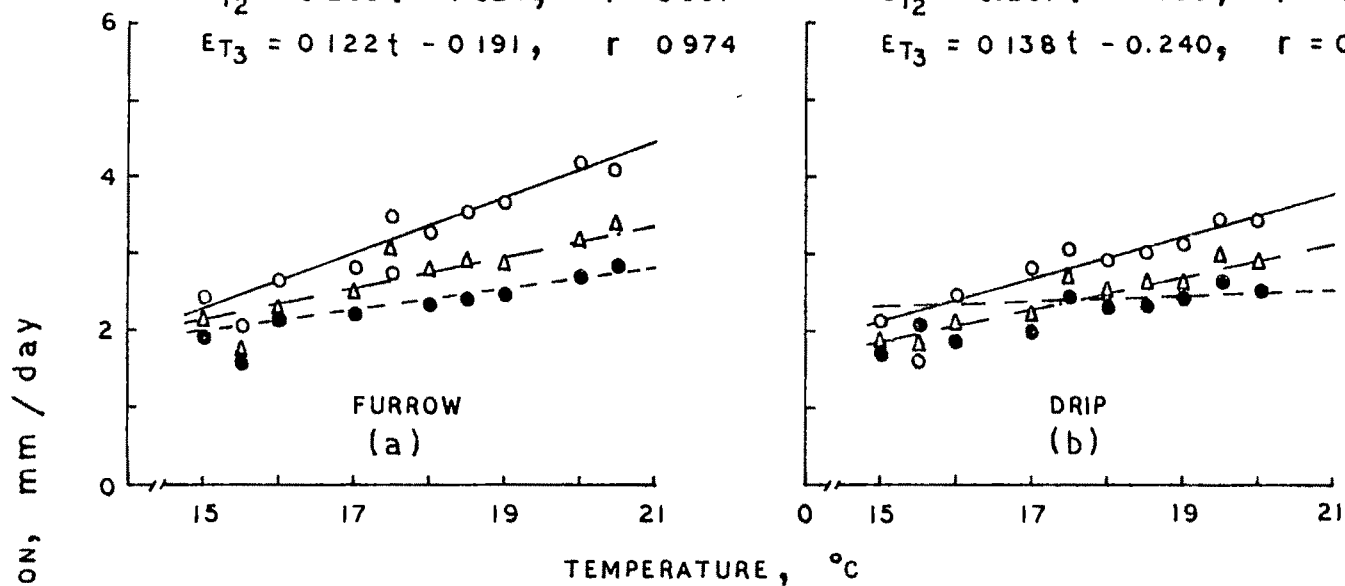


FIG 4 4 RELATIONSHIP BETWEEN MEAN AIR TEMPERATURE AND EVAPOTRANSPIRATION DURING THREE SEASONS

of mean air temperature considered in this study. The regression coefficients (Equations 4.1 to 4.6) indicate that higher rate of change in E_T is associated with the lower soil moisture tension due to more availability of water for E_T .

The relationship between t and E_T , averaged over soil moisture tension separately under furrow and drip systems (Figures 4.1c to 4.3c), indicates that E_T increases with the increase in t . The higher E_T from furrow irrigation is due to more surface wetness.

The following equations express the relationship (Figure 4.4c) between E_T and t .

$$\text{Furrow : } E_T = 0.412 t - 4.347, \quad r = 0.823 \quad (4.7)$$

$$\text{Drip : } E_T = 0.374 t - 3.996, \quad r = 0.819 \quad (4.8)$$

The linear relationship between t and E_T may be explained as follows. The effect of air temperature is mainly through the increase in vapour pressure gradient. Vapour pressure increases in a non-linear manner as the temperature increases. Thus a larger vapour pressure gradient is expected about the crop with higher air temperature (Jensen and Haise, 1963) resulting in more rapid removal of water vapour. The correlation between the air-temperature and E_T is due to the direct relationship of both parameters to radiation which causes E_T (Pelton et al., 1960, and Pruitt, 1964).

The results of this study are in general agreement with the observations of Norum and Larson (1960) and Sarkar (1975).

High correlation between these two factors were observed by Longacre and Blaney (1963), Pelton (1964), Baier and Robertson (1965); Maity and Pandya (1975) and Akopyan and Oganyan (1978).

4.1.1.1.2 Vapour pressure deficit

When weekly values of $(e_s - e_a)$ and E_T are plotted for three season, separately under furrow and drip irrigations (Figures 4.5, 4.6 and 4.7), a linear relationship is obtained. The relationship indicates that with the increase in $(e_s - e_a)$, E_T increases irrespective of soil moisture tensions and season. While the rate of change in E_T with the change in $(e_s - e_a)$ is greatest in lower soil moisture tension (0.4 atmosphere), it gradually decreases with the increase in soil moisture tension irrespective of furrow and drip irrigations.

When the average values of $(e_s - e_a)$ and E_T values under three soil moisture tensions together are considered (Figure 4.8) the following equations are derived.

$$\text{Furrow : } E_{T_1} = 0.756 (e_s - e_a), \quad r = 0.993 \quad (4.9)$$

$$E_{T_2} = 0.577 (e_s - e_a), \quad r = 0.997 \quad (4.10)$$

$$E_{T_3} = 0.562 (e_s - e_a), \quad r = 0.996 \quad (4.11)$$

$$\text{Drip : } E_{T_1} = 0.653 (e_s - e_a), \quad r = 0.991 \quad (4.12)$$

$$E_{T_2} = 0.534 (e_s - e_a), \quad r = 0.992 \quad (4.13)$$

$$E_{T_3} = 0.485 (e_s - e_a), \quad r = 0.997 \quad (4.14)$$

where, E_T = Evapotranspiration rate, mm/day and subscripts 1, 2 and 3 indicate soil moisture tension, atmosphere.

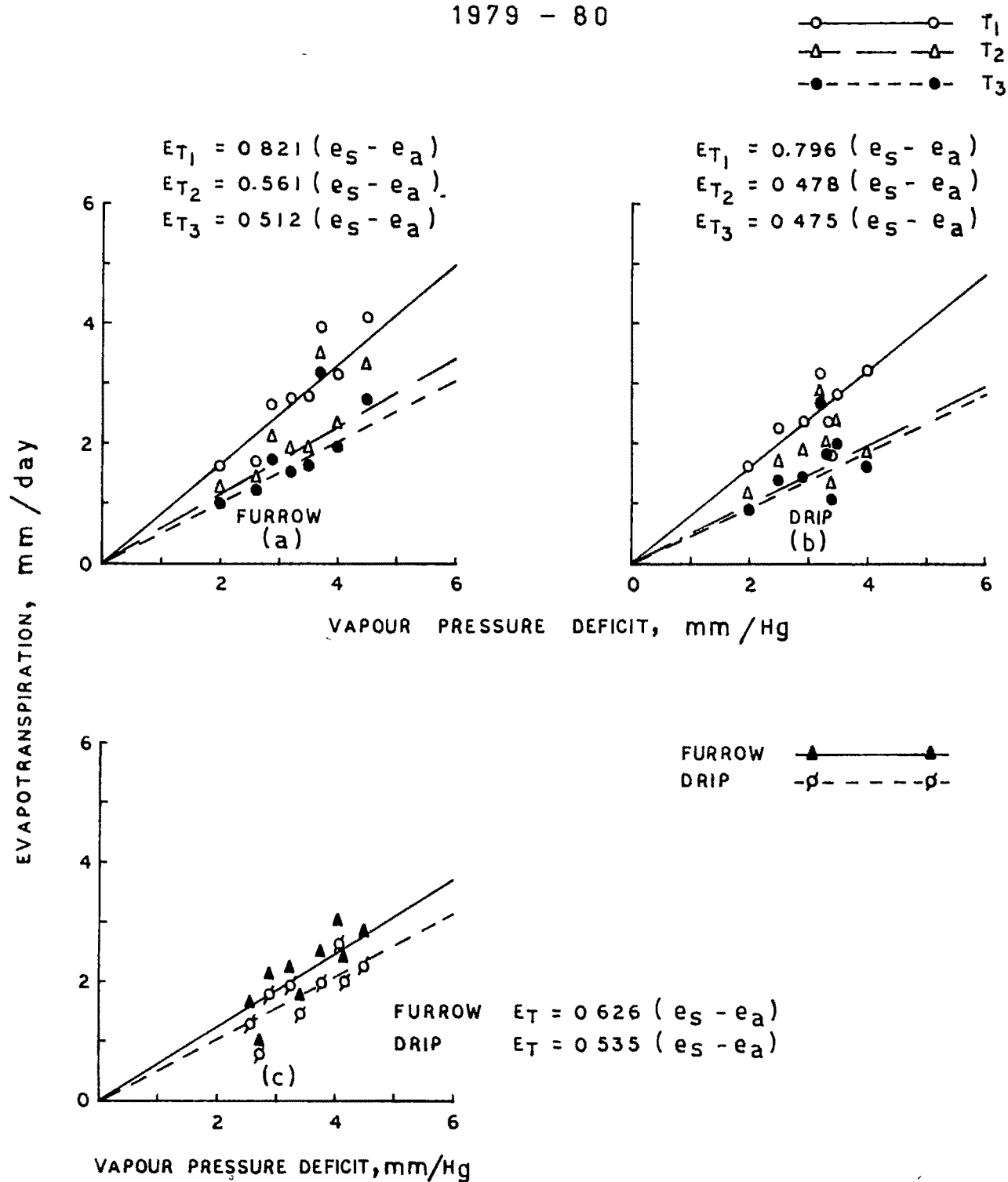


FIG 4.5 RELATIONSHIP BETWEEN VAPOUR PRESSURE DEFICIT AND EVAPOTRANSPIRATION

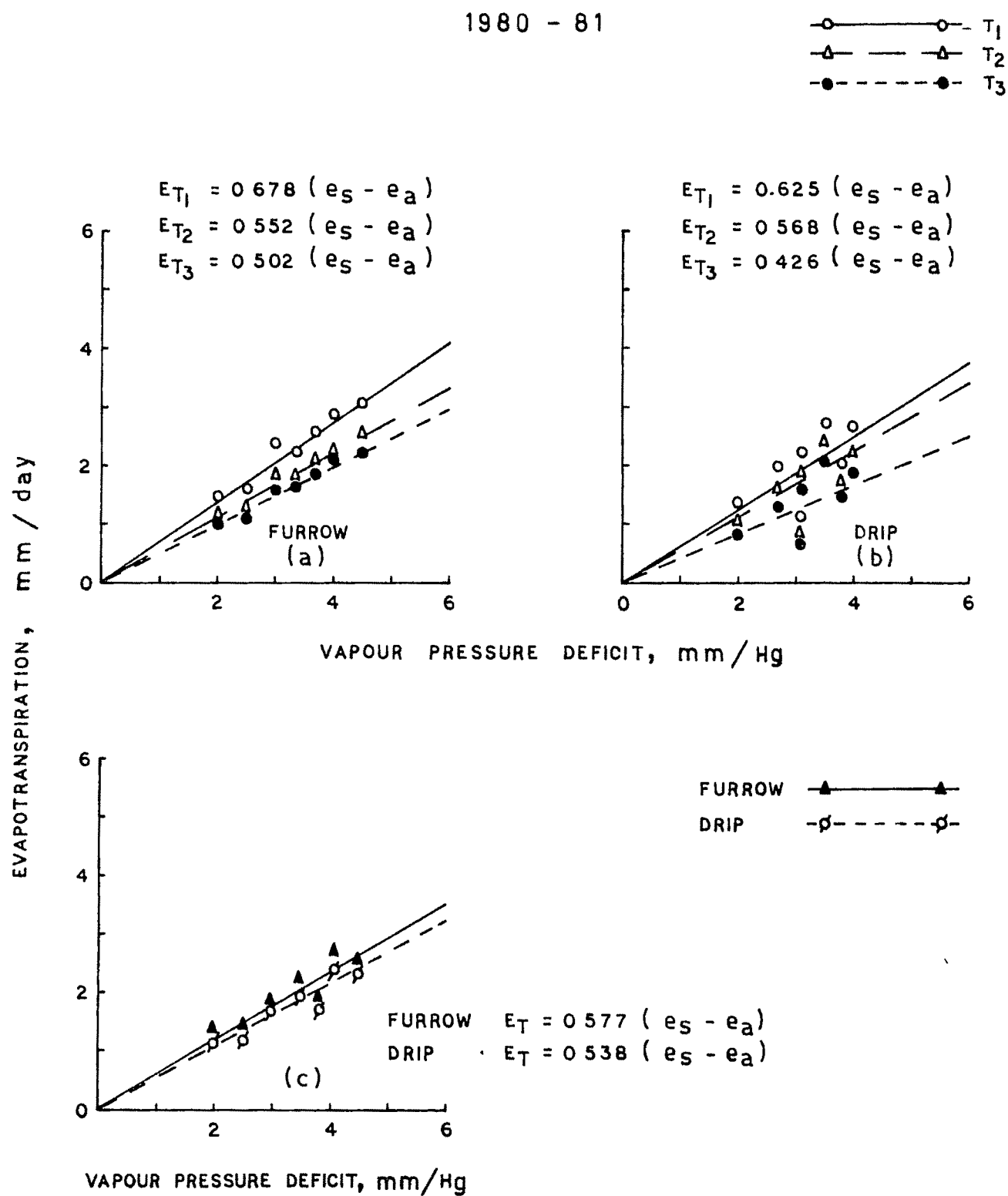


FIG 4 6 RELATIONSHIP BETWEEN VAPOUR PRESSURE DEFICIT AND EVAPOTRANSPIRATION

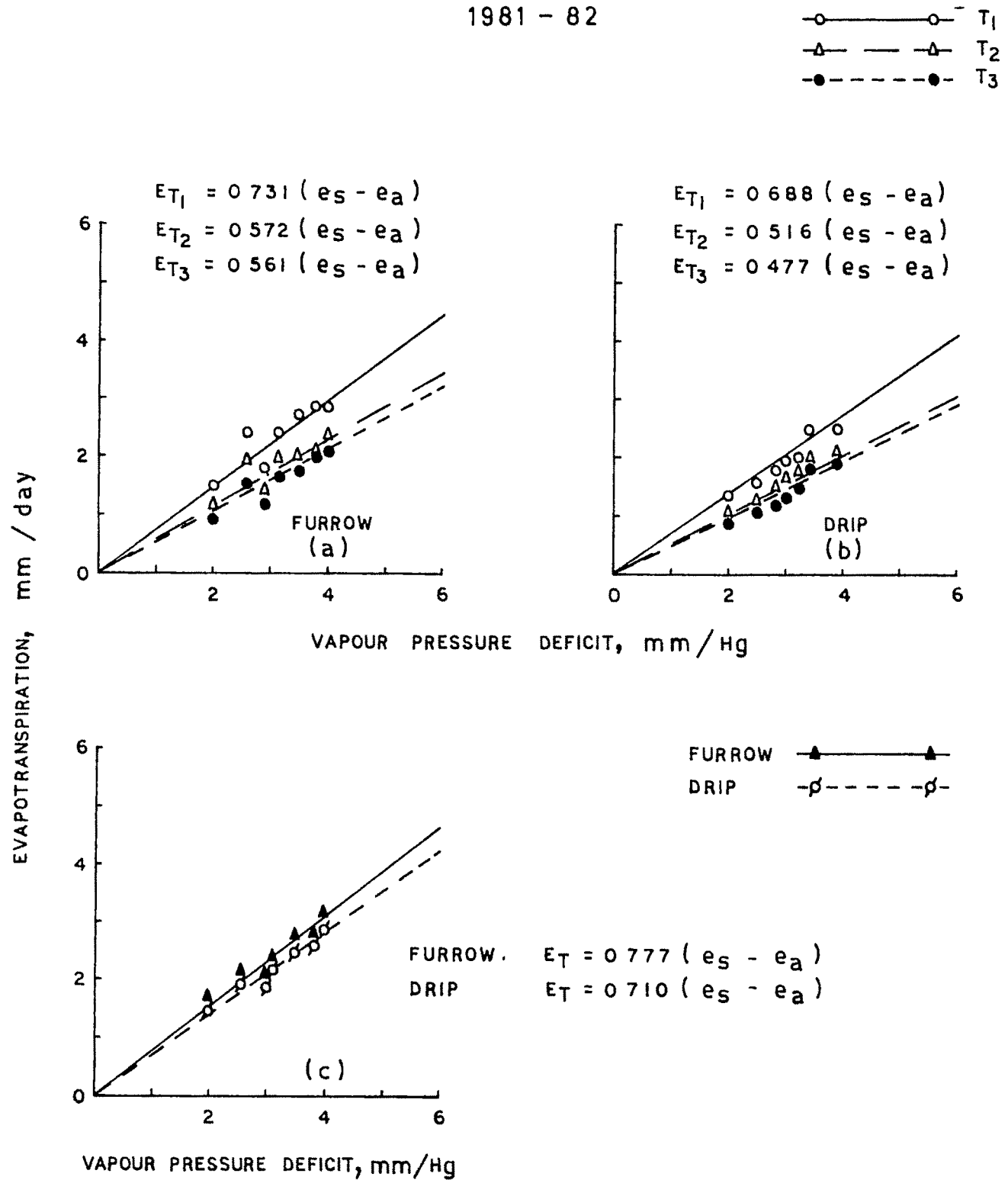


FIG 4 7 RELATIONSHIP BETWEEN VAPOUR PRESSURE DEFICIT AND EVAPOTRANSPIRATION

$(e_s - e_a)$ = Vapour pressure deficit, mm Hg.

The regression coefficients (Equations 4.9 to 4.14) indicate that higher rate of change of E_T is associated with the lower soil moisture tension.

The relationship between $(e_s - e_a)$ and E_T , averaged over soil moisture tensions separately under furrow and drip irrigations (Figures 4.5c to 4.7c), indicates that E_T increases with the increase in $(e_s - e_a)$ though the rate of change varies with irrigation systems. The higher value of regression coefficient (Figure 4.8c) is associated with the furrow irrigation. The equations are given below :

$$\text{Furrow : } E_T = 0.653 (e_s - e_a), \quad r = 0.997 \quad (4.15)$$

$$\text{Drip : } E_T = 0.542 (e_s - e_a), \quad r = 0.996 \quad (4.16)$$

It is evident (Figures 4.5 to 4.8) that all the lines pass through the origin as expected, implying that the E_T will be nil for zero difference in vapour pressure deficit (Pruitt, 1964). For the E_T to take place, there must be $(e_s - e_a)$ between the crop surface and air. The reasons for higher E_T with the increase in $(e_s - e_a)$ is mainly due to higher driving force.

These results are in agreement with that of Frost and Schwalen (1960); Pruitt (1964); Hobbs and Krogman (1966); Warrington (1970) and Maity and Pandya (1975). Similar results were obtained by Ghosh (1974) on wheat and Sarkar (1975) on boro paddy.

1979 - 1982

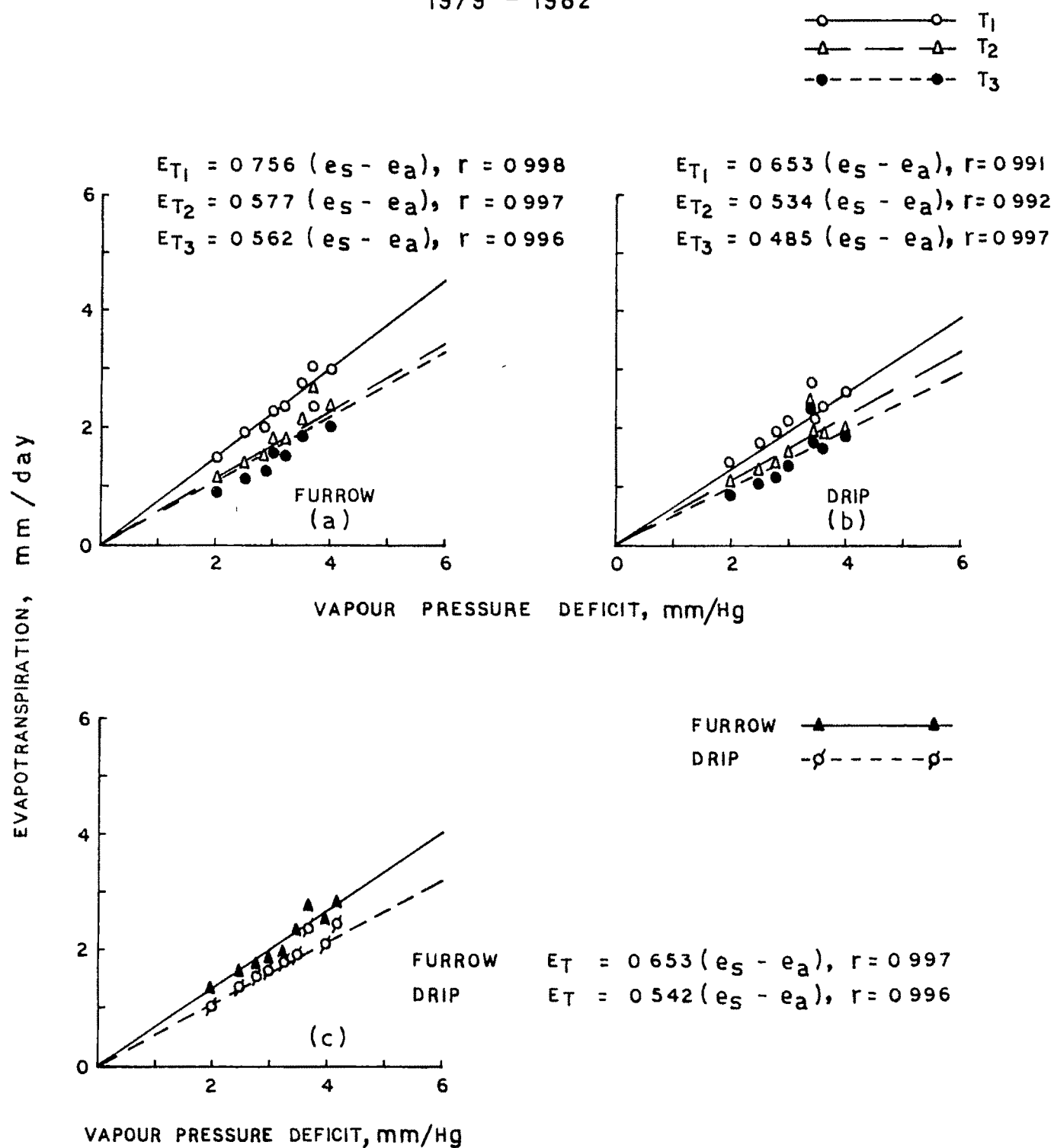


FIG 4 8 RELATIONSHIP BETWEEN VAPOUR PRESSURE DEFICIT AND EVAPOTRANSPIRATION DURING THREE SEASONS

4.1.1.1.3 Wind velocity

When seven days' average wind velocity in kilometers per hour is plotted against measure E_T for the same period, a linear relationship is obtained (Figures 4.9, 4.10 and 4.11). This relationship may be explained as follows. E_T is a diffusive process, partly turbulent and partly molecular on a very thin layer over the evaporating surface. According to the theory of turbulence, the upward flow of water vapour is equal to the product of vertical gradient of vapour pressure and rate of mixing which in turn depends on the rate of change of wind speed with height (Chang, 1968). If air around the leaves is still, the flow of water vapour will gradually increase the vapour pressure there and E_T will be reduced. However, in presence of wind, the vapour pressure gradient is maintained, and within limits an increase in wind speed will cause an increase in E_T (Angus, 1959, and Maity and Pandya, 1975).

The average weekly values of wind velocity and E_T for three seasons are considered (Figures 4.12) to obtain the following equations :

$$\text{Furrow : } E_{T_1} = 0.689 W + 1.070, \quad r = 0.911 \quad (4.17)$$

$$E_{T_2} = 0.592 W + 0.570, \quad r = 0.883 \quad (4.18)$$

$$E_{T_3} = 0.509 W + 0.449, \quad r = 0.877 \quad (4.19)$$

$$\text{Drip : } E_{T_1} = 0.548 W + 0.970, \quad r = 0.908 \quad (4.20)$$

$$E_{T_2} = 0.489 W + 0.712, \quad r = 0.873 \quad (4.21)$$

$$E_{T_3} = 0.448 W + 0.447, \quad r = 0.847 \quad (4.22)$$

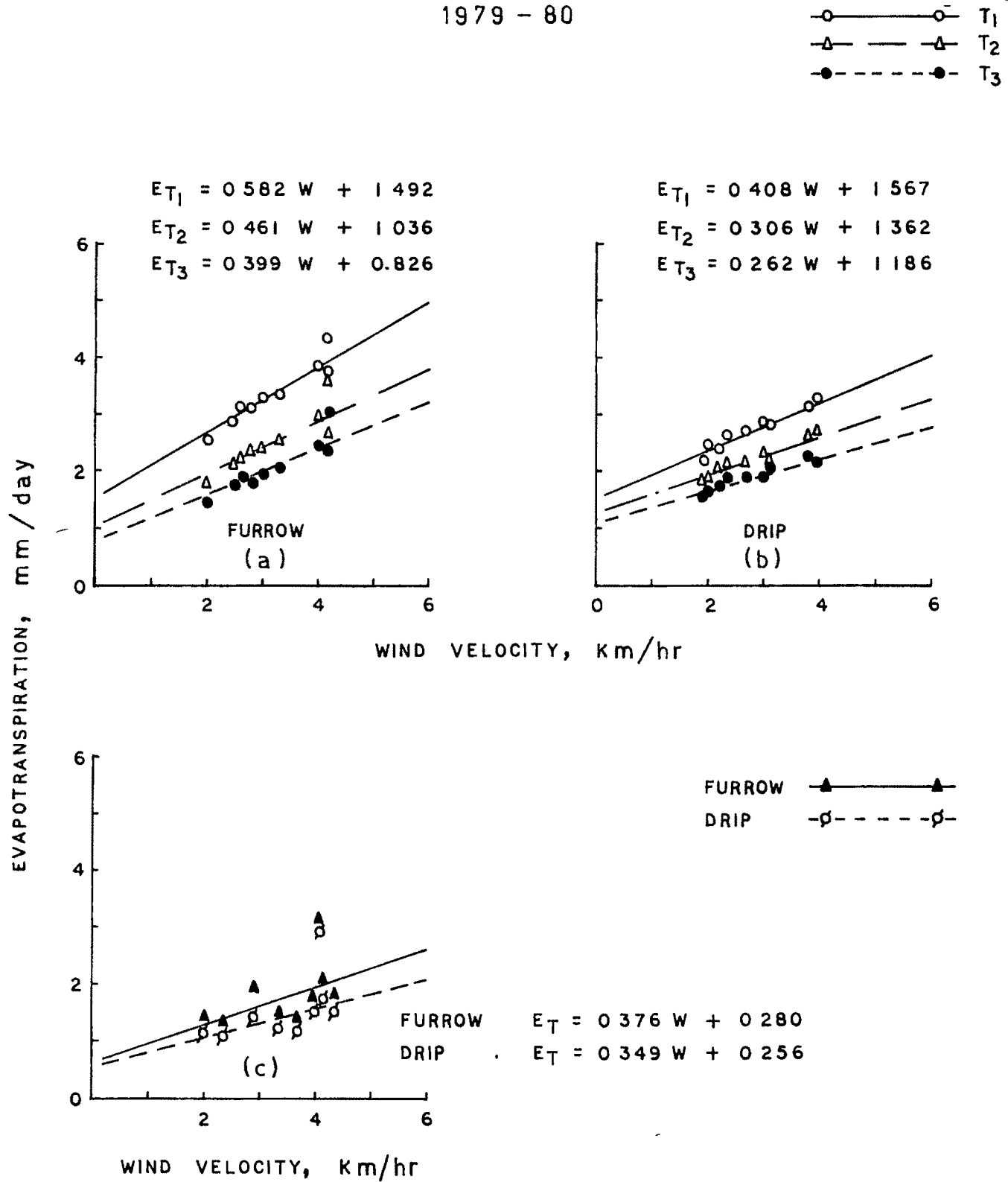


FIG 49 RELATIONSHIP BETWEEN WIND VELOCITY AND EVAPOTRANSPIRATION

$\circ$ — $\circ$ T_1
 $\triangle$ — $\triangle$ T_2
 $\bullet$ - - $\bullet$ T_3

