SOIL-PLANT-WATER RELATIONS, GROWTH AND YIELD OF GROUNDNUT UNDER MOISTURE STRESS

THESIS SUBMITTED TO THE
ANDHRA PRADESH AGRICULTURAL UNIVERSITY
IN PART FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF
DOCTOR OF PHILOSOPHY

BY
P.S. SARMA, M.Sc. (Ag.)

DEPARTMENT OF PLANT PHYSIOLOGY
COLLEGE OF AGRICULTURE
ANDHRA PRADESH AGRICULTURAL UNIVERSITY
RAJENDRANAGAR, HYDERABAD-500030

DECEMBER, 1983

SOIL-PLANT-WATER RELATIONS, GROWTH AND YIELD OF GROUNDNUT UNDER MOISTURE STRESS

THESIS SUBMITTED TO THE
ANDHRA PRADESH AGRICULTURAL UNIVERSITY
IN PART FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF
DOCTOR OF PHILOSOPHY

BY
P.S. SARMA, M.Sc. (Ag.)

DEPARTMENT OF PLANT PHYSIOLOGY
COLLEGE OF AGRICULTURE
ANDHRA PRADESH AGRICULTURAL UNIVERSITY
RAJENDRANAGAR, HYDERABAD-500030

DECEMBER, 1983

CERTIFICATE

This is to certify that the thesis entitled "Soil-Plant-Water relations, growth and yield of groundnut under moisture stress" submitted in partial fulfilment of the requirements for the degree of "Doctor of Philosophy" of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide research work carried out by Mr. P.S. Sarma under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma or has been published. Published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

Chairman of the Advisory Committee:

Thesis approved by the Student Advisory Committee

Chairman: Dr. M.V.K. Sivakumar
Principal Agroclimatologist
ICRISAT
Patancheru, A.P.

Co-Chairman: Dr. P.R. Reddy
Professor and University Head
Dept. of Plant Physiology and
Associate Director of Research
Regional Agricultural Research Station
Anakapalle, A.P.

Member: Dr. J.H. Williams
Principal Plant Physiologist (Groundnut)
ICRISAT

Member: Dr. M.S. Reddy
Agronomist
ICRISAT

Member: Dr. B. Gopal Singh
Assistant Professor
Department of Plant Physiology
College of Agriculture
Rajendranagar
Hyderabad.

CERTIFICATE

Mr. P.S. Sarma has satisfactorily prosecuted the course of research and the thesis entitled "Soil-Plant-Water relations, growth and yield of groundnut under moisture stress" submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been submitted by him for a degree of any University.

M.V.K. SIVAKUMAR
CHAIRMAN

TABLE OF CONTENTS

S.No.	Chapter		Pages
1.	I N T R O D U C T I O N	::	1 - 3
2.	REVIEW OF LITERATURE	::	4 - 38
3.	MATERIALS AND METHODS	::	39 - 64
4.	R E S U L T S ::	::	65 -198
5.	DISCUSSION AND CONCLUSIONS	::	199 -220
6.	S U M M A R Y ::	::	221 -223
7.	LITERATURE CITED ::	::	224 -244

LIST OF FIGURES

S.No.	Title	Page
1	Plan of Experiment No.I: Effect of Previous moisture stress on current season productivity of groundnut during the 1982-83 postrainy season.	46
2	Plan of Experiment No.II: Studies on the effect of early moisture stress on the productivity of groundnut during the 1982 rainy season.	49
3	Plan of Experiment No.III: Effect of moisture stress at different phenological stages of groundnut during the 1982-83 postrainy season.	51
4	Emergence percentage of groundnut seed with a previous history of moisture stress during the 1982-83 postrainy season.	70
5	Leaflet production upto 26 DAE in a groundnut seed crop with a previous history of moisture stress, during the 1982 rainy season.	72
6	Leaf area/leaflet of groundnut seed crop with a previous history of moisture stress, during the 1982 rainy season.	74
7	Leaf area/plant of groundnut seed crop with a previous history of moisture stress, during the 1982 rainy season.	75
8	Total dry matter of the above ground parts of groundnut seed crop with a previous history of moisture stress, during the 1982 rainy season.	77
9	Kernel yield of groundnut seed crop with a previous history of moisture stress, during the 1982 rainy season.	79
10	Leaf Area Index (LAI) of two groundnut cvs Robut and TMV-2 under two moisture treatments (c - covered; uc - uncovered) during the 1982 rainy season.	85
11	Production of pegs as a function of time in two groundnut cvs TMV-2 and Robut under two moisture treatments (c - covered; uc - uncovered) during the 1982 rainy season.	86
12	Pod production as a function of time in two groundnut cvs TMV-2 and Robut under two moisture treatments (c - covered; uc - uncovered) during the 1982 rainy season.	87

13	Dry matter distribution of groundnut cv. TMV-2 under two moisture treatments (c - covered; uc - uncovered) during the 1982 rainy season.	89
14	Dry matter distribution of groundnut cv. Robut under two moisture treatments (c - covered; uc uncovered) during the 1982 rainy season.	90
15	Changes in the pod growth of two groundnut cvs Robut and TMV-2 under two moisture treatments (c covered; uc - uncovered) during the 1982 rainy season.	91
16	Changes in the kernel growth of two groundnut cvs Robut and TMV-2 under two moisture treatments (c - covered; uc - uncovered) during the 1982 rainy season.	93
17	Relationship between dry matter accumulation and cumulative evapotranspiration (CET) of two groundnut cvs Robut and TMV-2 under two moisture treatments. (c - covered; uc - uncovered) during the 1982 rainy season	97
18	Seasonal changes in the soil temperature in groundnut under two moisture treatments (c - covered; uc - uncovered) during the 1982 rainy season.	99
20	Changes in the daily mean albedo during the period of early moisture stress in two groundnut cvs TMV-2 and Robut under two moisture treatments (c - covered; uc - uncovered) during the 1982 rainy season.	100
21	Pod and kernel yield of two groundnut cvs Robut and TMV-2 under two moisture treatments (c - covered; uc - uncovered) during the 1982 rainy season.	102
22	Seasonal changes in the available soil water at different soil depths in treatment 1 at a) 592 mm and b) 611 mm of ET levels during the 1982-83 postrainy season.	111
23	Seasonal changes in the available soil water at different soil depths in treatment 2 at a) 576 mm and b) 494 mm ET levels during the 1982-83 postrainy season.	112

23	Seasonal changes in the available soil water at different soil depths in treatment 3 at a) 546 mm and b) 401 mm ET levels during the 1982-83 postrainy season.	114
24	Seasonal changes in the available soil water at different soil depths in treatment 4 at a) 687 mm and b) 47 mm ET levels during the 1982-83 postrainy season.	115
25	Leaf Area Index (LAI) as a function of time at different ET levels for different treatments during the 1982-83 postrainy season.	120
26	Dry matter distribution in groundnut at two levels of ET a) 592 mm and b) 611 mm in treatment 1 during the 1982-83 postrainy season.	125
27	Dry matter distribution in groundnut at two levels of ET a) 576 mm and b) 494 mm in Treatment 2 during the 1982-83 postrainy season.	126
28	Dry matter distribution in groundnut at two levels of ET a) 546 mm and b) 401 mm in treatment 3 during the 1982-83 postrainy season.	127
29	Dry matter distribution in groundnut at two levels of ET a) 687 mm and b) 47 mm in treatment 4 during the 1982-83 postrainy season.	128
30	Changes in the pod growth at different ET levels for different treatments during 1982-83 postrainy season.	132
31	Changes in the kernel growth at different ET levels for different treatments durings 1982-83 postrainy season.	134
32	Relationship between dry matter production and cumulative evapoytranspiration (CET) at different ET levels for different treatments during the 1982-83 postrainy season.	136
33	Dry matter production at maturity of groundnut as related to total evapotranspiration (TET) for different treatments during the 1982-83 postrainy season.	137
34	Kernel yield at different ET levels (given in mm) for different treatments during the 1982-83 postrainy season.	140
35	Groundnut shelling % as a function of evapotranspiration during the 1982-83 post rainy season.	141

36	Seasonal variation in the stomatal conductance at different ET levels for different treatments during the 1982-83 postrainy season.	151
37	Diurnal variation in the stomatal conductance at different ET levels for different treatments on 75 DAE, during the 1982-83 postrainy season.	154
38	Diurnal variation in the stomatal conductance at different ET levels for different treatments on 118 DAE, during the 1982-83 postrainy season.	156
39	Stomatal conductance as a function of photosynthetic photon flux density in treatment 4 at a) 687 mm, and b) 47 mm ET levels during the 1982-83 postrainy season.	157
40	Stomatal conductance in Treatment 4 at 687 mm ET level as a function of photosynthetic photon flux density (PPFD) in different vapour pressure deficits (VPD) class during the 1982-83 postrainy season.	159
41	Seasonal variation in the transpiration at different ET levels for different treatments during the 1982-83 postrainy season.	160
42	Diurnal variation in the transpiration at different ET levels for different treatments on 75 DAE during the 1982-83 postrainy season.	162
43	Diurnal variation in the transpiration at different ET levels for different treatments on 118 DAE, during the 1982-83 postrainy season.	164
44	Seasonal changes in the leaf water potential at different ET levels of different treatments during the 1982-83 postrainy season.	165
45	Diurnal variation in the leaf water potential at different ET levels for differemt treatments on 75 DAE, during the 1982-83 postrainy season.	167
46	Diurnal variation in the leaf water potential at different ET levels for different treatments on 118 DAE, during the 1982-83 postrainy season.	169
47	Leaf water potential as a function of stomatal conductance. Data pooled over 3 different classes of vapour pressure dificit (VPD) during the 1982-83 postrainy season.	170
48	Seasonal changes in the canopy temperature at different ET levels for different treatments during the 1982-83 postrainy season.	172

49	Diurnal variation in the canopy temperature at different ET levels on 75 DAE, for different treatments during the 1982-83 postrainy season.	174
50	Diurnal variation in the canopy temperature at different ET levels for different treatments on 118 DAE, during the 1982-83 postrainy season.	176
51	Relationship between stress degree days and total evapotranspiration for different treatments during the 1982-83 postrainy season.	177
52	Seasonal variation in the (canopy - air) temperature at different ET levels for different treatments during the 1982-83 postrainy season.	179
53	Dirunal variation in the (canopy - air) temperature at different ET levels for different treatments on 75 DAE, during the 1982-83 postrainy season.	181
54	Diurnal variation in the (canopy - air) temperature at defferent ET levels for different treatments on 118 DAE, during the 1982-83 postrainy season.	182
55	Seasonal variation in the soil temperature at 10 cm depth at 687 mm and 47 mm ET levels in treatment 4 during the 1982-83 postrainy season . Air temperature (AT) shown as solid line.	184
56	Dirunal variation in the soil temperature at 10 cm depth at 687 mm and 47 mm ET levels in treatment 4 on 75 DAE, during the 1982-83 postrainy season.	185
57	Diurnal variation in the soil temperature at 10 cm depth at 687 mm and 47 mm ET levels in treatment 4 on 118 DAE, during the 1982-83 postrainy season.	186
58	Seasonal variation (soil - air) temperature at the three ET levels in treatment 4 during the 1982-83 postrainy season.	188
59	(Soil - air) temperature at the three ET levels in treatment 4 on 75 DAE, during the 1982-83 postrainy season.	189
60	(Soil - air) temperature at the three ET levels in treatment 4 on 118 DAE, during the 1982-83 postrainy season.	190
61	Seasonal variation in soil penetration resistance at different ET levels for different treatments during the 1982-83 postrainy season.	192

62	Mean soil penetration resistance as a function of evapotranspiration during the 1982-83 postrainy season.	194
63	Kernel yield as function of mean soil penetration resistance at different ET levels during the 1982-83 postrainy season.	195
64	Seasonal variation in the daily mean albedo in treatment 4 at two ET levels (687 mm and 47 mm) during the 1982-83 postrainy season.	196
65	Seasonal variation in the daily mean net radiation in treatment 4 at two ET levels (687 mm and 47 mm) during the 1982-83 postrainy season.	198
66	Relative dry matter production (DM/DMmax) in relation to relative evapotraspiration (ET/ETmax) of two groundnut cvs Robut and TMV-2 under two moisture treatments (c - covered; uc - uncovered) during the 1982 rainy season.	205
67	Relative kernel yield (KY/KYmax) in relation to relative evapotranspiration (ET/ETmax) of two groundnut cvs Robut and TMV-2 under two moisture treatments (c - covered; uc - uncovered) during the 1982 rainy season.	207
68	Relative kernel yield (KY/KYmax) in relation to relative evapotranspiration (ET/ ETmax) for different treatments during the 1982-83 postrainy season	208
69	Relative dry matter production (DM/DMmax) in relation to relative evapotranspiration (ET/ETmax) for different treatments during the 1982-83 postrainy season.	215

LIST OF TABLES

S.No.	Title	Page No.
1	Summary of results of critical moisture sutdies in groundnut.	8
2	Soil chemical properties by depth increments of the experimental plot.	39
3	Meteorological parameters during 1982 rainy season.	40
4	Meteorological parameters during the 1982-83 postrainy season.	40
5	Total amount of water (mm) applied to groundnut crop in different treatments during the 1981-82 postrainy season.	44
6	Proximate analysis of the kernels obtained from the experiment on the response of groundnut to moisture stress during the 1981-82 postrainy season.	66
7	Correlation matrix of seed quality parameters.	67
8	Final plant population, pod, kernel and haulms yield and some yield components of the groundnut seed crop with a previous history of moisture stress during the 1982 rainy season.	78
9	Results of analysis of 100 kernel weight, oil and protein contents of the experiment on the effect of previous moisture stress on current season productivity during the 1982 rainy season.	81
10	Dry matter distribution (%) in various plant parts at maturity of groundnut cvs Robut and TMV-2 under two moisture treatments (c-covered; uc-uncovered) during the 1982 rainy season.	88
11	Length and dry weights of roots at maturity of two groundnut cvs Robut and TMV-2 under two moisture treatments. (c-covered; uc-uncovered) during the 1982 rainy season.	92
12	Evapotranspiration (ET) as a function of time in two groundnut cvs Robut and TMV-2 under two moisture treatments. (c-covered; uc-uncovered) during the 1982 rainy season.	94
13	Final plant population, yield and yield components of two goundnut cvs Robut and TMV-2 under two moisture treatments (c-covered; uc-uncovered) during the 1982 rainy season.	103

14	Water use effeiciency and harvest index of two groundnut cvs Robut and TMV-2 under two moisture treatments (c-covered; uc-uncovered) during the 1982 rainy season.	104
15	100 seed weight, oil content, and protein content of two groundnut cvs Robut and TMV-2 under two moisture treatments (c-covered; uc-uncovered) during the 1982 rainy season.	105
16	Schedule of irrigations applied to groundnut in different treatments during 1982-83 porstrainy season.	109
17	Amount of water applied and ET in different treatments during the 1982-83 post rainy season.	116
18	Days atter emergence at different ET levels for different treatments during the 1982-83 postrainy season.	118
19	Number of pegs/plant as a function of time at different ET levels for different treatments during the 1982-83 postrainy season.	122
20	Number of pods/plant as a function of time at different ET levels for different treatments during the 1982-83 postrainy season.	124
21	Dry matter partitioning at maturity expressed as % among the various plant parts at different ET levels for different treatments during the 1982-83 postrainy season.	129
22	Plant population at harvest, pod and kernel yields at different ET levels for different treatments during the 1982-83 postrainy season.	138
23	Water use etficiency and harvest index at different ET levels for different treatments during the 1982-83 postrainy season.	142
24	Comparision of different parameters for different treatments (phenological stages) by covariate analysis method during the 1982-83 postrainy season.	144
25	Root components as affected by moisture stress at different ET levels for different treatments during the 1982-83 postrainy season.	146
26	100 seed weight, protein and oil content at different ET levels for different treatments during the 1982-83 postrainy season.	149

List of Plates

Plate 1. A view of the experimental plot covered with black polyethylene film during the 1982 rainy season. 47

Plate 2. General view of the experiment on the effect of moisture stress at different phenological stages of groundnut during the 1982-83 postrainy season. 52

Plate 3. Steady state porometer in use during the 1982-83 postrainy season. 60

Plate 4. Root distribution for TMV2 and Robut in the two treatments during the 1982 rainy season. 95

Plate 5. General view of the groundnut plants at maturity at a) 687 mm, b) 3 and c) 47 mm ET level in Trt.4 during the 1982-83 postrainy season. 131

Plate 6. Root distribution of groundnut at a) 687 mm and c) 47 mm ET levels in Trt.4 during the 1982-83 postrainy season. 147

ACKNOWLEDGMENT

I am deeply grateful to the Chairman of my Advisory Committee, Dr. M.V.K. Sivakumar, Principal Agroclimatologist, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh for suggesting the research problem and his immensely valuable guidance, kind encouragement and stimulating suggestions throughout the period of investigation and presentation of this thesis. The learning experience under his direction is an invaluable asset.

I am equally grateful to the co-Chairman of my Advisory Committee, Dr. P.R. Reddy, Professor and University Head of Plant Physiology and Associate Director of Research, Regional Agricultural Research Station, Anakapalli, for his valuable suggestions and kind encouragement during the course of my research work.

I wish to extend my deep sense of appreciation to Dr. J.H. Williams, Principal Plant Physiologist (Groundnut), ICRISAT, for his valuable suggestions and comments on a draft of my thesis. I am grateful to Dr. M.S. Reddy, Agronomist, ICRISAT and Dr. B. Gopal Singh, Assistant Professor, Department of Plant Physiology, College of Agriculture, Rajendranagar, Hyderabad, members of my Advisory Committee for their kind encouragement.

I am highly thankful to Dr. S.M. Virmani, Program Leader, FSRP, ICRISAT and to Dr. D.L. Oswalt, Principal Training Officer, ICRISAT for providing the necessary facilities and valuable guidance during the course of my investigation.

My sincere thanks go to Dr. Murari Singh and Mr. P. Venkateswarlu of the Statistics Unit, ICRISAT, for their valuable guidance and help in the statistical analysis of the data.

I also wish to express my appreciation to Dr Piara Singh and Messrs. Y.V. Sri Rama, J.G. Sekaran, S. Ramakrishna, P.V.V. Satyanarayana, P.G. Ananthaiah R. Mukunda Reddy, C.G. Thomas and other field staff of Agroclimatology subprogram at ICRISAT for their valuable assistance and cooperation with field data collection and analysis, during this investigation. My sincere thanks are also due to the staff members of Biochemistry Program in particular Mrs. Shubhada, Mrs. Lakshmi and Sekhar, Groundnut Physiology and Computer Services, for providing the necessary assistance.

I am thankful to Dr. A. Shiv Raj, Mr. L.M. Rao Mr. A. Anjaneyulu, Dr. K.S.P. Rao and Mr. P.V. Rao of Department of Plant Physiology, APAU, for their help.

I owe my gratitude to the Indian Council of Agricultural Research, New Delhi, for the award of Senior Research Fellowship and to the Andhra Pradesh Agricultural University authorities for granting study leave for prosecuting Ph.D studies.

I express my appreciation to my wife Narmada Prabhavathi and sons Srinivas and Narasimham and also to other members of my family, in particular to Mr. M.L. Sarma and Mrs. Padma, for their full cooperation and encouragement.

Finally, my grateful thanks go to Mr. R.L.N. Sastry, Secretary in Agroclimatology Subprogram, ICRISAT, who has so efficiently and neatly entered this thesis on the ICRISAT computer under severe time constraints with patience and deligence.

P.S. SARMA

ABSTRACT

Name	: P.S. Sarma
Title	: Soil-plant-water relations, growth and yield of groundnut under moisture stress.
Degree	: Ph.D.
Faculty	: Agriculture
Guide	: Dr MVK Sivakumar Principal Agroclimatologist International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Patancheru P.O. A.P. 502 324
University	: A.P. Agricultural University
Year of submission	: 1983

Studies were undertaken to investigate the effect of using seeds with a moisture stress history in the previous season on the current season productivity and to examine the effects of moisture stress at different phenological stages of groundnut during the 1982 rainy season and the 1982-83 postrainy season at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh.

In the experiment using seeds with a previous moisture stress history, early seedling vigor in terms of rate of seed emergence, leaflet number, leaf area per leaflet and plant, and dry matter production was evaluated at 3-day intervals from emergence up to 26 DAE. Quality of the seed samples with moisture stress history during the previous season and also of the seed obtained from the subsequent

crop was analysed.

The seeds with moisture stress history from emergence to peg initiation during the previous season gave higher seedling vigor in terms of leaf number, leaf area and superior dry matter production besides maximum pod and kernel yield.

In the investigations on the effect of water stress at different phenological stages, soil water, leaf area, plant growth and plant parameters of water stress such as stomatal conductance, transpiration, canopy temperature and leaf water potential and radiation measurements were measured at 7-10 day intervals. Soil temperature was monitored throughout the growing season. Soil penetration resistance was measured from 44 to 107 DAE. Root studies were made at maturity besides seed quality estimation.

The results indicated that considerable reduction in ET was achieved by imposition of early moisture stress (EMS) both in the rainy and postrainy seasons. Higher LAI, pegs and pods, higher dry matter production with better root and shoot growth were achieved besides enhanced pod and kernel growth. Higher water use efficiency, harvest index and improved seed quality in terms of increased seed weight, oil and protein contents were obtained with EMS treatment.

In the treatment where water stress was imposed continuously during the growing season the crop extracted water at all soil depths at the lowest ET levels. A 9-fold reduction in dry matter production occurred as compared to that at 687 mm of ET. Pod and kernel yields were reduced when stress was imposed from emergence to flowering and from flowering to last pod set.

Moisture stress imposed fom flowering to last pod set was a critical period since it affected the seed filling, protein and oil contents.

Seasonal pattern in the stomatal conductance in the treatments subjected to moisture stress from emergence to flowering and emergence to peg initiation indicated considerable recovery in the stomatal activity of the leaves after the moisture stress was released.

The transpiration rates were affected due to the decreased stomatal activity by both the seasonal variation as well as the diurnal variation for different treatments.

Increased canopy temperatures were observed in all the treatments during the growing season as well as on a diurnal basis at lower ET levels because of lack of transpirational cooling.

ABBREVIATIONS

AT	=	Air temperature
CATD	=	Canopy-air temperature differential
CO2	=	Carbon dioxide
CGR	=	Crop growth rate
CPE	=	Cumulative pan evaporation
DAE	=	Days after emergence
DAS	=	Days after sowing
DM max	=	Maximum drymatter
EMS	=	Early moisture stress
EO	=	Potential evapotranspiration
ET	=	Evapotranspiration
Et	=	Water use per day
ET max	=	Maximum evapotranspiration
HI	=	Harvest index
hr	=	Hour
hrs	=	Hours
IST	=	Indian standard time
IW	=	Irrigation water
KYmax	=	Maximum kernel yield
LAI	=	Leaf area index
LT	=	Canopy temperature
mb	=	Millibars
MPa	=	Mega Pascals
NAR	=	Net assimilation rate
PPFD	=	Photosynthetic photon flux density
r	=	Correlation coefficient
RBD	=	Randomized Block Design

Re	=	Effective rainfall
RWC	=	Relative water content
SAT	=	Semi arid tropics
SDD	=	Stress degree days
SPR	=	Soil penetration resistance
TET	=	Total evapotranspiration
Trt	=	Treatment
Trts	=	Treatments
VPD	=	Vapor Pressure deficit
Wd	=	Drainage from the zone sampled
WUE	=	Water use efficiency
Δ S	=	Thickness of each soil layer
θ	=	Volumetric water content, cm^3 cm^3
ψ W	=	Leaf water potential
ψ S	=	Osmotic potential

INTRODUCTION

SOIL-PLANT-WATER RELATIONS, GROWTH AND YIELD OF GROUNDNUT UNDER MOISTURE STRESS

1. INTRODUCTION

Groundnut (*Arachis hypogaea* L.) ranks thirteenth in its importance among the crop plants of the world. It was an important source of vegetable oil which was of high quality and was utilized for edible purposes.

India was the largest producer of the crop with an estimated production of 7.2 million tonnes grown in an area of 7.5 million hectares accounting for two fifths of the world acreage and a third of the world production (FAO, 1981). However the yield per hectare remained virtually stagnant at 950 kg/ha as against 2300 kg/ha in USA. In India groundnut was predominantly a rainfed crop. For example, in Andhra Pradesh 82% of the production of this crop comes from the rainy season with the rest of the crop produced with irrigation during postrainy season. The production of groundnut in India, especially in the dry areas has not kept pace with the increase in demand. Yields of groundnut in semi-arid tropical (SAT) India were low and variable due to erratic rainfall and other climatic factors (Kanwar et al., 1983).

The South-West monsoon over the Indian sub-continent was erratic in duration and distribution,thus creating a wide range of rainfall environments across SAT India. This was much more complicated when combined with soils of varying depth, texture and slope (Kanitkar, 1968). It was important to know at what stage of the groundnut crop moisture deficits which may affect the yield occur since moisture availability was considered a major constraint for groundnut yield. A precise study of plant responses to moisture stress during the rainy season was rather difficult, since the drought patterns were not predictable and unlike the rainy season the postrainy seasons were more regular because of a more predictable environment in which the crop grows. The incidence of pests and diseases was also less during the postrainy season.

Where water supply was limited or irregular, it was important to delineate the physiological stages when the water needs of the crop were critical. The effect of moisture stress at different phenological stages of groundnut depends on the severity of the moisture stress itself i.e., the intensity and duration of the water deficit and the degree of sensitivity of the stage of development of the crop during which the stress occurs. Several stages in the plant life cycle might be expected to be sensitive to drought, particularly the early vegetative growth, flowering and pegging, and the kernel maturation. Some stages had been found to be relatively more sensitive to water deficits than others (Klepper, 1973). When the stress was not severe, the phenological responses were not apparent; the effects were mainly on growth and yield. In the variable moisture environment, however, effects on phenology can be very evident, particularly when stress occurs before flowering. Moisture deficiency at a particular stage will affect the plant in a manner that may had a greater or lesser effect on final productivity (Sivakumar et al., 1982).

The effect of moisture stress at a given stage on the subsequent growth and yield has also not been studied in detail. Information on the effect of moisture stress during the preceding crop on the current season productivity and response of groundnut to moisture stress at different phenological stages was very meagre. Hence, three experiments (detailed below under I, II and III) were conducted during the 1982 rainy season and 1982-83 postrainy season with the following objectives:

I. To study germination, early seedling vigor, growth, yield and kernel quality of groundnut (cv Robut 33-1) during the 1982 rainy season from a seed crop which had moisture stress history during previous season on current season productivity.

II. 1) To study the yield response of two groundnut varieties (Robut 33-1 and TMV-2) to early moisture stress i.e., from the stage of emergence to the initiation of pegs, during 1982 rainy season.

2) To observe the variation in the quality of kernels, soil moisture extraction, dry matter accumulation, partitioning and leaf area development between the two varieties of groundnut due to the early moisture stress.

3) To evaluate the plant and environmental factors like albedo, and soil temperature which might determine the differences in the productivity of the two varieties of groundnut subjected to early moisture stress.

III.1) To study the yield response of Robut 33-1 to moisture stress at different phenological stages during 1982-83 postrainy season in terms of dry matter accumulation and partitioning, leaf area development, yield and yield components, and quality of kernels.

2) To observe the variation in the soil moisture extraction rate, water use, soil penetration resistance, root development, stomatal conductance, transpiration, and leaf water potential, due to the moisture stress imposed at different phenological stages in groundnut cv Robut 33-1.

3) To evaluate the plant and environmental factors like photosynthetic photon flux density, albedo, net radiation, vapor pressure deficit; soil, canopy and air temperatures which might affect yield as a result of moisture stress imposed at different phenological stages in groundnut cv Robut 33-1.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Groundnut (Arachis hypogaea L.) was one of the important legume crops of the Semi-Arid Tropics (SAT): approximately 70% of the world production comes from the developing countries many of which lie in the SAT. The groundnut was deep rooted and was unusual in having no root hairs since the epidermis was sloughed off as the root extends, thus destroying the basis for root hair production (Gregory et al., 1973). Moisture in groundnuts was absorbed in a region 8-10 mm behind the root cap (Purseglove, 1968). Flowering in groundnuts takes place over an extended period in both of its sub species hypogaea (alternate flowering group) normally having a longer flowering period than the sub species fastigiata (sequential group). Flowering commences early, builds up to a peak and then tails off as the crop approaches maturity (Airey, 1980). Groundnuts had specific moisture needs due to their peculiar feature of developing the pods produced just underground. The pods take up moisture and calcium, and were susceptible to attack from soil organisms. The soil must be in a friable condition both at the time of peg penetration into the soil and at harvest. All these features produce a number of individual peculiarities about the water requirements of groundnuts, some of which assist its drought tolerance, while others make it more prone to moisture stress (Airey, 1980). Hence the effect of water stress at different phenological phases of groundnut crop on the growth and yield needs to be studied extensively.

Maintenance of favourable plant water status was an essential prerequisite for favourable growth, nutrient accumulation and higher yield of crops. The influence of soil water potential in the root zone, and the atmospheric evaporative demand on plant water status was tempered by plant physiological conditions, principally stomatal distribution and activity. Hence in the soil-plant-atmosphere continuum, it was essential to examine and analyse the influence of each factor, so that valid conclusions can be drawn regarding the importance of each factor. The review presented here was divided into the following sections:

2.1.1 Moisture stress and crop phenology

2.1.2 Moisture stress and vegetative growth

2.1.3 Moisture stress and reproductive growth

2.1.4 Moisture stress and groundnut yield. Mechanism of yield increase or decrease under moisture stress.

2.1.5 Moisture stress and root growth

2.1.6 Moisture stress and quality

2.1.7 Moisture stress and subsequent yield

2.1.8 Water relations in groundnuts

2.1.8.1 Plant measurements as indicators of water stress

2.1.8.2 Stomatal diffusion resistance, its importance and factors affecting stomatal diffusion resistance.

2.1.8.3 Leaf water potential, its importance and factors affecting leat water potential.

2.1.8.4 Leaf and meristem temperatures, their importance and factors affecting them.

2.2 Soil Environment for Groundnuts.

2.2.1 Water relations and water loss.

2.2.2 Water use

2.2.3 Moisture stress and soil temperature

2.2.4 Moisture stress and soil penetration resistance.

2.3 Climate and Radiation Balance

2.3.1 Climate and yield variability.

2.3.2 Moisture stress and albedo.

2.3.3 Moisture stress and net radiation.

2.1.1 Moisture stress and crop phenology

Water status invariably affects plant growth and development since about 80% of plant fresh weight was water. Reduction of the plant water status much below this level causes visible wilting and affects the rate of many plant functions. Several stages in the plant life cycle might be expected to be sensitive to drought, particularly (1) early vegetative growth, (2) flowering and pegging down and (3) nut maturation. Some of these had been found to be more sensitive to water deficits than others, but none of them can proceed normally below some minimal plant water content. Research can clarify the limits of tolerance to water deficit for each of these phases of development. Considerable work was concerned with the problem of which of these stages was most sensitive to water stress, but unfortunately, plant water status has rarely been measured; often soil moisture was neither controlled nor measured. Since the plant water status was the result of a balance between water taken up from the soil and water lost to the atmosphere, it was a very dynamic property and must be monitored in definitive experiments (Klepper, 1973). Moisture stress in the early flowering phase (30-45 DAS) was not critical (Gowda, 1977).

Generally, very early growth was found to be not especially sensitive to drought, and pegging and nut maturation were less sensitive than the peak flowering stage. The water absorbed during the first month after sowing was found to be small compared to the quantity required during the second month (Su et al., 1964). This difference may explain why early growth was not as sensitive to drought as was later stage. The fact that peak flowering and maximum sensitivity to drought coincide could be a result of the increased demand for water by the growing top or it might be caused by the fact that the root system was less efficient during flowering. For some species, flowering can lead to a temporary depression of root growth so that the root system was less efficient during flowering than either before or afterwards, but no one has investigated this problem for groundnut plants (Klepper, 1973). The results of critical moisture period studies were summarised in Table 1.

2.1.2 Moisture Stress and Vegetative Growth

All plant processes take place in the aqueous medium, and water was involved as a transpiring agent and as a reactant in many of these processes. Therefore, moisture stress so severe as to cause the cells to become flaccid must affect almost all physiological processes (Rook, 1973). The review up to this point has shed some light on some of the physiological alterations brought about by moisture stress.

Table 1. Summary of results of critical moisture period studies in groundnut.

Sl.No.	Author(s)	Year	Critical moisture period
1.	Billaz and Ochs	1961	Days 50-80 (intense flowering)
2.	Fourrier and Prevot	1958	35-60, 60-85, 85-110 days all similar.
3.	Holford	1971	Second of 4 equal phases.
4.	Joshi and Kabaria	1972	51-80 days (full pegging to pod development).
5.	Meteierkamp	1975	Not in the early stages (first to 10 weeks).
6.	Pallas et al.	1979	The later in the season drought occurs more in the yield reduction.
7.	Prevot and Olagnier	1957	30-50 Days After Emergence (DAS)
8.	Subramanian et al.	1974	Pod formation
9.	Su and Lu	1963	Peak flowering to early fruiting or 30-60 days.
10.	Su et al.	1964	Days 50-69 (peak flowering - early fruiting).
11.	Williams et al.	1978	Early vegetative and late pod setting stages.
12.	Wormer and Ochs	1959	Days 30-60.

The growth and development of a plant depends, in simple terms, on continuing cell division, on the progressive initiation of tissue and organ primordia, and on the differentiation and expansion of component cells until the characteristic form of the plant was realized (Slatyer, 1970). Cell division was shown to be less sensitive to water stress than cell enlargement (Slatyer, 1967; Slavik, 1965; Vaadia et al., 1961). Reviewing the effect of moisture stress on cell division, Hsiao (1973) concluded that cell division, like cell enlargement, can be inhibited by rather long exposure to mild water stress. Il'ina (1959) found that leaves formed under stress had smaller cells than others.

Cell enlargement was affected at very slight stress levels (Hsiao et al., 1970). Slatyer (1970) concluded that reduction in cell enlargement was the main cause of stunting which was perhaps the most common sign of water stress under field conditions. A progressive decline in the rates of cell enlargement was observed as water deficits developed, with enlargement ceasing when turgor pressure levels were still at the level of several bars (Stransky and Wilson, 1964; Boyer, 1968).

2.1.2.1. Leaf area

The effect of stress on growth tends to be most pronounced in those tissues which were in rapid stages of development (Williams and Shapter, 1955; Gates, 1968). A key implication to final biological yield followed from the effect of reduction in cell expansion on total area. This reduced the size of the photosynthesising surface and can be expected to reduce crop growth rate (CGR) unless leaf area was not limiting to net assimilation rate (NAR) (Slatyer, 1970). It was observed that a reduction in the leaf area was more important than a reduction in NAR in causing decreased crop growth, when water stress occurred under field conditions (Watson, 1952).

Billaz and Ochs (1961) reported that late stress was most effective in reducing leaf numbers. When stress was induced from 50 to 80 days and then relieved, there was first a suppression of leaf growth then a considerable stimulus, resulting finally in higher leaf numbers than in the unstressed control. Forestier and Raffaillac (1980) observed that irrespective of soil fertility, the net assimilation rate was inversely proportional to leaf area index (LAI) during vegetative and reproductive stages and it was possible to define an optimum LAI for maximum dry matter production on a given soil. Fischer and Hagan (1965) concluded that crop growth rate appears to be sensitive to water stress mainly because leaf area was sensitive to water stress. Plant-water stress generally hastens senescence (Milthorpe, 1945; Asana, 1960).

2.1.2.2. Stem Growth

The effect of moisture stress on stem·growth seems to vary with the variety. A study in Florida by Gorbet and Rhoads (1975) showed a greater response by lateral branches to supplementary moisture in the variety Florigian than in Florunner. Droughted plants had been shown (Lin et al., 1963) to had smaller tops, fewer branches, and fewer flowers. Eventhough both leaf number and stem length were reduced, the latter decreases more markedly so that the leaves were arranged more compactly on the stems.

2.1.3. Moisture Stress and Reproductive Growth

Reproductive growth in the groundnut occurs over an extended period, of at least two months. There was thus considerable overlap between the vegetative and reproductive phases, though, for convenience sake they were treated separately here.

Moisture stress has a depressing effect on flowering while it lasts. The number of flowers produced was reduced both by effect of water stress on stem growth, reduction of number of nodes from which the flowers arise, and to a limited extent, on the flower buds themselves (Ochs and Wormer, 1959). If a short period of stress was induced, while the plant was in stress flowering was inhibited. Once the stress was removed, there was a flush of flowering which, depending on the period in the plants growth that was stressed, can result in a greater number of flowers than in the unstressed control. There was in this case a greater proportion of late produced flowers (Billaz and Ochs, 1961; Su et al., 1964).

Lin et al., (1963) had suggested that virginia bunch groundnuts (alternate group) were less drought susceptible than Spanish varieties (sequential group) due to their longer maturity duration which facilitates drought escape, since a smaller proportion of the flowering period was affected by a stress period of a given length. The flush of late flowering following mid-season drought means delayed maturation and late harvesting was recommended where possible to try to offset this (Boote et al., 1976).

Gynophore production seems relatively insensitive to early drought, but was reduced by moisture stress towards the end of the plant's growth (Billaz and Ochs, 1961). For fruiting to occur, the gynophore must enter the soil and its physical condition was important, since the gynophores were able to exert a force equivalent to only 3 or 4 grams on the soil (Underwood et al., 1971). Thus mechanical resistance such as might be experienced in a dry soil was a problem. However, entry could occur once the soil was rewet (Boote et al., 1976).

Pod weights appear to be affected in only a minor way by moisture stress. Stern (1968) recorded no reduction in pod weights, while Boote et al., (1976) observed only a minor change due to moisture stress. Cox et al., (1976) measured lower percentage of extra large pods with reduced moisture in either the rooting or fruiting zone. Shelling percentage was commonly lower under stress conditions (Stern, 1968). This suggests that under stress, many pods were partly empty and extra weight was transferred to the shell, hence maintaining nearly constant pod weight while reducing shelling percentage.

Kernel size itself seems to be slightly reduced under some conditions of stress. Cheema et al., (1977) reported higher kernel weights with irrigation than in the nonirrigated control.

2.1.4 Moisture Stress and Groundnut Yield

Groundnut yield was a function of many plant and environmental factors which were often interrelated. The yields were highly variable since the crop was grown under contrasting moisture regimes in a range of environments. The stage at which the moisture stress occurred plays a major role in the final yield of the crop. Billaz and Ochs (1961) found that the 50-80 days period was most susceptible to drought causing a 46% yield reduction while water stress in days 80-120 caused 27% reduction; days 10-30, 21.6%; and days 30-50, 18%. Fourrier and Prevot (1958) also observed that drought imposed at 35-60, 60-85, and 85-110 days resulted in the yield reductions at all these three stages. Stansell and Pallas (1979) reported that a 35-day drought spanning 71-105 days was more damaging than 35-day droughts at 36-70 or 106-140 days of age. A 70-day drought beginning at 36 days of age reduced the percentage of marketable seed to 34%, while pods from a 70-day drought treatment starting at 71 days of age reduced percentage of marketable seed to 69% compared with the control. Water stress beyond 0.8 IW/CPE (Irrigation water/cumulative pan evaporation) ratio at any growth stage was found detrimental in reducing pod yield (Shinde and Pawar, 1982) and 0.75 IW/CPE ratio (Khan and Datta, 1982). Several workers reported yield reductions with stress induced at different stages of growth in groundnut (Padma Raju et al., 1981; Balasubramanian and Yayock, 1981; Subramanian et al., 1974).

Work done at ICRISAT during 1980-81 and 1981-82 revealed that moisture stress during emergence to peg initiation had resulted in 13 to 30% increased yield over the treatment which received continuous irrigation at 10 days interval (ICRISAT, 1982 and 1983).

Summer season pod yield and oil yield in groundnut were much higher than the kharif season. High temperature coupled with more sunshine during summer caused a remarkable production of dry matter in the plant. Cloudy days and higher humidity during kharif season favoured the development of diseases and the leaf loss started even after 70 days of crop growth (Reddy and Patil, 1980).

In sandy loam soils of low water retention capacity, high yield could be obtained with frequent irrigation with the depth of water applied equal to that lost in ET (Reddy et al., 1980).

The partitioning of photosynthetic assimilate had the greatest effect on fruit yield and estimates of partitioning to fruit ranged from 41% in the first cultivar released to 98% in the most recently released cultivar. Crop growth rates did not differ significantly among groundnut cultivars (Duncan et al., 1979).

Darkness was found to be an essential factor for the indication of pod formation while it did not occur in the light including the application of different growth substances on the ovary. A mechanical stimulus was needed in addition to darkness for the normal thickening and diageotropic orientation of the pod (Zamski and Ziv, 1976).

2.1.4.1 Mechanism for Yield Reduction under Moisture Stress

Billaz and Ochs (1961) observed the greatest yield reduction in the 50-80 day stress treatment which corresponded to the peak flowering - early pod filling stage of the plant. Short periods of stress had little detrimental effect on final leaf number. At least 60% of the flowers in the 50-80 day treatment were produced after day 80 and the gynophores in this treatment produce very many pods - only approximately half of the number produced by the unstressed control. It seems likely that the latter produced flowers were largely ineffective in forming pods and this seems to be the reason for the reduction in yield.

Stern (1968) has pointed out the advantage for a large number of flowers to be produced early for maximum yields. The reason for the peak flowering period being most susceptible to moisture stress would seem to be that this causes the greatest delay in flowering, and therefore the biggest reduction in the capacity to form pods.

The second most serious period for moisture stress was the period of pod formation. Stress in this period would dry the soil surface and make the gynophore entry difficult since the soil penetration resistance under those conditions was definitely very high. For these gynophores already in the soil, moisture supplies would be low, and calcium uptake inadequate, which would lead to reduced pod formation and lower shelling percentage in the pods that were produced.

2.1.5 Moisture Stress and Root Growth

Groundnut was a comparatively deep rooting crop. Varying depths were quoted but the depths usually range from 150 cm (Metelerkamp, 1975) to 200 cm (Hammond et al., 1978). Despite this, most roots were in shallower soil regions. Hammond et al., (1978) quote root densities of 1.5 cm/cm in the 0-30 cm zone but only 0.1 cm/cm at greater depths.

Like most plants, groundnuts extract most moisture from the upper layers. Analysis of the International Irrigation Information Centre (1976) using data from two locations in Israel showed an average removal from two sites of 36% in the 0-30 cm depth, but only 7% in the region 120-150 cm.

Under conditions of moisture stress, however, the crop was forced to take moisture from greater depths. With increasing frequencies of irrigation, ranging from 40 to 10 days between waterings, the percent of total moisture extracted from the 0-30 cm layer declined from 15 to 5% (Mantell and Golden, 1964). Groundnut root growth (root length per unit area to a depth of 150 cm) was not affected by water management (Robertson et al., 1980).

Data of Lin et al., (1963) indicated that drought might increase rooting depth very slightly (5 to 10%) but reduced the radius of root distribution to about two thirds of the values for check plants. Slatyer (1955) reported the extent of the root system of groundnut plants to be intermediate between grain sorghum, which had many roots, and cotton, which had least of the three crops. It would appear that the extent of the root system was an important factor in drought resistance.

2.1.6. Moisture Stress and Quality

While the total definition of quality would vary with the requirements of the user, uniformity of product, biochemical constituents of the seeds, absence of kernel abnormalities and freedom from toxic infections were common to all quality requirements. It was emphasized that germination vigor was the most important seed quality factor in the efficient [redacted] production of crops and weak groundnut plants from ill filled seed never develop satisfactory pod set (Spain,1976). Seed size in conjunction with some vigor tests could serve as an index of field emergence in groundnut (Sivasubramaniam and Ramakrishnan, 1974).

There was a reduction in the proportion of sound mature kernels in the absence of irrigation, or with imposed moisture stress (Pallas et al., 1977). Varnell et al., (1976) attributed this to delayed fruit set following stress. Bold seeds yielded significantly more (Gorbert, 1977), increased seedling weight, rate of DM transfer and RGR (Naidu and Narayanan, 1981) and greater LAI and chlorophyll concentrations (Dhillon et al., 1981) than in the small seeds. Reddy (1978) observed increased germination %, plant height and spread, LAI, shelling %, seed oil, and protein with large sized seeds.

As to the proximate analysis, significantly higher protein yields were obtained by scheduling irrigation at 0.8 IW/CPE ratio (Birajdar et al., 1979). In groundnut, there was a negative correlation between oil and protein contents (Hung, 1975; Walker and Hymowitz, 1972; Rao and Rao, 1981).

2.1.7 Moisture Stress and Subsequent Yield

No published data was available as to the effect of moisture stress on the subsequent yield in groundnut when the seeds with previous moisture history were used.

2.1.8 Water Relations in Groundnuts

2.1.8.1 Plant Measurements as Indicators of Water Stress

Understanding of the response of crop foliage to changes in the amount and status of soil water in the root zone was far from complete. Physical processes within the plants depend on plant water status; however, supplemental water for crops was scheduled primarily from soil moisture and not plant water measurements (Haise and Hagan, 1967; Schockley, 1966). Kramer (1963) concluded that too much emphasis was placed on soil-water status and too little on plant-water status. Measurements of soil-water content or soil-water stress cannot themselves supply adequate informatin to evaluate the effects of water supply on plant processes and crop yields.

The status of water in the plants represents an integration of atmospheric demand, soil-water potential, rooting density and distribution, as well as other plant characteristics (Kramer, 1969). Therefore, to obtain a true measure of plant-water deficit, the measurement should be made on the plant and not in the soil or atmosphere.

Water flow into the plant occurs through a potential gradient between the soil and the plant, culminating in the vaporization of water through the stomates into the atmosphere (Cowan, 1965; Kozlowski, 1968). Transpiration rate was controlled by water-potential gradient and the diffusive resistances in the plant. As the water deficit develops in the leaf, leaf water potential decreases, and the stomatal resistance increases.

Practical thermocouple psychrometers, described by Monteith and Owen (1958), and Richards and Ogata (1958), stimulated interest in the measurements of water potential to indicate water status in the plant. Further advancements made in the measurement of water potential through pressure chambers (Scholander et al., 1965), and thermocouple psychrometers (Barrs, 1968; Boyer, 1969; Brown and Van Haveran, 1974; Kramer and Brik, 1965) made it possible to make reasonably accurate, simultaneous, nondestructive measurements of the water potential of leaves, roots and soil.

It was well documented that stomatal closure was the main cause for transpiration decline as water stress develops. Much of the early confusion on the cause of this decline was clarified by the introduction and use of resistance network analysis (Kuiper, 1961; Raschke, 1960). Gardner (1970) stated that stomatal resistance would seem to be the single, most useful, measurement for evaluation of the water factor in agroclimatology. A major contribution was the development of diffusion porometers with which diffusion resistance of leaves could be measured (Grieve and Went, 1965; Kanemasu et al., 1969; Van Bavel et al., 1965; Wallihan, 1964).

Recording a clear cut increase in the stomatal resistance with increase in the soil moisture stress, Ali-Ani and Bierhuizen (1971) concluded that stomatal resistance could be considered as an excellent criterion in estimating the water deficit in the plant. According to Ehrler and Van Bavel (1967), measurement of stomatal resistance was a logical method to characterize the plant response to soil-water depletion. Chen and Chong (1972) proposed that stomatal aperture should be used as a physiological indicator for irrigation requirements. With field studies on sorghum, Kanemasu et al., (1973) showed that stomatal resistance changed more than either leaf or soil-water potential in response to moisture stress.

Clark and Hiler (1973) used leaf-water potential, leaf-diffusion resistance and leaf-air temperature differential as plant measurements to indicate crop-water deficit. They concluded that leaf-diffusion resistance was the least responsive and leaf-water potential was the most responsive.

Boyer (1968) suggested that cell enlargement is more sensitive than photosynthesis to reduced leaf-water potential. Mederski et al., (1975) concluded that the leaf area is the best measure of the photosynthesizing capacity of the plant. The above discussion points to the definite possibility of using the changes in leaf area with time as a plant measurement to indicate water stress.

Another commonly used indicator of plant-water status was relative water content or RWC (Weatherly, 1950). Still less direct, but sometimes useful indicators of plant-water status, were leaf thickness and stem diameter. β -ray gauging of relative leaf thickness (Barrs, 1968) allowed a virtually continuous and non-destructive estimation of water status when properly calibrated against leaf-water potential or RWC.