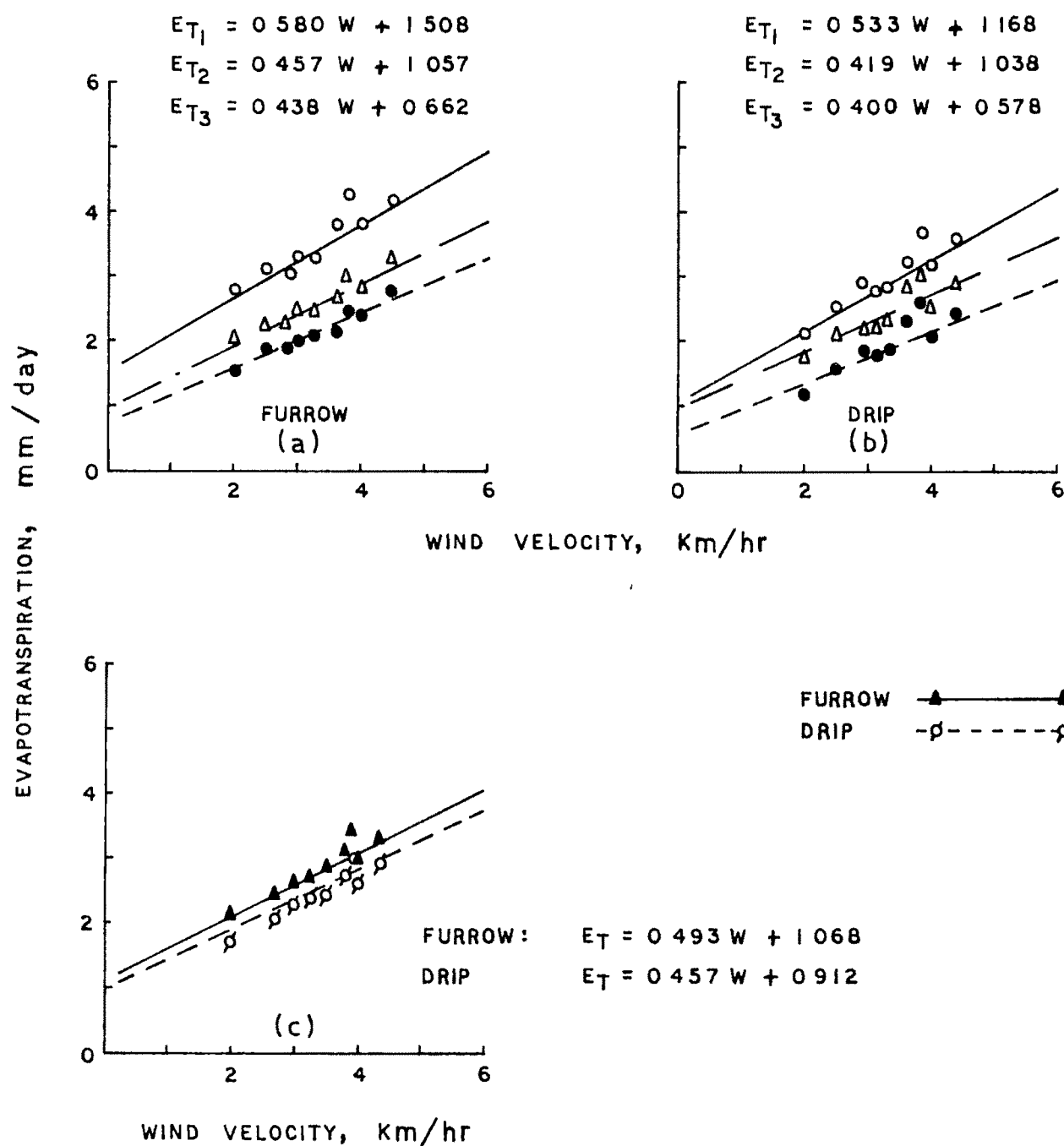


FIG 4 10 RELATIONSHIP BETWEEN WIND VELOCITY AND EVAPOTRANSPIRATION

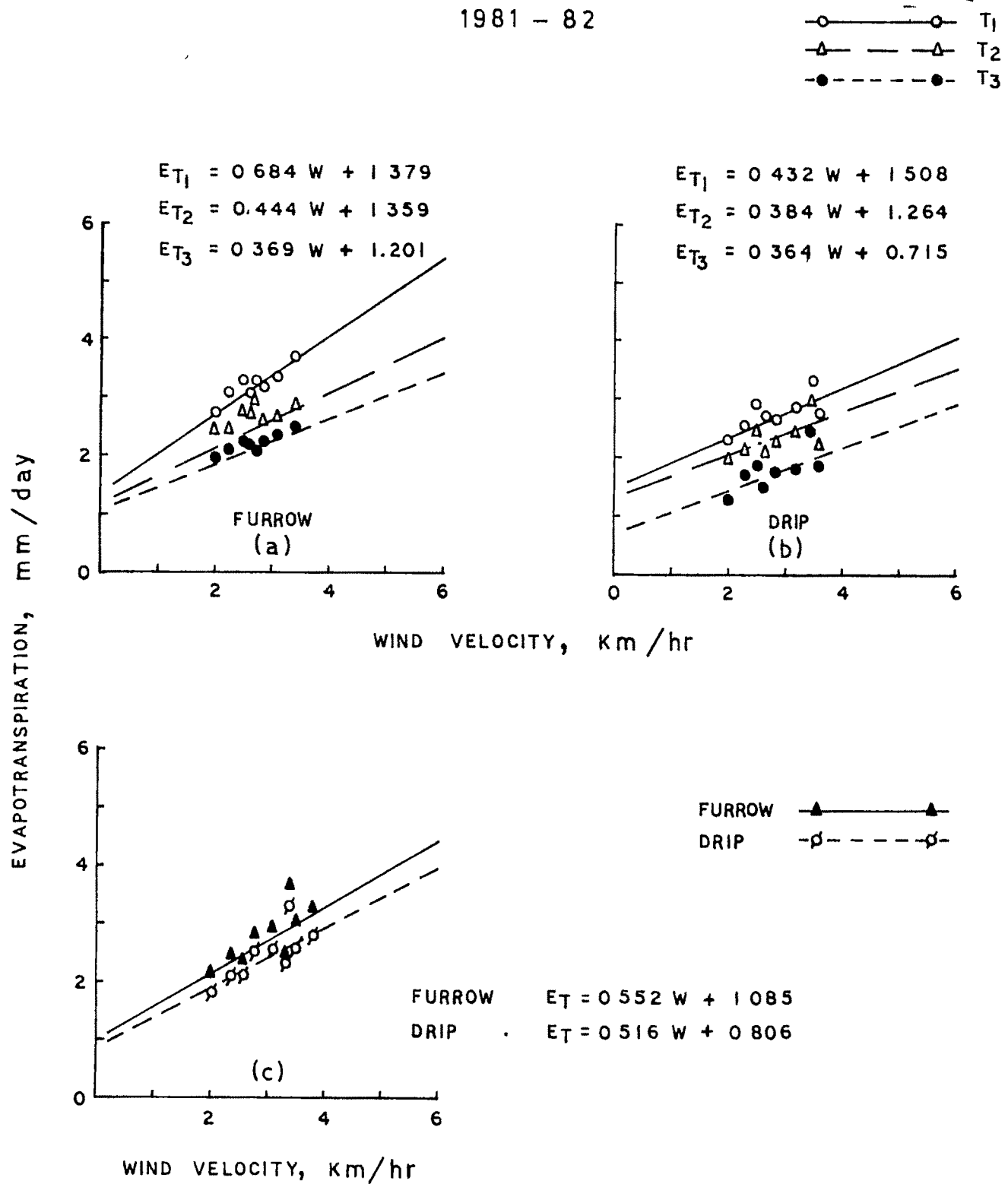


FIG 4 11 RELATIONSHIP BETWEEN WIND VELOCITY AND EVAPOTRANSPIRATION

1979 - 1982

66

○ — T₁
 △ — T₂
 ● — T₃

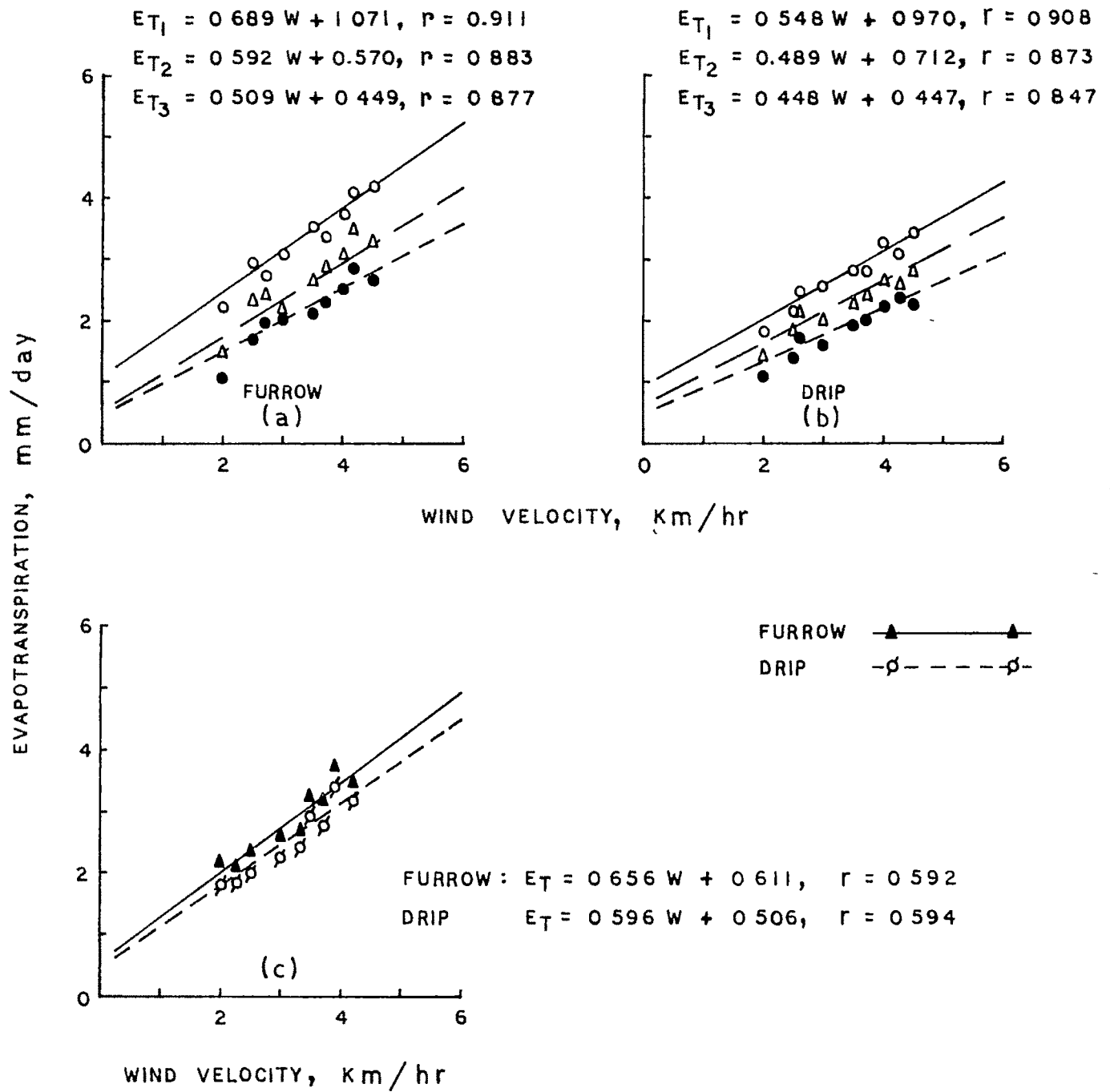


FIG 4 12 RELATIONSHIP BETWEEN WIND VELOCITY AND EVAPOTRANSPIRATION DURING THREE SEASONS

where, E_T = Evapotranspiration rate, mm/day and subscripts 1, 2 and 3 indicate soil moisture tension, atmosphere.

W = Wind velocity, km/hour.

The relationship indicates that with the increase of wind velocity, the E_T increases irrespective of soil moisture tension. The higher E_T is always associated with the lower soil moisture tension.

The relationship between W and E_T , averaged over soil moisture tensions separately under furrow and drip irrigation (Figures 4.9c to 4.11c), indicates that the higher E_T is due to higher values of W . The higher value of regression coefficient (Figure 4.12c) is associated with furrow irrigation. The equations are as follows :

$$\text{Furrow : } E_T = 0.656 W + 0.611, \quad r = 0.592 \quad (4.23)$$

$$\text{Drip : } E_T = 0.596 W + 0.506, \quad r = 0.594 \quad (4.24)$$

The results indicate a significant and positive correlation at 5 per cent level of significance. It may be mentioned that the results are in general agreement with those of Frost and Schwalen (1960) and Pelton (1967) who showed a reduction of 12 to 23 per cent evaporation from Bellani Plates due to reduction of wind travel by 15 to 49 per cent.

4.1.1.1.4 Sunshine hour

When the measured E_T (seven days' average) is plotted against the corresponding S hours, a linear relationship is obtained

1979 - 80

○ — T₁
 △ — T₂
 ● - - T₃

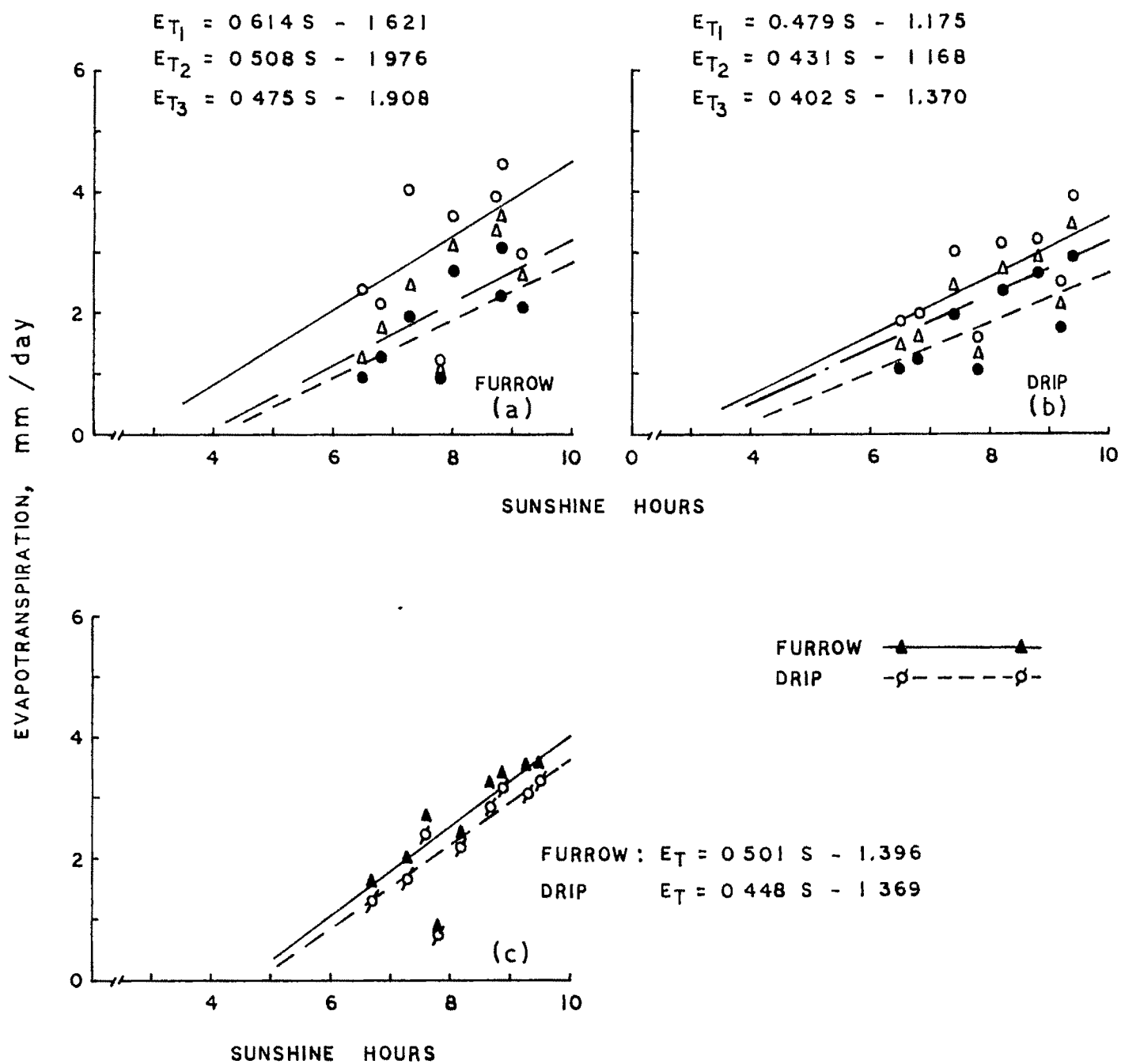


FIG 4 13 RELATIONSHIP BETWEEN SUNSHINE HOURS AND EVAPOTRANSPIRATION

—○— T₁
 —△— T₂
 -●- T₃

$E_{T_1} = 0.745 S - 3.011$
 $E_{T_2} = 0.590 S - 2.414$
 $E_{T_3} = 0.432 S - 1.529$

$E_{T_1} = 0.501 S - 1.287$
 $E_{T_2} = 0.462 S - 1.477$
 $E_{T_3} = 0.268 S - 0.278$

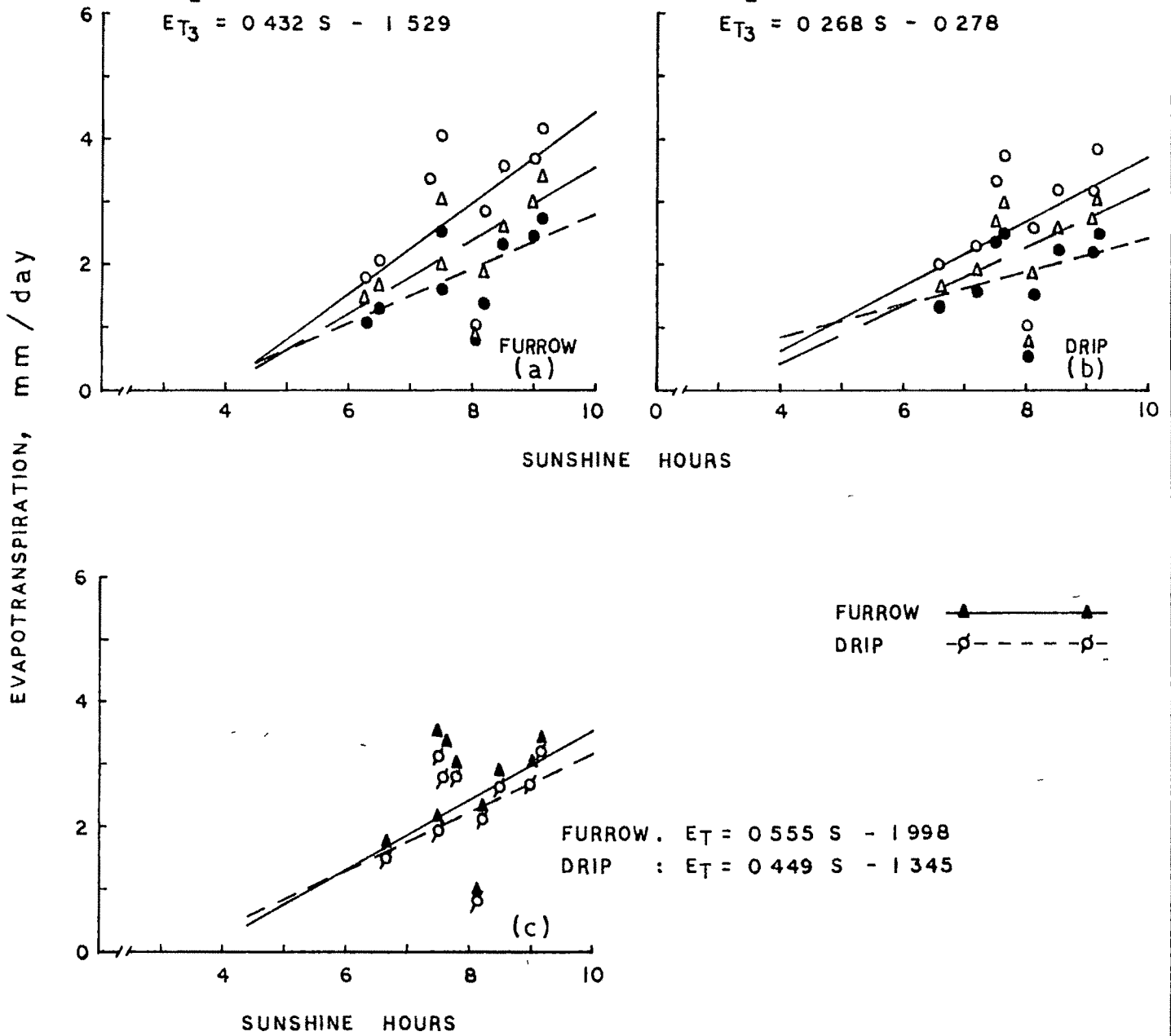


FIG 4 14 RELATIONSHIP BETWEEN SUNSHINE HOURS AND EVAPOTRANSPIRATION

1981 - 82

$\circ$ — $\circ$ T_1
 $\triangle$ — $\triangle$ T_2
 $\bullet$ - - $\bullet$ T_3

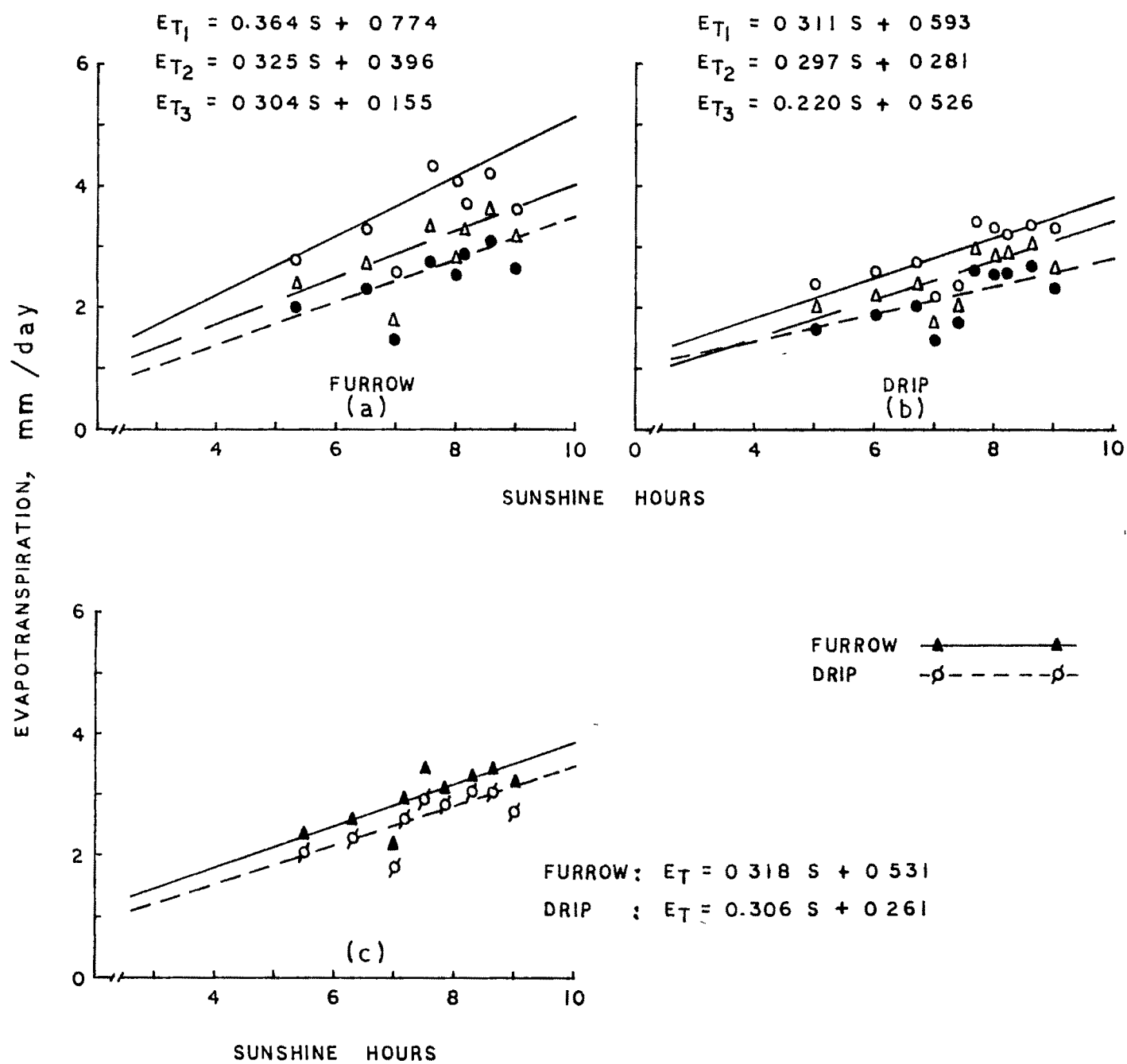


FIG 415 RELATIONSHIP BETWEEN SUNSHINE HOURS AND EVAPOTRANSPIRATION

(Figures 4.13, 4.14 and 4.15) for all the three seasons under furrow and drip irrigations. The relationship between sunshine hours and E_T , considering three seasons, data together (Figure 4.16), may be expressed by the following equations :

$$\text{Furrow : } E_{T_1} = 0.638 S - 1.590, \quad r = 0.940 \quad (4.25)$$

$$E_{T_2} = 0.508 S - 1.376, \quad r = 0.909 \quad (4.26)$$

$$E_{T_3} = 0.459 S - 1.335, \quad r = 0.917 \quad (4.27)$$

$$\text{Drip : } E_{T_1} = 0.431 S - 0.520, \quad r = 0.981 \quad (4.28)$$

$$E_{T_2} = 0.404 S - 0.740, \quad r = 0.963 \quad (4.29)$$

$$E_{T_3} = 0.351 S - 0.661, \quad r = 0.926 \quad (4.30)$$

where, E_T = Evapotranspiration rate, mm/day and subscripts
1, 2 and 3 indicate soil moisture tension, atmosphere.
S = Actual duration of bright sunshine hours.

The linear relationship indicates that with the increase in S hours, the E_T increases irrespective of soil moisture tension, methods of irrigation and season, although the rate of change in E_T is different. The equations (4.25 to 4.30) indicate that the influence of sunshine hours on E_T is more pronounced on wet soils. Its effect gradually decreases with the increase in soil moisture tension.

The relationship between S hours and E_T , averaged over soil moisture tensions (Figures 4.13c to 4.15c) separately under methods of irrigation, indicates that the rate of change of E_T is always higher in furrow irrigation. A significant and positive

1979 - 1982

72
 T_1
 T_2
 T_3

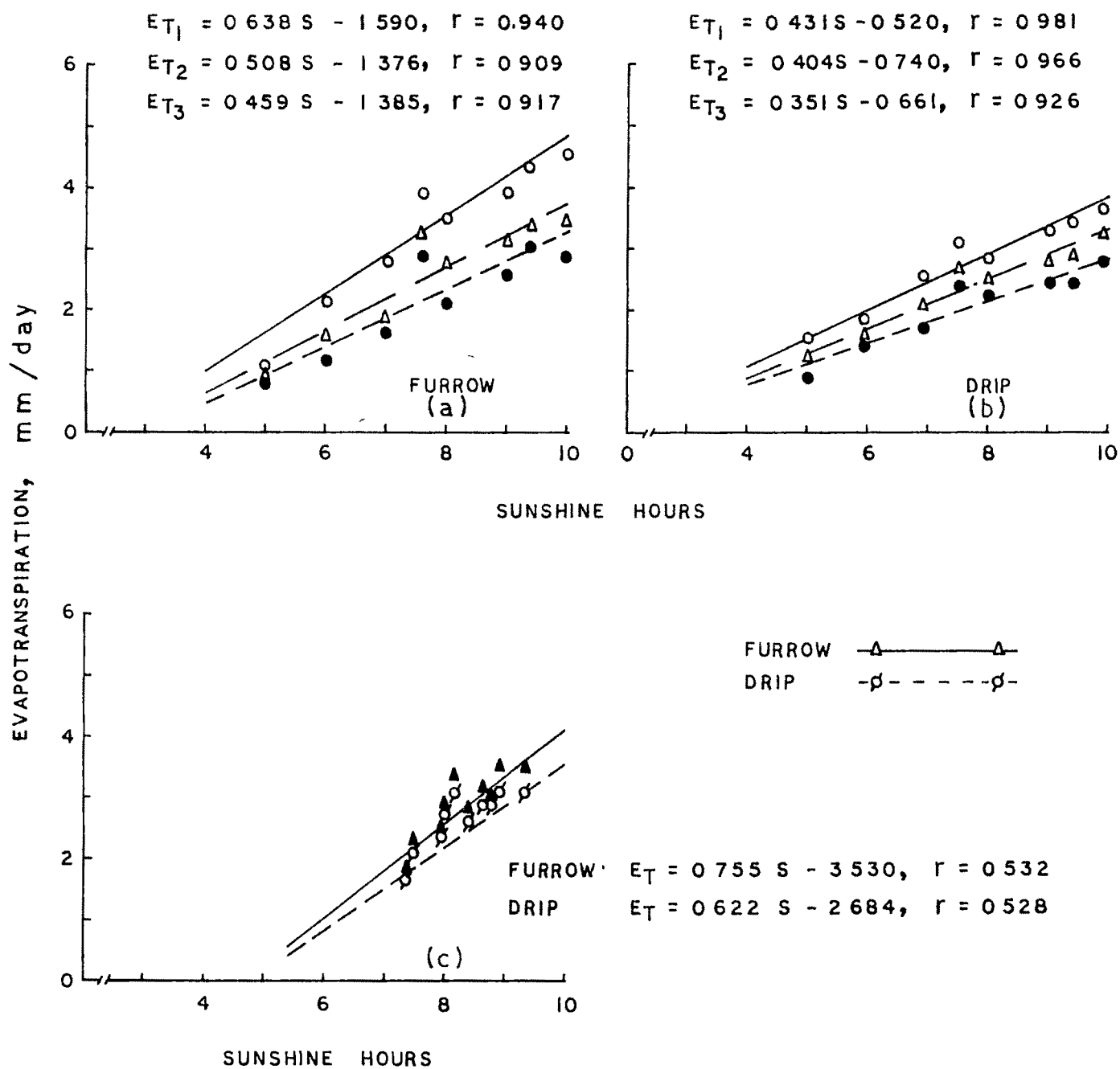


FIG 4.16 RELATIONSHIP BETWEEN SUNSHINE HOURS AND EVAPOTRANSPIRATION DURING THREE SEASONS

correlation exists between these two parameters at 5 per cent level of significance. The following equations have been obtained to express the relationship between sunshine hours and E_T (Figure 4.16c) in respect of methods of irrigation :

$$\text{Furrow : } E_T = 0.755 S - 3.530, \quad r = 0.532 \quad (4.31)$$

$$\text{Drip : } E_T = 0.622 S - 2.684, \quad r = 0.528 \quad (4.32)$$

The linear relationship between S and E_T may be explained as follows. Sunshine is a source of energy for the evapotranspiration process. In case of wet soil surface, the thermal contact coefficient of the soil is relatively large and more of net radiation enters the soil. As water is available, a large part of radiation is responsible for evaporation. The rate of evapotranspiration, which is more on bright sunny days, was reduced considerably when the sky was overcast with clouds. This is because during bright sunshine, all energy components are high (Burman and Loudon, 1968). These results are in agreement with those of Norum and Larson (1960), Ghosh (1974) and Maity and Pandya (1975).

4.1.1.2 Soil moisture tension

The relationship between E_T and three levels of soil moisture tension was studied. Starting from the beginning of irrigation treatments several observations were made on E_T under different soil moisture tension for each season. Best-fit polynomial regression equations are obtained and the curves are plotted to present E_T as a function of weeks of growth to show the influence of soil moisture tension on E_T throughout the growth period (Figures