2.1.8.2 Stomatal Diffusion Resistance

Importance of stomatal diffusion resistance:

Transpiration was directly proportional to the gradient of water vapor concentration from the internal evaporation surface to the bulk air outside the leaf, and inversely proportional to the total resistance to the water vapor transport of the air boundary layer and of the leaf. Since stomata control only part of the total resistance, their closure will vary in effect with the magnitude of stomatal resistance relative to the boundary layer resistance and cuticular resistance. Groundnuts were amphistomatous, having approximately equal number of stomates on the upper and lower epidermis (Il'ina, 1959).

Intensive studies (Troughton, 1969; Troughton and Slatyer, 1969; Boyer, 1970b; Slatyer, 1970) had provided evidence that the observed reduction in net photosynthesis with increasing stress can be completely attributed to stomatal closure until severe stress exists. Hesketh (1968) postulated that there may be two factors limiting the photosynthesis of leaves, the Carbon dioxide diffusion resistance and the biochemical reactions inside the leaf. The similarity of the effect of water stress on the rates of transpiration and photosynthesis (Brix, 1962), and the close phase relationship between oscillations of photosynthesis and transpiration (Troughton, 1969), both point to a dominant stomatal control of transpiration.

There was increasing evidence that stomatal closure indirectly by increasing leaf temperature and directly by impeding Carbon dioxide supply, was the mechanism by which water stress first leads to reduced net photosynthesis under field conditions. As stress becomes more severe and more protracted, direct effects will be observed (Slatyer, 1970). According to a number of authors (Harris, 1973; Dube et al., 1974; Neuman et al., 1974; Turner and Incoll, 1971), the photosynthetic rate was not affected below a critical resistance level was greater than the critical resistance. Hatfield (1975) reported that reduced Carbon dioxide uptake occurred through stomatal closure, as evidenced by increased stomatal resistance.

Mederski et al., (1975) investigated the aspect of carbon assimulation and stomatal resistance by forcing air through the leaf at constant rate to overcome the effects of change in stomatal resistance accompanying changes in leaf-water deficit. It was (1975) concluded that the inhibition of net carbon dioxide assimilation with increasing leat-water deficit was a consequence of an increase in the diffusive resistance to gas exchange and not of a change in apparent mesophyll resistance.

The high photosynthetic efficiency of groundnut cultivars as compared with certain other C3 species was associated with the greater conductance of carbon dioxide through their upper leaf surfaces (Pallas, 1980). Brown (1969) suggested that any attempt to calculate the photosynthetic rate of a leaf should include the components of leat resistance to Carbon dioxide diffusion. Allen et al., (1976) found that stomatal resistance increased to a maximum of 10 seconds per cm after 17 days drought in conditions of high evaporative demand compared to 2 seconds per cm in the irrigated plots, thus indicating reduced stomatal opening.

Factors affecting stomatal resistance:

The status of stomata in a plant or leaf was dynamic and changes in response to many environmental factors and endogenous factors.

Light: The total resistance of the leaf follows a diurnal pattern of behaviour. Higher resistance during the periods of darkness and lower resistances during the periods of light. Stomatal resistance has been shown to be a definite function of light intensity (Ehrler and Van Bavel, 1968; Kanemasu and Tanner, 1969). Turner (1970) reported that, in well-watered crops, light was a primary determinant of stomatal resistance. Kanemasu and Tanner (1969) showed light saturation of stomatal opening at 1% of full sunlight while Kuiper (1961) observed saturation around 10% of sunlight equivalent. However, mild stress seems to increase the light saturation values for stomatal opening (Hansen, 1971). Brown and Rosenberg (1970) reported that there was a lack of dependence between leaf age and stomatal resistance and the amount of leaf illumination controlled the stomatal resistance. Small reduction of irradiance was sufficient to cause an appreciable decrease in stomatal conductance in groundnut (Black and Squire, 1979).

Leaf Surface: Conductance to gaseous transfer was normally considered to be greater from the abaxial than from the adaxial side of a leaf. Measurements of the conductance to water vapor of groundnut leaves under well watered and stress conditions indicated a 2-fold higher conductance from the adaxial side of the leaf than from the abaxial (Pallas, 1980).

Canopy Depth: Kanemasu and Tanner (1969) had shown that the upper leaves in the canopy had a lower stomatal resistance than from the bottom leaves. They believed this was due, in part, to a physiological adaptation, which allowed the young meristematic portions of the plant to continue photosynthesis, at the expense of the older leaves. In contrast, Stevenson and Shaw (1971) found that the overall resistance of the leaf was always greater for the leaves in the middle of the canopy than for the leaves in the upper surface of the canopy.

Air Temperature: Dale (1961) showed stomatal opening o increase with air temperature. This was especially evident in the stomata on upper surface of the leaf. This relationship held only when the soil moisture supply was adequate. In leaves with low relative water content, the effects of water stress tended to override those due to other factors. Hsiao (1975) concluded that the direct effect of a few degrees of change in temperature on stomata would not be pronounced, unless the change occurred at the two extremes of the growing temperature range. But the indirect effect of the temperature on stomatal aperture was considered important. For example, a steep gradient of water vapor concentration from leaf to air, brought about by a rise of a few degrees in leaf temperature, may accelerate transpiration and cause a water deficit in the leaf sufficient to partially close stomata.

Leaf Water Deficit: Leaf-water deficit was another factor affecting stomatal aperture and leaf resistance to gas exchange. Water deficits can clearly exert a direct effect on the stomatal aperture by their effect on the relative and absolute turgor levels in guard cells and surrounding cells (Allerup, 1961; Ehlig and Gardner, 1964; Meidner, 1955; Stalfelt, 1961). Transpiration rates were controlled by leaf resistances. Decreases in transpiration with the onset of water stress, under constant microclimatic conditions, were caused by increases in leaf resistances (Baker and Musgrave, 1964).

Brix (1962) suggested that water stress effects influenced diffusive resistance through stomatal opening or by controlling the diffusion rate of Carbon dioxide through the mesophyll cells. Ehrler and Van Bavel (1967) noted that leaf resistance values were considerably higher throughout the day under low soil moisture conditions. This higher leaf resistance was attributed to an internal water deficit strong enough to counteract the stomatal opening effect of light. Kanemasu and Tanner (1969) reported that for snapbeans the adaxial and abaxial surface of the leaf respond differentially to water deficits in the leaves with the adaxial surface being more responsive. Brady et al., (1975) reported that the adaxial stomata of soybeans were more responsive than the abaxial to changes in soil-water content. With variation in saturation deficit between 1.5 and 3.0 K Pa at higher irradiances, 3-4 fold changes in leaf conductance occurred in well-watered groundnut plants while the stomatal response was greatly reduced or absent in unirrigated plants in which stomatal conductances were reduced (Black and Squire, 1979).

Relative Humidity: Low atmospheric humidity could cause some stomatal closure. Earlier evidence indicated that the humidity effect is indirect and mediated through an accelerated transpiration and a resultant poor leaf-water balance (Meidner and Ramsfield, 1968). Later data showed that in some species a low absolute humidity causes stomatal closure that was independent of the bulk water status of the leaf (Lange et al., 1971; Schulze et al., 1972).

2.1.8.3 Leaf-water Potential

Importance of Leaf-Water Potential:

The water potential of plant tissue has become a standard means of expressing plant-water status.There was no universal relationship between plant-water stress and soil-moisture level because while water absorption was mostly dependent on soil and plant factors, water loss through transpiration was dependent mainly on plant and meteorological parameters. Plant-water balance depends rather on the relative rates of water absorption and water loss rather than on the level of soil moisture or atmospheric demand alone. An insufficient understanding of this principle might lead to major misinterpretation of plant-water relationships and of irrigation experiments with crops grown in the field under conditions of severe moisture stress. This might be supported by the work of Letey and Peters (1957) who had found that the total amount of water used by maize could not be taken as a reliable criterion for yield responses of this crop because the soil water absorbed was closely related to the climatic conditions prevailing during each growing season.

Denmead and Shaw (1962) reported that the soil moisture at which the relative transpiration rate decreased varied from 23% (soil moisture by volume) when the potential transpiration rate was 1.4 mm per day to 34% when the potential transpiration rate exceeded 6 mm per day. Hence, there was a great need to closely monitor the plant-water status in relation to soil-water conditions and atmospheric demand. Rawlins and Raats (1975) reported that many plant processes were sensitive to water stress that reduced leaf-water potential by less than -10 bars. Groundnut could maintain a higher leaf water content in dry soil and could continue to carry on photosynthesis at a lower leaf water content than barley, wheat and soybeans (Iyama and Muratha, 1961a).

Johnson et al., (1974) reported that the rate of net photosynthesis and transpiration of both leaves and ears of barley and wheat decreased linearly with decreasing leaf-water potential. Sullivan and Brun (1975) showed that, under water stress, soybeans exhibited lower leaf-water potentials and photosynthetic rates. Clark and Hiler (1973) showed that leaf-water potential was more responsive to changes in plant-water status than either leaf-diffusion resistance or leaf-air temperature differential. Bennett et al., (1981) reported that in the field tests, zero turgor potential occurred at leaf water potential of - 1.6 M Pa and concluded that water relations of groundnut were similar to other crops with no unique drought resistance mechanism.

Factors Affecting Leaf-Water Potential:

The base level of water potential on any day for a given species will vary according to age or stage of growth, the prehistory, and the external environmental conditions prevailing, i.e. soil-water potential. Superimposed upon this base level of water potential is a diurnal variation in response to the external environment. This diurnal response was caused by the lag of absorption of water behind transpiration. Transpiration was governed by atmospheric factors such as radiation, air temperature, relative humidity and wind speed, and water absorption was governed partly by soil factors including water content and unsaturated conductivity.

Klepper (1968) measured the diurnal variation in water potential of leaves and roots and found that the daily variations in plant-water status were closely related to radiation load, or stress, while at night the plant-water potential reflected the soil-water status. These results indicate that during the day, roots could not absorb water fast enough to replace that lost by transpiration, even as the potential gradient increased.

Waring and Cleary (1967) showed that with adequate soil water, plant-water potential reached - 20 bars, even when soils were near field capacity if the radiation load was sufficiently high. Reicosky et al., (1975) also indicated that leaf-water potential of soybeans was closely related to the diurnal change of incoming energy. The minimum value, which occurred during the peak radiation load, or stress, was dependent on soil-matric potential and stage of development. Their results demonstrate the need to evaluate the influence of environmental and associated physiological processes. Smart and Barrs (1973) described empirical relationships between leaf-water potential and radiation, temperature, and saturation vapor deficit by multiple regression analysis. Their model accounted for up to 96% of the diurnal variation in leaf-water potential. For all species, insolation was the important environmental parameter. Stansell et al., (1973) concluded that clouds can cause significantly different changes in plant-water status in a short time. Therefore, they cautioned that care should be taken to sample different treatments under comparable radiation:

2.1.8.4 Leaf Temperature

Leaf Temperature:

Leaf temperature plays a major role on the closing and opening of stomata and thereby fluctuations in the transpiration. A steep gradient of water vapor concentration from leaf to air, brought about by a rise of a few degrees in leaf temperature, might accelerate transpiration and cause a water deficit in the leaf sufficient to partially close stomata (Hsiao, 1975). The leaf temperatures were influenced by the moisture stress on the plant at various phenological phases, air temperature, relative humidity, wind velocity etc.

2.2 SOIL ENVIRONMENT FOR GROUNDNUTS

2.2.1. Water Relations and Water Loss

It was well accepted that as available soil water decreases, sooner or later plants find it more difficult to extract moisture, and the rate of uptake fell below the plant's potential for using it.

A number ot studies on the pattern of changes in moisture loss in groundnuts with increasing moisture stress had been done. Slatyer (1955) examined the ratio of Et/EO 0.75 as moisture levels declined from field capacity to zero available soil moisture. He found a straight line relationship starting at a ratio value of 1.8 and approaching zero as available soil moisture did the same. Thus if Eo remained constant, ET would have declined proportionately to moisture availability in the profile.

Wormer and Ochs (1959) obtained a different relationship. They found that as soil moisture decreased, transpiration remained constant until a critical value was reached, the value depending on climate. Transpiration then declined to soil pF 4.2, at which point relative transpiration was still 66% of the maximum.

These two sets of results disagree both in the pattern of transpiration changes as stress increases and in the rate of transpiration at low moisture levels. The soil used by Slatyer had a narrow available moisture range and this could mean that the critical point described by Wormer and Ochs would not be easy to detect.

The second point of difference probably results from the use by Wormer and Ochs of one figure (pF 4.2) to describe the moisture status of the soil. There would in fact be a range of wetness in the soil, drier at the surface and more moist at depth, with this region supplying moisture for the continuing transpiration.

Bhagsari et al., (1976) in glasshouse work found an increase in diffusive resistance after withholding water for two days, and that after six days stress relative leaf water content was only 30-38% of that at full turgidity, far less than experienced in the field. Even then it was considered that stomata were not fully closed since diffusive resistance to water vapor increased further at night.

Groundnuts thus did not have complete stomatal control over transpiration loss but some extra resistance to moisture loss was achieved through the capacity of the plant to fold and orient its leaves parallel to the incoming radiation.

2.2.2 Water use

Water use can be considered from the point of view of total crop use, and patterns of use throughout the growing season.

2.2.2.1 <u>Total Use</u>

Total water use will be affected by climatic, agronomic, varietal, and moisture availability factors. The figures presented hereunder were therefore of interest only in so far as orders of magnitude were concerned but give some indication of the crop's requirements.

Panabokke (1959) quoted evapotranspiration from a 110 day crop of groundnuts grown between October and January as being 404 mm, while in a 126 day crop, Kassam et al., (1975) in Samaru, Nigeria measured water use at 438 mm, with a mean Et/Eo ratio from sowing to harvest of 0.74.

Charoy (1974) in Senegal, using a longer season variety of 148 days duration measured water usage of 510 mm in a year with normal rainfall on a tropical ferruginous soil of dune origin. This compared to 344 mm evaporation from the bare soil over the same period.

Levels of irrigation could have a major effect on the amount of water used, Mohmed Ali et al., (1974) measured moisture usage of groundnuts irrigated whenever moisture availability dropped to 60% of total available at 30 cm depth, at 530 mm. When irrigation was not undertaken until moisture availabiltiy dropped to zero, the usage declined to 293 mm.

Cheema et al., (1974) measured consumptive use values from 337 mm in a non-irrigated control, to 597 mm in a plot irrigated at 40% moisture depletion, while Mantell and Golden (1964) observed usage of from 403 to 687 mm with the optimum around 515 mm. Evapotranspiration requirement of groundnut was highest (560 mm) as compared to other crops during the winter season (Anand Reddy et al., 1980).

It would seem from these results that an upper limit of 600 mm could generally be put on the total moisture requirements for a groundnut crop, while some yield could be obtained with less than half of this amount. Since these figures do not take into account inefficiencies in rainfall distribution, seasonal rainfall levels considerably higher than 600 mm would normally be needed to ensure that a crop was adequately supplied with moisture, especially under tropical conditions.

2.2.2.2 Patterns of Water Use

Of greater significance than the total water use was the pattern of demand throughout the season, since highest yields would be obtained only if the water supply generally matched the requirements of the crop in its various growth phases.

Davidson et al., (1973) had proposed a model for water use by groundnuts in the US which showed under US conditions a sharply peaked pattern of water use per day (Et) which reaches a maximum midway through the growth of the crop; and a less sharply peaked pattern of potential evapotranspiration (Eo). From emergence onwards, the actual water use progressively approaches potential use until they become equal about midway through the growth of the crop, when presumably the canopy had closed over. From then on actual and potential water use remained equal to each other until harvest.

Results of Stansell et al., (1976) in Georgia agree generally with this pattern of water use but had shown variations in the three varieties tested. Recommendations for watering groundnuts in the Gezira scheme also followed this pattern, although the amounts involved were much higher than in the US and range from 4.4 mm per day at emergence in mid-June to a maximum of 7.6 mm in mid September declining to 3.6 mm in mid November at harvest.

Work in Zimbabwe (Metelerkamp, 1975) had demonstrated that all the varieties reached the maximum Et/Eo ratio at about half way through their growth period and remained there until just before harvest when the ratio dropped slightly, presumably due to senescence.

The pattern of water use could be modified by leaf diseases. Kassam et al., (1975) in Nigeria showed an Et/Eo pattern which reached a maximum, then declined rapidly following a heavy attack of cercospora leaf spot.

For annual crops, dry matter production was in most cases linearly related to evapotranspiration but the function was displaced from the origin. This resulted in increasing water use efficiency being maximum at maximum ET and dry matter production.

2.2.3 Moisture Stress and Soil Temperature

Soil temperature, particularly the extremes, influenced the germination of the seed, the functional activity of roots, the rate and duration of plant growth, and the occurrance and severity of plant diseases. The surface soil temperature, in particular was influenced by the soil moisture content. The temperature of a bare soil surface fluctuated in phase with incident radiant energy, the amplitude of diurnal fluctuation being affected by the radiation intensity, soil reflectivity, and soil moisture content. Penetration of the temperature wave into the soil was determined by the rate at which heat was transferred into the soil and the temperature rise that this heat produced. These vary with the soil type, tillage and moisture content (Sivakumar, 1978).

Soil temperature was reported to affect the groundnut yields markedly. Some of the best yields were reported from Rhodesia, Malawi and they were attributed to favourable soil temperature besides other favourable conditions (Kanwar et al. 1983). Unfortunately, there was little experimental evidence in India about the effect of temperature on this crop. A study conducted on black soils in Raichur (Karnataka) showed that fairly high temperature of soil at 5 cm depth during the months of August-October affected the crop yields favourably. The high temperature, perhaps helped the crop in geotropic action of the gynophores and other developmental activities. However, on the other hand it was observed that a long drought spell in any of the three months had a detrimental effect on the crop. It seems that soil temperature effect on yield needs critical evaluation (Kanwar et al., 1983).

Ono et al., (1974) reported that the time of initiation and rate of pod development were markedly affected by soil temperature in the podding zone. Optimum soil temperature was found to be 31-33 C, minimum soil temperature 15-17 C and maximum 37-39 C. Optimum soil moisture content was 40%.

Soil heating by mulching with transparent polyethylene increased soil temperatures killing the pathogens and also resulted in enhanced plant growth and increased concentration of organic matter and minerals (Chen and Katam, 1980).

Literature on the variation of soil temperature and its effect on the seed yield and dry matter production, when moisture stress was imposed on groundnut crop at different phenological phases, was very meagre.

2.2.4 Moisture Stress and Soil Penetration Resistance

Groundnuts had an unusual relationship with soil in that soil must supply water to roots and also must allow penetration of the gynophore. It was certain that the turgor of elongating cells in the gynophore supplies force for the penetration process so that pegging might be sensitive to soil water levels in the rooting zone (Klepper, 1973). The gynophore must enter the soil for fruiting to occur and hence, the physical condition of the soil was of importance, since the gynophores were able to exert a force equivalent to only 3 or 4 gm on the soil (Underwood et al., 1971). Thus mechanical resistance such as might be experienced in a dry soil was a problem. If the developing pod in the soil was subjected to soil's resistance due to water stress, pod development could be inhibited.

In the absence of excessive mechanical resistance, pods could olerate moisture levels down to 15 bars tension without ill effects n the productivity of kernels. They could not tolerate air dry soil, ven if the rest of the plant was well watered. It seems that under these conditions the plant could not transfer enough moisture for the development needs of the pods. Groundnuts grown in compacted soil showed a decrease in yield with increase in soil strength. Gabriilides and Akritidis (1971) reported that soil pressure significantly affected speed of emergence.

2.3 Climate and Radiation Balance

2.3.1 Climate and Yield Variability

Groundnut was one of the important legume crops of the semi-arid tropics (SAT) which were characterised by a high climatic water demand and by a variable and erratic rainfall. In semi-arid India moderate or worse droughts were likely to occur one year in every four. The problem essentially involves balancing or matching, over time, the discontinuous water supply with the continuous atmospheric evaporative demand. The resultant water stress, the intensity and duration of which varied from season to season, affects almost all physiological response that were observed, and their relative importance in crop productivity vary with species, soil type, nutrients and climate, but there were general features that could be identified and quantitatively modeled (Sivakumar et al., 1982).

For a rain grown groundnut crop to have a consistent level of yield, the water supply must be related to the plant's requirements in a constant manner from year to year. Thus both total rainfall and its within season distribution would need to be similar over the years. Variations in distribution within a season had resulted in the anomalous situation of higher yields being sometimes produced in years of lower rainfall (Sindagi and Reddy, 1968). Liu (1973) observed that atmospheric conditions had a greater effect than soil moisture on plant water balance.

Bhargava et al., (1974) accounted for 89% of yield variation over four regions in India as being due to rainfall variability in the August-December growing period. Contrary to this, McCloud (1977) observed that only 3% of yield variation was due to weather conditions during crop growth at Florida.

Thus, as would be expected from a crop with a range of types and grown over a wide geographic area, there was a wide variation in climatic response from year to year and season to season. The detailed reasons for these variations need to be understood, and either allowed for or their causes counteracted.

2.3.2 Moisture Stress and Albedo

The measurements of reflected radiation in an experiment where a groundnut crop was subjected to moisture stress at different phenological phases showed that the albedo (percent of reflected radiation) was always more in the treatment with severe stress as compared to no stress treatments. Under conditions of moisture stress the groundnut crop would show adaptations that would enable it to reduce the energy load on the crop by means of reflecting more light away from the crop canopy (Sivakumar et al., 1982).

2.3.3 Moisture stress and net radiation

In terms of the energy balance of the crop the net radiation would also be lower in the case where the groundnut crop was under moisture stress. This observation was also true in the case of a sorghum crop that was grown under limited water supply. Measurements of net radiation above the crop also showed that on a diurnal basis the irrigated sorghum crop intercepted about 31 langleys of net radiation that corresponded to approximately o.5 mm of water (Sivakumar et al. 1979). These data reflect the ability of the crop to extract more water from the soil in the irrigated treatment as compared to the non-irrigated moisture stress treatment (Sivakumar et al., 1982).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The experiments were conducted in the rainy season 1982 and postrainy season 1982-83 on a medium deep Alfisol (fine, clayey mixed Udic Rhodustalf) at the International Crops Research Institute for the Semi- Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh (17°32' Lat, 78°16'E Long).

3.1 Soil Analysis

The soil is well drained and has an estimated total moisture holding capacity of 254 mm in a 127 cm deep profile. Some soil chemical characteristics of the field, RCE3B, were listed in Table 2. The soil analysis was done in the ICRISAT Routine Analytical laboratory.

Table 2. Soil chemical properties by depth increments of the experimental plot.

Depth (cm)	pH	EC (m mhos/cm)	Available (Olson's) P ppm	Organic carbon (%)
0-15	6.6	¼ 0.15	11	0.61
15-30	6.7	¼ 0.15	8	0.44
30-60	6.7	¼ 0.15	1	0.31

3.2 Seasonal Weather

The meteorological data for the 1982 rainy season (June to October) and 1982-83 postrainy season (November to March) were presented in Tables 3 and 4.

Table 3. Meteorological parameters during the 1982 rainy season.

Month	Rainfall (mm) Normal*	Rainfall (mm) 1982	Temperature (°c) Normal** Man	Temperature (°c) Normal** Min	Temperature (°c) 1983 Max	Temperature (°c) 1983 Min	Pan Evaporation (mm)	RH % 0717 hrs	RH % 1417 hrs	Wind Kmph	Sun Shine (hr)	Solar Radiation MJ/m^2
June	115	193	34	24	34.3	24.1	265.5	77.3	49.4	17.2	5.5	18.50
July	171	155	30	22	31.2	22.6	212.7	84.5	57.5	16.1	5.9	18.46
August	156	69	29	22	30.0	22.5	179.2	86.2	60.5	13.5	4.2	16.78
Sept.	181	180	30	22	29.7	21.9	137.9	92.0	65.0	6.4	5.5	17.29
Oct.	67	59	30	20	30.3	19.8	148.9	89.4	49.8	5.8	8.3	18.21

Table 4. Meteorological parameters during the 1982-83 postrainy season.

Month	Rainfall (mm) Normal*	Rainfall (mm) 1982	Temperature (°c) Normal** Man	Temperature (°c) Normal** Min	Temperature (°c) 1982-83 Max	Temperature (°c) 1982-83 Min	Pan Evaporation (mm)	RH % 0717 hrs	RH % 1417 hrs	Wind Kmph	Sun Shine (hr)	Solar Radiation MJ/m^2
Nov. 82	23	0	29	16	28.5	17.3	132.3	90.9	49.1	7.6	8.1	16.95
Dec. 82	6	0	28	13	28.2	13.2	149.2	92.2	40.3	6.4	9.4	16.45
Jan. 83	6	0	29	15	28.8	13.1	169.9	85.8	33.4	6.6	10.0	18.67
Feb. 83	11	0	31	17	32.3	17.0	210.5	75.1	26.6	8.3	10.1	20.87
Mar. 83	13	0	35	20	36.5	19.9	303.9	61.1	22.5	8.2	10.3	22.52

*. Based on 1901-70 rainfall data.
**. Based on 1931-60 Temperature data.