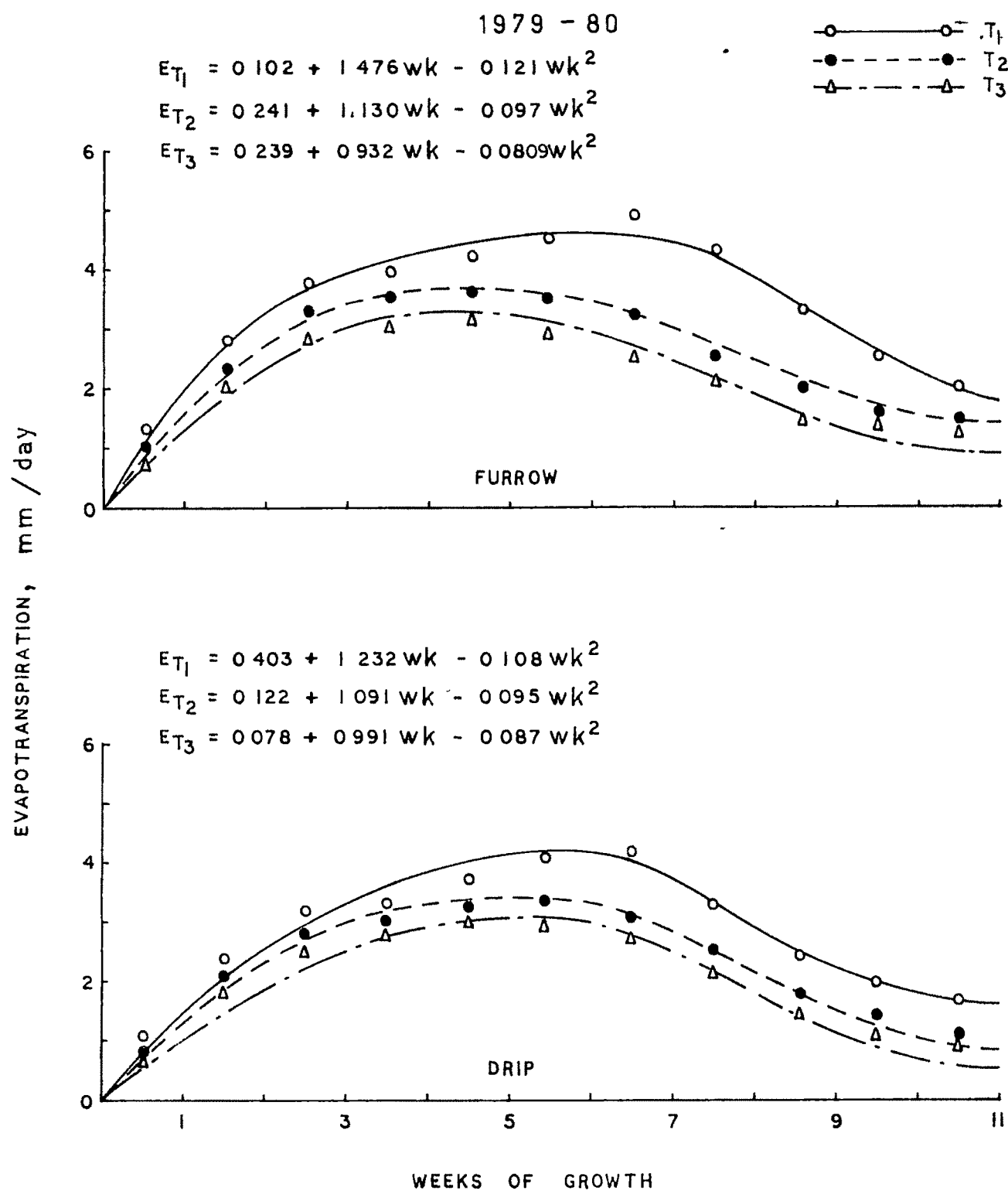


FIG 4.17 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF WEEKS OF GROWTH UNDER SOIL MOISTURE TENSIONS

1980 - 81

75

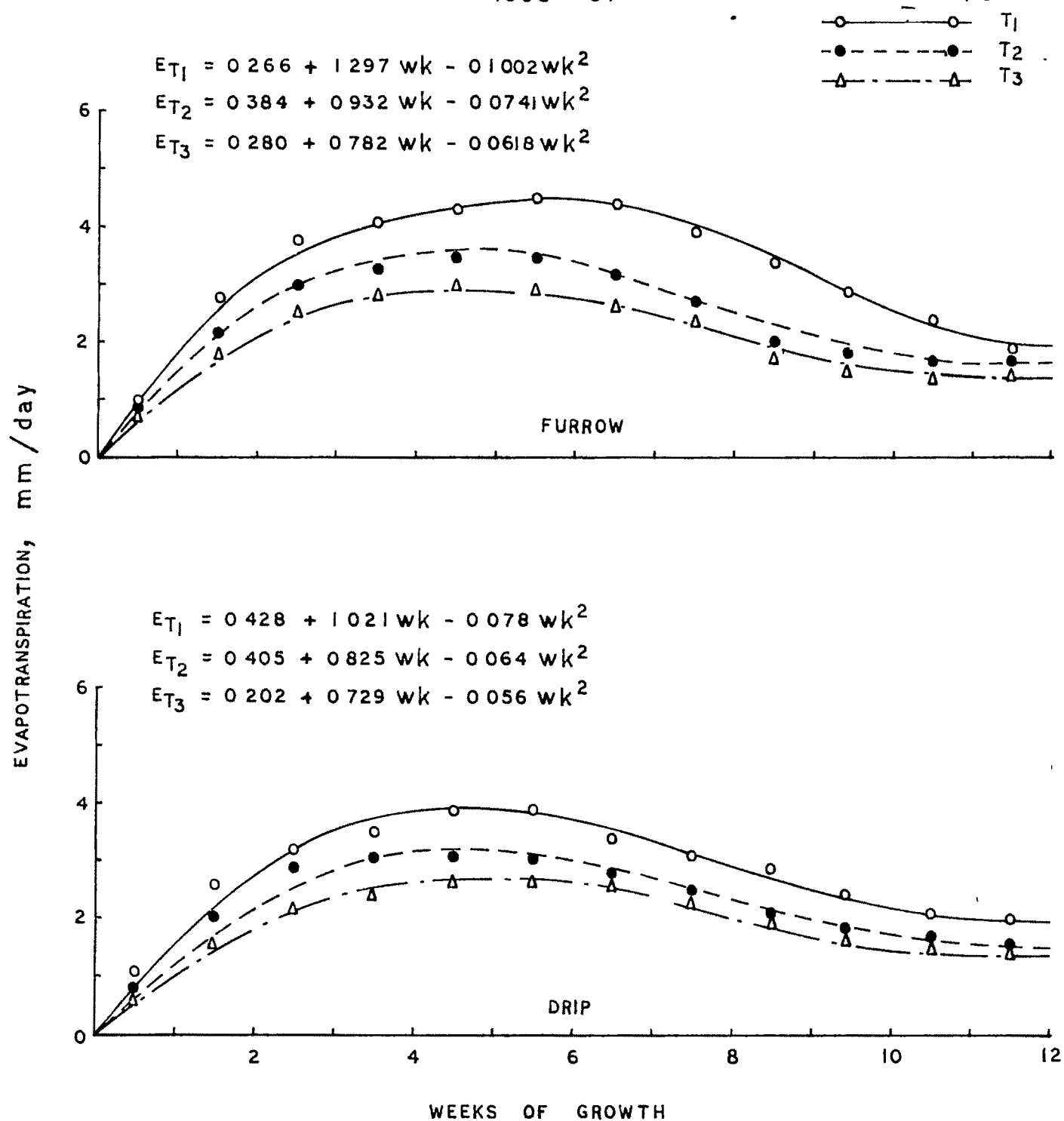


FIG 4 18

MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF WEEKS OF GROWTH UNDER SOIL MOISTURE TENSIONS

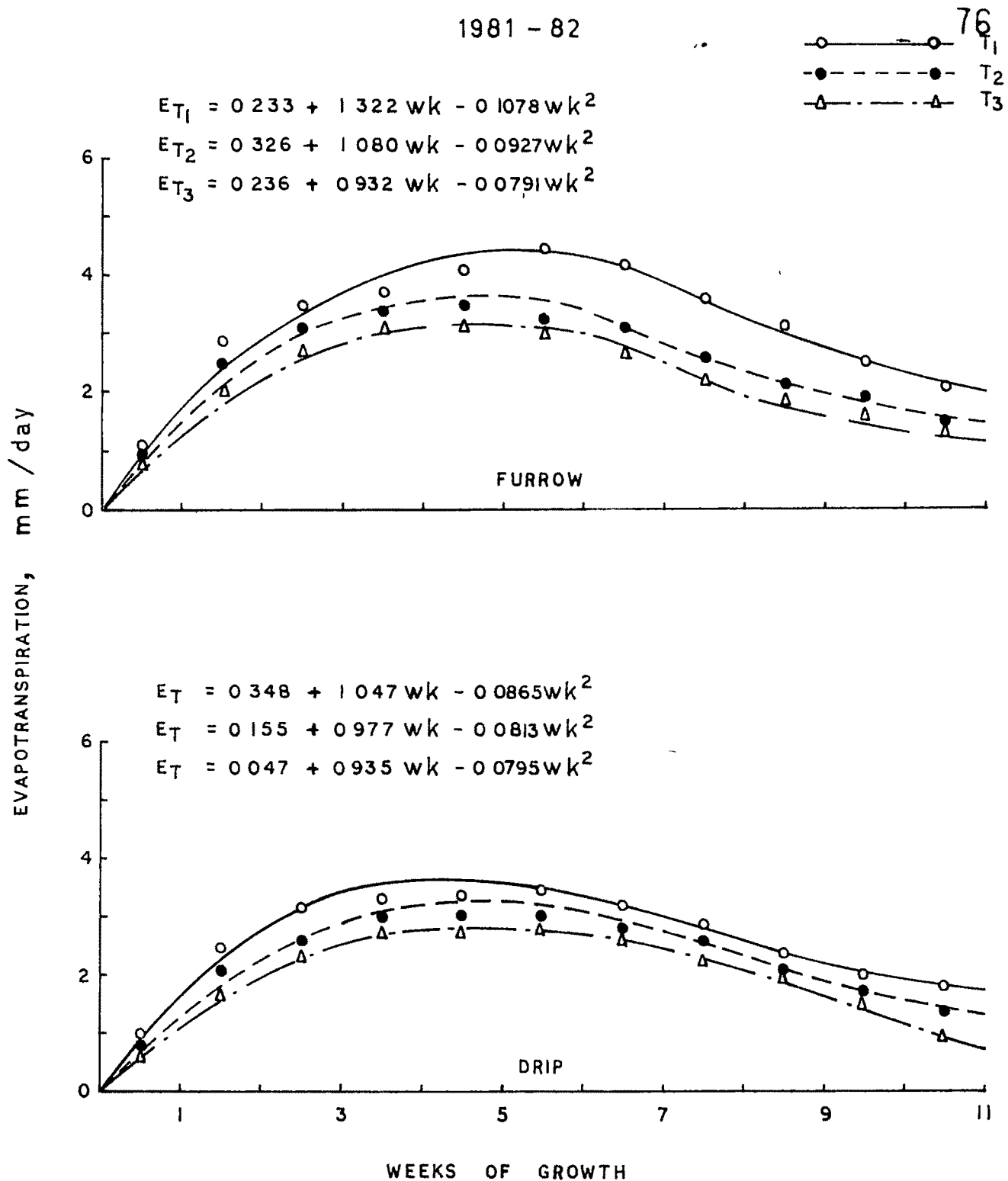


FIG 419 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF WEEKS OF GROWTH UNDER SOIL MOISTURE TENSIONS

4.17 to 4.20). The E_T gradually increases during the first part of the season until the peak is reached during the maximum plant growth (during 6th and 7th week after emergence). This trend is followed by a decreasing rate during the latter part of the season when possibly the physiological growth stage limited the plant growth. Although great similarity is observed in the nature of these three curves in all the three seasons, the rate of evapotranspiration varies with soil moisture tension and methods of irrigation. While the highest E_T is observed at 0.4 atmosphere in all three seasons in both systems of irrigation (Figures 4.17 to 4.20), it decreases with the increase in soil moisture tension.

The equations relating to the curves (Figure 4.20) for all three seasons considered together are :

$$\text{Furrow : } E_{T_1} = 0.164 + 1.401 \text{ WK} - 0.1134 \text{ WK}^2 \quad (4.33)$$

$$E_{T_2} = 0.153 + 1.101 \text{ WK} - 0.0941 \text{ WK}^2 \quad (4.34)$$

$$E_{T_3} = 0.231 + 0.910 \text{ WK} - 0.0789 \text{ WK}^2 \quad (4.35)$$

$$\text{Drip : } E_{T_1} = 0.116 + 1.261 \text{ WK} - 0.1069 \text{ WK}^2 \quad (4.36)$$

$$E_{T_2} = 0.182 + 1.002 \text{ WK} - 0.0843 \text{ WK}^2 \quad (4.37)$$

$$E_{T_3} = 0.071 + 0.916 \text{ WK} - 0.0776 \text{ WK}^2 \quad (4.38)$$

where, E_T = Evapotranspiration rate, mm/day and subscripts 1, 2 and 3 indicate soil moisture tension, atmosphere.

WK = Weeks of growth.

The total evapotranspiration, ($E_{T(s)}$), under three soil moisture tension (Table 4.1) decreases non-linearly with the

1979 - 1982

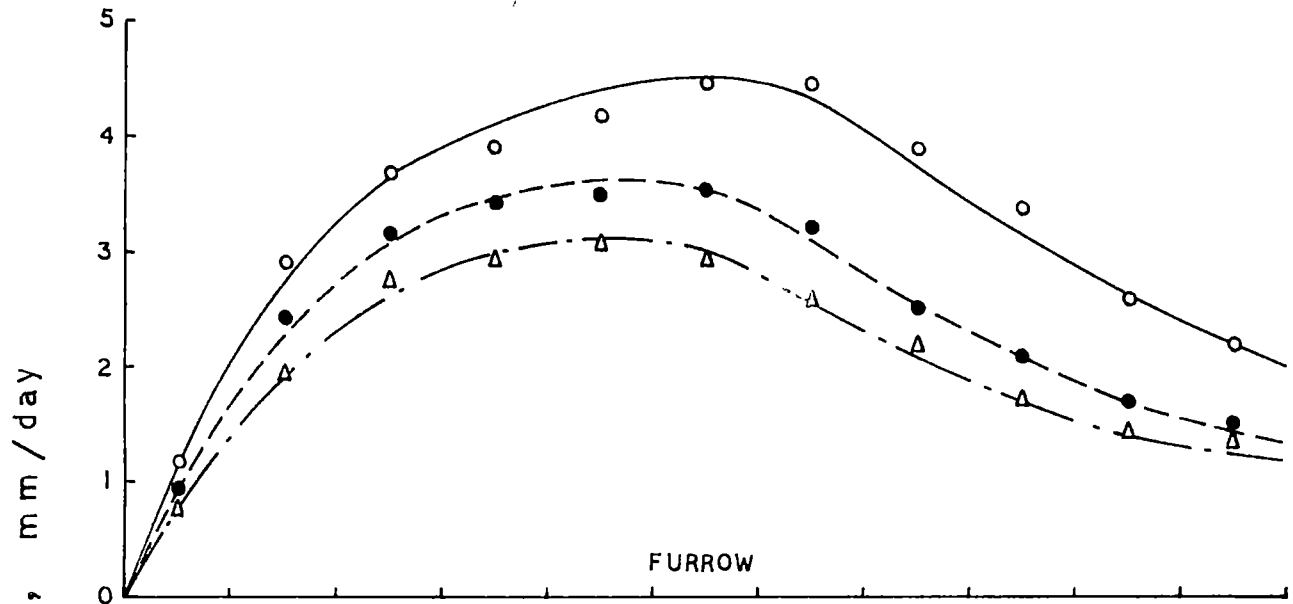
78

$$ET_1 = 0.164 + 1.401wk - 0.1134wk^2$$

$$ET_2 = 0.153 + 1.101wk - 0.0941wk^2$$

$$ET_3 = 0.231 + 0.910wk - 0.0789wk^2$$

○ — T₁
● - - T₂
△ - - T₃



$$ET_1 = 0.116 + 1.261wk - 0.1069wk^2$$

$$ET_2 = 0.182 + 1.002wk - 0.0843wk^2$$

$$ET_3 = 0.071 + 0.916wk - 0.0776wk^2$$

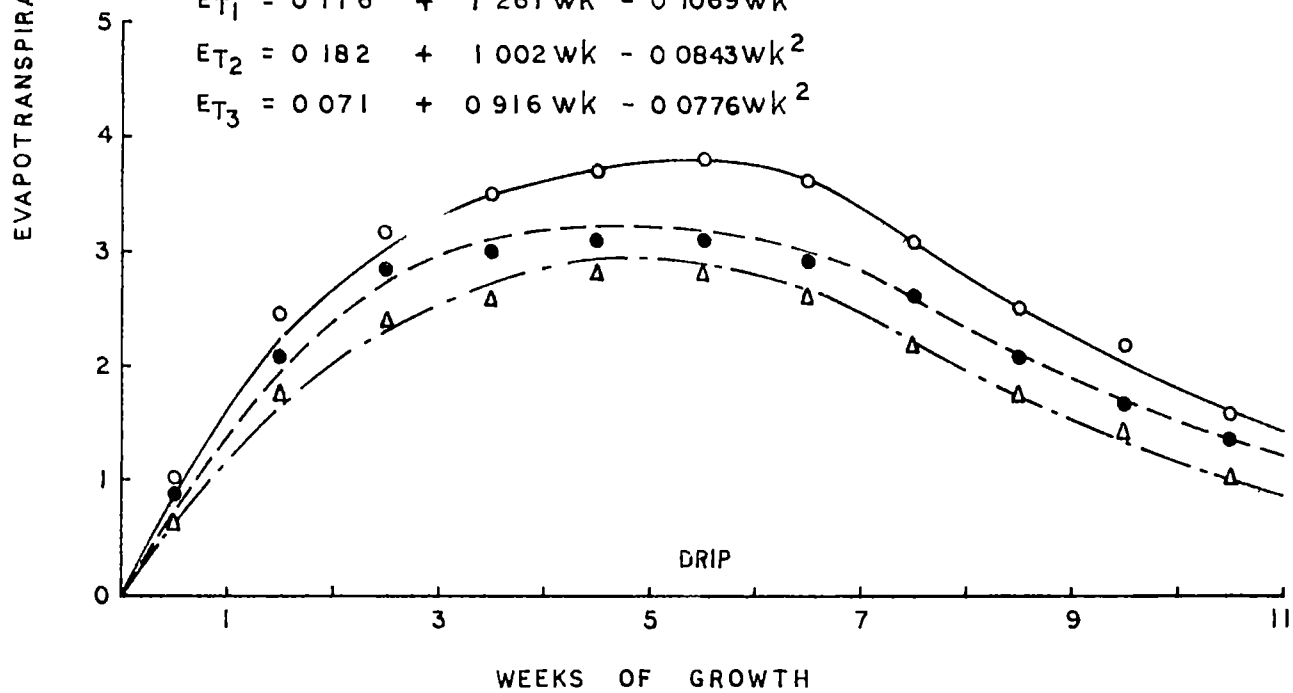


FIG 4 20 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF WEEKS OF GROWTH UNDER SOIL MOISTURE TENSIONS

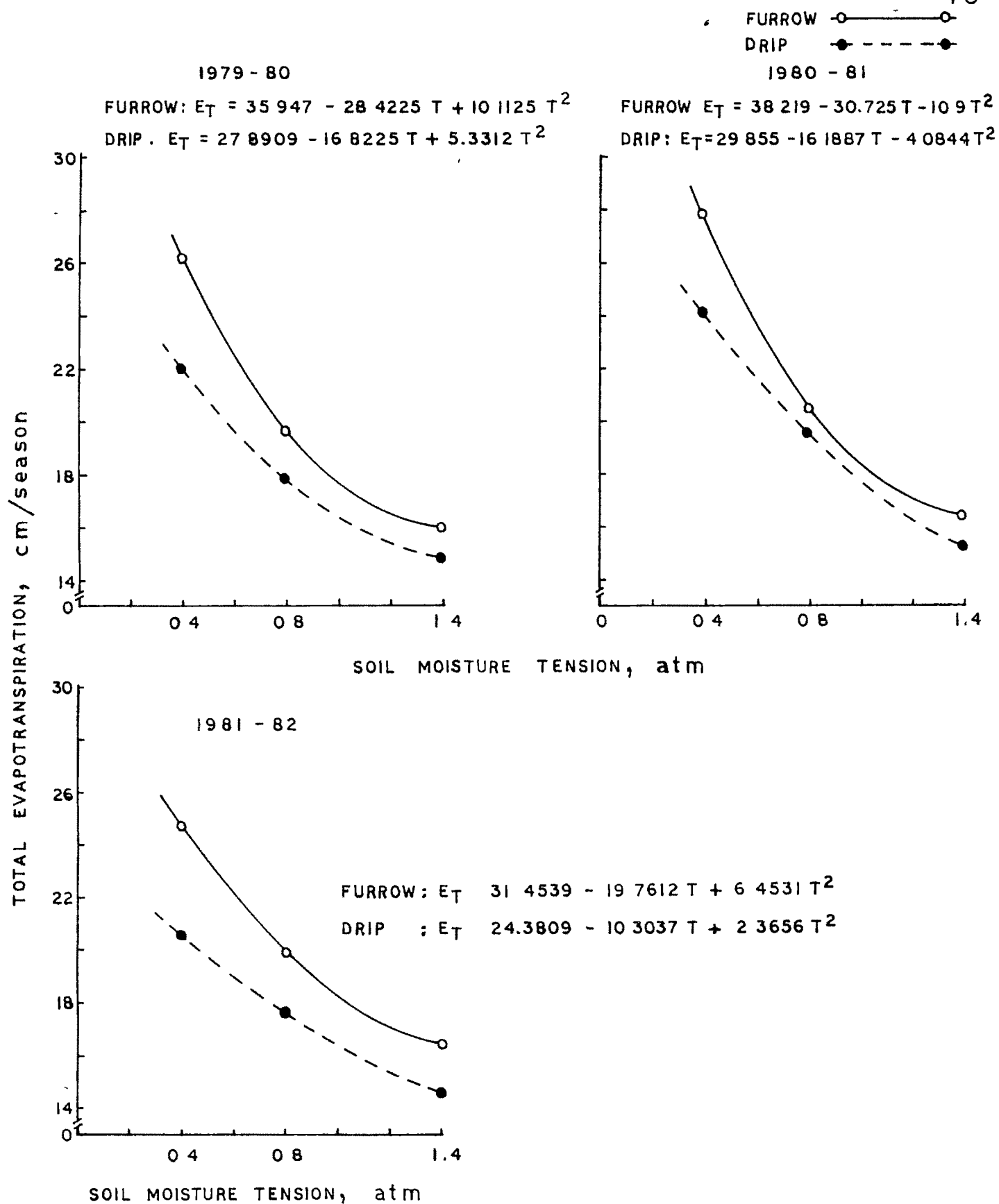


FIG 4 21 RELATIONSHIP BETWEEN TOTAL EVAPOTRANSPIRATION AND SOIL MOISTURE TENSION

increase of soil moisture tension irrespective of the methods of irrigation and seasons. The difference in $E_{T(s)}$ between levels of soil moisture tension is highly significant in all the three seasons. Significant differences in $E_{T(s)}$ between furrow and drip irrigations under any moisture tension are observed. Higher $E_{T(s)}$ value is associated with 0.4 atmosphere.

Table 4.1 Variation in total evapotranspiration (cm) with soil moisture tension and irrigation methods

Methods	Soil moisture tension, atmosphere			S.E.m $\pm$	C.D. at 5%
	0.4	0.8	1.2		
1979-80					
Furrow	26.229	19.722	16.727		
Drip	22.067	17.847	15.478	0.329	0.758
Average	24.148	18.784	16.103	0.232	0.536
S.E.m $\pm$	0.307				
C.D. at 5%	0.856				
1980-81					
Furrow	27.705	20.583	17.158		
Drip	24.002	19.530	16.462	0.388	0.894
Average	25.854	20.056	16.810	0.274	0.633
S.E.m $\pm$	0.412				
C.D. at 5%	1.285				
1981-82					
Furrow	24.614	19.807	17.117		
Drip	20.624	17.693	15.415	0.505	1.164
Average	22.619	18.750	16.266	0.357	0.823
S.E.m $\pm$	0.460				
C.D. at 5%	1.241				

The relationship between $E_{T(s)}$ and soil moisture tension (T) (Figure 4.21) is curvilinear. The following equations express the

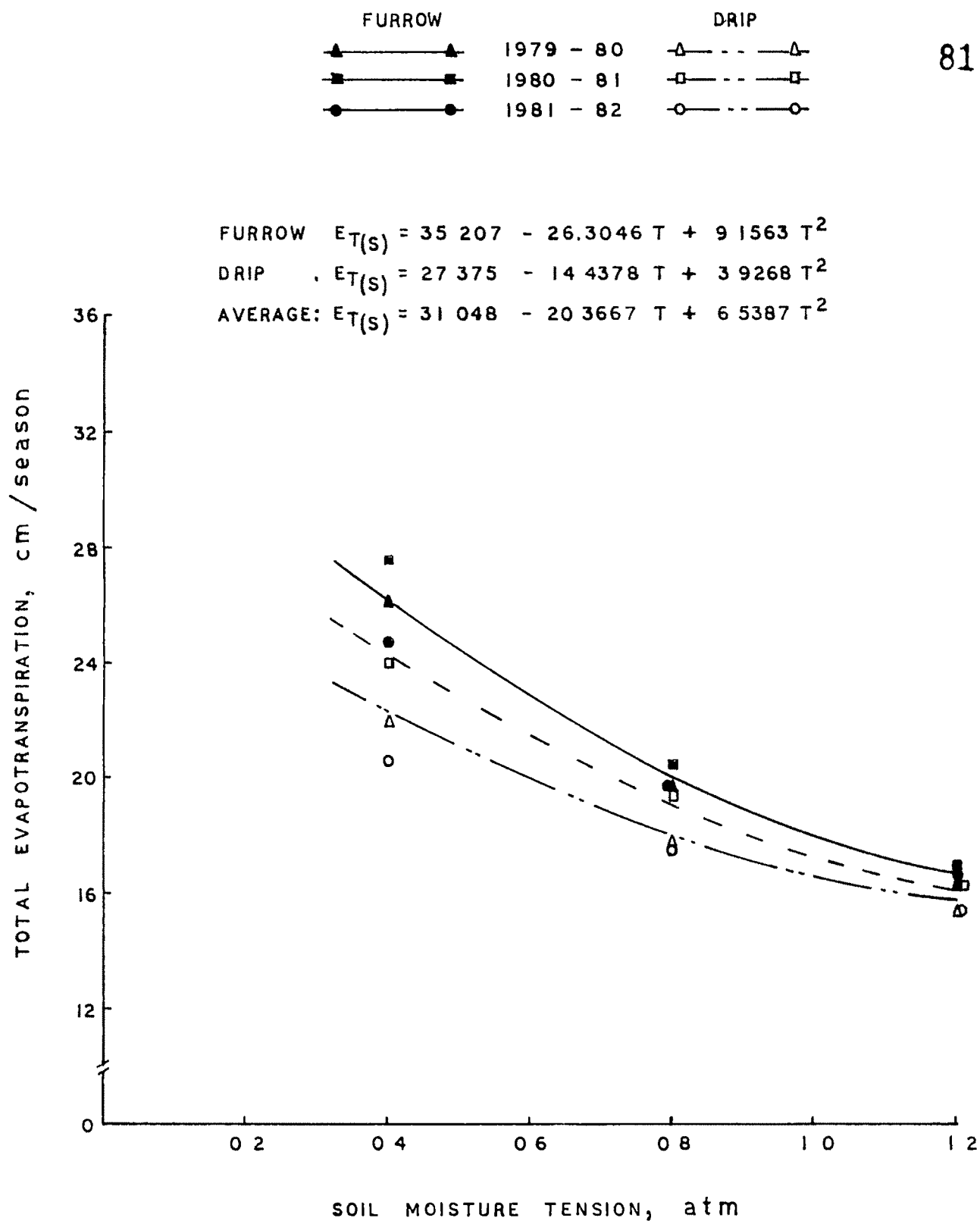


FIG 4 22 RELATIONSHIP BETWEEN TOTAL EVAPOTRANSPIRATION AND SOIL MOISTURE TENSION

relationship between $E_{T(s)}$ averaged over three seasons (Figure 4.22) and T under furrow and drip irrigations :

$$\text{Furrow : } E_{T(s)} = 35.207 - 26.3046 T + 9.1563 T^2 \quad (4.39)$$

$$\text{Drip : } E_{T(s)} = 27.375 - 14.4378 T + 3.9268 T^2 \quad (4.40)$$

$$\text{Average : } E_{T(s)} = 31.048 - 20.3667 T + 6.5387 T^2 \quad (4.41)$$

where, $E_{T(s)}$ = Total evapotranspiration measured, cm/season

T = Soil moisture tension, atmosphere.

The equations (4.39 to 4.41) indicate that E_T will decrease with the increase of T and the rate of decrease is non-linear. The decrease in $E_{T(s)}$ values with the increase in T (a) from 0.4 to 0.8 and (b) from 0.8 to 1.2 atmosphere are 23.42 and 15.96 per cent in (a) and 17.5 and 14.86 in (b) respectively under furrow and drip irrigations.

The higher E_T from low soil moisture tension can be explained by the fact that evapotranspiration is largely governed by the energy available for evaporating water only when the soil surface is wet because of the resistance to water loss in wet soil is small (Ritchie, 1971, and Maity, 1975). Moreover, the thermal contact coefficient of moist soil is relatively large and more of the net radiation enters the soil. Since water is available, large part of radiation is used up in evaporation rather than heating the soil. As soil surface begins to dry up and moisture is not conducted to the interface fast enough to meet the evaporative demand because

of increasing soil resistance to water flow, the evapotranspiration decreases (Hanks et al., 1968, and Black et al., 1969). As E_T proceeds, soil moisture tension increases, the length and tortuosity of the vapour pathway progressively increases and E_T declines (Millel, 1971, and Akopyan and Oganyan, 1978). The results are in conformity with that of Ghosh (1974).

4.1.1.3 Nitrogen

The influence of nitrogen (N) on E_T (Figures 4.23 to 4.26) indicates that E_T under four levels of N increases gradually till the peak is reached during the maximum plant growth and thereafter decreases gradually due to ageing of crop. This trend is observed in all the three seasons under four levels of N and two methods of irrigation. Although the E_T under four levels of N has similar trend, E_T decreases with the increase in nitrogen. The highest and lowest E_T are associated with 300 kg and 0 kg N/ha respectively.

The relationship between E_T and weeks of growth (Fig. 4.26) for all seasons considered together is given by the equations :

Furrow:

$$E_T(N_0) = 0.1188 + 1.0298 WK - 0.0856 WK^2 \quad (4.42)$$

$$E_T(N_1) = 0.1668 + 1.1263 WK - 0.0950 WK^2 \quad (4.43)$$

$$E_T(N_2) = 0.1999 + 1.1338 WK - 0.0946 WK^2 \quad (4.44)$$

$$E_T(N_3) = 0.2198 + 1.2173 WK - 0.1018 WK^2 \quad (4.45)$$

Drip :

$$E_T(N_0) = 0.0877 + 0.9238 WK - 0.0777 WK^2 \quad (4.46)$$

$$E_T(N_1) = 0.1304 + 1.0037 WK - 0.0844 WK^2 \quad (4.47)$$

$$E_T(N_2) = 0.1713 + 1.0760 WK - 0.0893 WK^2 \quad (4.48)$$

$$E_T(N_3) = 0.2051 + 1.1365 WK - 0.0944 WK^2 \quad (4.49)$$

1979 - 80

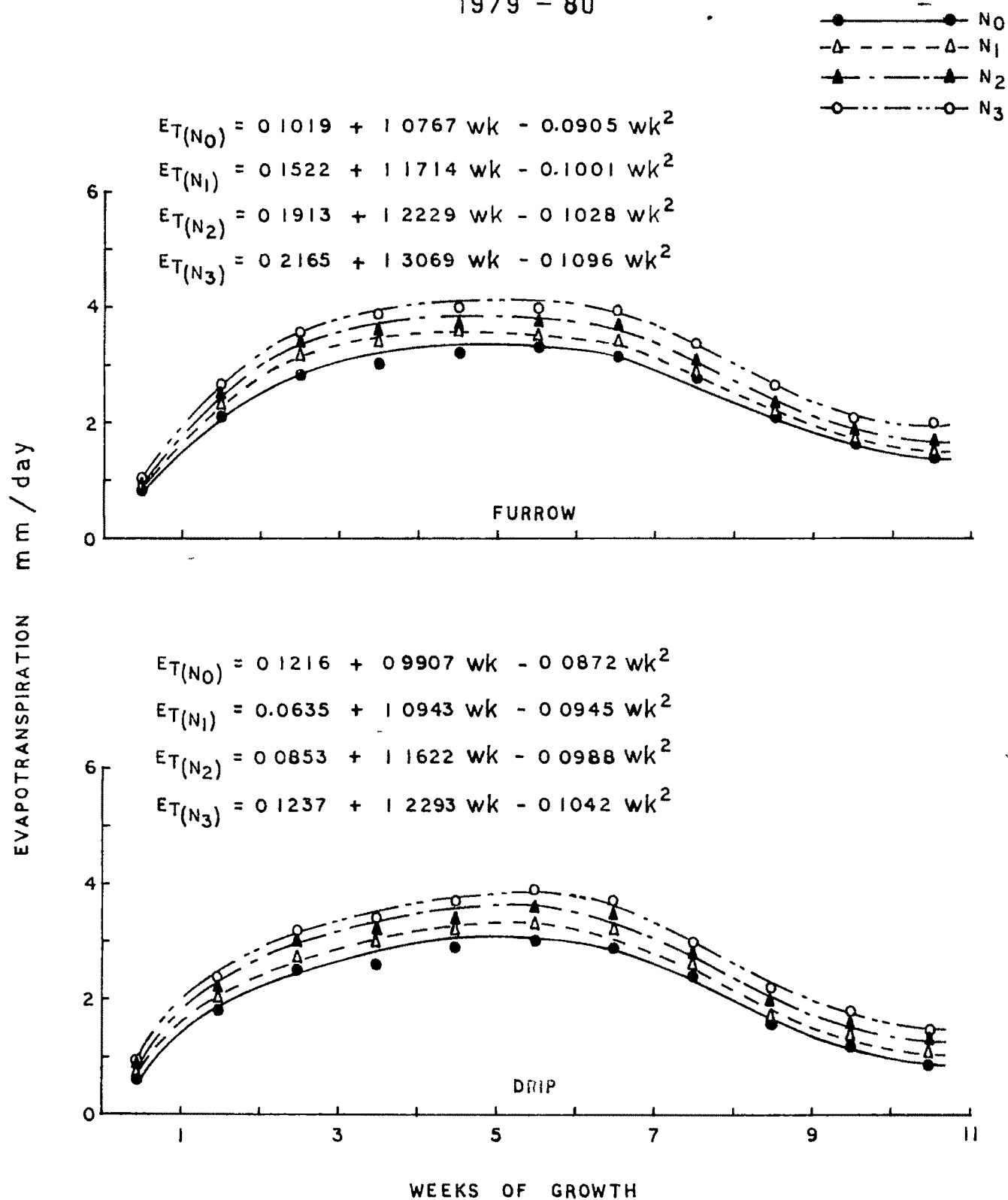


FIG 4 23 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF WEEKS OF GROWTH UNDER FOUR LEVELS OF NITROGEN

1980 - 81

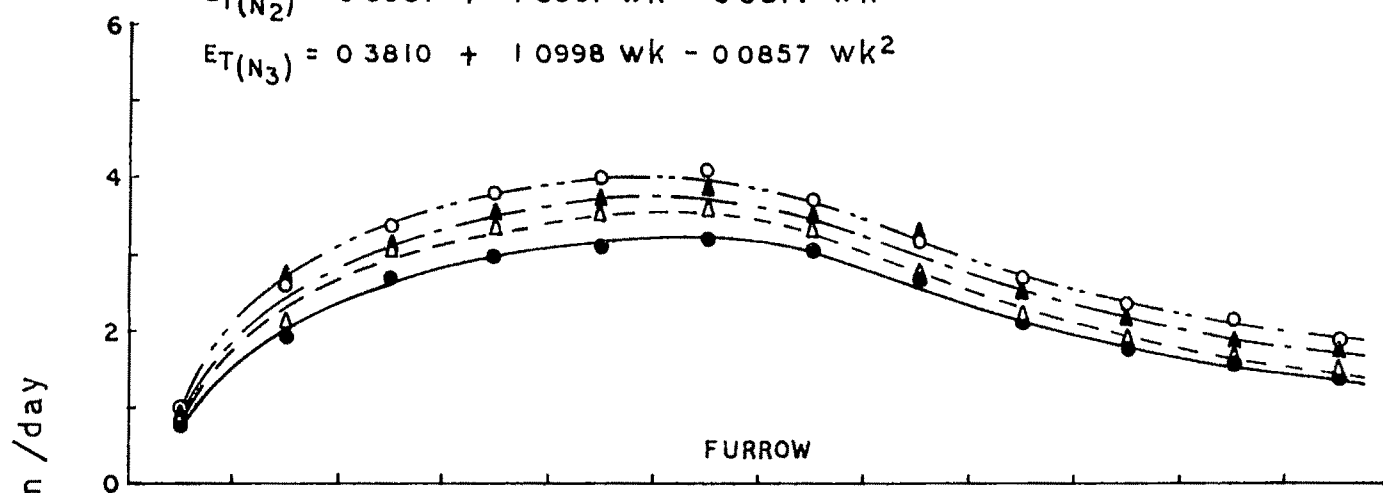
●——● N₀
 -Δ- -Δ- N₁
 ▲——▲ N₂
 ○——○ N₃

$$E_{T(N_0)} = 0.2197 + 0.9024 \text{ wk} - 0.0704 \text{ wk}^2$$

$$E_{T(N_1)} = 0.2922 + 0.9771 \text{ wk} - 0.0774 \text{ wk}^2$$

$$E_{T(N_2)} = 0.3981 + 1.0361 \text{ wk} - 0.0814 \text{ wk}^2$$

$$E_{T(N_3)} = 0.3810 + 1.0998 \text{ wk} - 0.0857 \text{ wk}^2$$



$$E_{T(N_0)} = 0.2615 + 0.7735 \text{ wk} - 0.0599 \text{ wk}^2$$

$$E_{T(N_1)} = 0.3065 + 0.8425 \text{ wk} - 0.0652 \text{ wk}^2$$

$$E_{T(N_2)} = 0.3958 + 0.9071 \text{ wk} - 0.0703 \text{ wk}^2$$

$$E_{T(N_3)} = 0.4115 + 0.9626 \text{ wk} - 0.0741 \text{ wk}^2$$

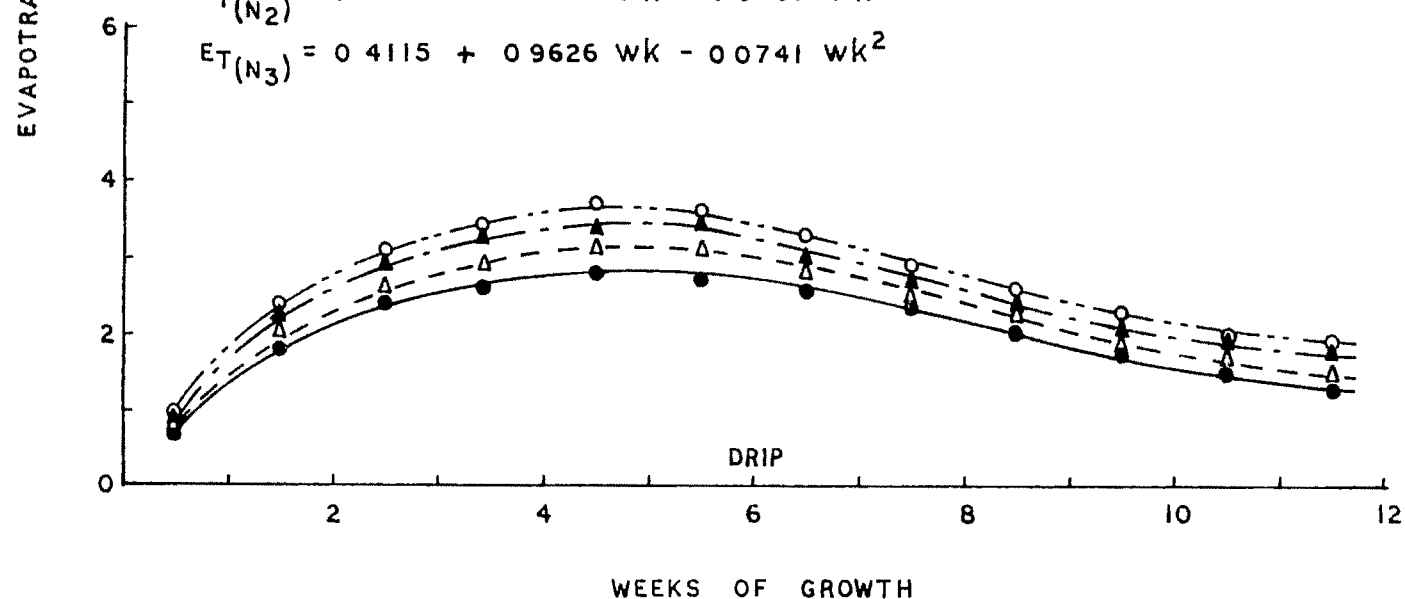


FIG 4 24 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF WEEKS OF GROWTH UNDER FOUR LEVELS OF NITROGEN

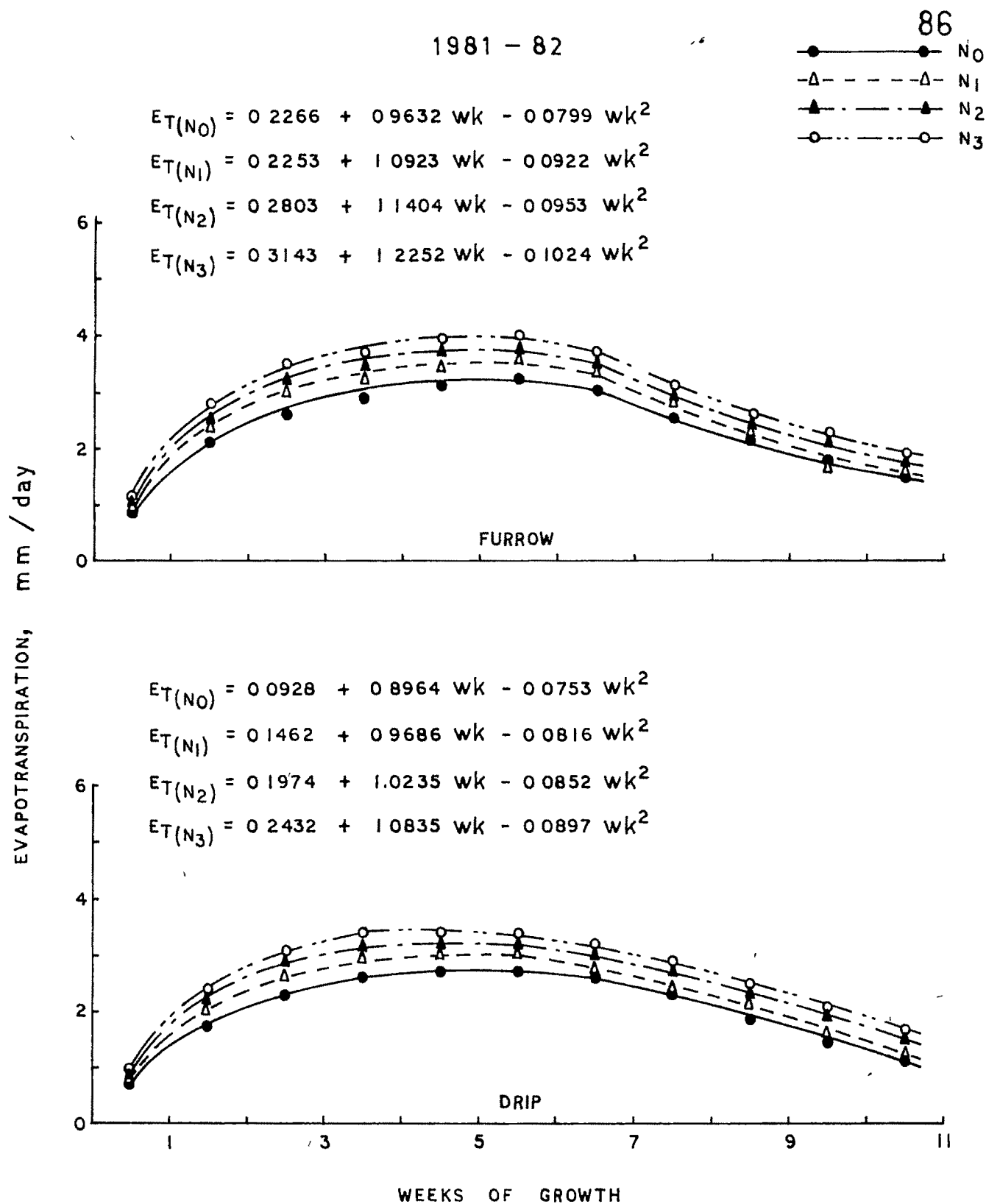


FIG 4 25 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF WEEKS OF GROWTH UNDER FOUR LEVELS OF NITROGEN

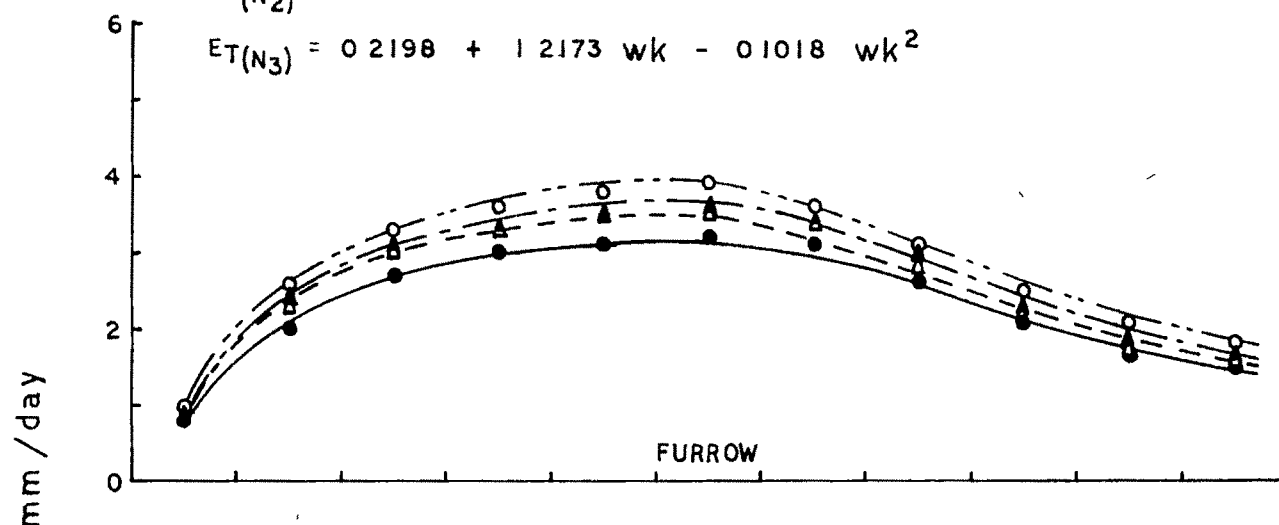
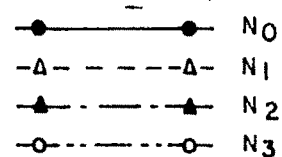
1979 - 1982

$$ET(N_0) = 0.1188 + 1.0298 \text{ wk} - 0.0856 \text{ wk}^2$$

$$ET(N_1) = 0.1668 + 1.1263 \text{ wk} - 0.0950 \text{ wk}^2$$

$$ET(N_2) = 0.1999 + 1.1338 \text{ wk} - 0.0946 \text{ wk}^2$$

$$ET(N_3) = 0.2198 + 1.2173 \text{ wk} - 0.1018 \text{ wk}^2$$



$$ET(N_0) = 0.0877 + 0.9238 \text{ wk} - 0.0777 \text{ wk}^2$$

$$ET(N_1) = 0.1304 + 1.0037 \text{ wk} - 0.0844 \text{ wk}^2$$

$$ET(N_2) = 0.17129 + 1.0760 \text{ wk} - 0.0898 \text{ wk}^2$$

$$ET(N_3) = 0.2051 + 1.1365 \text{ wk} - 0.0944 \text{ wk}^2$$

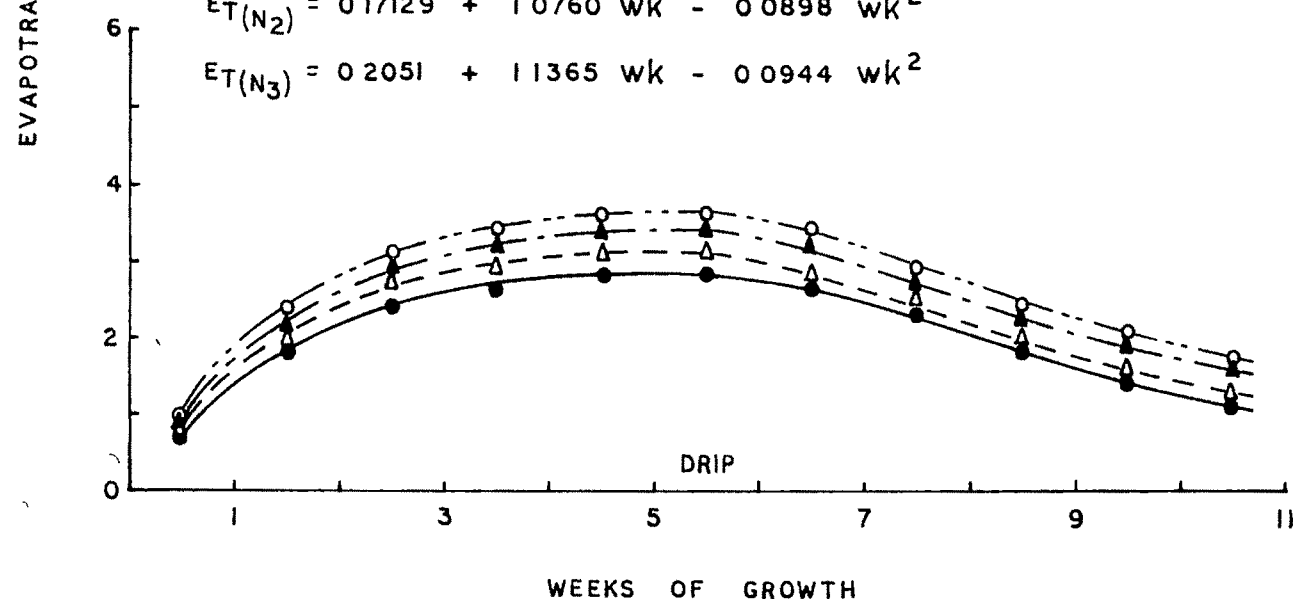


FIG 4 26 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF WEEKS OF GROWTH UNDER FOUR LEVELS OF NITROGEN DURING THREE SEASONS

where, E_T = Evapotranspiration rate, mm/day and subscripts N_0 , N_1 , N_2 and N_3 indicate levels of nitrogen, kg/ha.

WK = Weeks of growth.

These equations (4.42 to 4.49) can be used to find out E_T at any stage of growth under any four levels of N and methods of irrigation.

Higher $E_{T(s)}$ values are associated with 300 kg N in all the three seasons (Table 4.2). With the increase in nitrogen from (a) 0 kg to 100 kg, (b) 0 kg to 200 kg and (c) 0 kg to 300 kg, the $E_{T(s)}$ increases by 9.175 per cent in (a), 19.263 per cent in (b) and 28.686 per cent in (c) (Average data).

On further examination, the results (Table 4.2) reveal that under each level of N in all three seasons higher $E_{T(s)}$ values are from furrow irrigation. The differences in $E_{T(s)}$ values between two methods of irrigation are highly significant indicating the influence of methods of irrigation on evapotranspiration.

Considering three seasons data together the following equations have been developed to express the relationship (Figure 4.27) between $E_{T(s)}$ and nitrogen in respect of methods of irrigation and average data.

$$\text{Furrow : } E_{T(s)} = 18.6037 + 0.01517 N + 0.0000055 N^2 \quad (4.50)$$

$$\text{Drip : } E_{T(s)} = 16.3775 + 0.01392 N + 0.00000927 N^2 \quad (4.51)$$

$$\text{Average : } E_{T(s)} = 17.4276 + 0.01644 N + 0.00000108 N^2 \quad (4.52)$$

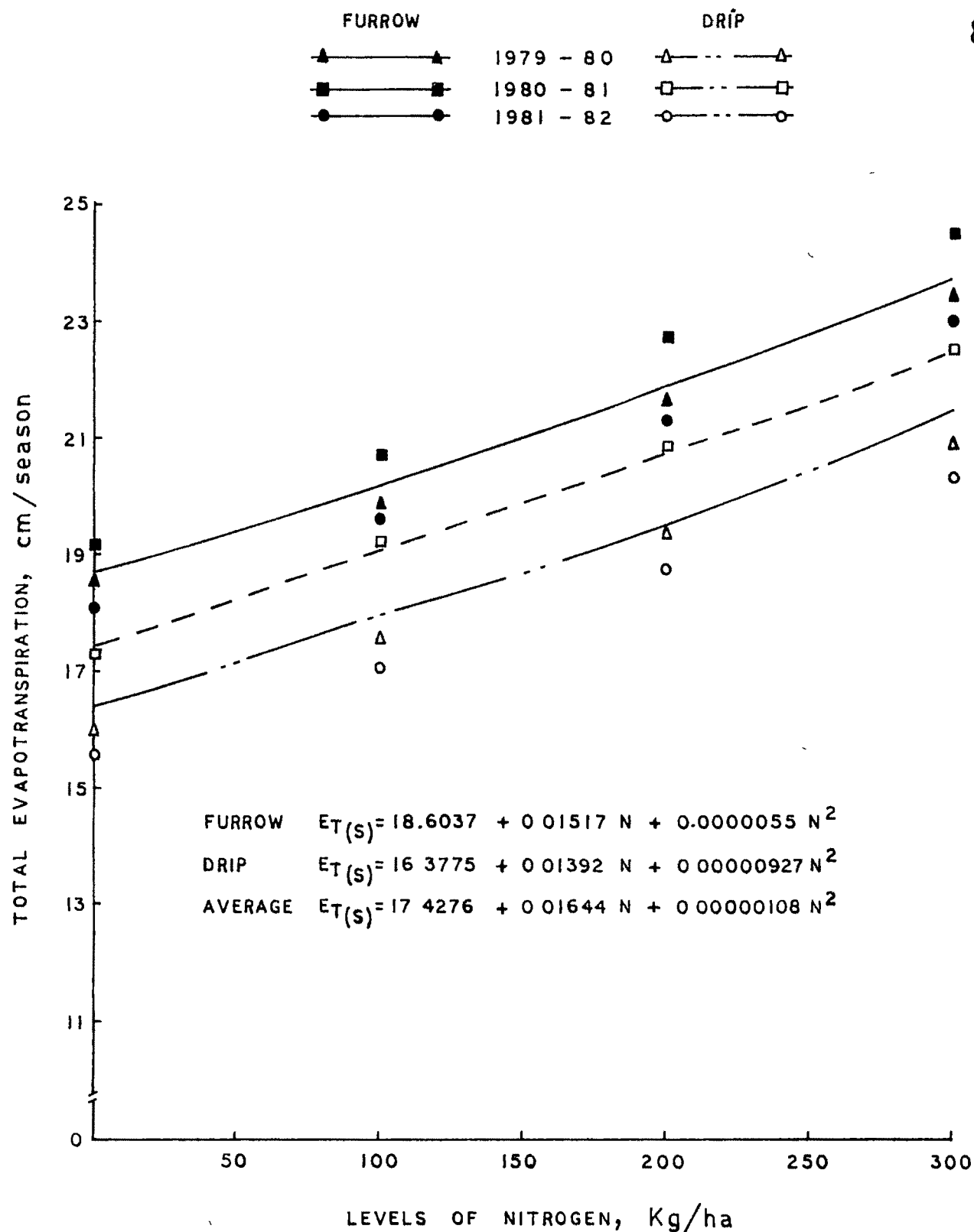


FIG 4.27 RELATIONSHIP BETWEEN TOTAL EVAPOTRANSPIRATION AND LEVELS OF NITROGEN

where, $E_T(s)$ = Total evapotranspiration measured, cm/season

N = Dose of nitrogen, kg/ha.

Equations (4.50 to 4.52) indicate that $E_T(s)$ will increase non-linearly with the increased application of nitrogen.

Table 4.2 Variation in total evapotranspiration (cm) with nitrogen and irrigation methods

Irrigation	Levels of nitrogen, kg/ha				S.E.m $\pm$	C.D.at 5%
	0	100	200	300		
1979-80						
Furrow	18.546	19.934	21.700	23.392		
Drip	15.909	17.613	19.425	20.910	0.151	0.307
Average	17.227	18.773	20.562	22.151	0.106	0.217
S.E.m $\pm$	0.199					
C.D.at 5%	0.406					
1980-81						
Furrow	19.246	20.727	22.750	24.539		
Drip	17.344	19.201	20.879	22.567	0.161	0.329
Average	18.295	19.964	21.815	23.553	0.114	0.232
S.E.m $\pm$	0.297					
C.D.at 5%	0.608					
1981-82						
Furrow	18.076	19.705	21.295	22.975		
Drip	15.528	17.072	18.756	20.284	0.152	0.311
Average	16.802	18.388	20.026	21.630	0.108	0.220
S.E.m $\pm$	0.243					
C.D.at 5%	0.496					

During the early stage of growth, the E_T was low because of less interception of radiation by the potato plants. Moreover, during this stage, the depth and spread of root system was less. As potato plants grew, the leaf area and depth and spread of the root system increased causing more transpiration through the stomatal opening. Increase in E_T with the increase in N application is due to decrease in stomatal resistance with the application of nitrogen (Nagarjah, 1981). E_T from annual row crops is proportional to leaf area (Penman et al., 1967) before plant leaves begin to shade one another. Since application of N fertilizer helps in increase of vegetative growth (Hunter et al., 1961) higher E_T resulting from higher interception of radiation is expected. The crop with its extensive root system can extract soil water under higher soil moisture tension and from greater depth (Viets, 1962). Moreover, extraction of soil water from a greater depth can be largely influenced by the increase of N fertilizer resulting in increase of total evapotranspiration (Brown, 1971). Therefore, with the increase in N application, leaf area increases for greater interception of radiation, root system increases for greater extraction of soil water from larger volume of soil and decrease in stomatal resistance ultimately helps in greater diffusion of water vapour, and all these contribute towards higher evapotranspiration.

4.1.1.4 Stages of growth

Evapotranspiration is influenced by different plant factors including stages of growth. Stages of growth being very important is discussed. Curves (Figures 4.20 and 4.26) indicate the change in

E_T from the emergence to maturity under different soil moisture tension and nitrogen levels. The variations in E_T under different stages of growth are presented in Table 4.3.

Table 4.3 Variation in evapotranspiration rate (mm/day) with soil moisture tension during different stages of growth

	Stolen formation			Tuber formation			Tuber growth and maturation		
	Soil moisture tension, atmosphere								
	0.4	0.8	1.2	0.4	0.8	1.2	0.4	0.8	1.2
1979-80									
Furrow	4.05	3.57	3.20	4.50	3.65	3.35	3.48	2.51	1.96
Drip	3.65	3.17	2.75	4.15	3.40	3.05	2.85	2.04	1.72
1980-81									
Furrow	4.10	3.40	2.82	4.40	3.60	2.90	3.36	2.38	2.00
Drip	3.80	3.05	2.57	3.95	3.15	2.70	2.74	2.20	1.91
1981-82									
Furrow	3.92	3.47	3.00	4.35	3.62	3.12	3.19	2.35	2.13
Drip	3.57	3.10	2.70	3.70	3.30	2.80	2.58	2.19	1.92

Results (Table 4.3) indicate that highest E_T is during tuber formation stage and least E_T is during the last stage of tuber growth and maturation under both methods of irrigation. At any stages of growth, E_T is highest at 0.4 atmosphere irrespective of methods of irrigation and seasons. E_T progressively decreases with the increase of soil moisture tension. Further examination reveals that in all stages of growth in all the three seasons, higher E_T is under furrow irrigation.

The reason for higher E_T during tuber formation is due to greater interception of radiation by the plants which covered the soil to a large extent (Tanner and Lemon, 1962). During this stage, while the flow of water in the soil to the soil surface rapidly becomes less than potential evaporation, transpiration continues for much longer period. Higher E_T at 0.4 atmosphere is due to wet surface. Since reflection from bare soil varies from 11 to 18 per cent for wet and dry soil surface respectively (Montieth, 1959), higher E_T from 0.4 atmosphere is logical. The decrease in E_T during tuber growth and maturation stage is probably a plant dependant factor (Lemon et al., 1957). It may be mentioned that during the first 10 days of this stage, the average E_T was 3.27 mm/day. It gradually decreased to 1.61 mm/day during the last 10 days. The decrease in average E_T during the last stage is, therefore, due to very low E_T in the last 10 days. Similar results on potato crop have been reported by Maity (1972).

4.1.1.5 Irrigation methods

The relationship between E_T from potato crop, irrigated by furrow and drip method, and weeks of growth (Figures 4.28 and 4.29) indicates that E_T , under two methods of irrigations, gradually increases after the emergence to reach the peak at about 5th week, and thereafter decreases gradually due to ageing of the crop in all seasons. While the trend of these curves is similar in all the three seasons, the higher E_T is always associated with furrow irrigation. The influence of each of four climatic factors (Figures 4.1 to 4.16) is more pronounced on E_T from potato crop

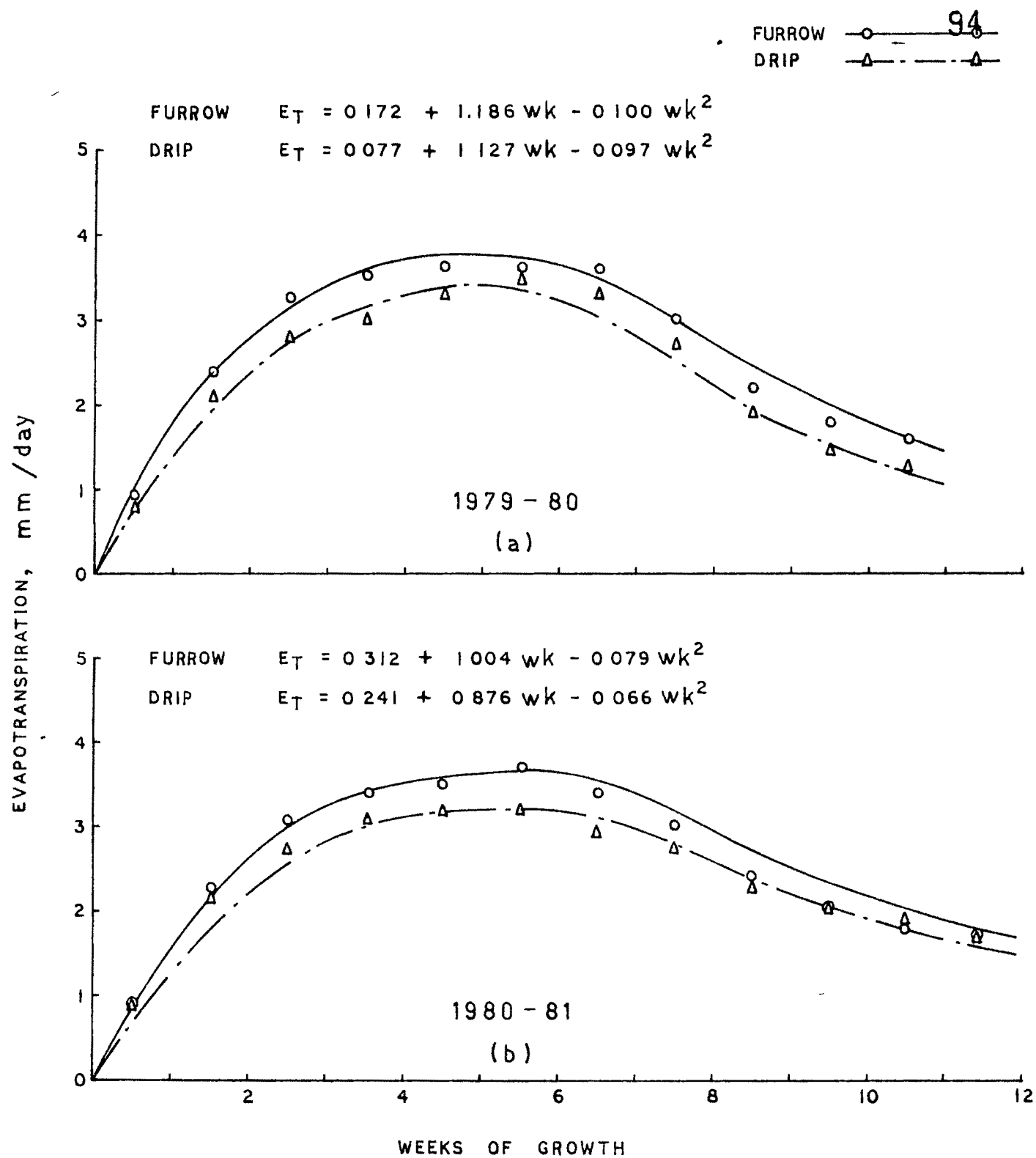


FIG 4 28 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF WEEKS OF GROWTH UNDER TWO METHODS OF IRRIGATION

irrigated by furrow. In analysing the influence soil moisture tension (Figure 4.20) and nitrogen (Figure 4.26) on E_T , it is observed that higher E_T is from furrow irrigated potato crop.

The following equations have been developed to express the relationship (Figure 4.29) between E_T (three seasons' data) and weeks of growth.

$$\text{Furrow : } E_T = 0.1993 + 1.1438 \text{ Wk} - 0.0956 \text{ Wk}^2 \quad (4.53)$$

$$\text{Drip : } E_T = 0.1525 + 1.0297 \text{ Wk} - 0.0860 \text{ Wk}^2 \quad (4.54)$$

where, E_T = Evapotranspiration rate, mm/day

Wk = weeks of growth.

These equations (4.53 and 4.54) can be used to find out the E_T at any stage of growth of potato under furrow and drip methods.

Measured total evapotranspiration values are significantly higher in furrow irrigation (Table 4.4) during all three seasons. Compared to the $E_{T(s)}$ values in drip, these values in furrow irrigation are 13.11, 9.15 and 14.51 per cent more during 1979-80, 1980-81 and 1981-82 respectively.