3.2.1 Rainfall Amount and Distribution

Rainy season: The total amount of rainfall recorded was 656 mm which was 5% less than the normal rainfall of 690 mm for the period from June to October 1982. Only during June 1982, the rainfall was more than the normal rainfall for the month.

Postrainy season: No rainfall was received from November 82 to March 83 as against a total normal rainfall of 59 mm during the same period.

3.2.2 Air Temperature

Rainy season: The diurnal range in temperature was lowest during the rainy season as compared to postrainy season. The maximum and minimum temperatures recorded from June to October 1982 were almost equal to normal temperatures.

Postrainy season: Highest maximum monthly temperature recorded was 36.5°C during March 1983. Lowest minimum monthly temperature of 13.1°C occurred during January 1983 in this season.

3.2.3 Relative Humidity

Rainy season: Relative humidity of air recorded at 0717 hrs was always higher when compared with the data recorded at 1417 hrs. During September and October, the relative humidity was higher than normal.

Postrainy season: Relative humidity was high during November and December 1982 and from then on started decreasing.

3.2.4 Wind Velocity

With the onset of monsoon, average wind speeds increased from June to August 1982 and then started decreasing.

3.2.5 Open Pan Evaporation

Rainy season: The daily pan evaporation was fairly high (between 6 to 9 mm/day) during June to August 1982 due to low rainfall, high temperatures, low relative humidity and high wind speeds.

Postrainy season: From November 1982, the daily pan evaporation started increasing from 4.4 mm/day to 9.8 mm/day during March 83 due to rise in temperatures from February 83 onwards.

3.2.6 Sunshine

Rainy season: The sunshine hours were less during this season due to cloudy skies.

Postriny season: The sunshine hours were more during this season due to clear skies.

3.2.7 Radiation

Rainy season: The solar radiation during this season was fairly high and uniform ranging from 16.8 to 18.5 $MJ/m^2/day$ due to clear skies on many days.

Postrainy season: The solar radiation started increasing from February 83 onwards due to clear skies.

3.3 Description of Experiments

Three experiments, two in the 1982 rainy season and one in 1982-83 postrainy season, were conducted. The details were presented for each experiment as detailed below.

3.3.1 Experiment I: The effect of moisture stress history during previous season on current season productivity (1982 rainy season)

The experiment was laid out in a randomized block design with three replications. Representative seed samples of the cv Robut 33-1 were drawn from 12 moisture stress treatments of a previous postrainy season experiment conducted during 1981-82 at ICRISAT Center. Those treatments comprised of 4 main treatments (i.e. phenological stages at which moisture stress was imposed) with 3 different levels of water depletion in each main treatment. The details of the main treatments imposed by means of line source sprinkler irrigation (Hanks et al., 1976) were:

Trt. 1: Line source irrigation at emergence, moisture stress imposed from emergence to initiation of pegs; no subsequent stress.

Trt. 2: No moisture stress up to first flush of flowering; line source at that time; moisture stress from flowering to last pod set; no stress afterwards.

Trt. 3: No moisture stress up to first kernel growth; line source at that time; moisture stress imposed from pod filling to maturity.

Trt. 4: Continuous stress imposed by line source given every 10 days.

The three different levels of water depletion (i.e. degree of stress) in each main treatment were obtained with the use of 'line-source' sprinkler irrigation based on the amount of water applied as a function of distance from line source. The three subtreatments A, B, and C within each main treatment were located at 6, 12 and 18 m respectively from the line source. The total amount of water applied in each treatment is given in Table 5.

Table 5. Total amount of water (mm) applied to groundnut crop in different treatments during the 1981-82 postrainy season.

S.No.	Treatı	Water applied (mm)
1	1A	735
2	1B	699
3	1C	671
4	2A	643
5	2B	552
6	2C	472
7	3A	578
8	3B	441
9	3C	312
10	4A	822
11	4B	446
12	4C	103

The seed from these treatments was sown on 19.6.82 and emergence was observed on 24.6.82. The plot size was 10 m x 4.5 m. The plot was laid out in broad-beds and furrows as described by Krantz et al., (1978). The spacing adopted on a broad bed was 30 cm between rows and 10 cm in between plants in a row. A basal dressing of 100 kg/ha of

Diammonium phosphate (18:20:0) was applied and necessary plant protection measures were taken. The plan of the layout is shown in Figure 1. The first bed was utilized for leaf area and dry matter sampling and other experimental measurements.

3.3.2 Experiment II: Studies on the effect of early moisture stress on the productivity of two groundnut cultivars (1982 rainy season)

This experiment was laid out in a split-plot design with four replications. The moisture treatment was in the main plot and the varieties in the sub-plots. The moisture treatment in the main plot was imposed through covering the entire area in two experimental plots with a 4 mil black plastic film and leaving the other two plots uncovered (Plate 1). The black plastic cover was used to induce early moisture stress by preventing the seepage of rain water into the soil upto initiation of pegs. Bamboo stakes were used at one-foot intervals to firmly secure plastic film on the ground. For the sake of simplicity,the treatments will be referred to as "covered" and "uncovered" to identify the black plastic and normal plots, respectively. Sowing was done on 19.6.82 and emergence occurred on 24.6.82. Two cultivars used were TMV2 and Robut 33-1. TMV2 is a "Spanish" bunch type with 90-100 days duration while Robut 33-1 is an early maturing "Virginia" spreading type with about 100-110 days duration. Each replicate consisted of four plots. The black plastic was removed at 44 days after emergence (DAE) after 50% of the pegs had been initiated.

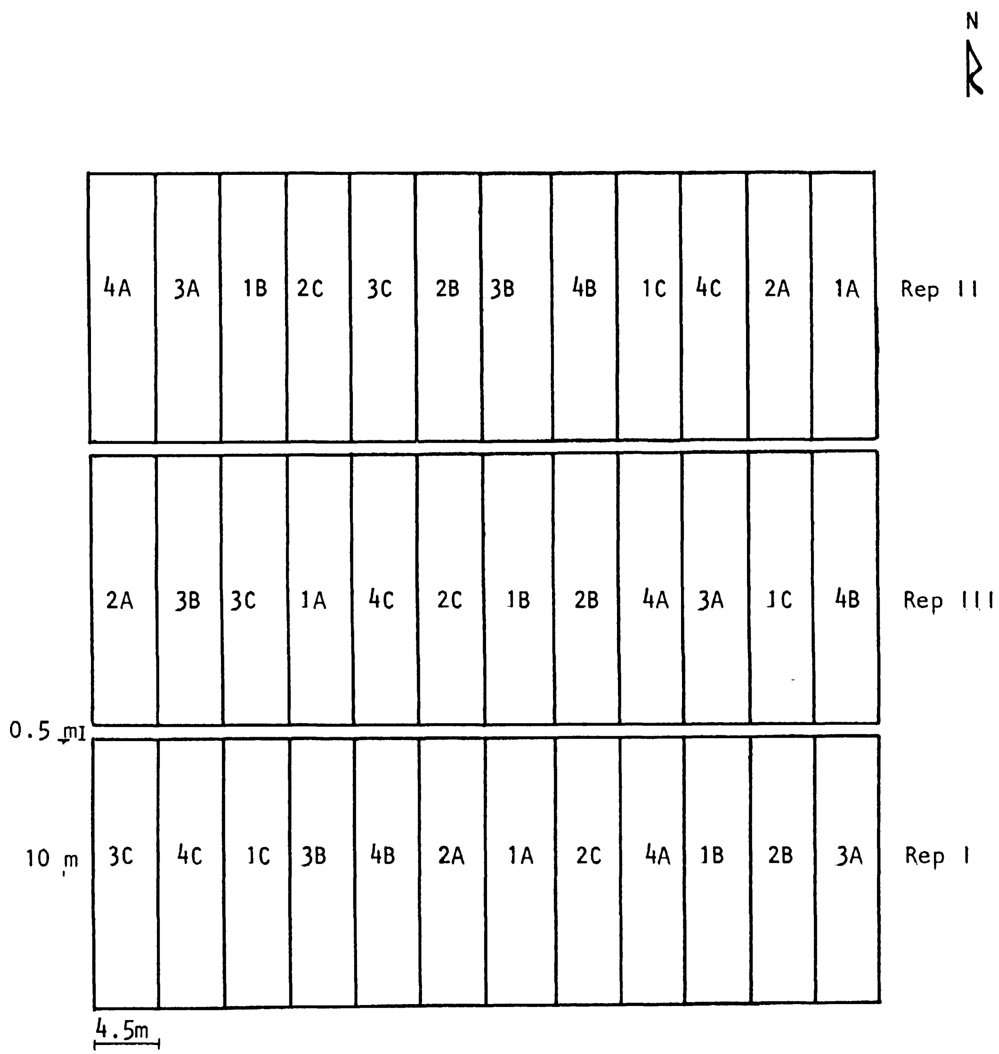


Figure 1. Plan of Experiment No.I: Effect of previous moisture stress on current season productivity of groundnut during the 1982 rainy season.

Plate 1. A view of the experimental plot covered with black polyethylene film during the 1982 rainy season.

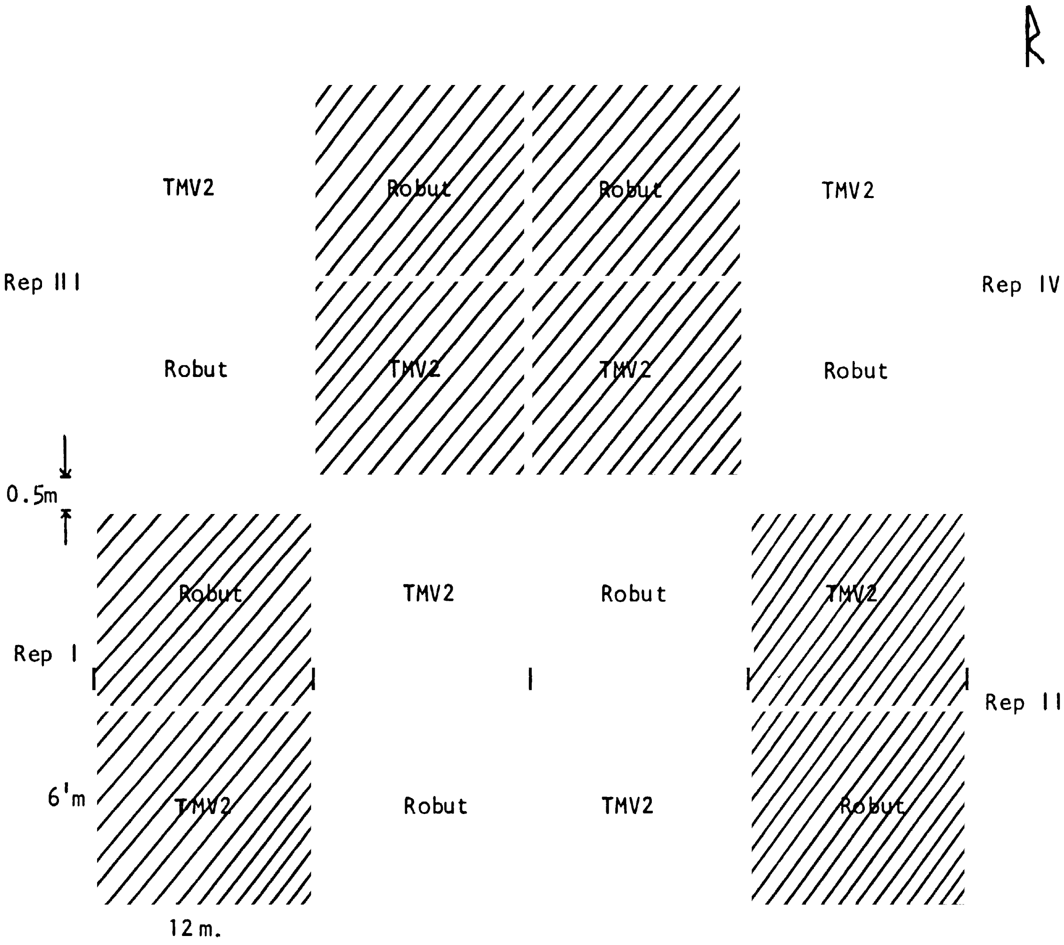
Individual plots were 6 m long and 13.5 m wide. Groundnut was sown in rows 30 cm apart with a plant-to-plant spacing of 10 cm. A basal dressing of 100 kg/ha of Diammonium phosphate (18:20:0) was applied and necessary plant protection measures were taken. An area of 9 m from the central three beds was used for final yield determination while the rest of the beds were utilized for dry matter sampling and root studies at the maturity of the crop. The plan of the layout is shown in Figure 2.

3.3.3 Experiment III: Studies on the effect of moisture stress at different phenological stages of groundnut (1982-83 postrainy season)

The experiment was laid out in a split-plot design with four replications.

Treatments	Phenological Stages
Treatment 1	Line source at emergence; moisture stress imposed from emergence to flowering; no stress afterwards.
Treatment 2	Line source at emergence; moisture stress imposed from emergence to pegging through the use of line source; no stress afterwards.
Treatment 3	Moisture stress from flowering to last pod set through the use of line source; no stress afterwards.
Treatment 4	Continuous stress imposed by line source given every 7 days.

To create a range of profile water depletion patterns, the technique of "line source" sprinkler irrigation as suggestd by Hanks et al., (1976) was used. This technique uses standard impulse sprinkler heads spaced at half their normal spacing along the irrigated line. This produces a continuously decreasing rate of water



Covered by black polyethylene film.

Not covered

Figure 2. Plan of Experiment No.II: Studies on the effect of early moisture stress on the productivity of groundnut during the 1982 rainy season.

application at right angles to the sprinkler line. Based on the amount of water applied as a function of distance from the line source i.e., at 3, 9 and 15 m in treatments 1 to 4, three subtreatments were identified in each treatment as A, B and C respectively. By this procedure, it was possible to had 12 different levels of profile water depletion (1A, 1B, 1C, 2A, 2B, 2C,3A,3B,3C,4A,4B and 4C). The replications and main treatments were randomized while the irrigation treatments could not be randomized due to the use of "line source" sprinkler type of irrigation system. The plan of the layout is shown in Figure 3.

The experiment was sown on 29.10.1982 and emergence was complete by 5 November. The genotype used was Robut 33-1 referred to as Robut. The plot size adopted was 14 m long and 18 m wide. The row spacing was 30 cm with 10 cm in between plants within each row. A basal dose of 100 kg/ha of Diammonium phosphate (18:20:0) was applied. Intensive plant protection was provided against leaf miner, *Cercospora* leaf spot, rust etc.

In each subtreatment of 4 beds, the first and third beds were utilized for dry matter samplings. For final yields, a central area of 9 m in the second bed was utilized. A general view of the experiment is shown in Plate 2.

Control of timing and amount of irrigation

The irrigation was given at weekly intervals depending on the treatments at 0.8 of the total evaporation for the week, as measured with a USA (Class 1) pan evaporimeter.

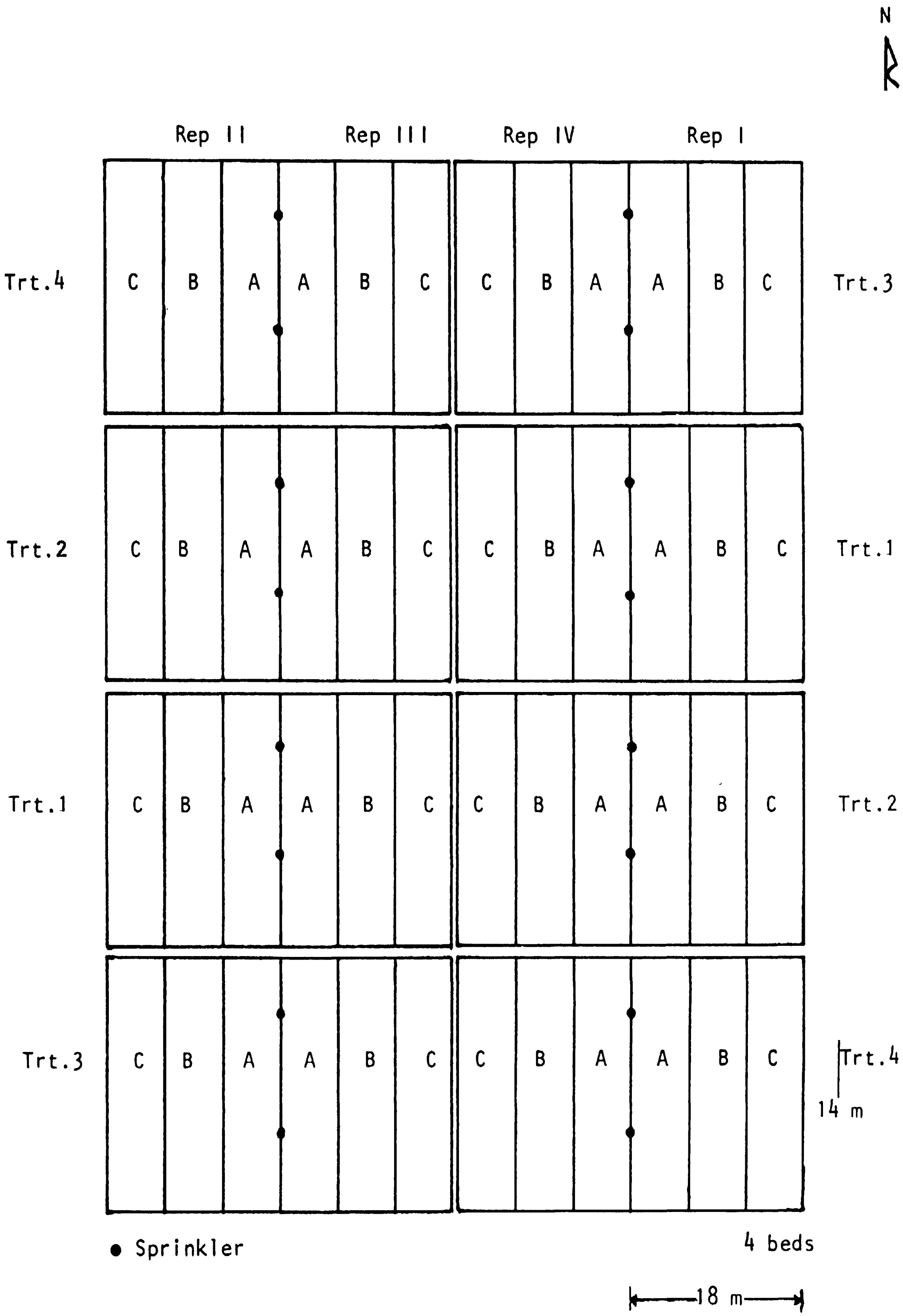


Figure 3. Plan of Experiment No.III. Effect of moisture stress at different phenological phases of groundnut during the 1982-83 postrainy season.

Plate 2. General view of the experiment on the effect of moisture stress at different phenological stages of groundnut during the 1982-83 postrainy season.

Plastic buckets with uniform volume were placed perpendicular to the line source in each treatment to measure the water applied at different distances from the line source.

3.4 Observations recorded in the Experiment I

3.4.1. Early Seedling Vigor

In order to examine the early seedling vigor, data on number of leaves and leaflets, leaf area and leaf dry weights were recorded at three-day intevals starting from 5 DAE. Leaf area was measured with an LI-3100 area meter (LI-COR, Ltd., Lincoln, Nebraska, USA). On each sampling dates, all the plants present in a 0.75 m^2 area were sampled in each treatment in the three replications and the above mentioned measurements were recorded. Plant parts were dried to constant weight in a forced draft oven at 65°C and then weighed.

3.4.2 Proximate analysis

3.4.2.1 Oil Content

Oil content was analyzed using Ab 3-49 method given by AOCS (1981) with the following modifications.

1. 18 hours extraction.
2. Filtration of extract using Whatman No.42 filter paper.

3.4.2.2 Protein

Protein was estimated by Microkjeldhal method (AOAC, 1975).

3.4.2.3 Sugars

Sugars were estimated by the Dubois et al.,(1956) method.

3.4.2.4 Starch

Starch was estimated by the Trivend et al., (1972) method.

3.4.3 Yield and Yield Components

Pod, kernel and haulms yield besides final plant population were obtained from a net area of 9 m^2.

3.4.3.1 Shelling %

The percentage of kernel to pod weight was determined and expressed as percentage.

3.5 Common observations that were recorded in Experiment II and Experiment III were:

3.5.1 Plant observations

3.5.1.1 Growth Measurements

Above-ground, whole plants were sampled at 7-10 days interval in a 0.75 m^2 area in each replicate. After counts of pegs and pods were taken. Leaf area of individual leaves was measured with an LI-3100 leaf area meter (LI-COR, Ltd., Lincoln, Nebraska). Plant parts were dried to constant weight in a forced draft oven at 65°C and then weighed.

3.5.1.2 Root Studies

Root studies were done when the crop reached maturity stage. Deep pits of about 3 m x 3 m x 2 m were dug in designated areas in both the experiments with the help of hydraulic diggers and whole plants with intact roots were isolated. Then the roots in the soil profile in each treatment were carefully and thoroughly washed with sprayers and then the whole plants with roots so seperated were placed in polyethylene bags. The plants with intact root system were spread on white card boards and ptotographs were taken immediately. Then the length of the roots was measured with the help of an Automatic Root Scanner (manufactured by University of Nottingham Applied Science Faculty Workshop). After the root lengths were measured, the root samples were dried to constant weight in a forced draft oven at 60°C and then weighed.

3.5.1.3 Harvest Index (HI)

$$HI = \frac{\text{Seed yield}}{\text{Total above ground biomass yield}} \times 100$$

3.5.1.4 Yield and Yield Components

Pod, kernel and haulms yield besides final plant population were obtained from a net area of 9 m^2.

3.5.1.4.1 Shelling

The percentage of kernels to pod weight was determined and expressed as percentage.

3.5.1.5 Oil and Protein Analysis

3.5.1.5.1 Oil Content

Oil content was analysed by Nuclear Magnetic Resonance Spectrometer (NMR) method (Tiwari et al., 1974).

3.5.1.5.2 Protein Content

Protein was estimated by Microkjeldhal method (AOCA, 1975).

3.5.2 Soil Observations

3.5.2.1 Soil Temperature

Soil temperature was also monitored with CR5 digital recorder (Campbell Scientific Inc., USA). Copper-constantan thermocouples were placed at 10 cm depth in the soil in each treatment and connected to the data acquisition system. The soil temperatures integrated over hourly intervals were recorded every day throughout the growing season.

3.5.2.2 Soil Water Content

A neutron moisture meter was used to determine the profile water content in the field. Neutron access tubes of 150 cm long were installed in all treatments of each replication. Neutron readings were taken at 7-10 days interval from 30 to 120 cm depth at a depth interval of 15 cm in the soil. The neutron scattering equipment was calibrated for the field where the experiments were conducted and volumetric water content was determined. Type I.H.II neutron moisture meter (Didcot Instrument Co.Ltd., Abingdon, Oxon, England 770804) was used in both the experiments.

The low degree of spatial resolution makes the neutron moisture meter unsuitable for detection of water content discontinuities or measurements close to the surface (Holmes, 1950). Hence, the soil moisture in the top 30 cm was measured by the gravimetric method. The gravimetric water content is the ratio of the weight loss in drying to the dry weight of the sample. The volumetric water content was determined by multiplying the values with the bulk density (1.5) of soil in RCE3 field. Available water at different soil depths was computed from the volumetric water contents and data on available water as per the procedure given by Russell (1980).

3.5.2.3 Evapotranspiration

The evapotranspiration (ET) was calculated by employing the following equation (Jenson, 1973).

$$E_T = \frac{W_{et}}{\Delta t} = \frac{\sum_{i=1}^{n_r} (\theta_1 - \theta_2)_i \Delta S_i - R_e - W_d}{\Delta t}$$

Where n_r is the number of layers to the depth of the effective root zone

ΔS_i is the thickness of each layer, mm

θ_1 and θ_2 were the volumetric water content on the first and second date for sampling respectively cm^3 cm^3

R_e is the rainfall that does not runoff the area, mm

and W_d is drainage from the zone sampled, mm.