Table 4.4 Total evapotranspiration (cm) under furrow and drip irrigation

Methods	Total evapotranspiration, cm		
	1979-80	1980-81	1981-82
Furrow	20.393	21.315	20.513
Drip	12.464	19.998	17.910
S.E.m $\pm$	0.150	0.263	0.204
C.D. at 5%	0.642	1.132	0.877

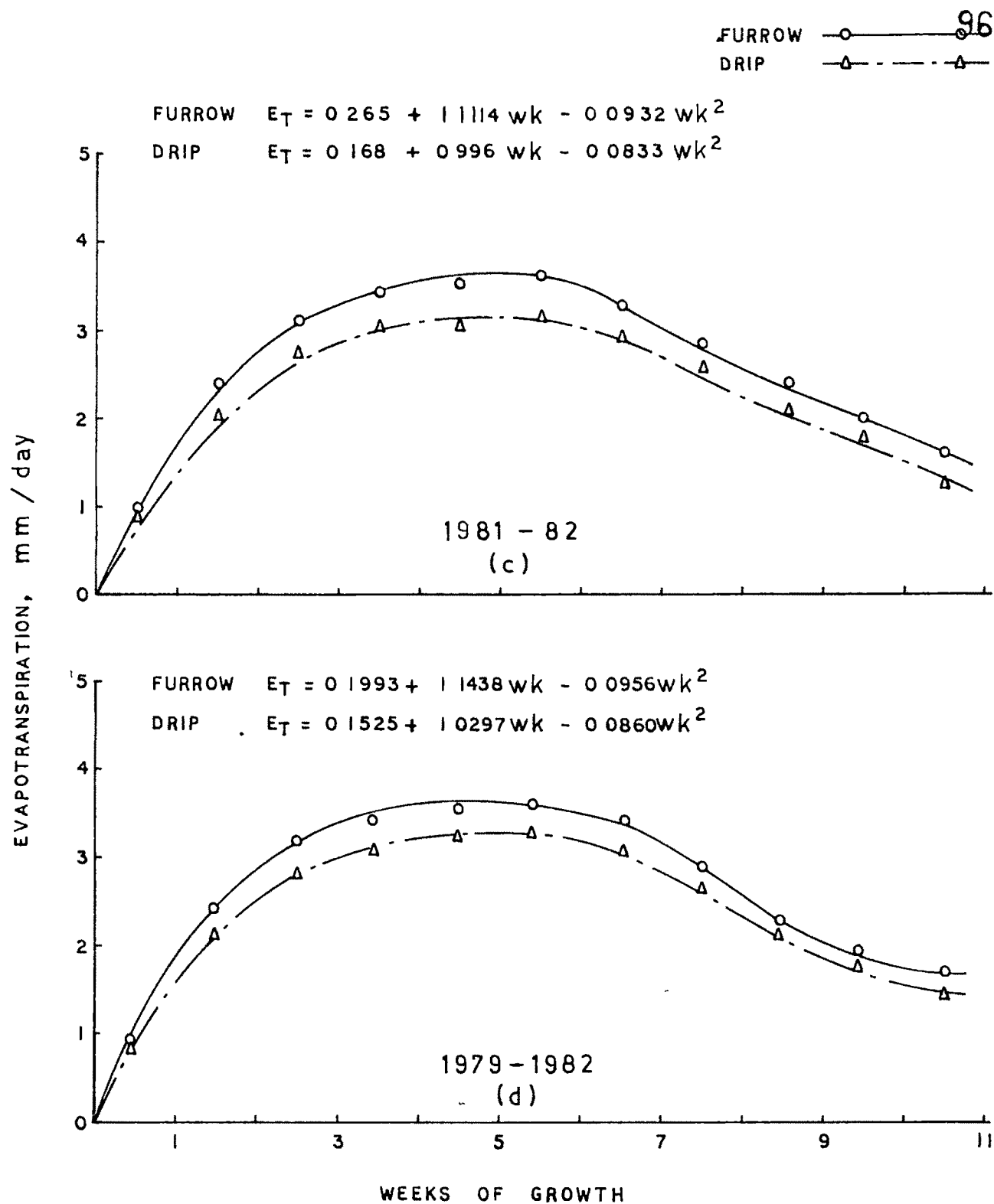


FIG 4 29 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF WEEKS OF GROWTH UNDER TWO METHODS OF IRRIGATION

The per cent difference in $E_T(s)$ between furrow and drip methods varies with soil moisture tension. While the difference is 17.775 per cent at 0.4 atmosphere, it is 9.151 per cent at 0.8 atmosphere and 7.697 per cent at 1.2 atmosphere (Table 4.1). At each of these three soil moisture tension, measured $E_T(s)$ values are higher from furrow irrigated potato crops. The $E_T(s)$ values from drip and furrow, increase with the increase in nitrogen level (Table 4.2) with significantly higher values in furrow irrigation. The equations, (4.50 and 4.51) indicate that at same level of nitrogen higher $E_T(s)$ values are from furrow irrigation. It may, therefore, be concluded that evapotranspiration from potato crop is influenced by the method of irrigation.

The reasons for higher evapotranspiration from furrow irrigated potato plants may be explained as follows. In both drip and furrow irrigations, calculated quantity of water was applied each time to meet the soil moisture deficit at each tension level. While the duration of application of water in furrows was lower (about 35 minutes) and soil moisture tension at the rootzone reached to zero or sometimes 0.1 atmosphere much quicker, a relatively longer period (10-12 hours) was needed for application through drip irrigation system. At the end of each drip irrigation cycle the soil moisture tension was maintained almost at pre-determined values. In other words, while the range of soil moisture tension maintained under furrow irrigation was between 0.1 to 0.4, 0.1 to 0.8 and 0.1 to 1.2 atmosphere, in drip, it was almost 0.4, 0.8 and 1.2 atmosphere for T_1 , T_2 , and T_3 treatments respectively. Maintenance of soil moisture tension lower than the predetermined values

in furrows decreases the resistance to flow of water causing more evapotranspiration (Ritchie, 1971, and Akopyan and Oganyan, 1978). Moreover, in furrow irrigation, the soil surface is wetted with more horizontal movement of water (Hachum et al., 1976) causing more E_T .

Since water is applied through small nozzles in drip irrigation to each plant in its root zone, the wetting patterns are almost narrow cones (Goode et al., 1978) and since drip irrigation is more effective in controlling the volume of return flow (Wierenga, 1977), the lower E_T seems logical. Ran and Singh (1976) reported that in drip irrigation, only one quarter amount of water was used compared to basin irrigation. Lower E_T in drip irrigation was reported by Joyce (1976), Sivanappan (1977-78) and Sourell et al. (1981).

4.1.2 Pan Evaporation and Measured Evapotranspiration

Since the actual measurement of evapotranspiration is time consuming, it is considered necessary to examine the relationship between evaporation from USWB Class A Pan (E_0) and measured E_T values.

The relationship between E_T and E_0 (Figure 4.30) for three seasons considered together under both furrow and drip irrigation methods are given below :

$$\text{Furrow : } E_{T1} = 0.4901 + 1.0083 E_0, \quad r = 0.5704 \quad (4.55)$$

$$E_{T2} = 0.7473 + 0.6399 E_0, \quad r = 0.4359 \quad (4.56)$$

$$E_{T3} = 0.6644 + 0.5246 E_0, \quad r = 0.4117 \quad (4.57)$$

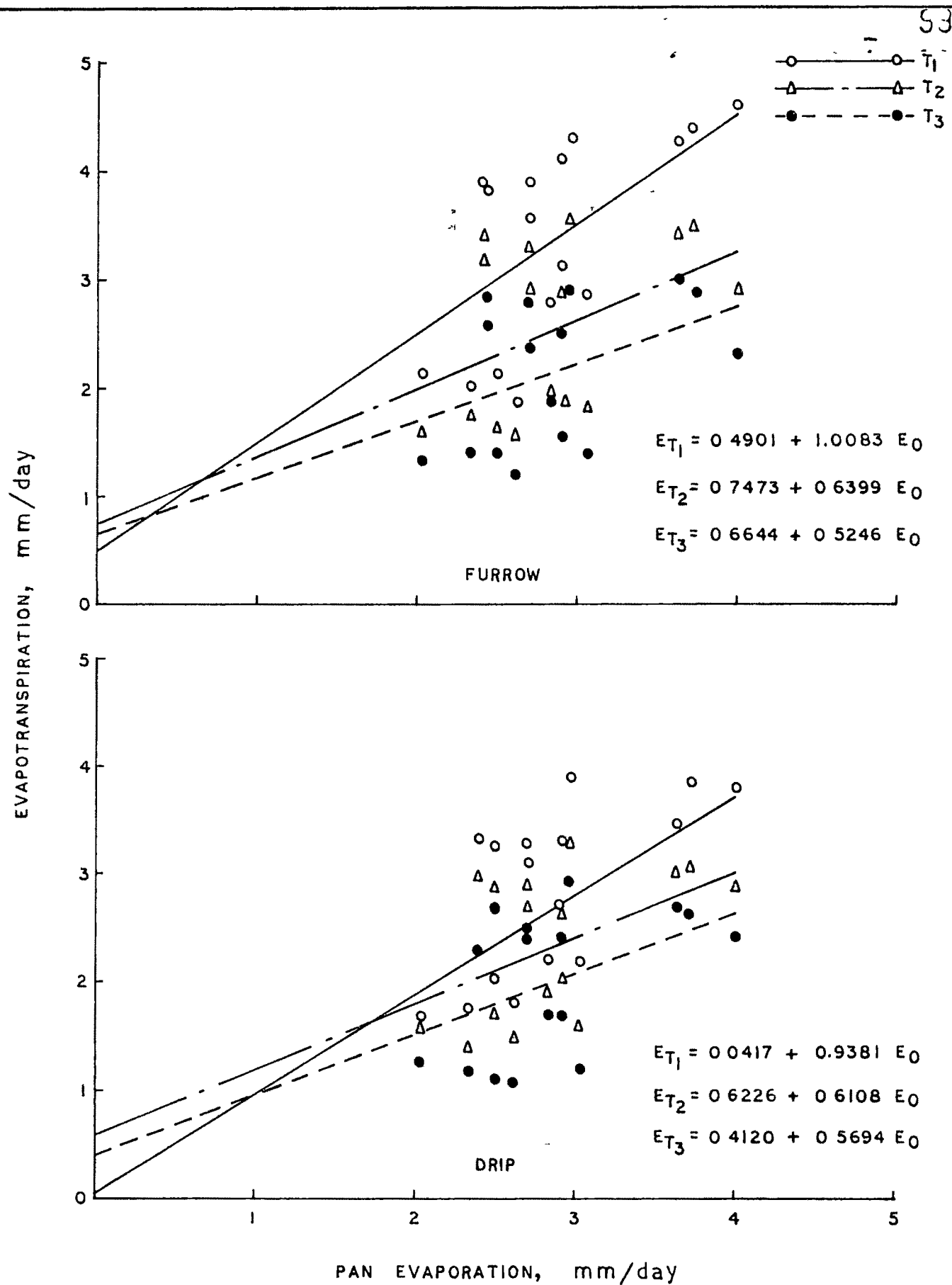


FIG 4 30 RELATION OF PAN EVAPORATION RATES TO MEASURED EVAPOTRANSPIRATION RATES

$$\text{Drip : } E_{T_1} = 0.0417 + 0.9381 E_0, \quad r = 0.6358 \quad (4.58)$$

$$E_{T_2} = 0.6226 + 0.6108 E_0, \quad r = 0.4849 \quad (4.59)$$

$$E_{T_3} = 0.4120 + 0.5694 E_0, \quad r = 0.4710 \quad (4.60)$$

where, E_T = Measured evapotranspiration rate, mm/day and the subscripts 1, 2 and 3 indicate soil moisture tensions, atmosphere.

E_0 = Pan evaporation, mm/day.

The regression coefficients (equations 4.55 to 4.60) indicate that the rate of change in E_T varies with soil moisture tension and methods of irrigation. A good agreement exists between E_0 and measured E_T at 0.4 atmosphere under furrow and drip irrigation. The correlation coefficient values are significant in respect of 0.4 atmosphere in furrow and 0.4 and 0.8 atmosphere in drip irrigation. However, the paired 't' test clearly indicates that on an average there is not much difference between E_0 and E_T values at 0.8 atmosphere under furrow and at 0.4 atmosphere under drip irrigation.

4.1.3 Comparison of Measured and Estimated Evapotranspiration

4.1.3.1 Penman formula

Since the Penman formula does not give accurate daily estimate and is usually accurate only for a period of five days or longer (Gilbert and vanBavel, 1954), monthly estimates of evapotranspiration rates were made for the three potato seasons of 1979-80, 1980-81 and 1981-82. The relationship (Figure 4.31) between measured evapotranspiration rates (E_T) and estimated values by Penman formula

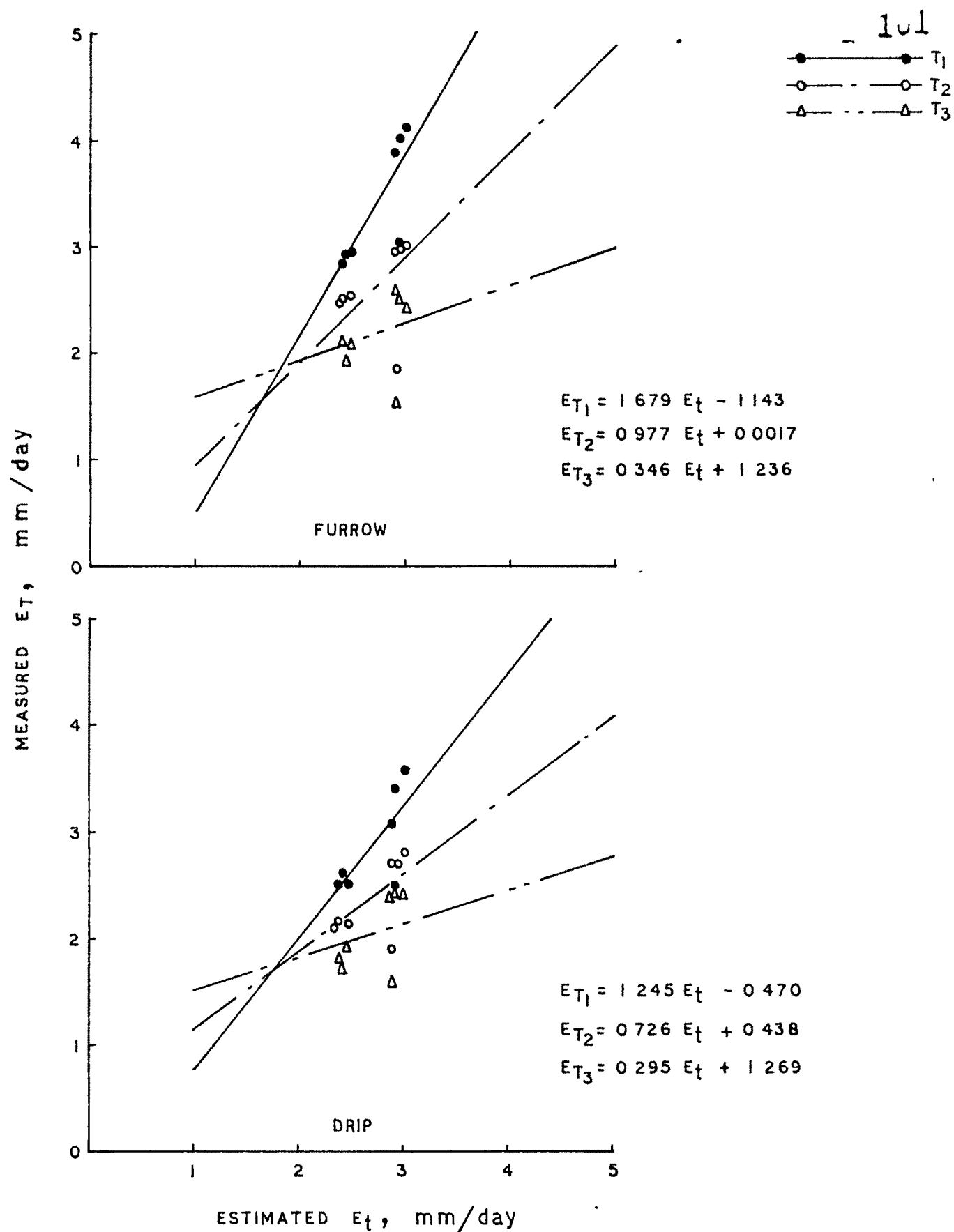


FIG 4.31 RELATION OF DAILY EVAPOTRANSPIRATION RATES ESTIMATED BY THE PENMAN FORMULA TO DAILY MEASURED RATES

(E_t) is given below :

$$\text{Furrow : } E_{T1} = 1.679 E_t - 1.143, \quad r = 0.791 \quad (4.61)$$

$$E_{T2} = 0.977 E_t + 0.0017, \quad r = 0.765 \quad (4.62)$$

$$E_{T3} = 0.346 E_t + 1.226, \quad r = 0.260 \text{ (N.S.)} \quad (4.63)$$

$$\text{Drip : } E_{T1} = 1.245 E_t - 0.470, \quad r = 0.726 \quad (4.64)$$

$$E_{T2} = 0.726 E_t + 0.438, \quad r = 0.572 \text{ (N.S.)} \quad (4.65)$$

$$E_{T3} = 0.295 E_t + 1.269, \quad r = 0.233 \text{ (N.S.)} \quad (4.66)$$

where, E_T = Measured evapotranspiration rate, mm/day subscripts
1, 2 and 3 indicate soil moisture tension, atmosphere.
 E_t = Estimated evapotranspiration by Penman method,
mm/day.

Examination of regression coefficients (equations 4.61 to 4.66) shows that the rate of change in E_T varies with the soil moisture tension and methods of irrigation. While a good agreement exists between E_T and E_t values at 0.3 atmosphere under furrow, and at 0.4 atmosphere under drip irrigation, a definite departure is observed in other cases. The paired 't' test between measured E_T and estimated E_t values also indicate that on an average there is not much difference between these values at 0.3 atmosphere (furrow irrigation) and at 0.4 atmosphere (drip irrigation). The results further indicate that the E_T values at 0.4 atmosphere (drip) and at 0.3 atmosphere (furrow) are 7.16 and 2.28 per cent higher than the E_t values. It may be mentioned that evapotranspiration from potato, paddy and sugarcane exceeded the estimated values E_t by 10 per cent (Maity,

1972); 50 per cent (Fao, 1970) and 10 per cent (Chang, 1961) respectively. Since Penman's formula works best for a soil having higher moisture, high correlation between E_T and E_t values during three seasons under 0.4 and 0.8 atmosphere is logical.

4.1.3.2 Blaney-Criiddle formula

Using monthly (average value) estimated values of crop coefficients k for potato crop (Table 4.5), evapotranspiration rates have been estimated. The relationship between estimated u and measured monthly evapotranspiration E_T' under three soil moisture tension is presented in Figure 4.32. The following regression equations are obtained for furrow and drip irrigation using three seasons' data.

$$\text{Furrow : } E_{T1}' = 1.276 u + 0.066, \quad r = 0.987 \quad (4.67)$$

$$E_{T2}' = 1.010 u + 0.012, \quad r = 0.989 \quad (4.68)$$

$$E_{T3}' = 0.825 u + 0.062, \quad r = 0.983 \quad (4.69)$$

$$\text{Drip : } E_{T1}' = 1.089 u + 0.060, \quad r = 0.997 \quad (4.70)$$

$$E_{T2}' = 0.921 u - 0.043, \quad r = 0.991 \quad (4.71)$$

$$E_{T3}' = 0.709 u + 0.248, \quad r = 0.823 \quad (4.72)$$

where, E_T' = Total evapotranspiration, cm/month, subscripts 1, 2 and 3 indicates soil moisture tension, atmosphere.

u = Total evapotranspiration estimated by Blaney-criiddle method, cm/month.

The regression coefficients indicate that a good agreement exists between estimated u and measured E_T' at 0.8 atmosphere

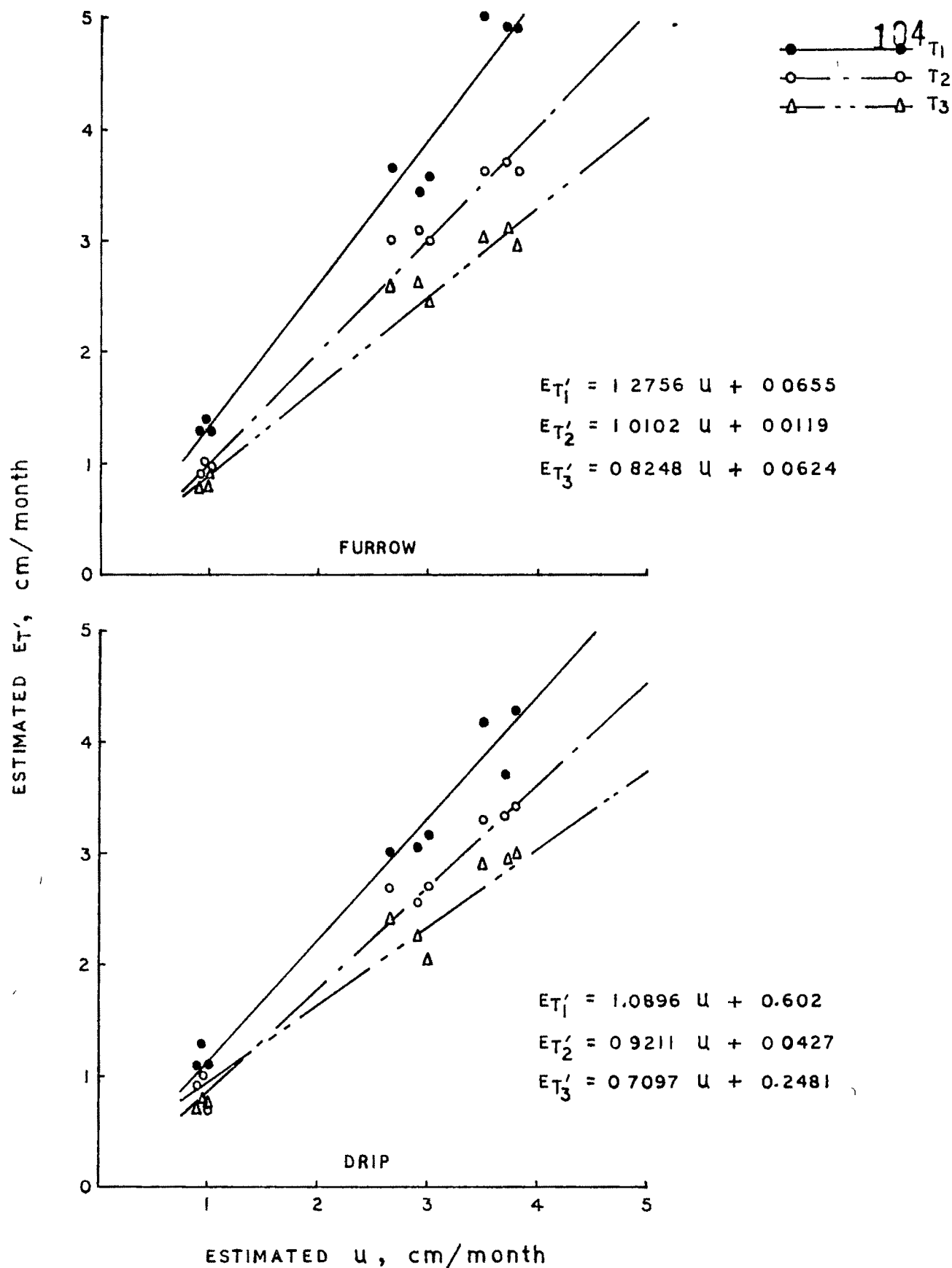


FIG 4 32 RELATION OF MONTHLY EVAPOTRANSPIRATION RATES ESTIMATED BY THE BLANEY-CRIDDLE FORMULA TO MEASURED RATES

soil moisture tension under both furrow and drip irrigation. A departure has, however, been observed at other soil moisture tensions.

However, on examination of the results (Table 4.6), it is observed that the ratio (E_T'/u) varies with season, soil moisture tension and methods of irrigation. Irrespective of systems of irrigation, higher values of these ratios are under lowest soil moisture tension. The mean seasonal coefficients (Table 4.6) indicate a closer agreement only at 0.8 atmosphere under both furrow (1.007) and drip (0.9172) irrigations. Measured E_T' values either at 0.4 atmosphere or at 1.2 atmosphere show a wider variation from estimated values. Close correlation between E_T' and u may be due to the values of crop coefficients (k) computed from the data obtained. The values of k varies with stage of growth, soil moisture tension and methods of irrigation (Table 4.5).

Table 4.5 Variation in crop-coefficient (k) with soil moisture tension

	Soil moisture tension, atmosphere			
	0.4	0.8	1.2	Average
Furrow				
December	0.634	0.549	0.453	0.545
January	0.810	0.601	0.503	0.638
February	0.209	0.146	0.123	0.161
Average	0.550	0.432	0.361	0.443
Drip				
December	0.553	0.478	0.405	0.479
January	0.632	0.557	0.438	0.576
February	0.180	0.136	0.109	0.142
Average	0.472	0.390	0.334	0.399
G. Average	0.513	0.411	0.343	0.424

During the early stage of growth in the month of December, the value of k , averaged over soil moisture tension and seasons, varies between 0.479 in drip and 0.545 in furrow. It gradually increases with tuber bulking and maturity to 0.576 in drip and to 0.638 in furrow and decreases to 0.142 and 0.161 in drip and furrow respectively during February. It may be mentioned that similar observations were made by Maity (1972).

Under the climatic conditions prevailing in this locality, the Blaney-Criddle formula gives a good agreement with the measured E_T' under 0.8 atmosphere soil moisture tension. It may be mentioned that outside the semi-arid climatic conditions of Western United States the performance of Blaney-Criddle formula is usually poor (Pruitt, 1960, and Stanhill, 1961).

Table 4.6 Ratio of measured E_T' under three soil moisture tensions to estimated u by the Blaney-Criddle formula

	Furrow			Drip		
	E_T'/u_1	E_T'/u_2	E_T'/u_3	E_T'/u_1	E_T'/u_2	E_T'/u_3
1979-80						
December	1.360	1.159	0.986	1.146	1.021	0.907
January	1.310	0.965	0.789	1.164	0.917	0.792
February	1.276	0.896	0.765	1.047	0.695	0.555
1980-81						
December	1.168	0.994	0.770	1.036	0.893	0.685
January	1.408	1.020	0.853	1.182	0.935	0.817
February	1.448	1.026	0.859	1.334	1.062	0.892
1981-82						
December	1.127	1.066	0.898	1.059	0.887	0.784
January	1.287	0.977	0.845	1.025	0.902	0.805
February	1.407	0.961	0.902	1.171	0.943	0.720
Total	11.851	9.064	7.667	10.164	8.255	6.957
Seasonal coefficient	1.317	1.007	0.852	1.129	0.917	0.773

4.1.4 Development of Equation

From what has been discussed in the preceding paragraphs, it may be said that, while evapotranspiration rate measured at 0.4 atmosphere under drip irrigation and at 0.8 atmosphere under furrow, agreed well with the estimated values by the Penman method, E_T' from 0.8 atmosphere under both drip and furrow irrigation correlated well with the estimated values by the Blaney-Criddle formula. These formulae give reliable results when applied to climatic conditions similar to those under which these two formulae were developed. Under different climatic conditions, soil moisture tension and levels of nitrogen, the success of these formulae depends upon calibration. It is, therefore, considered necessary to develop an equation with climatic variables, soil moisture tension and nitrogen levels. The climatic variables like temperature, vapour pressure deficit, sunshine hours and wind velocity, which are easily available have been considered. The proposed equation would relate these factors through multiple regression analysis as follows :

$$E_T = b_0 + b_1(t) + b_2(e_s - e_a) + b_3(S) + b_4(W) + b_5(T) + b_6(N) \quad (4.73)$$

where, E_T = Measured evapotranspiration rate, mm/day

t = Mean air temperature, degree centigrade

$(e_s - e_a)$ = Vapour pressure deficit, mm of mercury

e_s = Saturation vapour pressure at mean air temperature t ,
mm of mercury

e_a = Saturation vapour pressure at mean dew point, mm of
mercury

S = Actual bright sunshine hours

W = Measured wind velocity, km/hr

T = Soil moisture tension, atmosphere

N = Levels of nitrogen, kg/ha

$b_0, b_1, b_2, b_3, b_4, b_5$ and b_6 are empirical constants.

Using 14 days' average measured E_T under three soil moisture tensions and four levels of nitrogen during 1979-80 and 1980-81 potato growing seasons, the values of $b_0, b_1, b_2, b_3, b_4, b_5$ and b_6 are obtained by least square method separately for drip and furrow irrigation methods.

Constant	Drip	Furrow
b_0	12.7135	14.7054
b_1	-0.4331	-0.4867
b_2	-0.2440	-0.2931
b_3	0.0171	0.0396
b_4	-0.2173	-0.2999
b_5	-1.1508	-1.6906
b_6	0.0022	-0.0020

The resulting equations thus reduce to :

$$\begin{aligned} \text{Furrow : } E_T = & 14.7054 - 0.4867(t) - 0.2931 (e_s - e_a) + 0.0396 (S) \\ & - 0.2999(W) - 1.6906(T) + 0.0020(N) \end{aligned} \quad (4.74)$$

$$\begin{aligned} \text{Drip : } E_T = & 12.7135 - 0.4331(t) - 0.2440 (e_s - e_a) + 0.0171 (S) \\ & - 0.2173(W) - 1.1508(T) + 0.0022 (N) \end{aligned} \quad (4.75)$$

The high value of F in the analysis of variance (Tables 4.7

and 4.8) indicates that the equations account for a major portion of variations in the variables and hence the equations fit the data reasonably well.

Table 4.7 Analysis of variance for furrow irrigation

Source of variation	Degrees of freedom	Sum of square	Mean square	Variance ratio	Level of significance
Regression equation	6	39.0412	6.5068	25.577	$P < 0.001$
Error	63	16.0261	0.2544		
Total	69	55.0673			

Table 4.8 Analysis of variance for drip irrigation

Source of variation	Degrees of freedom	Sum of square	Mean square	Variance ratio	Level of significance
Regression equation	6	28.6567	4.7761	23.9608	$P < 0.001$
Error	63	12.5577	0.1993		
Total	69	41.2144			

Values of evapotranspiration computed from the equations (4.74 and 4.75) have been verified with the measured evapotranspiration under soil moisture tension and levels of nitrogen during 1981-82 potato season. The relationship (Figure 4.33) between measured and estimated evapotranspiration, averaged over season, is given by the

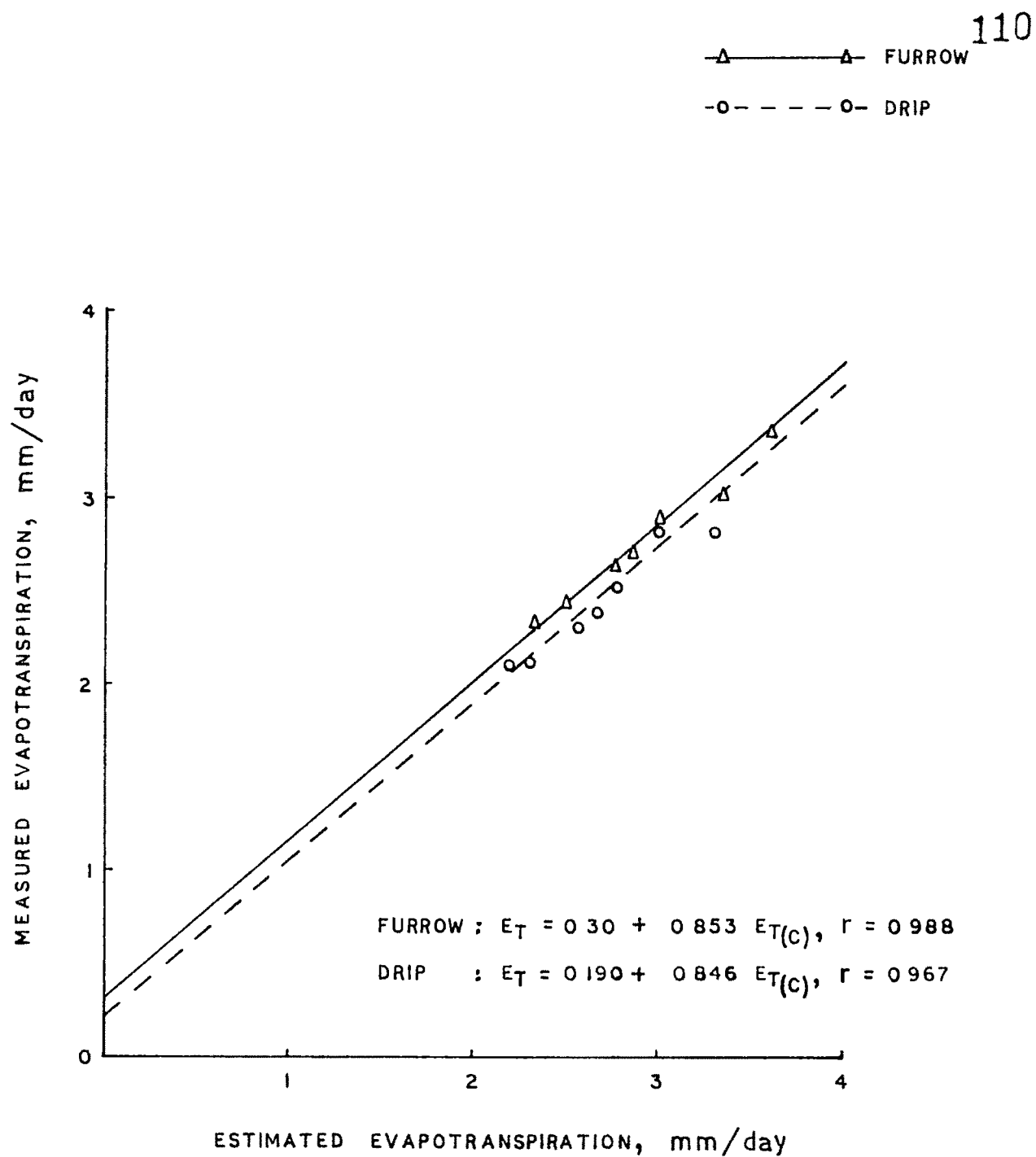


FIG 4 33 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION
MEASURED AND ESTIMATED

following equations :

$$\text{Furrow : } E_T = 0.30 + 0.853 E_{T(c)}, \quad r = 0.988 \quad (4.76)$$

$$\text{Drip : } E_T = 0.190 + 0.846 E_{T(c)}, \quad r = 0.967 \quad (4.77)$$

where, E_T = Measured evapotranspiration rate, mm/day

$E_{T(c)}$ = Estimated evapotranspiration rate, mm/day.