3.5.2.4 Water Use Efficiency (WUE)

$$\text{WUE} = \frac{\text{Total dry matter produced}}{\text{Calculated water use during that period}} \text{ kg/ha/cm}$$

3.5.3. Microclimatic Observations

The following microclimatic observations were taken during the 1982 rainy season and 1982-83 postrainy season when plant measurements were also being taken.

3.5.3.1 Radiation

Incoming solar radiation at 10-min intervals was measured with an LI-200S Pyranometer (LAMBDA Instruments Corporation, Lincoln, Nebraska, USA) connected to a LI-550 printing integrator.

3.5.3.2 Air Temperature

Air temperature integrated over an hour was recorded using the automatic data acquisition system - CR5 Digital Recorder (Campbell Scientific, Inc. USA) throughout the growing season.

3.5.3.3 Albedo

Reflected radiation (albedo) from the canopy was measured with a CN8 Albedometer (Middleton Instruments, Australia) in conjunction with net radiation measurements at 7-10 days interval throughout the crop growth period. The Albedo meter sensor was always placed at a height of half a meter above the crop canopy and the data were recorded at 10 minutes interval using an LI-550 printing integrator.

3.5.3.4 Net Radiation

Net radiation was measured with a precalibrated portable net radiometer (Swissteco Pty. Ltd. Melbourne Vic. Australia 3123), at a height of half meter above the canopy. Net and albedo measurements were recorded in all the 4 treatments in the Experiment II while in the Experiment III, the measurements were made only in treatment 4 at 687 and 47 mm ET levels. The measurements were made at 10-min intervals throughout the day at 7-10 day interval throughout the crop growth period.

3.6 Independent Observations recorded in the Experiment III

3.6.1 Diffusive resistance, transpiration, and photosynthetically active radiation (PAR)

The three measurements were recorded with an LI-1600 steady state porometer, (LI-COR, Ltd., Lincoln, Nebraska, USA 68504), a battery operated portable instrument (Plate No. 3).

Diurnal readings of these three parameters were recorded at weekly intervals from 0900 to 1700 hours (IST) at two hour intervals throughout the crop growth period starting from 19 days after emergence (DAE). The readings were made on 5 plants selected at random across the three replications. Direct values of stomatal resistance, transpiration and PAR recorded on fully opened and fully exposed leaves were used for this purpose and measurements were recorded on the abaxial side of the leaflet. Stomatal conductance is expressed as the reciprocal of the leaf stomatal resistance or diffusive resistance. PAR was measured with an LI-190S quantum sensor in conjunction with the steady state porometer.

3.6.2 Leaf-water potential measurements

Plate 3. Steady state porometer in use during the 1982-83 postrainy season.

Diurnal measurements of leaf-water potentials were always made in conjunction with the stomatal resistance measurements, using a pressure chamber (Scholander et al., 1965). The measurement on five plants across three replications was accomplished by placing a freshly cut tetrafoliate leaf into the pressure chamber with the cut end of the petiole protruding and then applying external pressure. The pressure to balance the internal stress of the leaf or shoot and return the liquid from xylem to the cut surface was considered equal to the negative hydrostatistic pressure which existed in the plant just before it was cut.

At equlibrium,

$$\psi_w = P \psi_s$$

Where, ψ_w is the water potential of the leaf cells, P is the negative component of the water potential of the xylem sap measured as the positive pressure in the pressure chamber, and ψ_s is the osmotic effect of the solutes in the xylem sap. ψ_s was shown to be negligibly small (Boyer, 1967) and hence P approximates to the leaf-water potential.

3.6.3 Canopy Temperature

Canopy temperature was measured by uisng a Barnes "Instatherm" temperature sensor (Barnes Engineering Company, 30 Commerce Road, Stanford, Connicticut).

Diurnal readings of canopy temperature were recorded at weekly interval in the Experiment III from 0700 to 1700 hours (IST) at two hour intervals during the growing season starting from 19 DAE in conjunction with canopy water potential. The canopy temperatures were recorded on 5 plants selected at random across the replications. Fully opened and fully exposed leaves were used for the purpose.

3.6.4 Wet and dry bulb temperatures

Wet and dry bulb temperatures were recorded with an Assmann Psychrometer (Wilh Lambrecht KG, Gottingen, West Germany).

Operation of the instrument consists of thoroughly wetting the muslin cloth in one of the bulbs, and winding the clock. After holding the instrument horizontally above the crop canopy for 1-2 minutes, the wet bulb and the dry bulb temperatures were noted.

Diurnal readings of wet and dry bulb temperatures with Assmann Psychrometer were recorded at weekly interval from 0700 to 1700 hours (IST) at two hour intervals during the growing season starting from 19 DAE in conjunction with leaf water-potential. The readings were noted at 5 places on the crop canopy in each treatment selected at random across the replications. Psychrometric tables were used to obtain vapor pressure deficit values.

3.6.5 Stress Degree Days (SDD)

Stress degree days were calculated by employing the following formula (Idso et al., 1977).

$$SDD = \sum_{i=1} (L_T - A_T)i$$

Where L = Canopy temperature (^oC)

A = Air temperature (^oC)

i = time interval between two samplings.

3.6.6 Soil penetration resistance

Soil penetration resistance was measured with a Proving Ring Penetrometer (Soil Test, Inc. 2205, Lee Street, Evanston, Illinois 60202, USA). It is a cone type penetrometer which serves as a rapid means for determining the penetration resistance of soils. This measurement was made by setting the dial indicator to the zero position and by pushing the cone point firmly and vertically down into the soil at a steady and uniform rate until the top of the cone goes just below the surface (about 5-6 cm deep). The dial indicator reading was then recorded, using the Proving Ring calibration chart, the maximum penetration load in kg/cm^2 was determined.

Soil penetration resistance was measured at 5 places in each treatment across 3 replications twice a week from 44 DAE (beginning of pegging) up to 107 DAE (pod development period).

3.6.7 Phenology

The duration to each specific reproductive stage of groundnut in each treatment was recorded as per the procedure given by Boote (1982).

3.7 Statistical Analysis

Experiment I

The data on seedling vigour were analysed in a split-plot design with the sampling dates as main plots and treatments as subplots. The yield and yield components were analysed using an Randomised Block Design (RBD).

Experiment II

Data were analysed in a split-plot design with the moisture treatments as main plots and the cultivars as subplots. In respect of peg and pod production, the data were analysed for each sampling day separately as a randomized block design.

Experiment III

In order to make a comparison of the phenological stages, the effect of evapotranspiration (assuming that it will not affect the phenological stages) was taken out using the analysis of variance model for growth effects with a linear term for evapotranspiration (as a covariate). Since the levels of ET could not be randomized due to the use of line source sprinkler irrigation system, the data were analysed for each treatment and for each sampling day separately in an RBD design and standard errors were given.

RESULTS

4. RESULTS

The results are discussed hereunder experimentwise for the three experiments conducted during the 1982 rainy season and the 1982-83 postrainy season.

4.1 Experiment 1: Effect of previous moisture stress on current season productivity (1982 rainy season)

The results of this experiment are discussed under the following headings:

4.1.1 Quality of seeds used from 1981-82 postrainy season experiment.

4.1.2 Early seedling vigor: This was assessed with the following parameters studied at 3-day interval continuously up to 26 days atter emergence (DAE).

4.1.2.1 Rate of seed emergence.

4.1.2.2 Final plant population.

4.1.2.3 Leaflet number per square meter.

4.1.2.4 Leat area per leaflet.

4.1.2.5 Leaf area per plant.

4.1.2.6 Dry matter production.

4.1.3 Yield and yield components.

4.1.4 Quality of seed obtained from 1982 rainy season.

4.1.1 Seed quality

Representative seed samples drawn from the plot harvests of 12 treatments described in Table 5 were analysed for seed quality.

The results of the proximate analysis of the seed samples obtained from 1981-82 postrainy season experiment are presented in Table 6.

Table 6. Proximate analysis of the kernels obtained from the experiment on the response of groundnut to moisture stress during the 1981-82 postrainy season.

Treatment	100 kernel wt. (g)	Oil %	Protein %	Sugars %	Starch %
1A	66.9	44.6	30.0	4.94	10.6
1B	68.2	43.3	30.5	4.58	10.4
1C	75.4	43.8	29.6	3.95	10.1
2A	54.1	44.4	28.6	5.09	11.1
2B	47.5	44.5	27.6	5.18	12.3
2C	26.3	39.5	24.5	6.32	15.4
3A	66.0	41.9	32.8	3.25	10.1
3B	66.6	41.3	33.9	3.74	11.4
3C	32.0	36.0	33.5	2.72	13.8
4A	68.5	40.6	27.7	2.91	13.4
4B	68.4	40.1	31.6	1.26	9.8
4C	19.7	38.5	23.9	3.61	16.8
SE ±	0.15	0.55	0.23	0.07	0.40

The correlation matrix of these characters is furnished in Table 7.

Table 7. Correlation matrix of seed quality parameters.

1. 100 seed weight (g)	1.00				
2. Oil %	0.60	1.00			
3. Protein %	0.55	-0.01	1.00		
4. Sugars %	-0.27	0.46	-0.50	1.00	
5. Starch %	-0.89	-0.63	-0.68	0.21	1.00
	1	2	3	4	5

The above results indicate that oil and protein are positively correlated with 100 seed weight while starch and sugars showed a negative correlation. Starch content was negatively correlated with oil and protein content of the groundnut seeds used. Oil, protein and sugars are not correlated significantly.

4.1.1.1 <u>100 Kernel weight:</u>

Among the main treatments (phenological stages), moisture stress imposed from flowering to last pod set (Trt.2) in general resulted in poor filling of seeds while the treatment which was under moisture stress from emergence to initiation of pegs (Trt.1) had a beneficial effect in seed filling. Except in Trt. 1, with the decrease of net amount of water applied in each of the main treatments (Table 6), the seed filling was very much affected. This effect was prominent in Trt. 4C when the kernal weight was only 19.7 g with 103 mm of water applied.

4.1.1.2 Oil content:

Among the phenological stages, moisture stress imposed from emergence to initiation of pegs (Trt. 1) had the highest mean oil content as compared to the rest of the treatments. As to the degree of moisture stress within each phenological stage, there was no clear trend. It was observed that except in Trt. 1 the oil content decreased with the decrease in the net amount of water applied.

4.1.1.3 Protein content:

Among the phenological stages, moisture stress imposed from pod filling to maturity (Trt. 3) resulted in the highest protein content of 33% as against 27.8% for the control (Trt. 4). Moisture stress imposed from flowering to last pod set (Trt. 2) had a depressing effect on the protein content. As to the degree of stress within each stage there was no clear trend. However, the maximum decrease was noticed with the least amount of 103 mm of water applied in Trt. 4.

4.1.1.4 Sugar content:

Among the phenological stages, moisture stress imposed from flowering to last pod set (Trt. 2) contained the maximum amount of sugars (5.5%) followed by the moisture stress imposed from emergence to initiation of pegs (Trt. 1) with 4.5% sugars. Moisture stress imposed from pod filling to maturity (Trt. 3) resulted in a mean sugar content of 3.2%. As to the degree of stress at each stage there was no clear trend as the sugar content varied among the stages. With 552 mm of water applied in Trt. 2C, a maximum sugar content of 6.3% was recorded. In treatments 1 and 3, the sugar content was affected with the decreasing amount of water applied.

4.1.1.5 Starch Content:

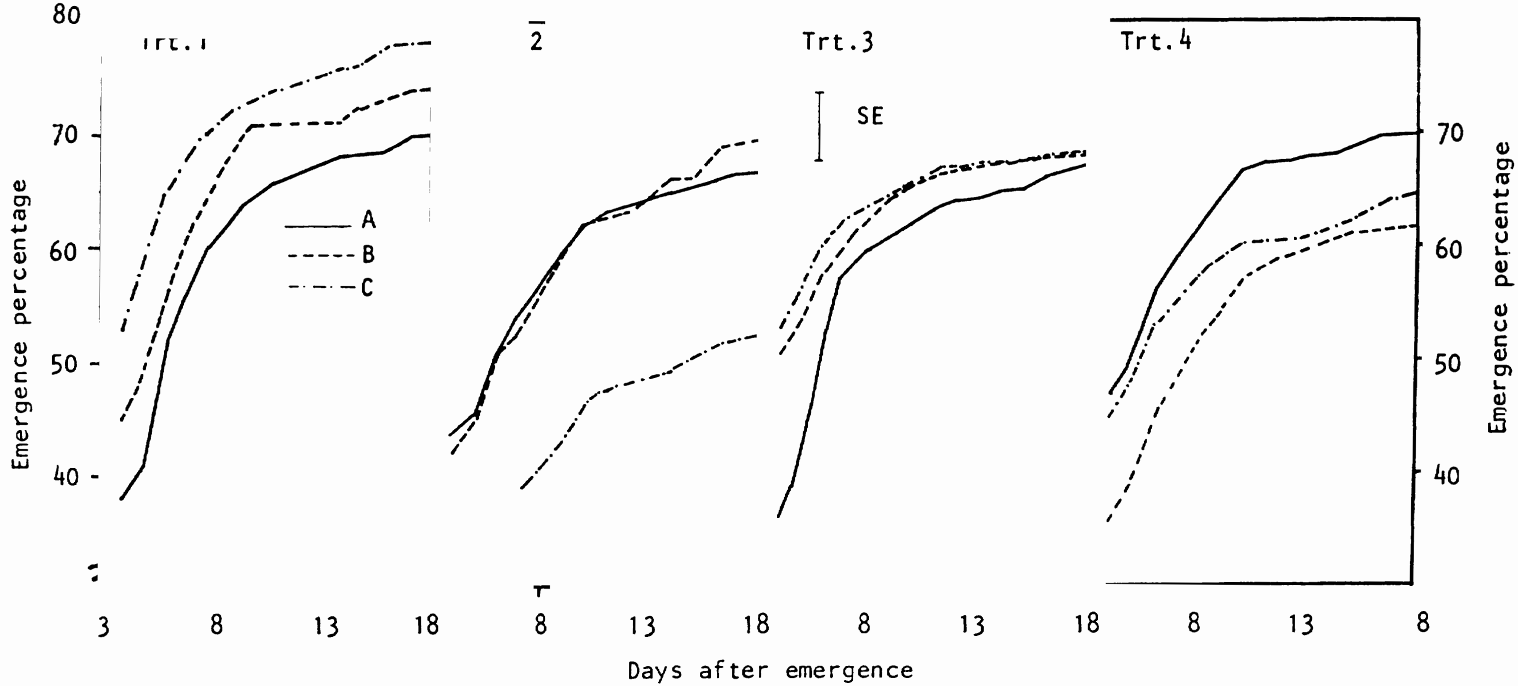
Among the phenological stages, the continuous moisture stress imposed by line source (Trt. 4) recorded the highest mean starch content of 13.3%. The least starch content of 10.4% was observed in Trt. 1 followed by Trt. 3 and Trt. 2. With regard to the degree of moisture stress in each stage, with the least amount of water applied (103 mm) Trt. 4C recorded significantly superior starch content (16.8%) over the rest of the treatments.

4.1.2. Early Seedling Vigor

4.1.2.1 Rate ot seed Emergence:

The rate of seed emergence for all the four treatments is shown in Figure 4. Among the phenological stages, the seeds with a previous moisture stress history from emergence to initiation of pegging (Trt. 1) recorded higher field emergence over rest of the three treatments including control (Trt. 4). Treatments 1 to 4 recorded mean emergence rate ot 74%, 62%, 68%, and 66% emergence respectively.

As to the degree of moisture stress, large differences were observed in the four main treatments. In Trt. 1, emergence percentage increased inversely with the amount of water applied and the highest emergence of 78% was in Trt. 1C while 1A recorded 70%. In Trt.2 significant differences were noticed among the three subtreatments with 2C had a significantly smaller emergence percentage than 2A and 2B which were on par. In Trt. 3, the subtreatments show very little difference. In Trt. 4, though the differences in emergence were not significant among the subtreatments, 4A recorded



Figu Emergence percentage o groundnut seed with a previous history of moisture tress during the 1982 rainy season at the ICRISAT Center. Details of the treatments are furnished n **Table 5.**

higher rate of emergence over 4B and 4C.

4.1.2.2 Final plant population:

The final plant population, along with yield and yield components are presented in Table 8. Among the phenological stages, Trt. 1 recorded highest mean final plant population of 1.47 lakh/ha followed by Trt. 4 (1.36), Trt. 3 (1.32) and Trt. 2 (1.28).

As to the degree of stress, higher plant populations were recorded in all the three subtreatments in Trt. 1 as compared to other subtreatments. Trt. 2C recorded the least plant population of 1.1 lakh/ha due to very poor germination of seed. This was closely followed by Trt. 3C which recorded 1.22 lakh/ha plant population.

4.1.2.3 Leaflet number per m^2

The number of leaflets/m^2 produced up to 26 DAE are furnished in Figure 5. In leaflet production also Trt.1 was better than the rest of the treatments. As to the degree of moisture stress within each main treatment, at 26 DAE Trt.1C was significantly superior to 1B. Further 1C showed a linear increase in the leaflet production up to 26 DAE. In respect of Trt.2 and Trt.3, there were no significant differences among the three subtreatments at 26 DAE. In the case of Trt.4, 4A was significantly superior to 4B and 4C in terms of leaflet production at 26 DAE. Subtreatments 3C, 4B and 4C recorded significantly less number of leaflets at 26 DAE.

4.1.2.4 Leaf area per leaflet:

Leaf area per leaflet as a function of time up to 26 DAE is presented

Figu e 5 .eaflet product on up to 26 DAE in a groundnut seed crop with a previous history of ıoisture stress during the 1982 rainy season at the ICRISAT Center. Details of the :reatments are urnished in Table 5.

in Figure 6. Among the phenological stages, Trt.1 recorded highest mean leaflet area of 2.45 cm as against 2.22 cm of Trt.4. Trt.2 recorded the least mean leaflet area of 1.97 cm while Trt. 3 recorded 2.28 cm.

As to the degree of moisture stress, all the 3 subtreatments in Trt.1 were at par with 4A (control) and superior to the rest of the subtreatments at 26 DAE. The rate of leaflet area development was much faster in 1A and 1B than the other subtreatments. The subtreatments in Trt.2 and Trt. 3 were not significantly different. In Trt.4, 4A was superior to 4B and 4C in terms of leaf area per leaflet at 26 DAE.

4.1.2.5 Leaf area per plant:

Leaf area per plant as a function of time is shown in Figure 7. Among the phenological phases, Trt.1 again proved its superiority over other treatments by recording higher leaf area per plant. In general, Trt.2 recorded less leaf area per plant compared to treatments 3 and 4.

The differences among the degree of moisture stress were quite large. In Trt.1, subtreatment B recorded the highest leaf area per plant compared to C. Subtreatments 1A and 1C were significantly superior to 4A (control) in respect of leaf area per plant at 26 DAE. In Trt.2, differences among the three subtreatments were significant at 26 DAE and 2A and 2B recorded more leaf area per plant than 2C. In Trt.3, differences were not much among the three subtreatments. In Trt.4, the differences in the leaf area production were significant between 4A and 4C while 4B was on par with 4A. Very low leaf area per plant at 26 DAE was recorded by subtreatments 2C and 4C.

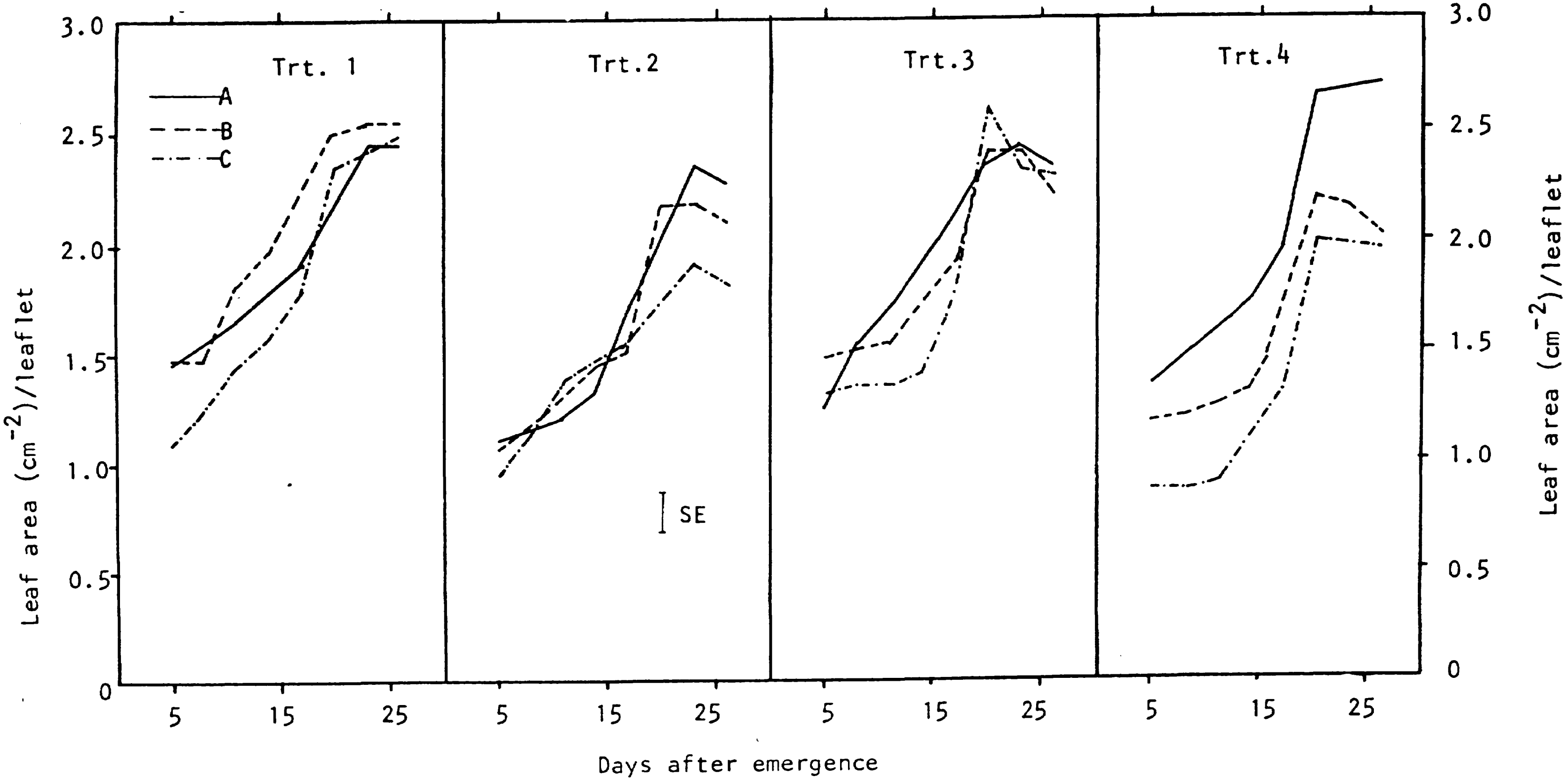


Figure 6. Leaf area/leaflet of groundnut seed crop with a previous history of moisture stress, during the 1982 rainy season at the ICRISAT Center. Details of the treatments are furnished in **Table 5.**

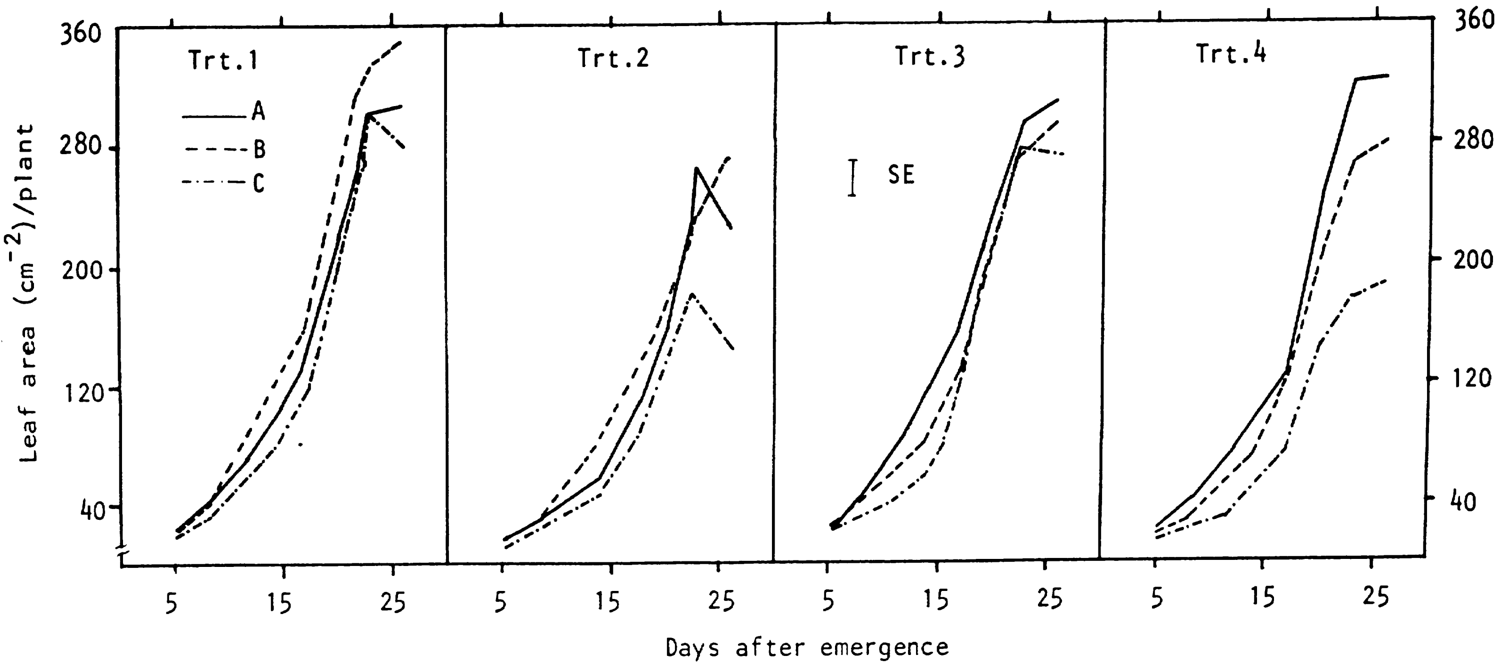


Figure 7. Leaf area/plant of groundnut seed crop with a previous history of moisture stress, during the 1982 rainy season at the ICRISAT Center. Details of treatments are furnished in Table 5.

4.1.2.6 Dry matter production:

The total dry matter produced at 3 day interval up to 26 DAE is shown in Figure 8. Among the phenological stages, Trt.1 was found to be better than the other treatments in dry matter production. Trt.4 produced the lowest dry matter at 26 DAE.

As to the degree of stress in each main treatment, 1A and 1C were significantly superior to 1B in respect of dry matter production. 1A recorded the maximum dry matter production at 23 DAE. In Trt.2, 2A and 2B were superior to 2C. Trt.2A recorded linear increase in dry matter production even up to 26 DAE. In the case of Trt.3, dry matter increase was rather slow up to 20 DAE but there was a steep increase up to 23 DAE and then decreased up to 26 DAE. In Trt. 4, the dry matter production was not significantly different amoung the 3 subtreatments.

4.1.3 Yield and Yield Components:

The yield and yield components along with final plant population are presented in Figure 9 and Table 8.

4.1.3.1 Pod Yield:

Among the phenological stages, the seed from the crop stressed from emergence to initiation of pegs (Trt.1) had the higher mean pod yield of 1866 kg/ha as against 1714 kg/ha from the crop stressed continuously (Trt.4). The lowest mean yield of 1540 kg/ha was obtained from the seed from the crop stressed from flowering to last pod set (Trt.2) which was 17.5% less than the Trt.1. The seed from the crop stressed from pod filling to maturity (Trt.3) gave a mean pod

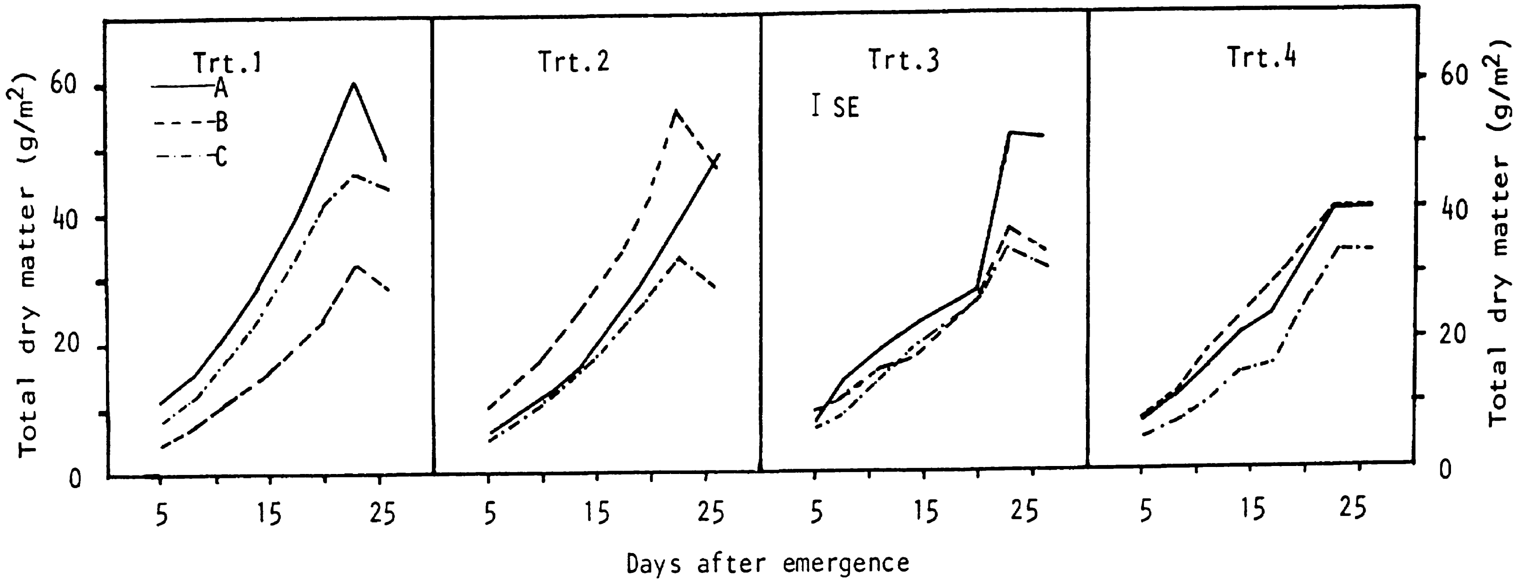


Figure 8. Total dry matter of the above ground parts of groundnut seed crop with a previous history of moisture stress, during the 1982 rainy season
Details of the treatments are furnished in Table 5.

yield of 1738 kg/ha which was 7% less than the Trt.1.

As for the degree of moisture stress, subtreatments 2B, and 2C were significantly less in respect of pod yield while the rest of 10 subtreatments were on par. Pod yield was fairly uniform among the 3 subtreatmetns in Trt.1, while in the rest of 3 main treatments, pod yield decreased with decreasing amount of water applied.

Table 8. Final plant population, pod, and haulms yield, and some yield components of the groundnut seed crop with a previous history of moisture stress, during the 1982 rainy season.

Treatment	Final plant population/ha ('000)	Pod yield kg/ha	Shelling %
1A	147.8	1893	71
1B	138.1	1824	61
1C	155.9	1882	63
2A	125.9	1852	55
2B	148.1	1516	60
2C	110.0	1253	69
3A	147.4	1818	55
3B	125.9	1776	57
3C	122.2	1619	60
4A	150.7	1751	66
4B	129.3	1755	57
4C	126.7	1636	61
SE ±	8.3	92	5

4.1.3.2 Kernel yield:

Among the different phenological stages, Trt.1 recorded maximum mean kernel yield of 1210 kg/ha (Fig.9), a 15% increase in yield over Trt.4 with a mean kernel yield of 1054 kg/ha. Both Trt.2 and Trt.3 recorded 23% and 16% less kernel yield respectively as compared to Trt.1.

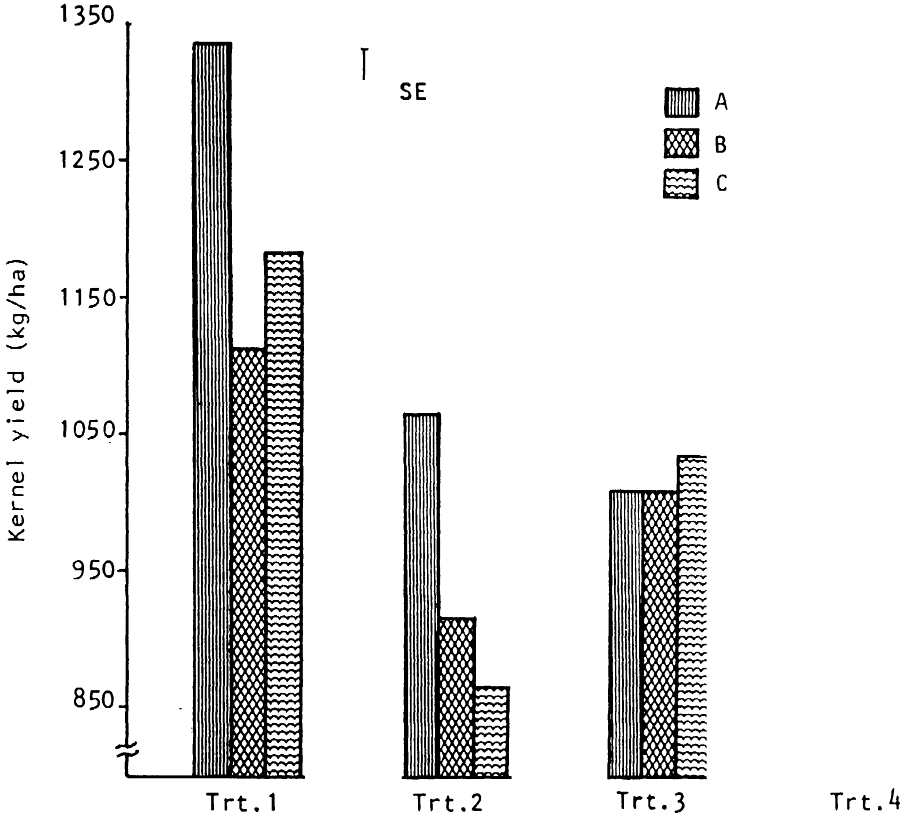


Figure 9. Kernel yield of groundnut seed crop with a previous history of moisture stress, during the 1982 rainy season at the ICRISAT Center. Details of the treatments are furnished in Table 5.

As to the degree of moisture stress, subtreatments 1A, 1B and 1C were on par with 4A (control) in respect of kernel yield. In Trt.2, subtreatments 2B and 2C with very low kernel yields were significantly less than 2A. In the case of Trt.3 and Trt.4, the differences in the kernel yield among the subtreatments were not significant.

4.1.3.3 Shelling %

Among the phenological phases, Trt.1 recorded a higher shelling percentage as compared to the other treatments. Among the degree of moisture stress, Trt.1A with 71 shelling percentage was significantly superior to all the other 11 subtreatments under study.

4.1.3.4 Haulm yield:

The variations among the phenological stages in respect of haulms yield were not much different.

Among the degree of stress, 4C alone recorded significantly less haulms yield over rest of the 11 subtreatments.

4.1.4 Quality of seed obtained from 1982 rainy season:

The seeds obtained from 1982 rainy season experiment were analysed for oil and protein besides 100 kernel weight at the biochemistry laboratory of ICRISAT and the results are presented in Table 9.

4.1.4.1 100 Kernel Weight:

Among the phenological stages, maximum mean 100 kernel weight (44g) was obtained in Trt.1 closely followed by Trt.2 with 40 g while Trt.3 and Trt.4 recorded the same value of 38 g/100 kernels.

Table 9. Results of analysis of 100 kernel weight, oil and protein contents of the experiment on the effect of previous moisture stress on current season productivity during the 1982 rainy season.

Treatment	100 kernel	Oil (%)	Protein (%)
1A	43.85	42.77	30.09
1B	44.24	40.11	29.77
1C	43.74	39.41	30.98
2A	41.02	40.76	30.31
2B	41.89	39.13	31.00
2C	38.46	40.86	29.30
3A	37.80	38.25	29.36
3B	38.18	38.17	30.83
3C	37.49	39.20	28.12
4A	40.75	40.35	30.25
4B	38.40	39.32	30.63
4C	34.13	39.27	29.65
SE ±	0.18	-	-

As to the degree of stress, subtreatments 1A, 1B and 1C were significantly superior to the rest of 9 subtreatments. In Trt.2, 2C recorded significantly less 100 kernel weight than 2A and 2B. In Trt.3, 100 kernel weight was significantly less in 3A and 3C than 3B. In Trt.4, 4A was superior to 4B and 4C. The least kernel weight (34 g) was recorded in 4C.

4.1.4.2 Oil content:

Among the phenological phases, Trt.1 recorded higher mean oil content (40.8%) closely followed by Trt.2 (40.3%) while Trt.3 and Trt.4 registered 38.5% and 39.6% mean oil content respectively.

As to the degree of stress, Trt.1A recorded highest oil content of 42.3% while the differences among the rest of the 11 subtreatments were not much different.

4.1.4.3 Protein Content:

There were no marked differences among the phenological stages and degree of stress also in respect of protein content except that Trt.3C recorded the least protein content of 28% as against 30% recorded in 4A (control).

4.2 Experiment II: Studies on the effect of early moisture stress on productivity of two groundnut cultivars (1982 rainy season)

The results of this experiment are discussed under the following headings:

4.2.1 Plant Measurements

4.2.1.1 Leaf Area Index

4.2.1.2 Number of Pegs

4.2.1.3 Number of pods

4.2.1.4 Dry Matter Distribution

4.2.1.5 Pod Growth

4.2.1.6 Kernel Growth

4.2.1.7 Root Studies

4.2.1.8 Evapotranspiration

4.2.1.9 Dry Matter Production in Relation to Cumulative Evapotranspiration

4.2.2 Soil Measurements

4.2.2.1 Soil Temperature

4.2.3 Radiation Balance

4.2.3.1 Albedo

4.2.4 Yield and Yield Components

4.2.4.1 Final Plant Population

4.2.4.2 Pod Yield

4.2.4.3 Kernel Yield

4.2.4.4 Haulms Yield

4.2.4.5 Water Use Efficiency and Harvest Index

4.2.4.6 Seed Quality

4.2.1 Plant Measurements

4.2.1.1 Leaf area index

Leaf area index (LAI) as a function of time in two groundnut cvs TMV2 and Robut under the two moisture treatments is shown in Figure 10. Among the two moisture treatments, covered treatment in both the cultivars was superior to the uncovered in respect of LAI. The maximum LAI recorded in the covered plots was 4.9 while it was 3.5 in the uncovered plots for TMV2. The corresponding values for Robut were 4.7 and 3.2 respectively.

Among the cultivars, Robut responded better to early moisture stress than TMV2 as suggested by the linear increase in LAI after the release of early moisture stress at about 44 DAE.

4.2.1.2 Number of pegs

Number of pegs as a function of time in two groundnut cvs. TMV2 and Robut under the two moisture treatments is shown in Figure 11. The peg production was more in the covered plots than uncovered plots in both the cultivars but more pronounced in Robut. In TMV2, peg production increased after the release of early moisture stress (covered plots) and started decreasing from 60 DAE. But in Robut the rate of increase in peg production was higher than in TMV2, up to 50 DAE in the covered plots and then started decreasing.

4.2.1.3 Number of pods

Seasonal changes in the pods in the two groundnut cvs TMV2 and Robut under the two moisture treatments is shown in Figure 12. The number of pods in general was observed to be more in the covered plots than in the uncovered plots but it was more pronounced in Robut than TMV2. Among the cultivars, Robut responded better in terms of pod production

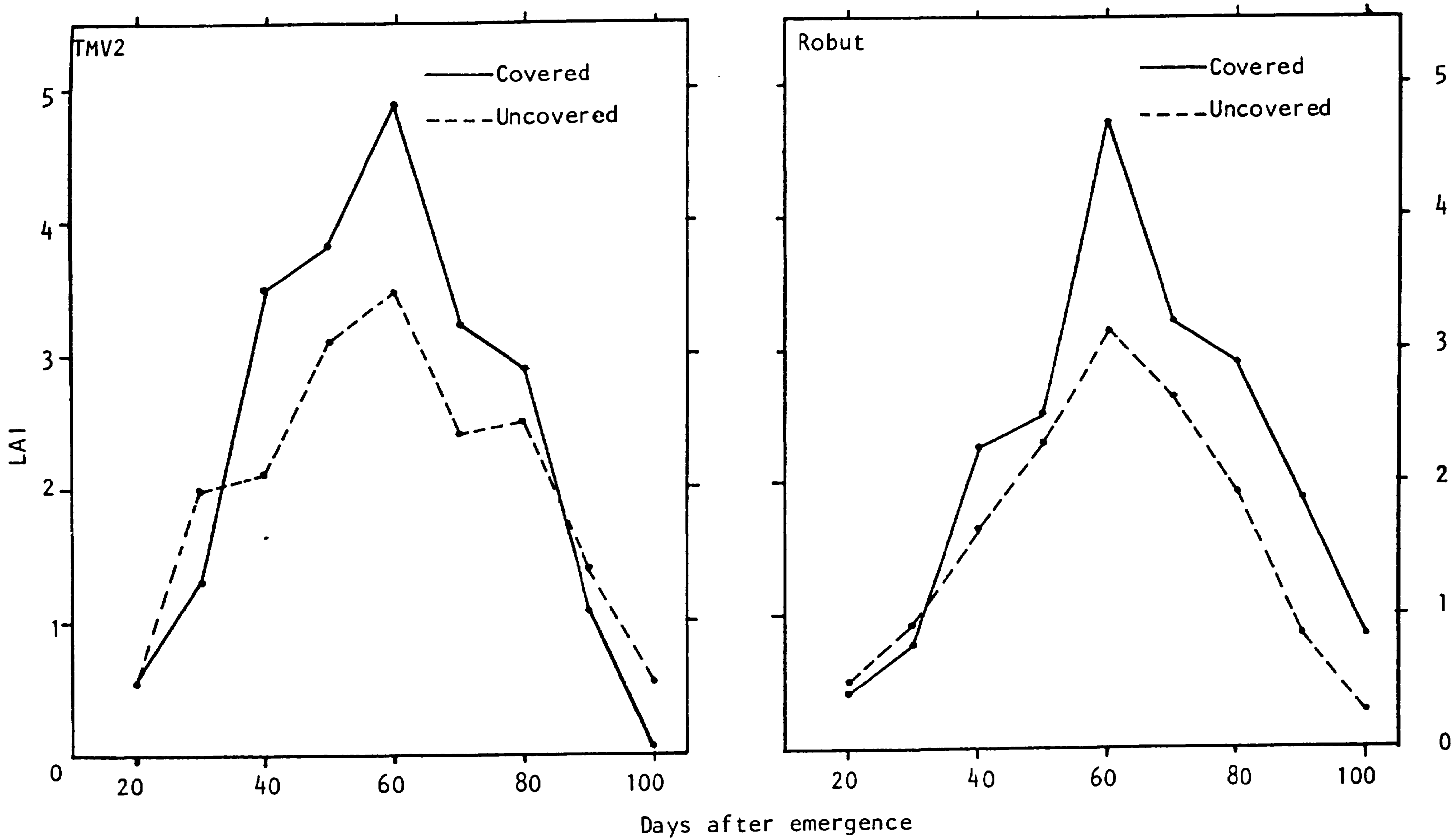


Figure 10. Leaf area index (LAI) of two groundnut cvs Robut and TMV2 under two moisture treatments (C - covered; UC - uncovered) in the 1982 rainy season.

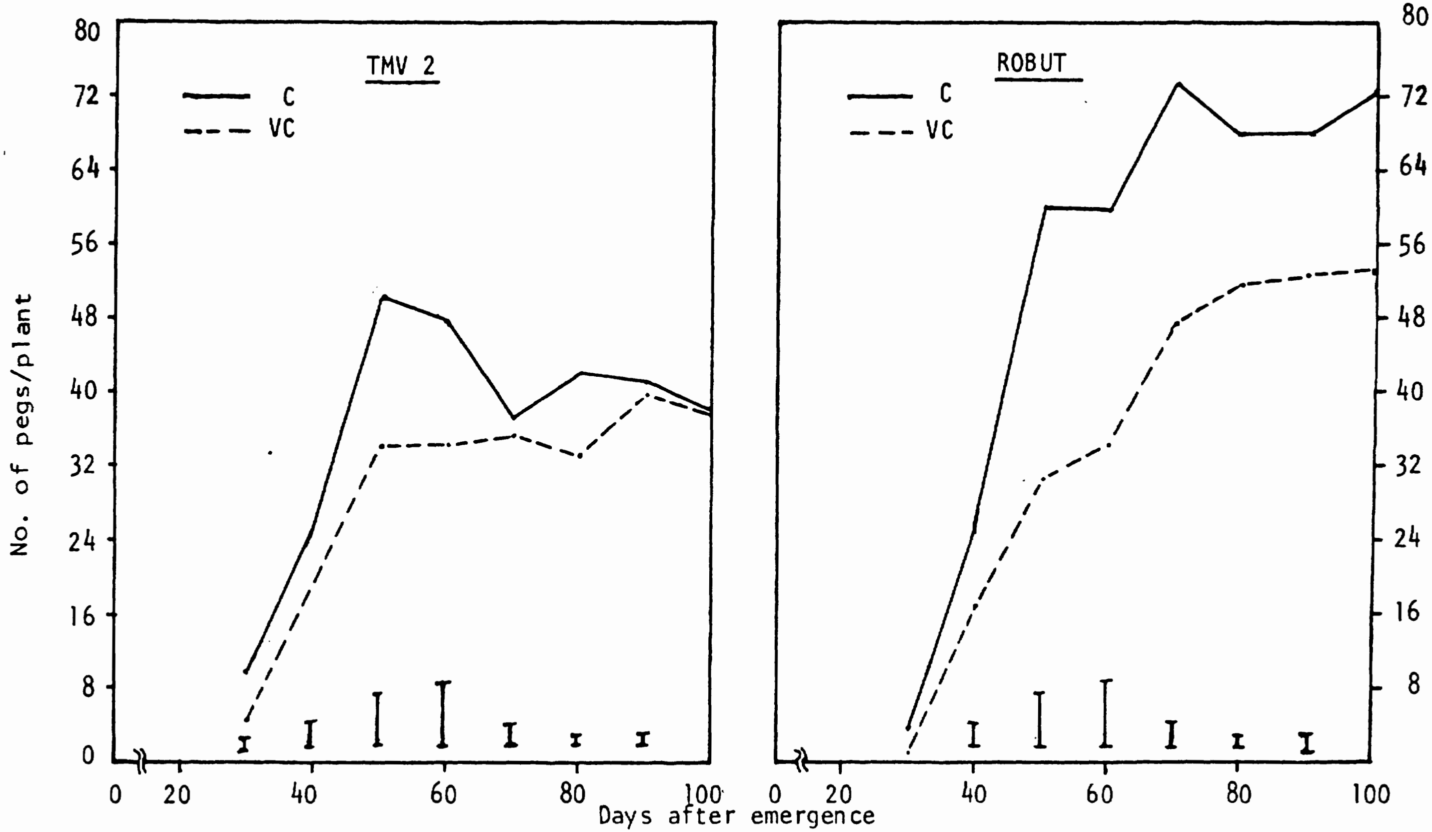


Figure 11. Production of pegs as a function of time in two groundnut cvs TMV2 and Robut under two moisture treatments (C - covered; UC - uncovered) in the 1982 rainy season.