The examination of regression coefficient indicate closer agreement between E_T and $E_{T(c)}$ values. Moreover, the correlation co-efficients are highly significant for two equations. Hence, these equations are valid and can be applied in this locality and other potato growing areas where similar climatic conditions prevail. To estimate evapotranspiration, only temperature, vapour pressure deficit, wind velocity, sunshine hours, soil moisture tensions and levels of nitrogen need be known.

4.2 Yield

The influence of soil moisture tension, nitrogen and methods of irrigation on the size distribution and on total yield of tuber was studied during three winter seasons of 1979-80, 1980-81 and 1981-82. The influence of each of soil moisture tension, nitrogen levels and methods of irrigation has been discussed separately. The size distribution of tuber has been expressed in per cent of total yield.

4.2.1 Soil Moisture Tension

4.2.1.1 Size distribution

Different sizes of tuber have been placed into five groups (Table 4.9). Within the size groups below 25 mm and 25-35 mm, the highest per cent (38.77) of total yield is under 1.2 atmosphere. The per cent of total yield significantly decreases with the decrease in soil moisture tension during three seasons. In the size group of 35-45 mm, the difference in per cent of total yield is not significant between 0.8 atmosphere and 1.2 atmosphere. However, significantly lower per cent is observed under 0.4 atmosphere in two out of three seasons. In the next higher size group (45-60 mm), significantly higher per cent (38-41 per cent) is under 0.4 atmosphere. The per cent decreases significantly with the increase of soil moisture tension. In the largest size group (above 60 mm), the trend of decrease is in the order of $T_1 > T_2 > T_3$ during 1979-80 and 1980-81 while that during 1981-82 is $T_1 > T_2 = T_3$. The results (Table 4.9) reveal further that the per cent of the total yield, in the size groups of 45-60 mm and above, is highest (51.9 to 57.16) under 0.4 atmosphere during three seasons. Three seasons results (Table 4.10) indicate that at three soil moisture tensions, higher per cent of the total yield in the smaller three groups (< 25 mm., 25-35 mm and 35-45 mm) is at 1.2 atmosphere and is under furrow irrigation and 58.35 per cent of yield under drip irrigation, is in the size groups of 45-60 mm and above and at 0.4 atmosphere (Table 4.10a). Significant differences in per cent of total yield between 0.4 and 0.8 atmosphere treatments are observed under both drip and furrow irrigations in various size groups (Tables 4.10

Table 4.9 Variation in size distribution of tuber with soil moisture tension

Soil moisture tension, atm.	<25 mm	25-35 mm	35-45 mm	45-60 mm	> 60 mm
1979-80					
0.4	9.893 (2.915)	17.562 (9.355)	33.486 (30.593)	40.249 (41.829)	22.725 (15.337)
0.8	15.709 (7.517)	23.953 (16.945)	36.851 (36.074)	33.528 (30.794)	16.797 (8.752)
1.2	19.338 (11.346)	27.846 (22.235)	37.650 (37.401)	28.806 (23.514)	13.264 (5.45)
S.E.m $\pm$	0.646	1.639	0.618	1.556	1.242
C.D. 5%	1.491	3.781	1.426	3.587	2.865
1980-81					
0.4	9.920 (3.091)	20.632 (12.756)	34.403 (32.239)	37.911 (38.195)	21.285 (13.721)
0.8	14.221 (6.119)	27.624 (21.865)	37.999 (37.639)	30.025 (25.454)	16.780 (8.911)
1.2	17.567 (9.568)	31.610 (27.804)	35.958 (34.791)	28.198 (22.733)	13.148 (5.180)
S.E.m $\pm$	0.573	1.437	1.377	0.955	0.309
C.D. 5%	1.321	3.314	3.179	0.202	1.867
1981-82					
0.4	12.629 (5.050)	20.787 (12.841)	32.403 (28.80)	38.324 (38.547)	22.423 (14.764)
0.8	18.375 (10.152)	28.591 (22.449)	34.103 (31.529)	30.855 (26.459)	17.751 (9.434)
1.2	21.300 (13.194)	31.322 (27.017)	32.638 (29.016)	28.141 (22.446)	16.619 (8.375)
S.E.m $\pm$	0.750	1.128	1.066	0.699	0.645
C.D. 5%	1.729	2.601	2.458	1.613	1.437

Values in parenthesis indicate actual per cent of total yield.

Table 4.10 Variation in size distribution of tuber with soil moisture tension and irrigation methods

Irrigation methods	< 25 mm			25-30 mm			35-40 mm		
	Soil moisture tension, atmosphere			Soil moisture tension, atmosphere			Soil moisture tension, atmosphere		
	0.4	0.8	1.2	0.4	0.8	1.2	0.4	0.8	1.2
1979-80 Furrow	10.508 (3.170)	16.73 (8.389)	20.268 (12.276)	18.350 (10.171)	24.761 (18.008)	28.409 (23.062)	35.633 (34.031)	37.110 (36.490)	33.152 (38.282)
Drip	9.277 (2.661)	14.690 (6.644)	18.407 (10.415)	16.774 (8.540)	23.145 (15.833)	27.282 (21.508)	31.333 (27.155)	36.592 (35.659)	37.141 (36.521)
1980-81 Furrow	10.352 (3.310)	14.543 (6.638)	12.633 (10.579)	21.890 (14.137)	28.171 (22.833)	32.117 (28.657)	36.609 (35.72)	38.913 (39.587)	35.077 (33.502)
Drip	9.488 (2.872)	13.874 (5.600)	16.521 (8.558)	19.373 (21.876)	27.077 (20.848)	31.103 (26.952)	32.197 (28.758)	36.684 (35.780)	36.838 (36.080)
1981-82 Furrow	13.163 (5.331)	19.876 (11.769)	21.571 (13.441)	22.561 (14.885)	29.467 (24.240)	32.379 (28.675)	32.948 (29.554)	34.312 (31.834)	32.780 (29.091)
Drip	12.096 (4.77)	16.873 (8.535)	21.028 (12.948)	19.013 (10.798)	27.716 (20.659)	30.066 (25.360)	31.858 (28.046)	33.893 (31.224)	32.484 (28.941)

1. Values in parenthesis indicate actual per cent of total yield

	1979-80	1980-81	1981-82	1979-80	1980-81	1981-82	1979-80	1980-81	1981-82
2. Difference between two tension means at the same level of irrigation	S.E.m $\pm$ 0.914	0.810	1.061	2.318	2.032	1.595	0.874	1.947	1.507
	C.D.5% 2.108	1.868	2.446	5.346	4.687	3.678	2.017	4.489	3.476
3. Difference between two irrigation means at the same level of tension	S.E.m $\pm$ 0.783	0.999	0.867	2.046	1.703	1.394	0.874	1.622	1.402
	C.D.5% 1.806	2.304	2.000	4.718	3.928	3.214	2.016	3.742	3.232

Table 4.10a Variation in size distribution of tuber with soil moisture tension and irrigation methods

Irrigation methods	45-60 mm			60 mm		
	Soil moisture tension, atmosphere					
	0.4	0.8	1.2	0.4	0.8	1.2
1970-80						
Furrow	38.899 (39.488)	32.151 (29.209)	27.268 (21.344)	20.919 (13.106)	15.972 (7.998)	12.907 (5.026)
Drip	41.598 (44.171)	34.542 (32.379)	30.344 (25.684)	24.531 (17.569)	17.622 (9.506)	13.620 (5.874)
1980-81						
Furrow	35.644 (34.713)	28.280 (22.804)	27.879 (22.368)	20.031 (12.137)	15.658 (8.141)	13.180 (5.121)
Drip	40.179 (41.678)	31.771 (28.105)	28.516 (23.108)	22.538 (15.306)	17.903 (9.681)	13.115 (5.24)
1981-82						
Furrow	37.149 (36.528)	29.030 (23.652)	26.991 (20.812)	21.665 (13.757)	16.829 (8.547)	16.380 (8.046)
Drip	39.499 (40.567)	32.680 (29.266)	29.291 (24.081)	23.181 (15.771)	18.672 (10.321)	16.858 (8.705)

1. Values in parenthesis indicate actual per cent of total yield

		1979-80	1980-81	1981-82	1979-80	1980-81	1981-82
2. Difference between two tension means at the same level of irrigation	S.E.m $\pm$	2.200	1.350	0.989	1.757	1.145	0.912
	C.D.5%	5.073	3.114	2.280	4.052	2.640	2.104
3. Difference between two irrigation means at the same level of tension	S.E.m $\pm$	1.854	1.325	1.523	1.562	0.940	0.962
	C.D.5%	4.275	3.055	3.511	3.601	2.169	2.218

and 4.10 a).

4.2.1.2 Total yield

The relationship between soil moisture tension and total yield (Figure 4.34) indicates that the yield decreases significantly with the increase in soil moisture tension non-linearly, in all seasons under two methods of irrigation. Although the influence of soil moisture tension on the total yield varies with season (Table 4.11), the maximum total yield is under 0.4 atmosphere tension during all the three seasons from drip irrigation.

Table 4.11 Variation in total yield (t/ha) with soil moisture tension and irrigation methods

Method	Soil moisture tension, atm.			S.Em $\pm$	C.D. at 5%
	0.4	0.8	1.2		
1979-80					
Furrow	261.836	235.680	165.704		
Drip	279.795	238.305	182.997	5.553	12.806
Average	270.815	231.993	174.300	3.927	9.055
S.Em $\pm$	5.438				
C.D. at 5%	15.853				
1980-81					
Furrow	251.337	216.179	151.347		
Drip	272.059	235.087	169.222	8.965	20.674
Average	261.698	225.663	160.284	6.339	14.618
S.Em $\pm$	7.926				
C.D.at 5%	20.610				
1981-82					
Furrow	264.198	218.976	183.035		
Drip	285.063	244.466	207.109	6.752	13.787
Average	274.630	231.721	195.272	4.774	11.009
S.Em $\pm$	5.588				
C.D.at 5%	13.185				

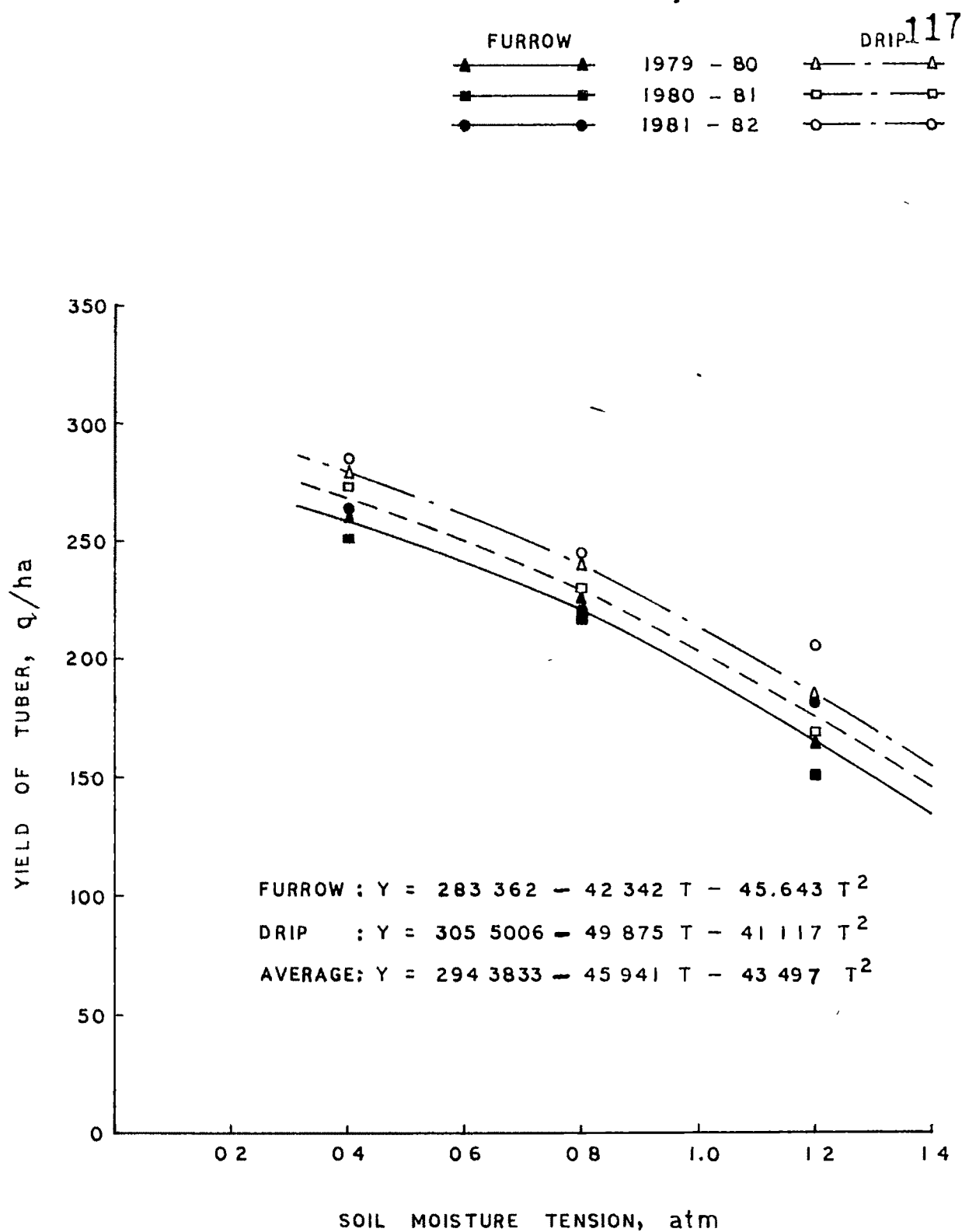


FIG 4 34 RELATIONSHIP BETWEEN YIELD OF TUBER
AND SOIL MOISTURE TENSION

While with the increase of soil moisture tension (a) from 0.4 to 0.8 atmosphere, the total yield decreases by 14.335 per cent, the decrease in yield is 24.863 per cent (Table 4.11) for further increase in moisture tension (b) from 0.8 to 1.2 atmosphere during 1979-80 (average data). The total yield decreases by 13.76 and 15.624 per cent in (a) and 28.971 and 15.729 per cent in (b) during 1980-81 and 1981-82 respectively. The results indicate similar trends of decrease in yield under drip and furrow irrigations during all the three seasons.

The relationship between the total yield of tuber, averaged over the seasons, and soil moisture tension in respect of averaged data and methods of irrigation may be expressed by the following equations :

$$\text{Furrow : } Y = 283.362 - 42.342 T - 45.643 T^2 \quad (4.78)$$

$$\text{Drip : } Y = 305.501 - 49.875 T - 41.117 T^2 \quad (4.79)$$

$$\text{Average : } Y = 294.384 - 45.941 T - 43.497 T^2 \quad (4.80)$$

where, Y = Yield of tuber, g/ha

T = Soil moisture tension, atmosphere.

The equations (4.78 to 4.80) indicate that the yield of tuber is sensitive to soil moisture tension and the increase in tension has depressing effect on tuber yield. These equations may be used to predict the total yield.

Results clearly indicate (Table 4.9) that maximum tuber bulking

is under 0.4 atmosphere and it gradually decreases with the increase in soil moisture tension. Since individual weight of tuber depends on its bulking and since higher (51.9 - 57.16) per cent of total yield is in the larger two size groups (45-60 mm and > 60 mm), higher total yield under 0.4 atmosphere is logical. Similarly, lowest total yield under 1.2 atmosphere is due to 72.39 per cent of the total yield in smaller three size groups. Moreover, moisture stress produces spindled and cracked tubers (Robins and Domingo, 1956). The reasons for the decrease in total yield is also due to reduction in leaf area and/or photosynthesis per unit area (Loon, 1981) under high soil moisture tension. Lower soil moisture tension also maintains an optimum hydrothermal regime for better growth and higher yield of potato by lowering the maximum soil temperature and raising minimum soil temperature (Grewal and Singh, 1978). These results are in conformity with those of Bravo et al. (1968); Maity and Pandya (1975); Grewal and Singh (1978), and Giovanardi (1980).

4.2.2 Nitrogen

4.2.2.1 Size distribution

In the smallest size (< 25 mm), while the per cent of total yield is highest at 300 kg N during two seasons (Table 4.12) and lowest at 100 kg N in all seasons, there is no significant difference between 300 kg and 0 kg N treatments. Significantly higher per cent is under furrow irrigation (Table 4.13) at 0 kg (1981-82) and at 200 kg (1979-80, 1981-82).

Table 4.12 Variation in size distribution of tuber with nitrogen

Nitrogen	< 25 mm	25-35 mm	35-45 mm	45-60 mm	> 60 mm
1979-80					
0 kg	16.331 (8.323)	23.073 (15.933)	36.974 (36.274)	34.174 (31.997)	15.259 (7.442)
100 kg	12.789 (5.359)	19.544 (12.094)	34.962 (33.004)	38.305 (38.950)	19.239 (11.051)
200 kg	14.338 (6.671)	23.611 (16.369)	35.752 (34.320)	33.407 (30.709)	19.416 (11.936)
300 kg	16.462 (8.684)	26.253 (20.379)	36.291 (35.168)	30.891 (26.861)	16.358 (8.907)
S.Em $\pm$	0.851	1.192	0.801	0.855	0.725
C.D. at 5%	1.737	2.436	1.636	1.746	1.482
1980-81					
0 kg	15.836 (7.681)	28.244 (23.149)	36.457 (35.378)	29.804 (25.531)	16.033 (8.150)
100 kg	12.093 (4.892)	23.340 (16.106)	33.619 (30.977)	36.597 (35.902)	20.017 (12.199)
200 kg	12.455 (5.137)	24.374 (17.631)	37.085 (35.456)	33.909 (31.484)	17.146 (9.307)
300 kg	15.235 (7.327)	30.531 (26.345)	37.050 (36.565)	27.870 (22.316)	15.088 (7.427)
S.Em $\pm$	0.932	0.959	1.272	1.069	1.135
C.D. at 5%	1.904	1.958	2.598	2.183	2.317
1981-82					
0 kg	18.376 (10.372)	27.308 (21.601)	33.733 (30.850)	31.389 (27.442)	17.976 (9.752)
100 kg	15.808 (7.262)	24.478 (17.938)	31.805 (27.974)	35.662 (34.247)	20.497 (12.611)
200 kg	17.419 (9.405)	27.116 (20.531)	33.755 (30.779)	32.065 (28.534)	18.968 (10.810)
300 kg	18.856 (10.822)	28.565 (23.007)	32.846 (29.506)	30.645 (26.359)	18.284 (10.259)
S.Em $\pm$	0.646	1.986	0.755	0.546	0.703
C.D. at 5%	1.319	4.057	1.543	1.116	1.437

Values in parenthesis indicate actual per cent of total yield.

The lowest and highest per cent of tuber in size (25-35 mm) is at 100 kg and 300 kg N treatments respectively during 1979-80 and 1980-81. Except during 1979-80, there is no difference between 100 kg and 200 kg N treatments. There is no difference due to methods of irrigation (Table 4.13).

The yield of tuber in the size (35-45 mm) is lowest under 100 kg N during 1980-81 only (Table 4.12). The results further indicates that there is no significant difference amongst 0 kg, 200 kg and 300 kg N treatments and between the methods of irrigation (Table 4.13).

In the next size (45-60 mm) the difference in yield (per cent) between 100 kg and each of other three treatments is significant. While there is no significant difference in yield between 0 kg and 200 kg treatments during 1979-80 and 1981-82, the difference between 200 kg and 300 kg treatments is significant in all the three seasons. Significantly higher per cent is under drip irrigation at 100 kg during 1979-80 and at 200 kg treatment during 1979-80, 1981-82 seasons (Table 4.13 a).

The largest size (> 60 mm) of tuber is significantly higher under 100 kg N/ha in two seasons (Table 4.12). Although the difference between 100 kg and 200 kg treatments is not significant only in 1979-80, the yield (per cent) under either 100 kg or 200 kg is significantly superior to 0 kg or 300 kg treatments. Significantly higher per cent is under drip irrigation (Table 4.13 a).

Table 4.13 Variation in size distribution of tuber with nitrogen and irrigation methods

Irrigation methods	< 25 mm			25-35 mm			35-45 mm		
	0	100	200	300	0	100	200	300	0
1979-80									
Furrow	16.405 (8.249)	13.405 (5.862)	15.826 (7.951)	17.703 (9.719)	23.838 (16.784)	19.982 (12.777)	24.477 (17.182)	27.063 (21.575)	38.070 (38.120)
Drip	16.258 (8.397)	12.170 (4.857)	12.850 (5.391)	15.221 (7.649)	22.308 (15.082)	19.107 (11.42)	22.744 (15.566)	25.442 (19.183)	35.878 (34.428)
1980-81									
Furrow	17.017 (9.106)	13.334 (5.703)	12.508 (5.102)	15.185 (7.459)	29.086 (24.390)	22.908 (15.435)	25.653 (19.131)	31.923 (28.609)	37.390 (36.842)
Drip	14.654 (6.257)	10.852 (4.082)	12.383 (5.172)	15.288 (7.196)	27.402 (21.908)	23.771 (16.777)	23.096 (16.132)	29.138 (24.082)	35.524 (33.914)
1981-82									
Furrow	19.474 (11.403)	15.147 (7.181)	18.786 (10.722)	19.407 (11.413)	28.334 (22.974)	25.965 (19.723)	28.815 (23.358)	29.438 (24.346)	33.593 (30.546)
Drip	17.278 (9.341)	15.028 (7.344)	16.052 (8.088)	18.305 (10.231)	26.283 (20.229)	23.001 (16.153)	25.417 (17.705)	27.693 (21.668)	33.871 (31.154)

1. Values in parenthesis indicate actual per cent of total yield

	1979-80	1980-81	1981-82	1979-80	1980-81	1981-82	1979-80	1980-81	1981-82
2. Difference between two nitrogen means of the same level of irrigation	S.Em $\pm$	1.389	1.523	1.055	1.948	1.566	2.809	1.309	2.078
	C.D.5%	2.837	3.110	2.155	3.978	3.199	5.737	2.673	4.244
3. Difference between two irrigation means of the same level of nitrogen	S.Em $\pm$	1.227	1.517	0.916	1.857	1.410	2.483	1.241	1.829
	C.D.5%	2.505	3.098	1.871	3.793	2.879	5.071	2.533	3.724

Table 4.13a Variation in size distribution of tuber with nitrogen and irrigation methods

Irrigation Methods	45-60 mm				> 60 mm			
	Levels of nitrogen, kg/ha							
	0	100	200	300	0	100	200	300
1979-80								
Furrow	33.032 (30.307)	36.736 (36.578)	31.447 (27.698)	30.362 (26.14)	14.437 (6.481)	18.989 (10.685)	18.471 (11.032)	14.279 (6.642)
Drip	35.317 (33.687)	39.874 (41.322)	35.367 (33.720)	31.421 (27.583)	16.081 (8.404)	19.487 (11.417)	20.360 (12.940)	18.436 (11.172)
1980-81								
Furrow	28.134 (23.408)	35.868 (34.575)	31.627 (27.939)	26.775 (20.592)	13.801 (6.119)	19.869 (12.072)	17.673 (9.621)	13.816 (6.054)
Drip	31.474 (27.755)	37.327 (37.029)	34.191 (35.03)	28.963 (24.041)	18.266 (10.182)	20.164 (12.326)	16.619 (8.993)	16.360 (8.801)
1981-82								
Furrow	30.267 (25.699)	34.867 (32.951)	29.648 (24.796)	29.444 (24.502)	17.565 (9.430)	19.214 (11.116)	18.574 (10.292)	17.814 (9.629)
Drip	32.510 (29.185)	36.456 (35.543)	34.482 (32.273)	31.845 (28.217)	18.388 (10.074)	21.778 (14.107)	19.362 (11.328)	18.754 (10.890)

1. Values in parenthesis indicate actual per cent of total yield

		1979-80	1980-81	1981-82	1979-80	1980-81	1981-82
2. Difference between two nitrogen means at the same level of irrigation	S.E.m $\pm$	1.396	1.746	0.893	1.185	1.853	1.149
	C.D.5%	2.852	3.565	1.823	2.421	3.785	2.347
3. Difference between two irrigation means at the same level of nitrogen	S.E.m $\pm$	1.293	1.681	1.316	1.198	1.634	1.167
	C.D.5%	2.641	3.433	2.688	2.446	3.337	2.382

4.2.2.2 Total yield

The relationship between nitrogen level and the total yield of tuber (Figure 4.35) indicates that the yield increases with the increase in nitrogen levels upto 117 kg N/ha. The results indicate (Table 4.14) that with the addition of first 100 kg N/ha, the yield increases by 16.837, 23.431 and 28.529 per cent during 1979-80, 1980-81 and 1981-82 respectively.

Table 4.14 Variation in total yield (q/ha) with nitrogen and irrigation methods

Method	Levels of nitrogen, kg/ha				S.E.m $\pm$	C.D. at 5%
	0	100	200	300		
1979-80						
Furrow	219.55	253.65	219.77	177.98		
Drip	233.39	275.55	229.97	195.76	10.11	20.64
Average	226.46	264.59	224.87	186.87	7.15	14.59
S.E.m $\pm$	9.25					
C.D. at 5%	21.101					
1980-81						
Furrow	199.81	244.60	212.05	168.69		
Drip	220.07	273.651	239.68	168.42	9.23	18.84
Average	209.94	259.134	225.86	168.56	6.52	13.32
S.E.m $\pm$	8.55					
C.D. at 5%	19.907					
1981-82						
Furrow	213.09	280.38	229.99	165.35		
Drip	242.05	304.62	263.26	172.26	12.13	24.77
Average	227.57	292.49	246.63	168.81	8.57	17.52
S.E.m $\pm$	10.54					
C.D. at 5%	21.714					

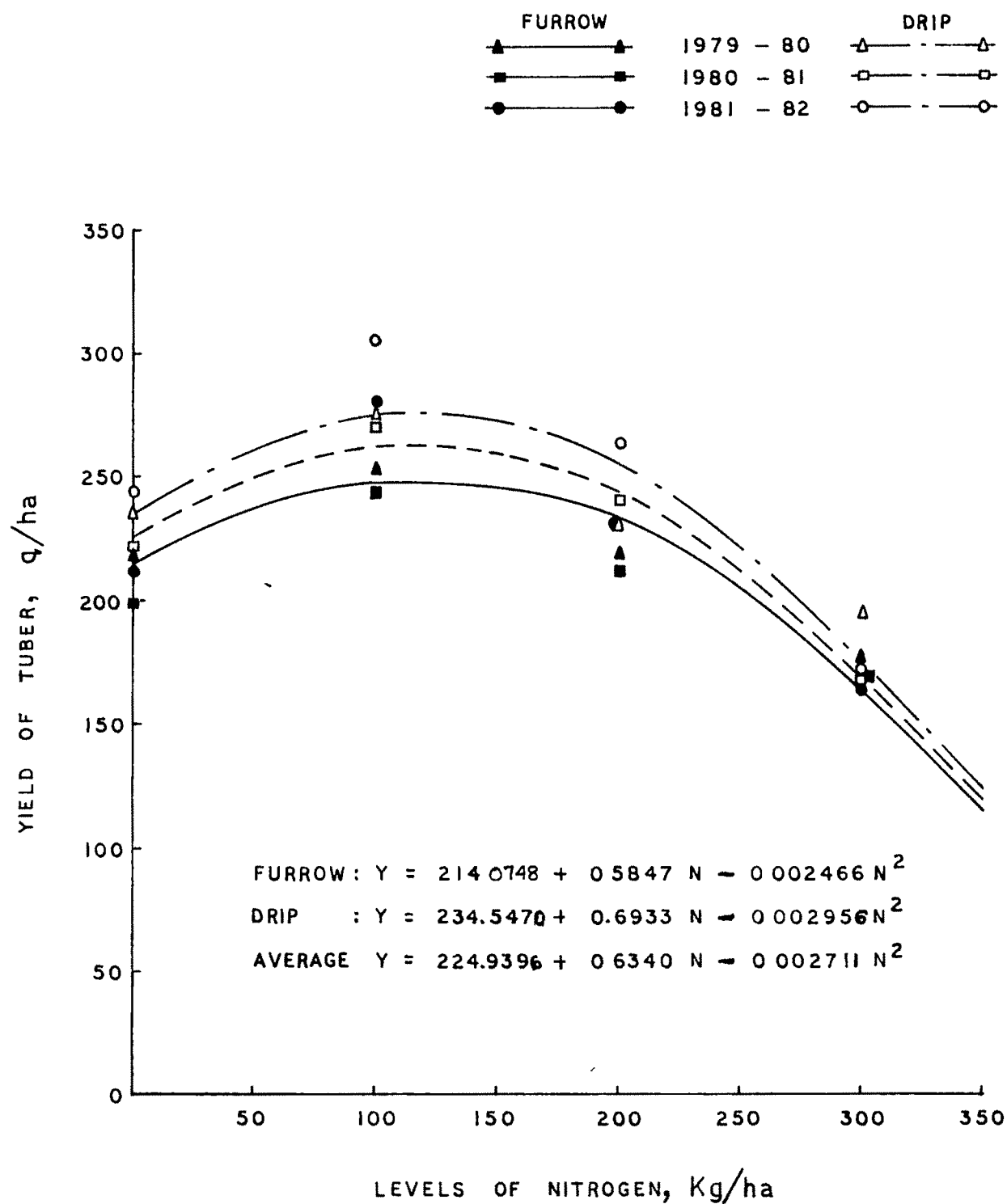


FIG 4 35 RELATIONSHIP BETWEEN YIELD OF TUBER
AND LEVELS OF NITROGEN

However, when three seasons' data are considered, the per cent increase in yield over 0 kg N is 22.93 at 100 kg and 5.03 at 200 kg. Although the influence of nitrogen varies with season and methods of irrigation (Table 4.14), the maximum and minimum yields are obtained at 100 kg N/ha and at 300 kg N/ha respectively. Significantly higher yield is under drip irrigation at 100 kg N/ha during all the three seasons and at 0 kg and 200 kg N/ha levels during 1980-81 and 1981-82 seasons.

The relationship between the total yield of tuber averaged over the seasons and levels of nitrogen (Figure 4.35) in respect of average data and methods of irrigation is given below :

$$\text{Furrow : } Y = 214.0748 + 0.5847 N - 0.002466 N^2 \quad (4.81)$$

$$\text{Drip : } Y = 234.547 + 0.6934 N - 0.002956 N^2 \quad (4.82)$$

$$\text{Average: } Y = 224.9396 + 0.634 N - 0.002711 N^2 \quad (4.83)$$

where, Y = Yield of tuber, g/ha

N = Dose of nitrogen, kg/ha

These equations (4.81 to 4.83) indicate that the yield of tuber can be changed by the application of nitrogen and at very high dose, the yield will decrease. The maximum doses of nitrogen calculated from the equations 4.81, 4.82 and 4.83 are 118.55 kg, 117.286 kg and 116.93 kg/ha respectively.

Three seasons results (Table 4.12) indicate that the per cent of total yield under 0 kg, 200 kg and 300 kg N/ha treatments increases with the size up to 35-45 mm group and then decreases.

However, under 100 kg N treatment, the per cent of the yield increase gradually with the size and reaches maximum at the 45-60 mm group. The results further reveal that there is no significant difference in per cent between 100 kg and 200 kg N treatments in two seasons in the smaller two size groups, but in the size group of 35-45 mm significantly higher per cent is under 200 kg during 1980-81 and 1981-82 seasons. Except for the season 1979-80 is the size >60 mm, significantly higher per cent of yield in the larger two groups is under 100 kg nitrogen treatment. Therefore, the utilisation of nitrogen is more under 200 kg treatment only in the smaller three groups, while that is more under 100 kg in larger two groups. The individual weight of tuber depends on tuber bulking. Significantly higher bulking of tubers under 100 kg nitrogen treatment is probably due to better utilisation of nitrogen. Higher doses of nitrogen did not help in tuber bulking instead it reduces the yield. The reduction in yield is probably due to more protein synthesis and less of accumulation of starch under higher dose of nitrogen. Higher per cent of better size tubers (45 mm to >60 mm) contributes towards the highest yield under 100 kg N treatment. These results are in conformity with that of Nazir and Gill, (1967), Munster (1969), Misra and Pati (1970), and Tsvetkova (1972).