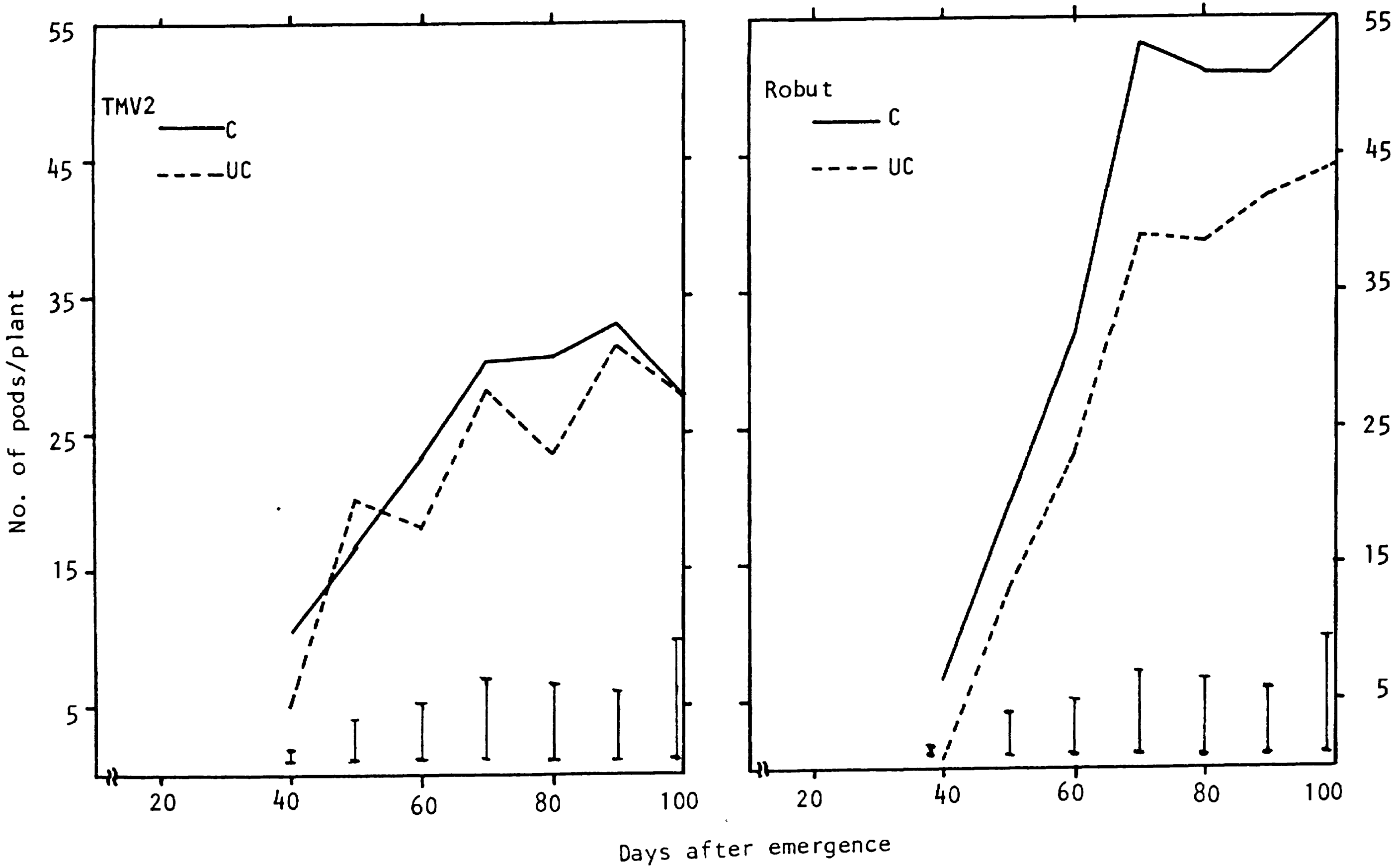


Figure 12. Pod production as a function of time in two groundnut cvs TMV2 and Robut under two moisture treatments (c - covered; uc - uncovered) in the 1982 rainy season.

for early moisture stress than TMV2. The total number of pods produced was significantly higher in Robut.

4.2.1.4 Dry matter distribution

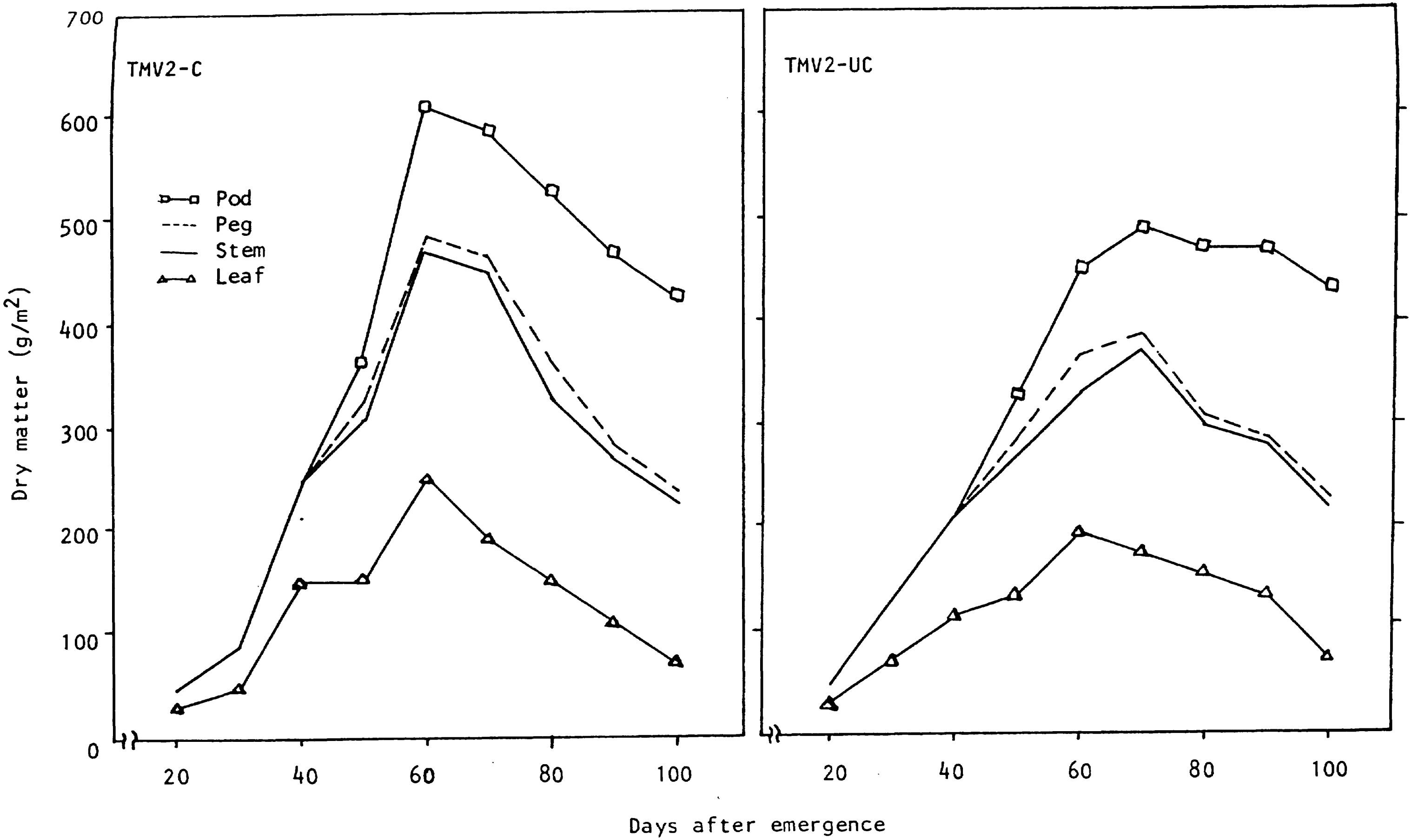
Dry matter distribution as a function of time in two groundnut cvs TMV2 and Robut under the two moisture treatments is shown in Figures 13 and 14 while the percentage of dry matter distribution in various plant parts at maturity for the above treatments is shown in Table10. There were no marked differences between the covered and uncovered treatments in TMV2 in respect of dry matter distribution at maturity of the crop. But in the case of Robut, higher accumulation of photosynthates in the pods was noticed in the covered treatment as compared to the uncovered treatment, the increase being about 3%.

Table 10. Dry matter distribution (%) in various plant parts at maturity of groundnut cvs TMV2 and Robut under the two moisture treatments (C - covered; UC - uncovered) during the 1982 rainy season.

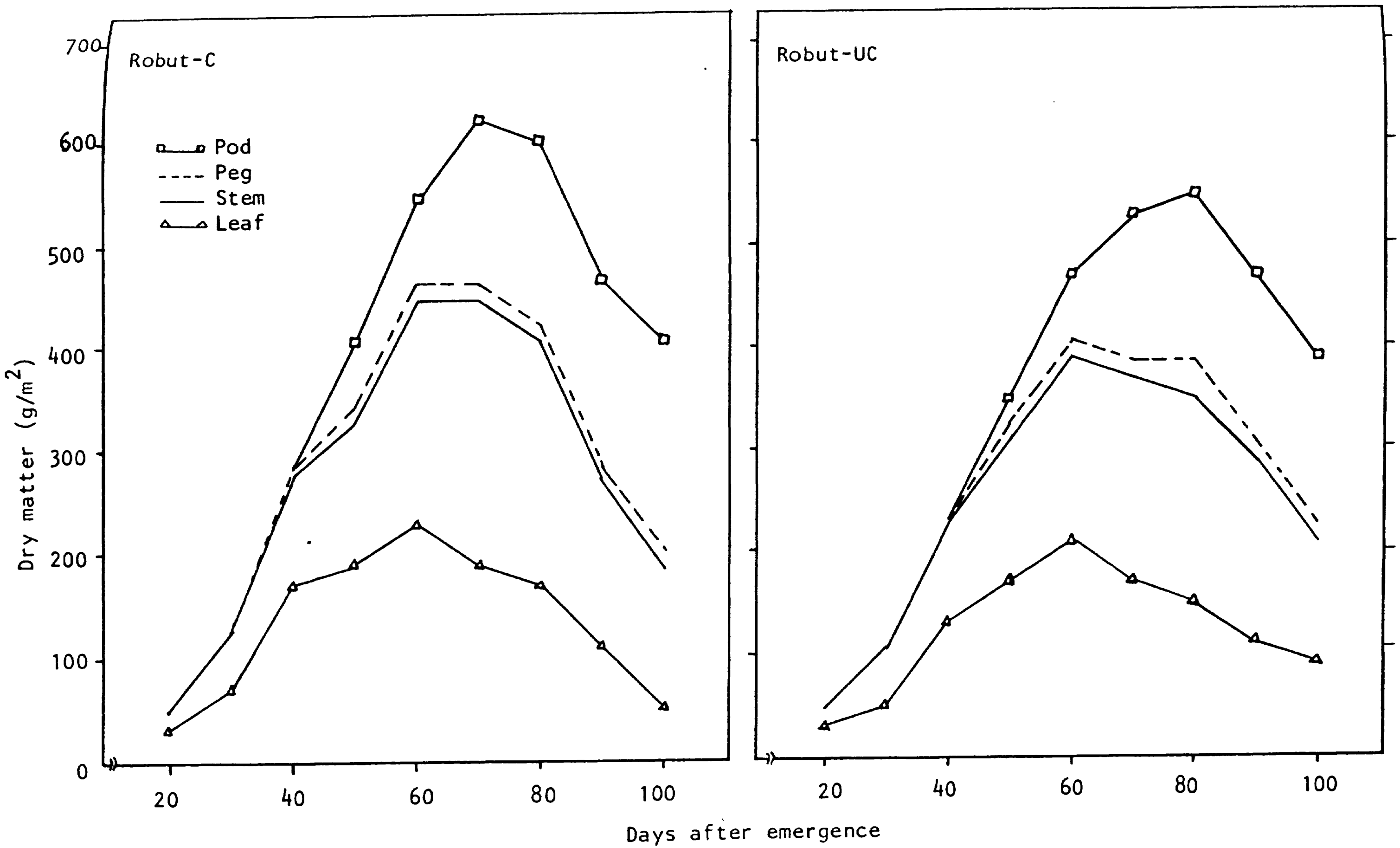
Plant part	Dry matter distribution (%)			
	TMV2-C	TMV2-UC	Robut-C	Robut-UC
Leaves	10.0	11.6	9.3	14.5
Stems	28.0	27.6	27.1	27.7
Pegs	2.7	2.2	2.3	2.8
Pods (include kernel)	59.3	58.6	60.3	55.0

4.2.1.5 Pod growth

Pod growth as a function of time in two groundnut cvs TMV2 and Robut under the two moisture treatments is shown in Figure 15. The covered treatment in both the cultivars was found to be superior to the uncovered treatment in respect of pod growth. The pod growth was enhanced in both the cultivars after the release of early moisture stress (44 DAE). Among the cultivars, pod growth in TMV2 was



'igure 13. Dry matter distribution of groundnut cv TMV2 under two moisture treatments (C - covered; UC - uncovered) in the 1982 rainy season.



ure 14. Dry matter distribution of groundnut cv Robut under two moisture treatments (C - covered; UC - uncovered) in the 1982 rainy season.

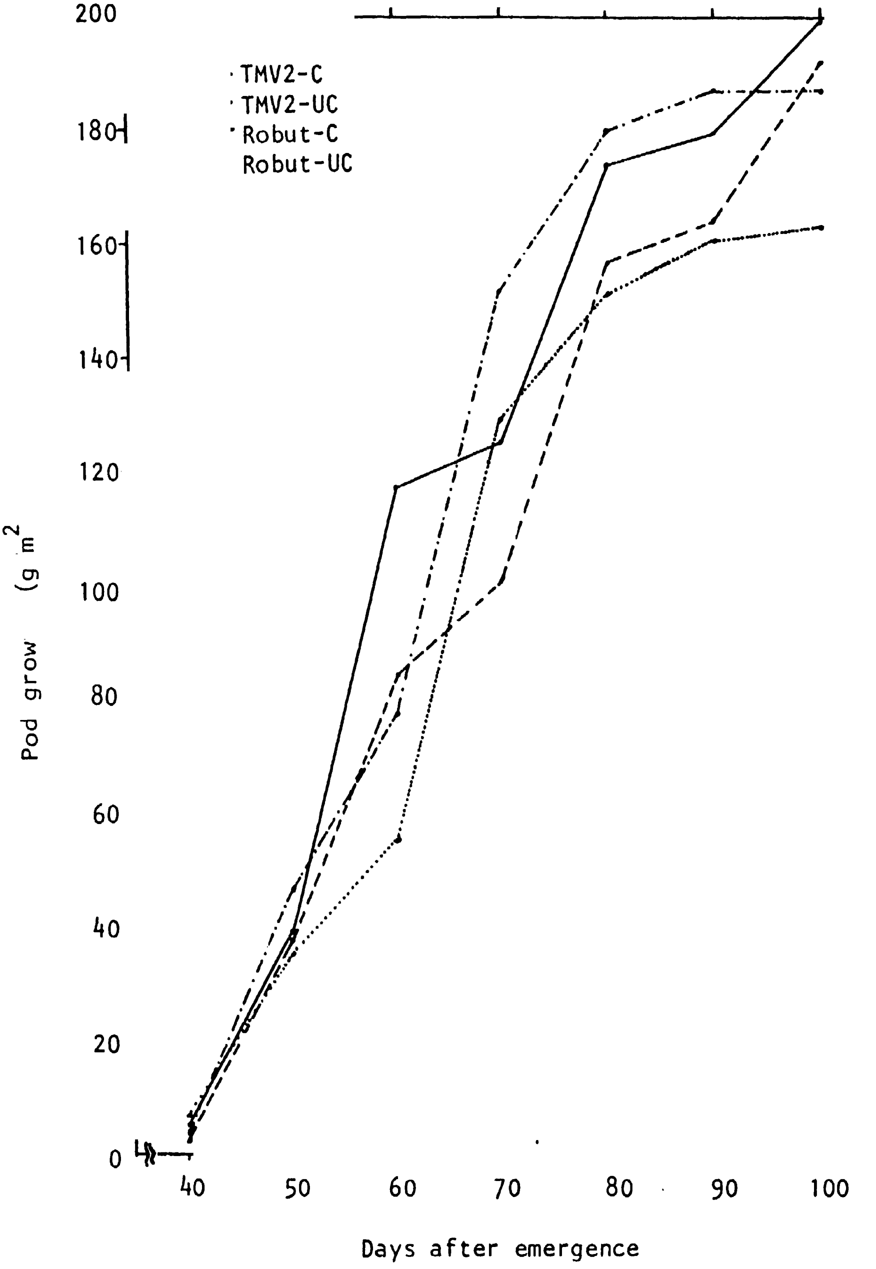


Figure 15. Changes in the pod growth of two groundnut cvs Robut and TMV2 under two moisture treatments (C - covered; UC - uncovered) in the 1982 rainy season.

initially more but later growth was better in Robut. Final pod dry matter was higher in TMV2.

4.2.1.6 Kernel growth

Kernel growth as a function of time in two groundnut cvs TMV2 and Robut under the two moisture treatments is shown in Figure 16. Kernel growth followed almost the same pattern of pod growth. The covered treatment in TMV2 produced a much faster rate of seed growth than in Robut starting from 80 DAE. This was revealed by the fact that in the covered treatment in TMV2, the kernel growth continued up to 100 DAE while in the covered plots in Robut, kernel growth slowed down after 80 DAE.

4.2.1.7 Root studies

Data on root length and dry matter in two groundnut cvs TMV2 and Robut at maturity under the two moisture treatments are shown in Table 11.

Table 11. Length and dry weight of roots at maturity of two groundnut cvs TMV2 and Robut under the two moisture treatments (C - covered; UC - uncovered) during the 1982 rainy season (mean for three plants).

Treatment	Length of tap root (cm/plant)	Total length of root system (cm/plant)	Dry weight of total root system (g/plant)
TMV2-C	75	1499	1.014
TMV2-UC	48	914	0.548
Robut-C	67	1431.	0.989
Robut-UC	52	1299	0.948

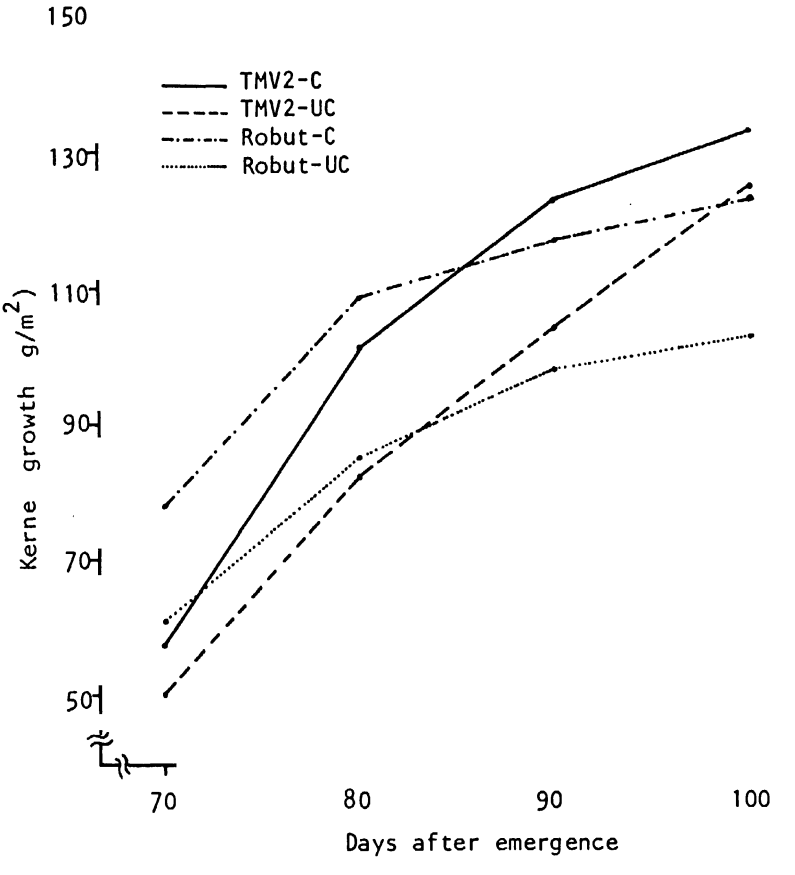


Figure 16. Changes in the kernel growth of two groundnut cvs Robut and TMV2 under two moisture treatments (C - covered; UC - uncovered) in the 1982 rainy season.

The covered plots in both the cultivars proved superior to the uncovered treatments in respect of length of tap root, total length and dry weight of root system.

Among the cultivars, TMV2 in the covered plots had longer tap root, total length and dry weight of root system than in Robut. Root distribution for the two cultivars in the two treatments is shown in Plate 4.

4.2.1.8 Evapotranspiration

Water use in terms of evapotranspiration (ET) as a function of time in two groundnut cvs TMV2 and Robut under the two moisture treatments is shown in Table 12.

Table 12. Evapotranspiration (ET) as a function of time in two groundnut cvs TMV2 and Robut under the two moisture treatments (C - covered; UC - uncovered) during the 1982 rainy season.

DAE	Evapotranspiration (mm)			
	TMV2-C	TMV2-UC	Robut-C	Robut-UC
24-32	7.0	22.6	8.9	21.9
33-42	7.4	59.6	9.5	54.8
43-50	14.6	44.2	13.3	43.9
51-57	16.0	19.7	10.1	24.3
58-67	1.4	1.5	1.8	3.4
68-75	10.6	12.0	14.7	18.9
76-85	46.4	53.3	43.2	62.1
86-94	32.1	50.9	44.2	51.5
95-104	37.7	51.9	43.8	37.7
105-116	14.7	17.1	4.5	10.6
Total	187.9	332.8	194.0	329.1

Plate 4. Root distribution for TMV2 and Robut in the two treatments during the 1982 rainy season.

Among the two moisture treatments, there was considerable reduction in the ET in the covered plots than the uncovered plots in both the cultivars of groundnut.

During the early moisture stress period (44 DAE), the ET in the covered plots in both the cultivars was far less than the values obtained in the uncovered plots. Lateron the differences in ET between the covered and uncovered plots were narrowed down in both the cultivars. But the covered plots continued to show less ET values than the uncovered plots even up to maturity in both the varieties.

When cumulative ET over the crop growth season is considered, the covered plots in TMV2 recorded a reduced ET of about 145 mm over the uncovered plots. In the case of Robut, the ET reduction was to an extent of 135 mm between the covered and uncovered plots.

Among the cultivars, TMV2 was more efficient in the total water use than Robut.

4.2.1.9 Dry matter production in relation to cumulative evapotranspiration

Dry matter production as a function of cumulative evapotranspiration (CET) of two groundnut cvs TMV2 and Robut under the two moisture treatments is shown in Figure 17.

Among the moisture treatments, higher dry matter production was obtained in the covered plots than the uncovered plots at the minimum values of CET in both the cultivars.

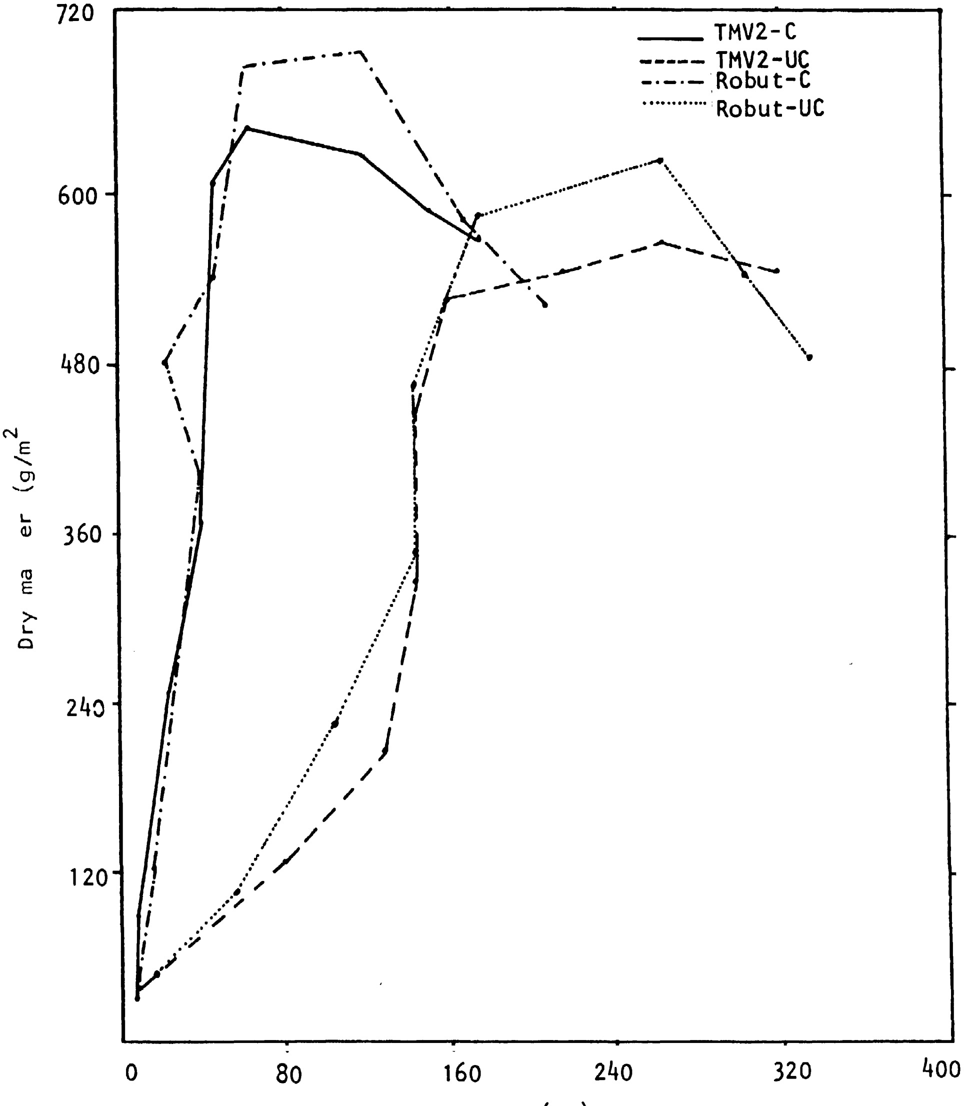


Figure 17. Relationship between dry matter accumulation and cumulative evapotranspiration (CET) of two groundnut cvs Robut and TMV2 under two moisture treatments (C - covered; UC - uncovered) in the 1982 rainy season.