4.2.3 Methods of Irrigation

4.2.3.1 Size distribution

Three seasons data (Table 4.15) indicate that higher per cent of total yield is under furrow irrigation in respect of < 25 mm,

Table 4.15 Variation in size distribution of tuber with irrigation methods

Method	< 25 mm	25-35 mm	35-45 mm	45-60 mm	> 60 mm
1979-80					
Furrow	15.835 (7.945)	23.84 (17.079)	36.967 (36.267)	32.773 (30.181)	16.599 (8.710)
Drip	14.125 (6.573)	22.400 (15.310)	35.022 (33.112)	35.495 (34.078)	18.591 (10.983)
S.Em $\pm$	0.2375	0.7768	0.5048	0.4586	0.6174
C.D.at 5%	1.029	3.3426	2.1720	1.9734	2.6567
1980-81					
Furrow	14.511 (6.842)	27.393 (21.891)	36.866 (36.149)	30.601 (26.628)	16.290 (8.467)
Drip	13.294 (5.676)	25.851 (19.724)	35.240 (33.539)	33.489 (30.964)	17.852 (10.075)
S.Em $\pm$	0.7493	0.3847	0.3236	0.7346	0.1044
C.D.at 5%	3.22464	1.6553	1.3926	3.1609	0.449
1981-82					
Furrow	18.203 (10.130)	28.135 (22.660)	33.347 (30.130)	31.056 (26.997)	18.291 (10.116)
Drip	16.666 (8.751)	25.598 (18.939)	32.745 (29.395)	33.823 (31.304)	19.570 (11.599)
S.Em $\pm$	0.06976	0.4966	0.6710	0.7429	0.6088
C.D.at 5%	0.3002	2.0015	2.8873	3.1975	2.6198

Values in parenthesis indicate actual per cent of total yield.

25-35 mm and 35-45 mm sizes. While the yield difference between the furrow and drip irrigation is significant during 1979-80 and 1981-82 in < 25 mm size, significant difference is observed in one season amongst 25-35 mm and 35-45 mm sizes of tubers, though the range of difference varies. The results also reveal that higher per cent of yield is always under drip irrigation when the larger two sizes (45-60 mm and > 60 mm) are considered together.

At soil moisture tension at 0.4 and 0.8 atmosphere, significantly higher per cent of yield is limited to three smaller size groups (Table 4.10) under furrow irrigation and that under drip irrigation to larger two sizes (Table 4.10 a). Therefore, higher tuber bulking is under drip irrigation and lower soil moisture tensions. The influence of nitrogen also varies with the method of irrigation. While significantly higher per cent of the yield under furrow irrigation (Table 4.13) is in size < 25 mm at 0 kg (1981-82) and 200 kg nitrogen, (1979-80, 1981-82), under drip irrigation, it is in larger two groups at 100 kg treatment (Table 4.13 a).

4.2.3.2 Total yield

During all three seasons, significantly higher yields are from drip irrigated plots (Table 4.16).

Table 4.16 Variation in total yield (q/ha) under two methods of irrigation

Method	1970-80	1980-81	1981-82
Furrow	217.740	206.288	222.203
Drip	223.665	225.456	245.546
S.E.m $\pm$	3.003	3.042	0.914
C.D. at 5%	12.912	13.088	3.934

Three seasons results indicate (Table 4.11) that the maximum yield is always under 0.4 atmosphere soil moisture tension and it decreases significantly with the increase of soil moisture tension in two methods of irrigation. Under any soil moisture tensions, the difference in the total yield between drip and furrow irrigations is significant except that under 0.8 atmosphere during 1979-80 and 1980-81 and 1.2 atmosphere during 1980-81. Considering all seasons data together the total yield in furrow is 7.114, 7.943 and 10.591 per cent less respectively under 0.4, 0.8 and 1.2 atmosphere soil moisture tension.

The influence of nitrogen on the total yield of tuber under drip and furrow irrigations (Table 4.14) indicate that higher yield is always under drip irrigation. However, the difference in the total yield between drip and furrow irrigation is significant in two seasons at 0 kg N, in three seasons at 100 kg N and in two seasons at 200 kg N.

The results clearly indicate the significant influence of drip irrigation on the size distribution and on the total yield. Higher yield under drip irrigation may be explained as follows :

Significant tuber expansion under 0.4 atmosphere soil moisture tension under drip irrigation (Table 4.9 and 4.10 a) indicates the need of maintenance of soil moisture tension at this level. Higher tuber bulking is also at 100 kg and 200 kg nitrogen treatments. Because of higher tuber bulking, the total yield under drip irrigation (Average data) at 0.4 atmosphere is 17.08 per cent more than that at 0.8 atmosphere and 52.38 per cent more than that at 1.2 atmosphere (Table 4.11). Due to higher tuber bulking, the total yield (Average data) under drip irrigation at 100 kg is 22.76 per cent, 16.49 per cent and 59.16 per cent more than that under 0 kg, 200 kg and 300 kg nitrogen treatments respectively (Table 4.14). Moreover, 3.83 per cent higher tuber bulking over furrow irrigation (Table 4.15) at large three groups under drip irrigation contributes towards its higher total yield. Higher tuber bulking (under drip irrigation) resulting in higher total yield is probably due to very slow rate of application of water within the root zone. The slower rate of application of water maintains soil moisture tension almost at predetermined value and looseness of soil. Higher yield is also due to better utilization of nitrogen in drip irrigation (Chesness and Couvillon, 1976) where leaching is minimum. Higher yield under drip irrigation was reported by Grainer et al. (1976) for tomato, melon and cucumber,

Abreu et al. (1978) for melon, Goldberg et al. (1976) for tomato, carrot and onion; El Awady et al. (1976) for pea, Locascio et al. (1977) for strawberries, Hill (1977) for sugarcane and Delver (1977) for pippinapple.

4.2.4 Interaction

The interactions of soil moisture tension and nitrogen on the size distribution and on total yield of tuber during three seasons have been discussed below.

4.2.4.1 Size distribution

In the lower two size groups of less than 25 mm and 25-35 mm and at any nitrogen level, the difference in per cent of total yield between 1.2 atmosphere and 0.4 atmosphere is significant during all the three seasons (Table 4.17). Within the same size groups, at any soil moisture tension, per cent of total yield at 300 kg N treatment is superior to that at 100 kg N. Smaller size tubers are, therefore, produced under higher soil moisture tension and higher dose of nitrogen. In the next size group, 35-45 mm at any nitrogen levels, higher per cent of tuber is either at 0.8 atmosphere or at 1.2 atmosphere during two seasons, though there is no difference between 0.8 and 1.2 atmosphere during 1981-82. However, lowest per cent of total yield is at 100 kg N with 0.4 atmosphere in three seasons and at 100 kg N with 0.8 atmosphere at one season.

In the larger two size groups (45-60 mm and above 60 mm), higher per cent of total yield is under 0.4 atmosphere irrespective

Table 4.17 Variation in size distribution of tuber with soil moisture tension and nitrogen

Soil moisture tension (atm)	< 25 mm				25-35 mm				35-45 mm			
	Levels of nitrogen, kg/ha											
	0	100	200	300	0	100	200	300	0	100	200	300
1979-80												
0.4	10.682 (3.185)	8.521 (2.283)	9.126 (2.648)	11.061 (3.546)	17.749 (9.385)	13.949 (5.976)	18.484 (10.191)	20.067 (11.869)	34.561 (32.285)	32.494 (29.045)	31.067 (26.719)	35.819 (34.32)
0.8	17.840 (9.428)	13.572 (5.575)	15.627 (7.378)	15.900 (7.686)	24.355 (17.212)	21.267 (14.34)	24.497 (16.904)	25.693 (19.324)	36.562 (35.515)	34.387 (31.820)	37.523 (37.156)	38.933 (39.627)
1.2	20.293 (12.355)	16.373 (8.221)	18.261 (9.987)	22.425 (14.819)	27.115 (21.202)	23.417 (15.980)	27.851 (22.012)	32.999 (29.944)	39.799 (41.022)	38.004 (37.968)	38.665 (39.087)	34.119 (31.53)
1980-81												
0.4	10.643 (3.386)	9.694 (2.870)	8.206 (2.098)	11.063 (3.81)	20.718 (12.553)	19.140 (10.095)	18.957 (10.881)	23.713 (16.635)	36.221 (35.048)	29.102 (23.872)	35.224 (33.316)	37.066 (36.720)
0.8	18.151 (8.703)	11.578 (4.305)	12.335 (4.786)	14.840 (6.680)	28.503 (22.690)	22.781 (15.095)	25.873 (19.118)	33.341 (30.285)	37.947 (37.845)	37.415 (37.006)	37.969 (37.983)	37.863 (37.898)
1.2	18.714 (10.753)	15.067 (7.502)	16.759 (8.526)	19.731 (11.491)	35.510 (33.935)	28.098 (22.27)	28.294 (22.895)	34.538 (32.116)	35.204 (33.466)	34.341 (32.054)	38.603 (38.608)	36.222 (35.078)
1981-82												
0.4	13.419 (5.496)	9.809 (2.951)	12.500 (4.964)	14.789 (6.787)	20.535 (12.363)	17.103 (9.010)	21.002 (13.061)	24.508 (16.930)	34.478 (31.894)	29.949 (24.999)	33.054 (29.773)	32.132 (28.484)
0.8	19.992 (11.831)	15.738 (7.396)	18.723 (10.648)	19.045 (10.733)	27.878 (21.893)	27.751 (21.767)	30.756 (24.121)	27.980 (22.019)	34.584 (32.318)	34.414 (32.018)	33.983 (31.398)	33.420 (30.379)
1.2	21.716 (13.938)	19.715 (11.439)	21.033 (12.603)	22.735 (14.946)	33.512 (30.549)	28.581 (23.036)	29.589 (24.413)	33.208 (30.079)	32.137 (28.437)	31.188 (26.904)	34.228 (31.116)	32.975 (29.657)

1. Values in parenthesis indicate actual per cent of total yield

	1979-80	1980-81	1981-82	1979-80	1980-81	1981-82	1979-80	1980-81	1981-82
2. Difference between two nitrogen means at the same level of tension	S.E.m _t 1.702	1.865	1.292	2.386	1.918	3.441	1.603	2.545	1.511
	C.D.5% 3.475	3.809	2.639	4.872	3.918	7.027	3.273	5.197	3.087
3. Difference between two tension means at the same level of nitrogen	S.E.m _t 1.609	1.714	1.347	2.637	2.196	3.186	1.510	1.376	1.168
	C.D.5% 3.287	3.500	2.751	5.386	4.486	6.506	3.103	2.811	3.447

of nitrogen level (Table 4.17 c). At any tension level, the difference in per cent of the total yield between 10 kg N and 300 kg N is highly significant at the size 45-60 mm. Except for 1.2 atmosphere (1980-81) and 0.8 atmosphere (1981-82), lower per cent is always at 300 kg N irrespective of any tension. Therefore, higher tuber bulking is at 100 kg N under 0.4 atmosphere.

4.2.4.2 Total yield

The results (Table 4.18) indicate that at any soil moisture tension, the total yield increases significantly with the addition of first 100 kg nitrogen during all the three seasons. Application of 200 kg nitrogen increases the yield over 0 kg N by 7.58 per cent during 1980-81 and 8.31 per cent during 1981-82 (average data). The yield at 300 kg nitrogen decreases significantly irrespective of soil moisture tension and seasons. At 100 kg N, the rate of increase in the total yield varies with soil moisture tension and season (Table 4.18). The increase in total yield at 100 kg N over 0 kg N treatment is 18.1 per cent at 0.4, 23.62 per cent at 0.8 and 23.71 per cent at 1.2 atmosphere (Average data).

At any nitrogen level, the maximum total yield is at 0.4 atmosphere and it gradually decreases with the increase in soil moisture tension indicating the need of lower soil moisture tension for tuber expansion. The depressing effect of increased soil moisture tension is probably compensated well by the addition of 100 kg nitrogen over 0 kg at 0.8 atmosphere resulting in greater

Table 4.18 Variation in total yield (q/ha) with nitrogen and soil moisture tension

Soil moisture tension, atm	Level of nitrogen kg/ha				S.E.m $\pm$	C.D.at 5%
	0	100	200	300		
1979-80						
0.4	279.01	307.65	266.88	229.92		
0.8	234.29	277.19	221.97	194.51	12.38	25.28
1.2	166.10	208.95	185.76	136.39		
Average	226.46	264.59	224.87	186.87	7.15	14.59
S.E.m $\pm$	11.42					
C.D.at 5%	23.672					
1980-81						
0.4	253.51	307.78	279.26	206.24		
0.8	217.11	276.08	232.80	176.55	11.30	23.07
1.2	159.20	193.52	165.53	122.89		
Average	209.94	259.13	225.86	168.56	6.52	13.32
S.E.m $\pm$	11.66					
C.D.at 5%	24.722					
1981-82						
0.4	275.36	337.10	291.08	194.98		
0.8	217.38	305.21	237.93	166.35	14.85	30.34
1.2	189.97	235.18	210.86	145.08		
Average	227.57	292.49	246.63	168.81	8.57	17.51
S.E.m $\pm$	13.72					
C.D.at 5%	28.464					

increase of yield. On examination of results, it is revealed that at any level of nitrogen, the difference between the yield due to soil moisture tension are significant except that between 0.8 and 1.2 atmosphere under 200 kg and 300 kg N during 1981-82 season.

The maximum yield under 100 kg Nitrogen and at 0.4 atmosphere is mainly due to higher per cent of total yield at larger two size groups. The results are in conformity with those of Hukkeri and Moolani (1965), Misra and Pati (1970), Gerasimov (1970), and Tsvetkova (1972).

4.3 Evapotranspiration and Yield

The relation between the total evapotranspiration in a season and the total yield of tuber is presented in Figure 4.36. This figure carries three seasons' data for furrow and drip irrigations. The regression equations are :

$$\text{Furrow : } Y = 9.425 E_{T(s)} + 17.474, \quad r = 0.963 \quad (4.84)$$

$$\text{Drip : } Y = 13.882 E_{T(s)} - 25.470, \quad r = 0.981 \quad (4.85)$$

where, Y = Yield of tuber, q/ha

$E_{T(s)}$ = Total measured evapotranspiration, cm/season.

The value of r for each equation indicates a highly significant linear relation between the total yield and $E_{T(s)}$. The yield increases with the increasing amount of water used up by

FURROW		DRIP	
▲	1979 - 80	△	138
■	1980 - 81	□	
●	1981 - 82	○	

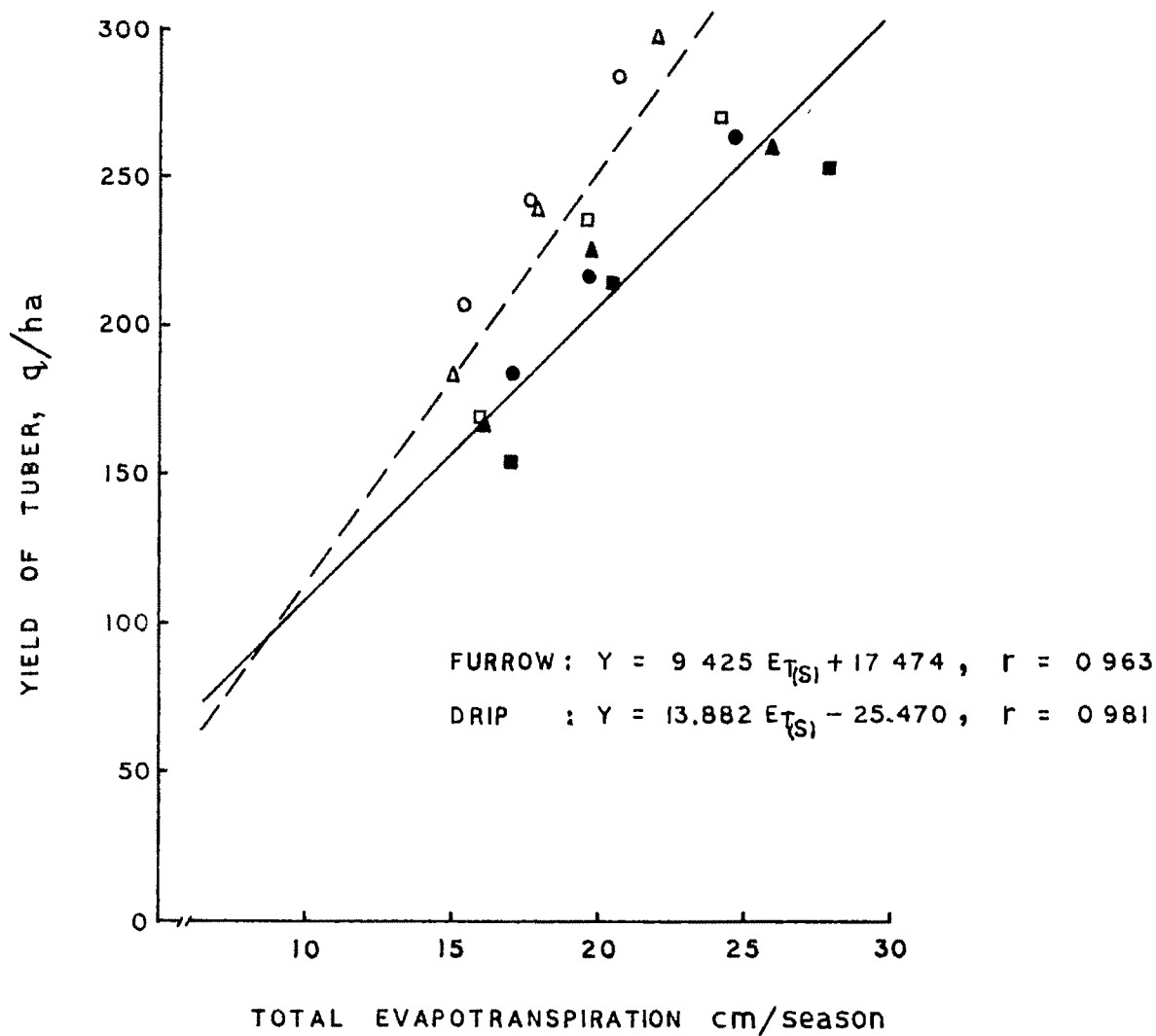


FIG 4.36 RELATIONSHIP BETWEEN YIELD OF TUBER AND TOTAL EVAPOTRANSPIRATION

the potato plants irrespective of methods of irrigation. The rate of increase in yield is, however, higher under drip irrigation. The slopes of these lines represent the response of the crop to different methods of irrigation. For each cm of water used up, while the yield under furrow irrigation is 9.425 g/ha, under drip irrigation it is 13.882 g/ha. It may be mentioned that similar relationship was reported by Penman (1963), Nijtoma and Gabriella (1970) and Maity (1972).

4.4 Water-use Efficiency

Water-use efficiency is defined as the quotient of the total yield of tuber (kg/ha) and the total evapotranspiration (mm) for its production. Water-use efficiency (W_{eff}) was calculated under three soil moisture tensions and four levels of nitrogen separately for furrow and drip irrigation (Tables 4.19 and 4.20).

The results indicate that except for 0.4 atmosphere under drip irrigation during 1981-82 (Table 4.19), the W_{eff} increases with the increase in soil moisture tension up to 0.8 atmosphere under both methods of irrigation during all the three seasons and then it decreases at 1.2 atmosphere. The relationship is, therefore, curvilinear. The higher W_{eff} at 0.8 atmosphere is due to higher reduction (Table 4.1) of the total evapotranspiration (20.69 per cent) compared to the decrease (Table 4.11) in the total yield (14.59 per cent) for the increase in soil moisture tension from 0.4 to 0.8 atmosphere (Average data).

Table 4.19 Variation in water-use efficiency, (kg/h)/mm, with soil moisture tension and irrigation methods

Methods	Soil moisture tension, atm.	Season			Average
		1979-80	1980-81	1981-82	
Furrow	0.4	99.82	90.72	107.34	99.29
	0.8	114.43	105.03	110.35	110.00
	0.2	99.06	88.21	106.93	98.07
	Average	104.44	94.56	103.27	
Drip	0.4	126.79	113.35	138.22	126.12
	0.8	133.53	120.37	138.17	130.69
	1.2	118.23	102.79	134.35	118.45
	Average	126.18	112.17	136.91	

The results (Table 4.20) indicate a curvilinear relationship between W_{eff} at 100 kg N treatment in both methods of irrigation during all the three seasons. The lowest W_{eff} at 300 kg N treatment is due to lowest total yield (Table 4.14) and highest total evapotranspiration ($E_{T(s)}$). Since the maximum total yield (Table 4.14) is at 100 kg N (an increase of 22.93 per cent over 0 kg) and since $E_{T(s)}$ at 100 kg N has increased only by 9.17 per cent (Table 4.2) over 0 kg N, higher W_{eff} seems logical.

Results further indicate that higher W_{eff} is under drip irrigation irrespective of soil moisture tension and levels of nitrogen. Higher W_{eff} in drip irrigation is due to 8.29 per cent

Table 4.20 Variation in water-use efficiency (kg/ha)/mm
with levels of nitrogen and irrigation methods

Methods	Levels of nitrogen, kg/ha	SSeason			Average
		1970-80	1980-81	1981-82	
Furrow	0 kg	118.38	103.82	117.88	113.36
	100 kg	124.24	118.01	142.29	129.18
	200 kg	101.28	93.21	108.00	100.83
	300 kg	76.08	68.74	71.97	72.26
	Average	105.74	95.94	110.03	
Drip	0 kg	146.70	126.88	155.88	143.15
	100 kg	156.45	142.52	178.43	159.13
	200 kg	118.39	114.79	140.36	124.51
	300 kg	93.63	74.63	84.92	84.39
	Average	128.79	114.70	139.90	

higher total yield and 10.83 per cent lower $E_T(s)$ values compared to furrow irrigation (Tables 4.4 and 4.16). The results are in general agreement with those of Maity (1972) on potato, Ghosh (1974) on wheat and Sarkar (1974) on paddy.

4.5 Concluding Remarks

The influence of mean air temperature, vapour pressure deficit, sunshine hours, wind velocity, soil moisture tension, nitrogen level, stages of growth and irrigation methods on evapo-transpiration has been discussed. While the E_T increases with the

increase of these four climatic variables linearly, the rate of increase varies with the soil moisture tension and nitrogen levels. The relationship between the total evapotranspiration and each of soil moisture tension and levels of nitrogen is curvilinear. Total measured evapotranspiration values are significantly higher in furrow irrigation. While E_T varies with the stages of growth, the highest E_T is during tuber formation stage. In wet soil, the resistance to the water loss is small and the thermal contact coefficient is relatively large and since water is available, large part of radiation is used up contributing higher E_T . With the increase in nitrogen application, the leaf area increases for greater interception of radiation, root system increases for greater extraction of soil water from larger volume of soil and decrease in stomatal resistance ultimately helps in greater diffusion of water vapour, and all these contribute towards higher E_T . Higher E_T in furrow irrigation is due to greater wet surface.

On account of the varying success of the Penman and the Blaney-Griddle formulae, two equations (one for furrow and the other for drip) involving four climatic parameters like mean air temperature, vapour pressure deficit, sunshine hours and wind velocity, soil moisture tension and levels of nitrogen have been developed and verified with the measured E_T . Since a good agreement exist between the measured and estimated values, these equations can be successfully applied in this locality and in other potato growing areas where similar climatic conditions prevail.

Higher tuber bulking is under drip irrigation at 0.4 atmosphere soil moisture tension with 100 kg nitrogen. The highest total yield is at 0.4 atmosphere with 100 kg N/ha. The relationship between the total yield and each of soil moisture tension and nitrogen level is curvilinear. Because of higher tuber bulking, the total yield of tuber in drip irrigation is 8.29 per cent more than that in furrow irrigation. Higher total yield in drip irrigation is probably due to very slow rate of application of water which maintains soil moisture tension at predetermined value and looseness of soil. Higher yield is also due to better utilization of nitrogen in drip irrigation where leaching is minimum.

CHAPTER - V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSIONS

5.1 Summary

Evapotranspiration and yield analysis on potato, irrigated by furrow and drip, was made mainly because potato is an important food crop in India. Since potatoes are very sensitive to soil moisture change, maintenance of proper quantity of water in the root zone is important. Timely application of proper quantity of water, particularly during the critical stages of growth, not only saves the wastage of water to a large extent, but also assures an increase in yield. Methods of irrigation play an important role in saving of water to a large extent. Irrigation studies are required for scheduling irrigation of a particular crop. In the absence of such study, recommendation for scheduling of irrigation can be made from soil and root system, together with the estimate of evapotranspiration rate (E_T).

This study was conducted during three seasons of 1979-80, 1980-81 and 1981-82 at Kalyani, West Bengal, to examine :

1. (a) The inter-relationship amongst measured E_T , climatic variables, soil moisture tensions, nitrogen levels, stages of

growth and methods of irrigation,

(b) the applicability of Penman and Blaney-Criddle formulae in predicting E_T ,

(c) the influence of soil moisture tension, nitrogen levels and methods of irrigation on the size distribution and on the total yield of tuber, and

2. To develop an equation for estimating E_T using meteorological variables, soil moisture tension and nitrogen levels.

5.1.1 Evapotranspiration

The influence of four climatic variables - temperature, vapour pressure deficit, wind velocity and sunshine hours on E_T measured under furrow and drip irrigation was studied. The relationship amongst each of these climatic variables and E_T was found to be linear, irrespective of seasons, methods of irrigation and soil moisture tension. While the highest rate of change in E_T was found under 0.4 atmosphere soil moisture tension, it gradually decreased with the increase of soil moisture tension irrespective of methods of irrigation.

Irrespective of the seasons, mean evapotranspiration rate, under three soil moisture tensions, gradually increased during the first part of the season until the peak was reached during the maximum plant growth and then decreased due to ageing. Although

similarity was observed in the rate of change in E_T with weeks of growth, E_T varied with the soil moisture tension and methods of irrigation. The highest E_T was observed under 0.4 atmosphere under both methods of irrigation. The relationship between total evapotranspiration and soil moisture tension was found to be curvilinear and is expressed by the following equations :

$$\text{Furrow : } E_{T(s)} = 35.2070 - 26.3046 T + 9.1563 T^2$$

$$\text{Drip : } E_{T(s)} = 27.3750 - 14.4378 T + 3.9268 T^2$$

where, $E_{T(s)}$ = Total evapotranspiration measured, cm/season

T = Soil moisture tension, atmosphere.

The influence of nitrogen on E_T indicated that higher E_T was always associated with higher doses of nitrogen irrespective of seasons and methods of irrigation. The relationship between total evapotranspiration and the doses of nitrogen was curvilinear and is expressed by the following equations :

$$\text{Furrow : } E_{T(s)} = 18.6037 + 0.01517 N + 0.0000055 N^2$$

$$\text{Drip : } E_{T(s)} = 16.3775 + 0.01392 N + 0.00000927 N^2$$

where, $E_{T(s)}$ = Total evapotranspiration measured, cm/season

N = Dose of nitrogen, kg/ha.

Total evapotranspiration at 0 kg N was 26.64 per cent less compared to that at 300 kg N/ha.

Evapotranspiration rate varied with the stages of growth.

The highest and lowest E_T values were during tuber formation stage and tuber growth and maturation respectively under both furrow and drip irrigations during all the three seasons.

The curvilinear relationship between weeks of growth and E_T under furrow and drip irrigation is given by the equations :

$$\text{Furrow : } E_T = 0.1993 + 1.1438 \text{ wk} - 0.0956 \text{ wk}^2$$

$$\text{Drip : } E_T = 0.1525 + 1.0297 \text{ wk} - 0.0860 \text{ wk}^2$$

where, E_T = Evapotranspiration rate, mm/day

wk = Weeks of growth.

Measured total evapotranspiration, $E_{T(s)}$, values were significantly higher in furrow irrigation during all the three seasons. Compared to $E_{T(s)}$ values in drip, these values, in furrow irrigation, were 13.16, 9.10 and 14.51 per cent more during 1979-80, 1980-81 and 1981-82 respectively.

The paired 't' test indicated that there was not much difference between pan evaporation (E_0) and E_T values at 0.8 atmosphere under furrow and at 0.4 atmosphere under drip irrigation.

Measured E_T values were compared with the estimated values (E_t) by Penman formula. A good agreement was found to exist between E_T and E_t values at 0.8 atmosphere under furrow and at 0.4 atmosphere under drip irrigation. The paired 't' test indicated that on an average there was not much difference between these values at 0.8 atmosphere (furrow) and 0.4 atm (drip). There was

also a good agreement between estimated 'u' by Blaney-Criddle formula and measured E_T only in respect of 0.8 atmosphere under both furrow and drip irrigations. The mean seasonal coefficients indicated a closer agreement only at 0.8 atmosphere under both furrow (1.007) and drip (0.9172) irrigations.

Two formulae (one for drip and the other for furrow) were developed for estimating the evapotranspiration for the potato crop using 14 days average E_T values under three soil moisture tensions and four levels of nitrogen during two seasons (1979-80 and 1980-81). These formulae are :

$$\begin{aligned} \text{Furrow : } E_T = & 14.7054 - 0.4867 (t) - 0.2931 (e_s - e_a) + 0.0396 (S) \\ & - 0.2999 (W) - 1.6906 (T) + 0.0020 (N) \end{aligned}$$

$$\begin{aligned} \text{Drip : } E_T = & 12.7135 - 0.4331 (t) - 0.2440 (e_s - e_a) + 0.0171 (S) \\ & - 0.2178 (W) - 1.1508 (T) + 0.0022 (N) \end{aligned}$$

where, E_T = Measured evapotranspiration, rate mm/day
 t = Mean air temperature, degree centigrade
 $(e_s - e_a)$ = Vapour pressure deficit, mm of mercury
 S = Actual bright sunshine hours
 W = Measured wind velocity, km/hr
 T = Soil moisture tension, atmosphere
 N = Levels of nitrogen, kg/ha.

Each formula was verified separately with measured E_T values obtained during 1981-82 season. A good agreement was found to

exist between measured and estimated values.

5.1.2 Yield

The influence of soil moisture tension on the size distribution of tuber and on the total yield was studied. The per cent of total yield in the size groups 45 to 60 mm and above was highest (51.90 to 57.16) under 0.4 atmosphere during all the three seasons, and it gradually decreased with the increase in soil moisture tension. However, the per cent of total yield in three smaller groups (< 25 mm, 25-30 mm and 35-45 mm) varied between 60 and 65 under 0.8 atmosphere and between 69 and 71 under 1.2 atmosphere,

The total yield of tuber decreased with the increase of soil moisture tension and the highest yield was always under 0.4 atmosphere. The relationship between the total yield of tuber, averaged over seasons and soil moisture tension, is expressed by the following equations :-

$$\text{Furrow : } Y = 283.362 - 42.342 T - 45.643 T^2$$

$$\text{Drip : } Y = 305.501 - 49.875 T - 41.117 T^2$$

where, Y = Total yield of tuber, q/ha

T = Soil moisture tension, atmosphere.

Three seasons results indicated that the per cent of total yield under 0 kg, 200 kg and 300 kg nitrogen per hectare increased with the sizes up to 35-45 mm groups and varied between

22 to 37 per cent. However, under 100 kg nitrogen, the per cent of total yield increased with the sizes up to 45-60 mm size group. The per cent of the total yield of tuber in 45-60 mm and above 60 mm size, was significantly higher under 100 kg nitrogen.

The relationship between the total yield of tuber and nitrogen, indicated that the yield increased up to 117 kg and then decreased considerably at 300 kg nitrogen. Although the influence of nitrogen varied with the season and methods of irrigation, the maximum and minimum yield were obtained at 100 kg and 300 kg nitrogen per hectare respectively. The relationship between the total yield of tuber and levels of nitrogen, averaged over three seasons, is given below :

$$\text{Furrow : } Y = 214.0748 + 0.5847 N - 0.002466 N^2$$

$$\text{Drip : } Y = 234.547 + 0.6934 N - 0.002956 N^2$$

where, Y = Total yield of tuber, q/ha

N = Dose of nitrogen, kg/ha

Three seasons data indicated that higher per cent of total yield was under furrow irrigation in respect of less than 25 mm, 25-35 mm and 35-45 mm size groups. However, in the two large size groups (45-60 and above 60 mm) the per cent of total yield was higher under drip irrigation in all the three seasons.

The difference in the total yield of tuber between furrow and drip irrigations under any soil moisture tension, was significant

except that under 1.2 atmosphere in 1980-81. Considering all the data together, the yield under furrow irrigation was 7.14, 7.943 and 10.521 per cent less under 0.4, 0.8 and 1.2 atmosphere soil moisture tension respectively. The influence of nitrogen on the total yield of tuber also indicated that higher yield was always under drip irrigation.

At 0.4 atmosphere with 100 kg nitrogen, higher per cent of yield was obtained in the case of larger two groups, while the per cent of yield was lowest for the smaller three groups. For any nitrogen level, the maximum yield was at 0.4 atmosphere and it gradually decreased with the increase of soil moisture tensions. The maximum total yield was obtained with 100 kg nitrogen at 0.4 atmosphere during all the three seasons.

The relationship between the total yield of tuber and total evapotranspiration in both methods of irrigation was linear. The yield increased with the increasing amount of water used up by the potato plant irrespective of methods of irrigation.

5.2 Conclusions

Evapotranspiration is not only influenced by temperature, vapour pressure deficit, sunshine hours and wind velocity, but also is influenced by levels of nitrogen and soil moisture tension. The influence of soil moisture tension and nitrogen is very much pronounced. While total evapotranspiration at 0.4 atmosphere was 35.64 per cent higher than that at 1.2 atmosphere,

it was 26.64 per cent less at 0 kg N compared to that at 300 kg N/ha. Therefore, for any evapotranspiration study, climatic variables, soil moisture tensions and nitrogen levels need be included.

The influence of methods of irrigation is also very important in saving of water. At 0.4 atmosphere soil moisture tension, drip irrigation saved over 17 per cent water. Therefore, in limited water supply areas, drip irrigation has an important role to play.

Prediction of evapotranspiration can be made from pan evaporation data.

Since actual measurement of evapotranspiration is time consuming, evapotranspiration may be estimated by formulae developed for this purpose. The varying success of Penman and Blaney-Criddle formulae for soil moisture tension, nitrogen level and climatic conditions different from those under which these formulae were developed, indicate the need of proper calibration.

For estimating evapotranspiration for potato crop irrigated by furrow and drip methods, two equations have been developed and verified with the measured evapotranspiration rates. These equations can be successfully applied in this locality and in other potato growing areas where similar climatic conditions prevail.

For production of higher per cent of large size tubers,

maintenance of 0.4 atmosphere soil moisture tension in the root zone and application of 100 kg nitrogen is necessary. Higher soil moisture tension with either lower or higher dose of nitrogen produce, small size tubers.

CHAPTER - VI

FUTURE SCOPE OF RESEARCH

FUTURE SCOPE OF RESEARCH

The evapotranspiration rate depends on the vapour pressure gradient between the saturated cell wall and free air above the plant and is regulated by the diffusion resistance in the substomatal, stomatal and boundary layer regions of the diffusion path. The measurement of the diffusion resistance may be included in future study.

Although the highest total yield of tuber was under 0.4 atmosphere with 100 kg nitrogen, the relationship between yield and each of soil moisture tension and levels of nitrogen is curvilinear. A further study is required to know the relationship between yield and soil moisture tension with levels of nitrogen beyond the range of this investigation.

Apart from saving considerable amount of water, drip irrigation not only produces higher total yield but also higher per cent of large size tuber. A further study is, therefore, required to know the economics of drip irrigation and possibility of its use in wider areas.

CHAPTER - VII

BIBLIOGRAPHY

B I B L I O G R A P H Y

- Abreu, T.A. De., Olitta, A.E.L., and Marchetti, D.A.B. (1978)
Comparison of two irrigation methods (Furrow and drip) on
melon in the San Francisco Valley. *Pesquisa Agropecuaria
Brasileira*, 13(3), 35-45.
- Akopyan, G.A., and Oganyan, E.A.(1978) Evaporation during the
cultivation of vineyard soils. *Pochvovedenie* No. 7,
97-100.
- Angus, D.E.(1959) Water and its relation to soils and Crops :
C. Agricultural water use. *Advances in Agronomy*. 11,
19-35.
- Baier, U., and Robertson, G.U. (1965) Estimation of latent
evaporative from simple weather observations, *Can. J.
Plant Sci.* 45, 276-284.
- Black, F.A., Gardner, W.B., and Thurtell, G.W.(1969) The predic-
tion of evaporation drainage and soil water storage for a
bare soil. *Soil Sci. Soc. Amer. Proc.* 33, 655-660.
- Blake, G.F., Brill, G.D., and Campbell, J.C. (1955) Studies on
the supplemental irrigation of potato in New Jersey. *Amer.
Potato J.* 32, 327-331.

- Blaney, H.F., and Criddle, W.D.(1950) Determining water requirement in irrigated areas from climatological and irrigation data. U.S. Deptt. Agri. Soil Conservation Serv. SCS-TP-96, 48.
- Bond, J.J., Power, J.F., and Willis, W.O. (1971) Soil water extraction by nitrogen fertilized spring wheat. Agron. J. 63, 280-283.
- Bradley, G.A., and Pratt, A.J. (1955) The effect of different combinations of soil moisture and nitrogen levels on early plant development and tuber set of the potato. Amer. Potato J. 32, 254-258.
- Bravo, M., Vargas, L., and Alvin, P. De. T. (1968) Effect of 4 irrigation frequencies on LAI and yield of potato. Turrialba, 18(2), 179-181.
- Brown, P.L.(1971) Water use and soil water depletion by dryland winter wheat as affected by nitrogen fertilization. Agron. J. 63, 43-46.
- Burman, R.D., and Loudon, T.L.(1968) Evapotranspiration and micro-climate of irrigated pastures and alfalfa under high altitude conditions. Trans. ASAE, 11(1), 128-129, 128.
- Chandani, J.J., Gandhi, R.T., Pandey, S.L. and Bodade, V.N.(1962) Studies on the effect of delta of irrigation, depth of irrigation and levels of nitrogen on potato crop. Indian J. Agron. 7(1), 22-28.
- Chang, Jen-Hu (1961) Micro-climate of sugarcane. Hawaiian Planters' Record. 56, 195-223.

- Chang, Jen-Hu (1968) 'Climate and Agriculture'. Aldine Publishing Company, Chicago.
- Channappa, T.C. (1979) Drip irrigation increases water use efficiency. Trans. Indian Society of Desert Technology and University Centre of Desert Studies 4(1), 15-21.
- Chesness, J.L., and Couvillon, G.A.(1976) Nutrient management of Peach trees with drip irrigation. ASAE. Paper, No. SER-104.
- Choudhuri, H.C., and Ray, A.W. (1964) Irrigation and fertilization affects on yield of potatoes in West Bengal. Amer. Potato J. 41(12), 406-410.
- Christiansen, J.E. (1968) Pan evaporation and evapotranspiration from climatic data. J. Irri. and Drain. Div. ASCE. Vol.94, I.R.2. Proc. Paper No. 5988, p. 243-265.
- Cochran, M.G., and Cox, G.M.(1955) "Experimental Designs". 2nd Ed. John Willey, New York, PP. 1-611.
- Criddle, Wayne, D. (1952) Methods of computing consumptive use of water. ASCE. Paper 1507.
- Dashevskii, I. (1971) Irrigation and Potato Yield. Kartoffel' i Ovoshchi No. 7 : 10.
- Delis, B.R., Ponce, I. and Tizio, R. (1964) Studies of water requirement of Horticultural crops. I. Influence of draught at different growth stages of potato on the tuber yield. Agron. J. 56(4), 377-381.
- Delver, P. (1977) Experiences with trickle irrigation (1) Fruittcult, 67(24), 778-781.

- Derco, M. (1968) The influence of several factors on the yield of early potatoes under irrigation. Restl. Vyroba 14(41). (F.C.A.Vol.22, 465).
- de Vries, D.A., and van Duin, R.H.A.(1953) Some consideration on the diurnal variations of transpiration. Nath. J. Agri. Sci. 1, 27-34.
- Drewitt, E.C.(1970) The effect of irrigation on the yield and quality of potatoes. Tech. Rep. 3 Winchmore Irrig. Res. Stn. PP.31.
- Dunton, E.M., Jr. (1968) Effect of fertilizer analysis and Irrigation on yield and quality of potatoes in Eastern Virginia, Amer. Potato J. 45, 12-16.
- Eagleman, J.R., and Decker, W.L.(1965) The role of soil moisture in evapotranspiration. Agron. J. 57, 626-629.
- Ekeren, P.C. Jr., Robins, J. S., and Staple, W.J.(1967) Soil and Cultural factors affecting evapotranspiration in "Irrigation of Agricultural land", edited by Hagan, Haise and Edminister. Amer. Soc. Agron. Monogr. 11.
- El. Awady, M.N., Amerhom, G.W., and Zaki, M.S.(1976) Trickle irrigation trial on pea in conditions typical of Qalyobela, Egypt. Egyptian J. of Hort. 3(1),99-110.
- Elwynn Taylor, S. (1980) Utility of differential leaf and air temperature measurements in determining plant water stress, Proc. of 72nd Annual meeting, Agronomy abstracts.

- Eric, Lecnad, J. (1968) Management : A key to irrigation efficiency J. Irri. and Drain. Div. ASCE. 94(103), Proc. Paper No.6107, pp. 286-293.
- Floeker, I.J., and Tinn, Norman (1966) Effect of soil moisture tension and physical condition of soil on utilization of water and nutrients by potatoes. Agron. J. 58, 290-293.
- Frost, K. R., and Schvalon, H. C. (1960) Evapotranspiration during sprinkler irrigation. Trans. ASAE 3(1), 18-20, 24.
- Fulton, J.A. (1958) Irrigating early potatoes in South Western Ontario. Publ. 1028 Can. Dept. Agri. Ottawa, P.13.
- Gandar, P. (1975) Growth and water relations in potatoes (*Solanum tuberosum* L.) Dissert. Abst. International, B. 33(3), 1010.
- Gardner, W.R. (1965) Dynamic aspects of soil water availability to plants. Ann. Rev. of Plant Physio. 16, 323-342.
- Cates, R. David, and Banks, L.J. (1967) Plant factors affecting evapotranspiration. In 'Irrigation of Agricultural Land' edited by Hagan, Raize and Edminister, Amer. Soc. Agron. Monogr. 2011.
- Gerasimov, A.A. (1970). Effect of mineral fertilizers and irrigation on the yield of early potatoes grown flood-plant peat soil. Khimiya Sel'khoz, 8(2), 10-14.
- Ghosh, K.K. (1974) Studies on Evapotranspiration and yield of wheat. Unpublished Ph.D. thesis. Sidnan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal, India. P. 211.

- Gibson, W. (1976) Hydraulics, mechanics and economics of sub-surface and drip irrigation of Hawaiian sugarcane. *International Sugar J.* February, 40-43.
- Gilbert, M.J., and van Bavel, C.M.H. (1954) A simple field method for measuring maximum evapotranspiration. *Trans. Amer. Geophysical Union.* 35, 937-942.
- Giovanardi, R. (1980) Biological and yield aspects and evapotranspiration of potato (*Solanum tuberosum* L) as a function of soil water regime. *Revista di Agronomia* 14 (4, Suppl.), 503-514.
- Goldberg, S.D., Ben-Ashar, J., and Gornat, B. (1976) Soil and plant water status under sprinkling and trickling. *Agricultural Water Management.* 1(1), 33-40.
- Gomez, K.A., and Gomez, A.A. (1976) 'Statistical procedure for Agricultural Research with emphasis on rice' IRRI, Los Banos, Philippines. P. 294.
- Goode, J.E., Higgs, K.H., and Hyrycz, K.J. (1978) Trickle irrigation in apple trees and the effects of liquid feeding with NO_3^- and K^+ compared with normal manuring. *J. of Hort. Sci.* 53(4), 307-316.
- Grahm, H.G., and King, K. M. (1961) Short wave reflection coefficient for a field of maize. *Quart. J. Royal Meteorol. Soc.* 87, 425-428.
- Grainer, J., Daly, P., and Parfait, F. (1976). The yields of some vegetable crops as a function of the amounts of water applied and the method of irrigation in South Martinique. *Nouvelles Agronomiques des Antibes et de la Guyane.* 2(1), 59-72.

- Greasley, A.S., and Lather, C.J.(1971). Effects of various irrigation regimes on yield and quality of potato. Queensland J. of Agriculture and Animal Sciences, 28(4),181-189.
- Grewal, S.S., and Singh, N.T.(1978) The effect of different Moisture Regimes on Soil Temperature and the yield and quality of potatoes in Northern India. Indian J. Agron. 23(2), 130-136.
- Hachum, A.Y., Alfaro, J.F., and Villardson, L.S.(1976). Water movement in soil from Trickle source, Irri. and Drain. Div. ASCE. Vol. 102, No. IR2, Proc. Paper 12204 (2), 179-192.
- Haddock, Jay, L. (1961). The influence of irrigation regime on yield and quality of potato tubers and nutritional status of plant. Amer. Potato J. 38, 423-433.
- Halstead, M. R., and Covey, W. (1957). Some meteorological aspects of evapotranspiration. Proc. Soil Sci. Soc. Amer. 21, 461-464.
- Hanks, R.M., Gardner, H.R., and Florian, R.L.(1968) Evapotranspiration climate relations for several crops in the central great plains. Agron. J. 60, 538-542.
- Hansen, V.E. (1963) Unique consumptive curve related to irrigation practice. J. Irrl. and Drain. Div. Proc. ASCE. Vol. 89, No. IR 1, 43-50.
- Hani, M.D.(1966) The effect of light on relationship between pan evaporation and evapotranspiration by beans under controlled environment. Unpublished M.S. Thesis, Washington State University.

- Hill, R.T. (1977) Is drip irrigation paying off ? In Hawaiian Sugar Technologist's 1976 report, Aiea, Hawaii, U.S.A. 168-170.
- Hillel, D. (1971) "Soil and water : Physical Principles and Processes". Academic Press, WC, 111 Fifth Avenue, New York, New York 10003. PP.1-288.
- Hobbs, E.H., and Krogman, K.K. (1966) Evapotranspiration from alfalfa as related to evaporation and other meteorological variables. Can. J. Plant Sci. 46, 271-277.
- Holmes, R.M., and Robertson, G.W. (1963) Application of the relationship between actual and potential evapotranspiration in dry land agriculture. Trans. ASAE 6(1), 65-67.
- House, G.J., Rider, N.E., and Tugwell, C.P. (1960) A surface energy balance computer. Quart. J. Royal Meteorol. Soc. 86, 215-231.
- Hukkeri, S.B., and Moolani, H.K. (1965) The effect of levels of fertilization and irrigation on the yield of potato (*Solanum tuberosum* L.). Sci. Cult. 31(1), 36-38.
- Hunter, A.S., Alban, L.A., Gevard, D.J., Hall, W.E., Cushmen, H.E., and Peterson, R.G. (1961) Fertilizer needs of wheat in the Columbia basin dryland wheat area of Oregon. Oregon. Agri. Exp. Sta. Tech. Bull. 57, 1-59.
- Inoue, E. (1963) The environment of plant surfaces. In Environment control of plant growth (L.T. Evans ed.).
- Jackson, E.A. (1960) Water consumption by lucerne in Central Australia. Aust. J. Agri. Res. 11, 715-722.

- Jacob, W.C., Russell, M.B., Lute, A.K., Levine, G., and Grossman (1952) The influence of irrigation on the yield and quality of potato on long Island. Amer. Potato J. 29(12), 292-296.
- Jaeger, S. (1966) Water budget of *Avena sativa* L. at increasing rates of complete mineral nutrients. 1. Ecological investigations. Pl. Soil. 24(1), 24-32.
- Jensen, C.M.(1967) Growth chamber studies of evapotranspiration by Red Kidney Beans. Trans. ASAE 10(5), 611-614.
- Jensen, M.E., and Haise, J. R. (1963) Estimating evapotranspiration from solar radiation. J. Irri. and Drain. Div. ASCE, 89(IR-4), 15-41.
- Jones, S.T., and Johnson, W.A.(1958) Effect of irrigation at different minimum levels of soil moisture of imposed draughts on the yield of onions and potatoes. Proc. Amer. Soc. Hort. Sci. 71, 440-445.
- Joyce, T. (1976) The Viallo system of drip irrigation with Porous tubes. Informatore di ortofloro frutticoltura, 17(5), 7-12.
- Koren, E. and Shlevin, E. (1977) Effects of trickle irrigation on soil-applied herbicides. Weed Research, 17(2),133-138.
- Kuzniar, K. (1968) The dynamics of potato yield (Dar variety) in relation to soil moisture content and some meteorological factors. Modwla Rosl. Aklim Nasienn. 12(2),159-175.

- Lemon, E.R., Glaser, A. H., and Satterwhite, L. E.(1957) Some aspects of the relationship of soil, plant and meteorological factors to evapotranspiration. Soil Sci. Soc. Amer. Proc. 21, 464-468.
- Linacre, E.T.(1963) Determining evaporation rates. J. Aust. Inst. Agri. Sci. 29, 165-177.
- Linacre, E.T. (1967) Climate and evaporation from crops. J.Irrig. and Drain. Div. ASCE, 93 (IR-4), 61-79.
- Little, M. Thomas (1966) 'Correlation and Regression - A supplement to Experimental Methods for Extension Workers'. University of California Agricultural Extension Service. P.1-62.
- Llewelyn, J.C. (1963) Irrigation of potatoes. Rep. Nottingham Univ. Sch. Agric. 47-51.
- Locascio, S.J., Myers, J.M., and Martin, F.S. (1977) Frequency and rate of fertilization with trickle irrigation for Strawberries. Amer. Soc. Hort. Sci. 102 (4), 456-458.
- Longacre, L.L., and Blaney, M.F. (1963) Evaporation at high elevation in California. Closure discussion. Irrig. and Drain. Div. ASCE 89 (1 & 2), 79-80.
- Loon, C.D. Van (1981) Effect of water stress on potato growth, development and yield. Amer. Potato J. 58(1), 51-59.
- Luebs, R.E. and Lang, A.E. (1967) Nitrogen effect on leaf area, yield and nitrogen uptake of barley under moisture stress. Agron. J. 59., 219-222.

- Luebs, R.E. and Lang, A.E. (1969) Evapotranspiration and water stress of barley with increased nitrogen. *Agron.J.* 61, 921-924.
- Maity, S.P. (1964-65) The study of moisture extractions pattern of potato plant. *Agricultural Engineer* (10), 21-24.
- Maity, S.P. (1972) Evapotranspiration analysis on potato. Unpublished Ph.D.thesis, Kalyani University, PP.196.
- Maity, S.P. (1974) The influence of evapotranspiration and soil matric suction on yield of potato. *J. Agril. Engg.* XI (5-6), 9-12.
- Maity, S. P. (1975) Effect of soil matric suction on the evapotranspiration of Potato. *J. Indian Soc. Soil Sci.* 23(3), 286-290.
- Maity, S.P., and Pandya, A.C. (1975) Evapotranspiration analysis on potato. *Proc. Second World Congress. IWRA, New Delhi*, 1, 363-372.
- Maity, S.P., and Sarkar, M.K. (1982) Estimation of evapotranspiration for the paddy crop. 12th International Congress on Soil Sci. New Delhi.
- Makkink, G.F. (1957) 'Ekzamene de la formula de penman' Examining the Penman formula. *Neth.J. Agric.Sci.*, 5, 290-305.
- Marlatt, W.E. (1961) The interactions of microclimate, plant cover, and soil moisture content affecting evapotranspiration rates. *Colo.St.Univ., Dep. Atmos. Sci. Tech. Paper* 23.
- Mech, S.J. (1969) Minimizing irrigation water use through management. *Proc. 7th Congress on Irrigation and Drainage. International Commission on Irrigation and Drainage, Mexico, Question 23, Part 11.*

- Melstad, J.D., and Deboer, D. (1978) Drip and Sprinkler irrigation of Carrots and Onions. ASAE, Paper No. 77-2013. Agri. Engg. Abst. 3(4).
- Michael, A. M. (1978) Irrigation theory and practice. Vikas Publishing House Pvt. Ltd., New Delhi, P. 801.
- Milthorpe, F.L.(1960) The income and loss of water in arid and semi arid zones. Arid. Zone Res. 15, 9-36.
- Misra, A., Pati, B. (1970) Effect of levels of irrigation and fertility on the growth and yield of potato (*Solanum tuberosum*). Indian J. Agron. 15(3), 293-297.
- Monteith, J.L.(1959) The reflection of shortwave radiation by vegetation. Quart. J. Roy. Meteorol. Soc. 85, 386-392.
- Munster, J.(1969) Effects of nitrogen fertilizers on the growth of young plants of early potatoes. Revue Suisse Agric. 1(1), 13-17.
- Mukammal, E.I., and Bruce, J.P.(1960) Evaporation measurements by pan and atmometer. International Union of Geodesy and Geophysical Association of Scientific Hydrology, No. 53, 408-420.
- Myhre, D.L.(1958) Water-furrow irrigation of potatoes. Amer. Potato J. 35.
- Nagarjah, S. (1981) The effect of nitrogen on plant water relations in tea (*Camellia sinensis*). Physiologia Plantarum 51(3), 304-308.

- Nagawiecka, H., and Boron, K. (1974) Evapotranspiration and field water consumption by crops at Chelm near Karkow. Zeszyty Problemowa postepow Nauk Rolniczych 161, 155-168.
- Namken, L.N., Gerard, C.J., and Brown, R.G. (1968) Evapotranspiration of cotton and estimation methods. Agron. J. 60, 4-7.
- Narang, G.R., and Dastane, N.G. (1971) Climatological based empirical formulae for planning irrigation schedule and estimating use of water in onions (*Allium cepa* L.) Indian J. Agron. 16(1), 88-94.
- Nazir, M.S., and Gill, M.S. (1967) Effect of irrigation frequencies, nitrogen rate and time of application on the yield of potato (*Solanum tuberosum*). Agric. Pakist. 18(1), 27-29.
- Norum, M.E., and Larson, C.L. (1960) Evaporation losses from standard non-recording, rain ganges. Trans. ASAE. 3(82), 83-86.
- Nosenko, V.F., and Koryagin, A.N. (1975) Synchronous drip spring-kling Vestrisk Sel'skokhozyaistvenoi Nauki Moskva 7, 81-91.
- Oebker, Norman, F. (1962). Potato Research in Arizona. Twelfth Natl. Potato Utiliz. Conf.
- Oliver, H. (1961) 'Irrigation and Climate'. Edward Arnold Publishers' Ltd., London.
- Olson, R.A., Thompson, C.A., Grabowski, P.H., Stakenholt, D.D., Frank, R.D., and Dreir, A.F. (1964). Water requirement of grain crops as modified by fertilizer use. Agron. J. 56, 427-432.
- Pelton, W.L., King K.M., and Tanner, C.B. (1960) An evaluation of the Thornthwaite and mean temperature methods for determining potential evapotranspiration. Agron. J. 52, 387-395.

- Pelton, W.L. (1964) Evaporation from atmometers and pans. Can. J. Plant Sci. 44, 397-404.
- Pelton, W.L. (1967) The effect of wind break on wind travel, evaporation and wheat yield. Can. J. Plant Sci. 47, 209-214.
- Penman, H.L. (1948) Natural evaporation from open water, bare soil and grass. Proc. Royal Soc. Series A. 193, 120-146.
- Penman, H. L. (1952) The physical bases of irrigation control. In respect of the nineteenth international Hort. Congress, London.
- Penman, H.L. (1956) Evaporation : An introductory survey. Noth. J. Agril. Sci. 4, 9-25.
- Penman, H.L. (1963) Weather and water in the growth of potatoes in "Growth of Potato", Ivins and Milthorpe editors, Butterworths, London.
- Penman, H.L., Angus, D.E., and van Davel, C.H.M. (1967) Micro-climatic factors affecting evaporation and transpiration. In "Irrigation of Agricultural Land", edited by Hagen, Haise and Edminister. Amer. Soc. Agron. Monogr. No. 11.
- Pereira, H.C. (1951) A cylindrical gypsum block for moisture studies in deep soil. J. Soil Sci. 2, 212-213.
- Perez, P.L., Garcia, C., and Calzada, E.J. (1961) Irrigation of potatoes in the costa central of Peru (Spanish). Publ. 4 Esta. Exp. Agric. de la Molina, Peru, P.19.
- Pruitt, W.O. (1960) Correlation of climatological data with water requirements of crops. Department of Irrigation, University of California, Davis.

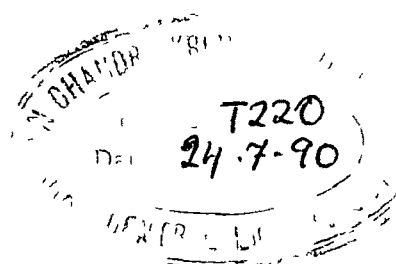
- Pruitt, W.O. (1960) Relation of consumptive use of water to climate. Trans. ASAE 339-13, 17.
- Pruitt, W.O.(1964) Cyclic relations between evapotranspiration and radiation. Trans. ASAE. 7(3), 271-275, 280.
- Pruitt, W.O. and Zensen, H.C.(1955) Determining when to irrigate. Agril. Engineering. 36, 389-393.
- Pam, R.S., and Singh, R.M.(1976) Comparative studies on trickle and surface methods of irrigating eucalyptus plants grown in light soils of Rajasthan. Indian J. Agric. Sci. 46(2), 79-80.
- Rao, K.V.P.(1970) The effect of subsurface-bedding and nitrogen levels on water requirement and performance of rice. Unpublished Ph.D.thesis, I.I.T.,Kharagpur.
- Rathore, S.S., and Singh, R.M.(1976) Consumptive use of water by dwarf wheat and its relationship with climatological parameters. Indian J. Agron. 21(1), 33-38.
- Ravelo, C.J., Hiler, E.A., and Howell, T.A.(1977) Trickle and sprinkler irrigation of grain sorghum. Trans. ASAE, 20(1), 96-99.
- Reeder, B.D., Neuman, J.S., and Worthington, J.L.(1976). Trickle irrigation on Peaches. Publication Texas Agricultural Experiment Station. 21 - 3437, 2 pp.
- Renea, S. and Gerindei, H.(1969) Effects of some husbandary measures on tuber yield of early potatoes under irrigation. Analale Institutului de Cercetari Pentru cultura cartofului si Sfeclor de Zohar. Brasov, Cartoful, 1, 163-170.

- Rijtena, P.E., and Gabriella, Erdodi (1970) Calculation of production of potatoes. *Neth. J. Agric. Sci.* 18, 26-36.
- Ritchie, Joe, T. (1971) Dry Land Evaporative flux in a sub-humid climate - I. Micrometeorological influences. *Agron. J.* 63, 51-55.
- Ritchie, Joe T., and Burnett, Earl (1971) Dry land evaporative flux in a subhumid climate : II. Plant Influence, *Agron. J.* 63, 56-62.
- Robins, J.S., and Domingo, C.E. (1956) Potato yield and tuber shape as affected by severe soil moisture deficit and plant spacing. *Agron. J.* 48, 11, 488-492.
- Sanchez-Diaz, M., Salaverri, J., and Grau, J. (1974) Effects of water stress on carbohydrate content and on yield of potato (*Solanum tuberosum* L.) 33 (11/12), 967-977.
- Sarkar, M.K. (1975) Studies of evapotranspiration and yield of paddy. Unpublished Ph.D. Thesis, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal, India. P. 203.
- Shoji, K. (1977) Drip irrigation. *Scientific American*. 237(5), 62-68.
- Shuravilin, A. (1977) A comparative study of sprinkler and furrow irrigation to cotton. *Trudy vsesoyuznykh Nauchno-issledovatel'skii. Institut Khlopkovo-dstva.* 34, 74-80.
- Singh, A., and Bains, S.S. (1971) Consumptive use and moisture extraction pattern by sorghum as influenced by nitrogen and plant population. *Ind. J. Agron.* 16(4), 490-493.
- Singh, Gurbachan (1969) A review of the soil-moisture relationship in potatoes. *Amer. Potato J.* 46(10), 398-403.

- Sivanappan, R. K. (1977-78) Trickle irrigation for water scarcity areas. *Agricultural Engineer*, 20, 23-25.
- Slatyer, R.O. (1967) *Plant-water relationships*. Academic Press. New York, 683 P.
- Slatyer, R.O., and Mellory, I.C. (1961) *Practical microclimatology* Comm. Sci. and Ind. Res. Organisation, Australia.
- Sourell, H., Brann, A., and Schon., M. (1981) Trickle irrigation in row cropping. *Tropfbewässerung in landwirtschaftlichen Reihenkulturen*, *Landtechnik* 36(10), 461-464.
- Stanhill, G. (1961) A comparison of methods calculating potential evapotranspiration from climatic data. *Israel J. Agri. Res.* 11, 159-171.
- Stegman, E.C., and Nelson, D.C. (1973) Potato response to moisture regime Research Report, North Dakota Agricultural Experiment Station No. 44, 16 pp.
- Steineck, G. (1959) Irrigation of the potato. *Dtsch. Landw. Pr.* 81 (19), 185-186.
- Stockton, J.R. (1962) Potato irrigation studies, Twelfth Natl. Potato Utilis. Conf.
- Struhtemeyer, R.A. (1961). Efficiency in the use of water by potatoes. *Amer. Potato. J.* 38 (1) : 22-24.
- Supersberg, M. (1967) Field irrigation trials 1955-65 at Gross Engersdorf *Bodenkultur*, 18(2), 157-82 (Bibl. 77, Austria).
- Swinbank, W.C. (1958) Turbulent transfer in the lower atmosphere. *Climatology and Microclimatology. Proc. of the Canberra Symposium. Arid Zone Res.* 11; 35-37.

- Tanner, C. B. (1963) Basic instrumentation and measurements for plant environment and micrometeorology. Soils Bull. No. 6, Univ. of Wisconsin, Madison, 156, P.
- Tanner, C.B.(1967) Measurement of evapotranspiration. In irrigation of Agricultural lands edited by Hagan, Haise and Edminister. Amer. Soc. Agron. Monograph No. 11.
- Tanner, C.B., Lemon, E.W.(1962) Radiant energy utilized in evapotranspiration. Agron. J., 54, (2), 207-212.
- Tanner, C.B., and Pelton, W.L.(1960) Energy balance data. University of Wisconsin, Soil Bull. 2.
- Thornthwaite, C.I.(1948) An approach towards a rational classification of climate. Geographical Review 38, 55-91.
- Thornton, J.W.(1961) Moisture use by cotton in Piedmont of Georgia Trans. ASAC 4(1), 37-40, 44.
- Till, H.R.(1963) Potato irrigation trials. 1. Trials during 1959-60, season. Exp. Rec. Dept. Agric. S. Aust. 1, 31-37.
- Tsvetkova, P. (1972) Fertilizer and irrigation for potato. Krtofel' i Ovashchi 2, 13-14.
- van Dijk, P., and deVries, D.A.(1954) Evapotranspiration. Neth. J. Agri. Sci. 2, 425-445.
- Viet, G., F.G., Jr. (1962) Fertilizer and efficient use of water. Adv. Agron. 14, 223-264.
- Varrington, G.E.(1970) Transpiration and dry matter response to atmosphere humidity, matrix suction and fertility. Unpublished Ph.D.Thesis, Utah State University, Logan Utah.
- Wellings, L.L.(1969) Irrigation of early potatoes grown in beds and rows. Expt. Husb. (18), 66-73.

- Wiegand, C.L.(1962) Drying patterns of a sandy clay loam in relation to optimal depth of seeding. Agron. J. 54, 473-476.
- Vierenga, P.J.(1977) Influence of trickle and surface irrigation on return flow quality. Final report environmental protection Agency. No. EPA/600/2-77-093, 178 P.
- Wilcox, J.C. (1963) Effects of Weather on evaporation from Bellani Plates and evapotranspiration from Lysimeter. Can. J. Plant. Sci. 43, 1-11.
- Willatt, S.T.(1969) Moisture withdrawal pattern of maize at different fertility levels. Rhodesian J. Agril. Res. 7(1), 51-54.
- Wilson, J.H. (1963) Spray irrigation of Potatoes. Tasman. J. Agric. 24(4), 305-312.
- Wolf, P von (1976) Trickle irrigation in Great Britain. Tropof bewässerung in Grossbritannien Tropenlandwirt. 77(2),70-78.
- Yu, I.P., and Gitlin, H.M. (1973) Irrigation efficiencies of surface, Sprinkler and drip irrigation. Proc. Second World Congress on Water Resources IMFA 1.



633.49197
BEH