Among the cultivars, Robut was more efficient in dry matter production since it produced more dry matter for the same units of ET in the covered plots. In Robut, the covered plots recorded maximum dry matter production at a very low CET (61 mm) as against a CET value of 260 mm for uncovered plots. Robut recorded more dry matter both under covered and uncovered conditions than TMV2. In the case of TMV2, maximum dry matter production was recorded in the covered plots at a low CET (66 mm) as against a CET value of 266 mm for the uncovered plots.

4.2.2 Soil measurements

4.2.2.1 Soil Temperature

Seasonal changes in soil temperature of groundnut under the two moisture treatments are shown in Figure 18. During the early moisture stress period i.e., up to 44 DAE, the soil temperature in the covered plots was higher by about 4°C than the uncovered plots. After the release of early moisture stress, the differences in soil temperature between covered and uncovered plots were small. The fluctuations in the soil temperature after the release of early moisture stress were due to the occurrence of drought for short periods.

4.2.3 Radiation Balance

4.2.3.1 Albedo

The percent albedo in two groundnut cvs TMV2 and Robut under the two moisture treatments is shown in Figure 19. Among the moisture treatments, albedo was more in the uncovered plots than the covered plots in both the cultivars.

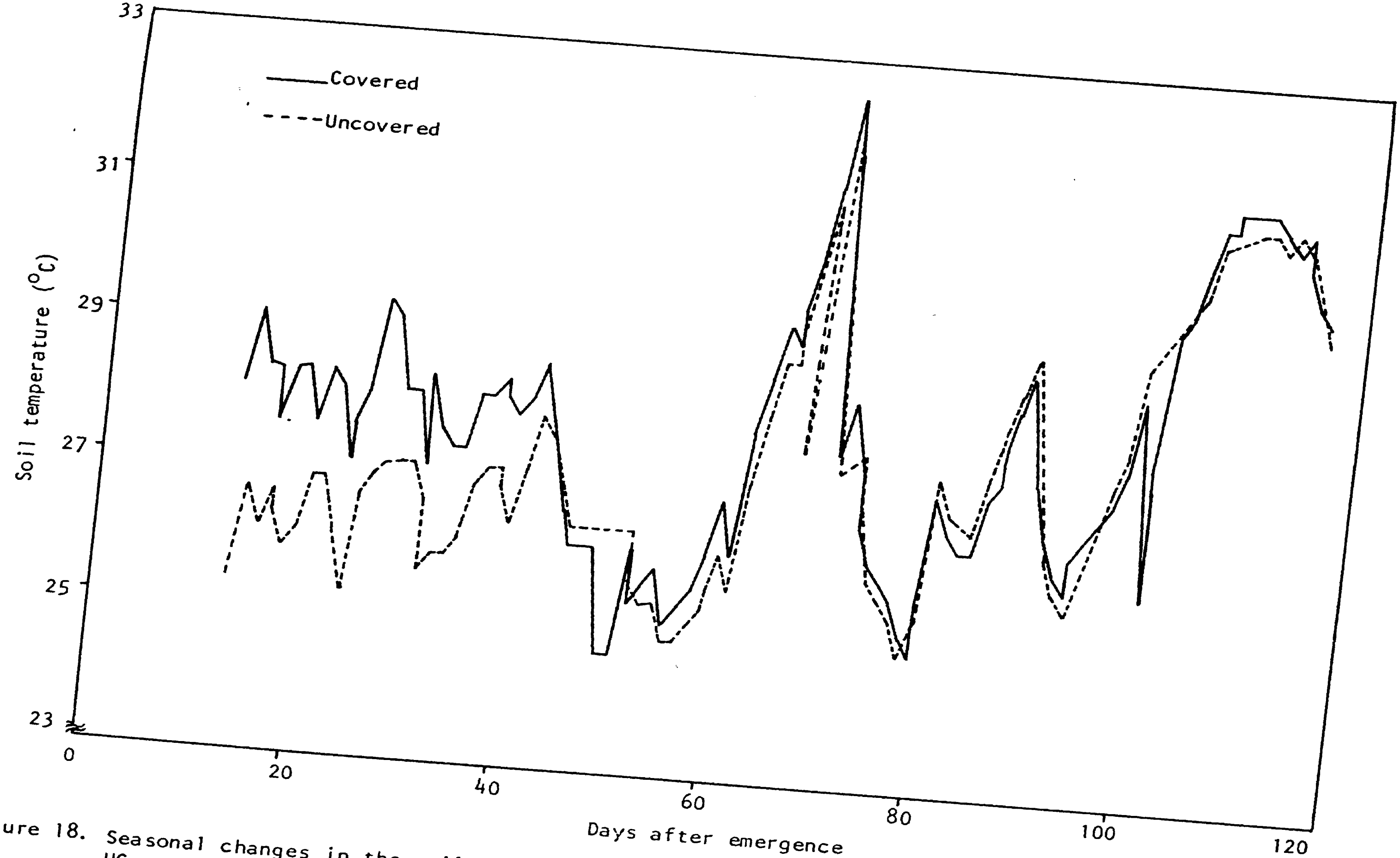


Figure 18. Seasonal changes in the soil temperature in groundnut under two moisture treatments (C - covered; UC - uncovered) in the 1982 rainy season.

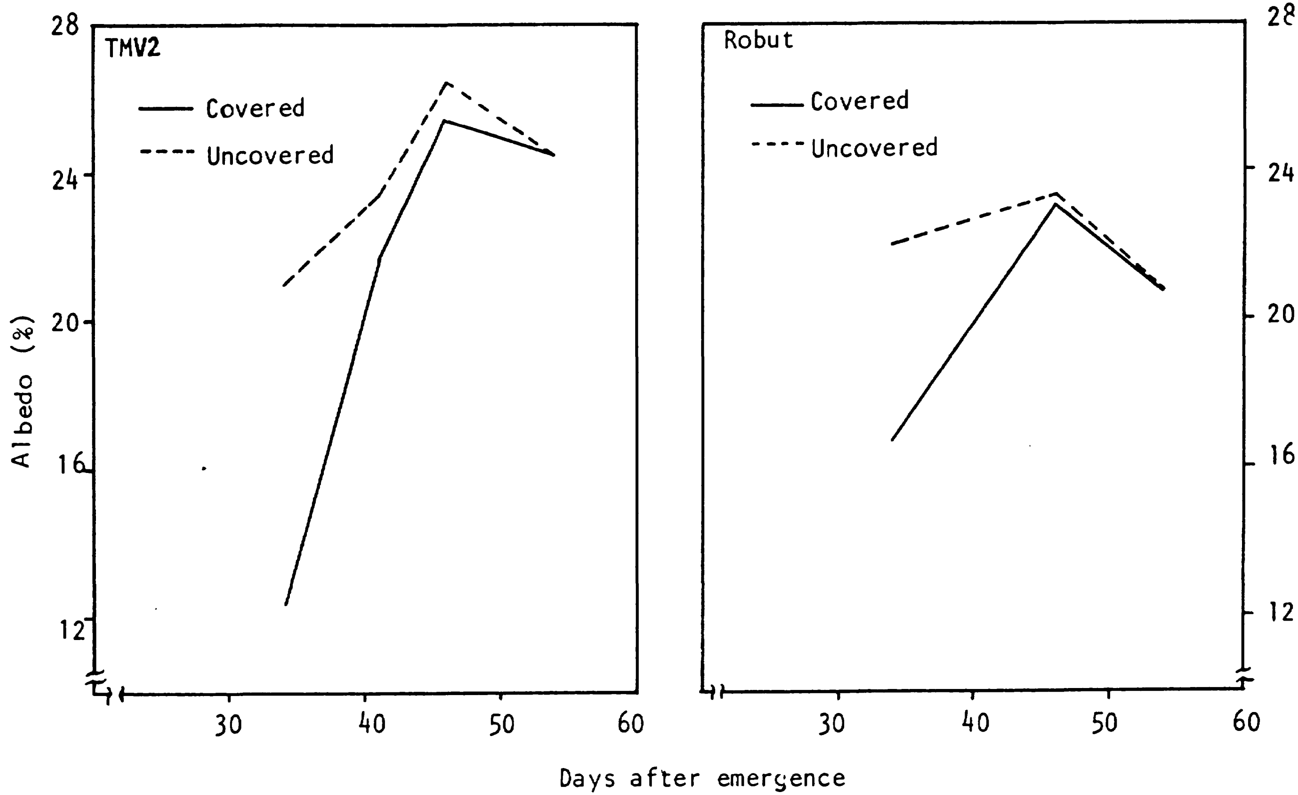


Figure 19. Changes in the daily mean albedo during the period of early moisture stress in two groundnut cvs TMV2 and Robut under two moisture treatments (C - covered; UC - uncovered) during the 1982 rainy season.

Among the cultivars, the albedo was double on 34 DAE in TMV2 than in Robut in the uncovered plots. The albedo increased in both the cultivars until the release of early moisture stress (44 DAE) and started reducing lateron.

4.2.4 Yield and Yield components

Yield and yield components together with final plant population of two groundnut cvs TMV2 and Robut under the two moisture treatments are shown in Figure 20 and Table 13.

4.2.4.1 Final Plant Population

The differences among the treatments were not significant statistically. However, it was observed that the final population in the covered treatments of both the cultivars was more than the uncovered treatments.

4.2.4.2 Pod Yield:

In the covered plots TMV2 gave a 21% increased yield over that in the uncovered plots while about 28% increased pod yield was obtained from the covered plots of Robut over the uncovered ones.

4.2.4.3 Kernel Yield:

Kernel yield in the covered plots of TMV2 was 25% higher over the uncovered plot yields, while the covered plots of Robut yielded 11% increased kernel yield over the uncovered ones (Fig.20).

4.2.4.4 Haulms Yield:

The covered plots in both cultivars TMV2 and Robut yielded more haulms

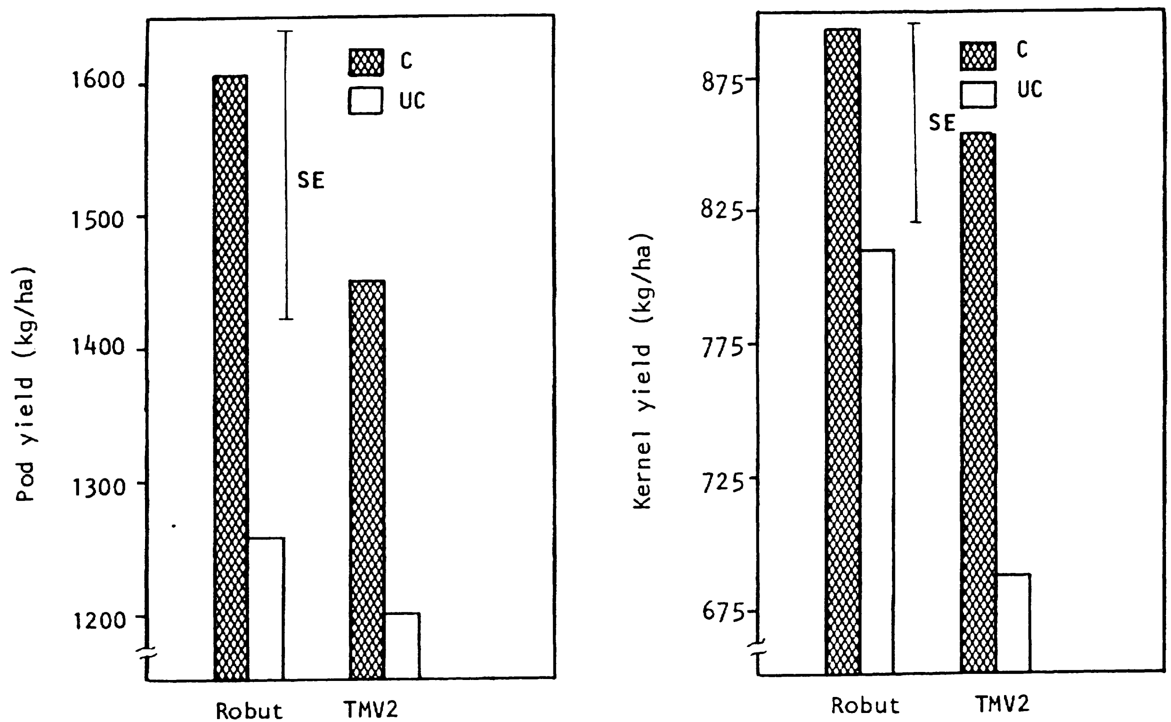


Figure 20. Pod and kernel yield of two groundnut cvs Robut and TMV2 under two moisture treatments (C - covered; UC - uncovered) in the 1982 rainy season.

Table 13. Final plant population, yield and yield components of two groundnut cvs TMV2 and Robut under the two moisture treatments (C - covered; UC - uncovered) during the 1982 rainy season.

Cultivar	TMV2	Robut	SED ± @	SED ±
Final plant population/ha ('000)				
C	142.6	134.0	17.5	17.2
UC	124.2	125.4		
Pod yield (kg/ha)				
C	1451	1606	216	199
UC	1200	1258		
Kernel yield (kg/ha)				
C	853	893	145	125
UC	684	810		
Haulms yield (kg/ha)				
C	4157	3946	384	567
UC	3700	3131		

@:SED between 2 subplot treatment means (cultivars) at the same level of main plot treatment (moisture treatments).

*:SED between 2 main plot treatment means for the same subplot treatment mean or for different levels of the subplot treatment.

than the uncovered plots.

4.2.4.5 Water Use Efficiency and Harvest Index:

The data on water use efficiency (WUE) and harvest index are presented in Table 14. Robut showed a higher WUE over TMV2 and in the covered plots in both the cultivars WUE was greater than in uncovered plots.

Table 14. Water use efficiency and harvest index of two groundnut cvs TMV2 and Robut under the two moisture treatments (C-covered; UC-uncovered) during the 1982 rainy season.

Treatment	Water use efficiency (Kg/ha/cm)	Harvest Index
TMV2-C	45.4	40
TMV2-UC	20.5	32
Robut-C	46.0	48
Robut-UC	24.6	40

In the covered plots in both the cultivars HI was higher than the uncovered plots. Between the two cultivars, Robut gave a higher harvest index over TMV2.

4.2.4.6 Seed Quality

The 100 seed weight, oil and protein contents of two groundnut cvs TMV2 and Robut under two moisture treatments are presented in Table 15.

The covered plots recorded higher seed weight, oil and protein contents in both the cvs than the uncovered plots.

Table 15. 100 seed weight, oil content and protein content of two groundnut cvs TMV2 and Robut under the two moisture treatments (C - covered; UC - uncovered) during the 1982 rainy season.

Treatment	100 seed weight (g)	Oil %	Protein %
TMV2-C	31.4	40.1	31.1
TMV2-UC	28.2	37.2	30.6
Robut-C	40.3	39.4	30.4
Robut-UC	36.8	38.4	29.3
SE ±	0.13	0.1	0.12

4.3 Experiment III: Studies on the effect of moisture stress at different phenological stages of groundnut (1982-83 postrainy season)

The results of this experiment are discussed under the following headings.

4.3.1	Water Applied, Available Water and Evapotranspiration
4.3.1.1	Amount of Water Applied
4.3.1.2	Available Soil Water
4.3.1.3	Evapotranspiration
4.3.2	Plant Measurements
4.3.2.1	Phenology
4.3.2.2	Leaf Area Index
4.3.2.3	Number of Pegs
4.3.2.4	Number of Pods
4.3.2.5	Dry Matter Distribution
4.3.2.6	Pod Growth
4.3.2.7	Kernel Growth
4.3.2.8	Dry Matter Production & Evapotranspiration
4.3.2.9	Yield and Yield Components
4.3.2.9.1	Plant Population
4.3.2.9.2	Pod Yield
4.3.2.9.3	Kernel Yield
4.3.2.10	Shelling Percentage and Evapotranspiration
4.3.2.11	Water Use Efficiency and Harvest Index
4.3.2.11.1	Water Use Efficiency
4.3.2.11.2	Harvest Index
4.3.2.12	Covariate Analysis of treatment effects

4.3.2.13 Root Studies

4.3.2.13.1 Length of Tap Root

4.3.2.13.2 Total length of Roots

4.3.2.13.3 Dry Weight of Total Root System

4.3.2.14 Seed Quality

4.3.2.14.1 100 Kernel Weight

4.3.2.14.2 Protein Content

4.3.2.14.3 Oil Content

4.3.3 Plant Water Stress Measurements

4.3.3.1 Stomatal Conductance

4.3.3.1.1 Seasonal Variation

4.3.3.1.2 Diurnal Variation

4.3.3.1.3 Response to Photosynthetic Photon Flux Density

4.3.3.1.4 Stomatal Conductance as a Function of Photosynthetic Photon Flux Density at three Classes of Vapor Pressure Deficit.

4.3.3.2 Transpiration

4.3.3.2.1 Seasonal Variation

4.3.3.2.2 Diurnal Variation

4.3.3.3 Leaf Water Potential

4.3.3.3.1 Seasonal Variation

4.3.3.3.2 Diurnal Variation

4.3.3.3.3 Leaf Water Potential as a Function of Stomatal Conductance at Three Classes of Vapor Pressure Deficit

4.3.3.4 Canopy Temperature

4.3.3.4.1 Seasonal Variation

4.3.3.4.2 Diurnal Variation

4.3.3.4.3 Relationship Between Stress Degree Days and Total Evapotranspiration

4.3.3.5 Canopy-air Temperature Differential

4.3.3.5.1 Seasonal Variation

4.3.3.5.2 Diurnal Variation

4.3.4 Soil Temperature

4.3.4.1 Seasonal Variation

4.3.4.2 Diurnal Variation

4.3.4.3 Seasonal Variation in (Soil-air) Temperature

4.3.4.4 Diurnal Variation

4.3.5 Soil Penetration Resistance

4.3.5.1 Seasonal Variation

4.3.5.2 Soil Penetration Resistance and ET Levels

4.3.5.3 Soil Penetration Resistance and Kernel Yield

4.3.6 Radiation Balance

4.3.6.1 Albedo

4.3.6.2 Net Radiation

4.3.1 Water applied, available water and evapotranspiration

4.3.1.1 Amount of water applied

Irrigation was given at weekly intervals depending on the treatments. The schedule of irrigation given to groundnut in different treatments is furnished in Table 16.

Table 16. Schedule of irrigation applied to groundnut in different treatments during 1982-83 postrainy season.

Date	Days after emergence	Trt.1	Trt. 2	Trt. 3	Trt.4
09 Nov 1982	2	GI[a]	GI	UI	GI
16 Nov 1982	9	--	--	UI	GI
22 Nov 1982	15	GI	GI	UI	GI
29 Nov 1982	22	--	--	UI	GI
06 Dec 1982	29	UI[b]	GI	GI	GI
13 Dec 1982	36	UI	--	--	GI
20 Dec 1982	43	UI	GI	GI	GI
27 Dec 1982	50	UI	--	--	GI
03 Jan 1983	57	UI	UI	GI	GI
10 Jan 1983	64	UI	UI	--	GI
17 Jan 1983	71	UI	UI	GI	GI
24 Jan 1983	78	UI	UI	--	GI
31 Jan 1983	85	UI	UI	GI	GI
07 Feb 1983	92	UI	UI	UI	GI
14 Feb 1983	99	UI	UI	UI	GI
21 Feb 1983	106	UI	UI	UI	GI
28 Feb 1983	113	UI	UI	UI	GI
07 Mar 1983	120	UI	UI	UI	GI
14 Mar 1983	127	UI	UI	UI	GI
21 Mar 1983	134	UI	UI	UI	GI
28 Mar 1983	141	UI	UI	UI	GI

a = Gradient irrigation (GI) applied through the use of line source.

b = Uniform irrigation (UI) applied through the use of perforated pipes.

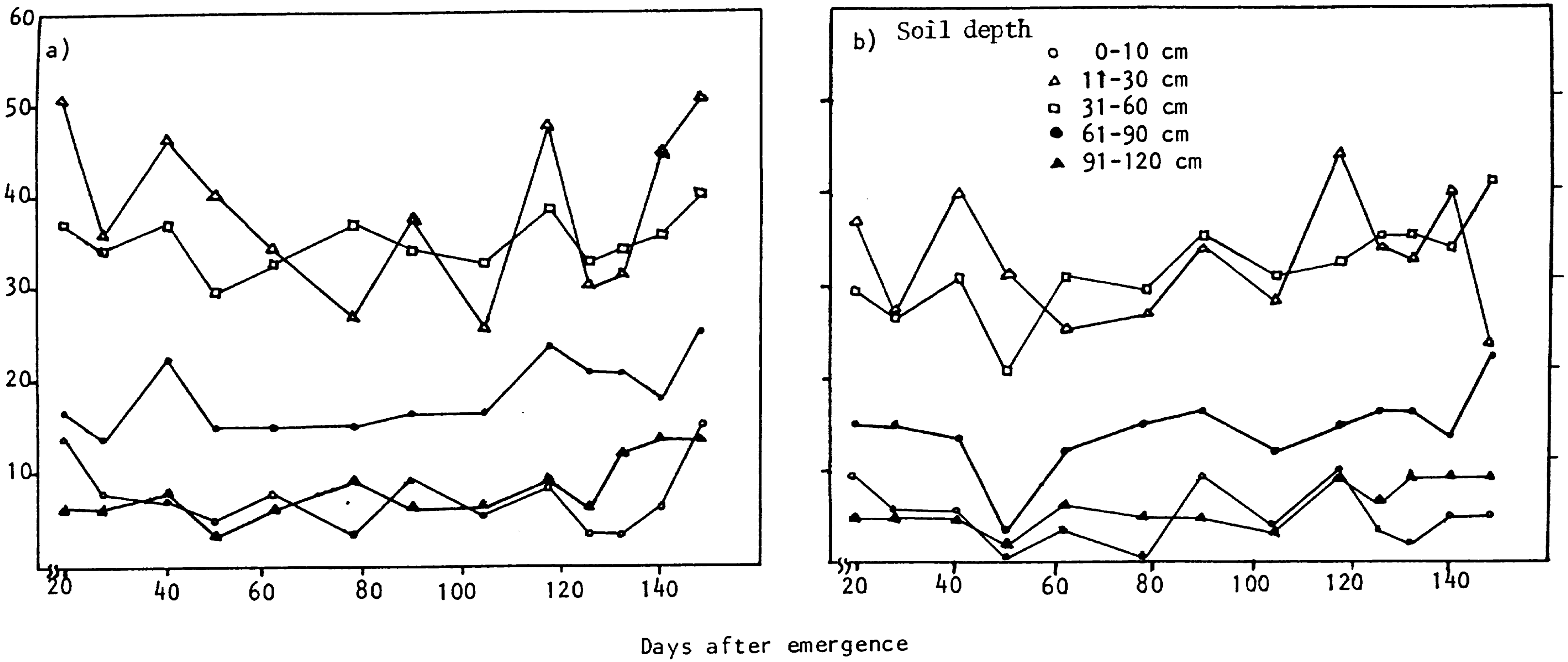
4.3.1.2 Available Soil Water

Available soil water was measured in the 0-120 cm soil profile for all the four treatments at the three ET levels in each treatment on a seasonal basis. Although data were collected at all ET levels, for the sake of comparison only data at the high and low ET levels in each treatment are presented here. Available soil water in all the four treatments at two levels of ET is shown in Figures 21-24.

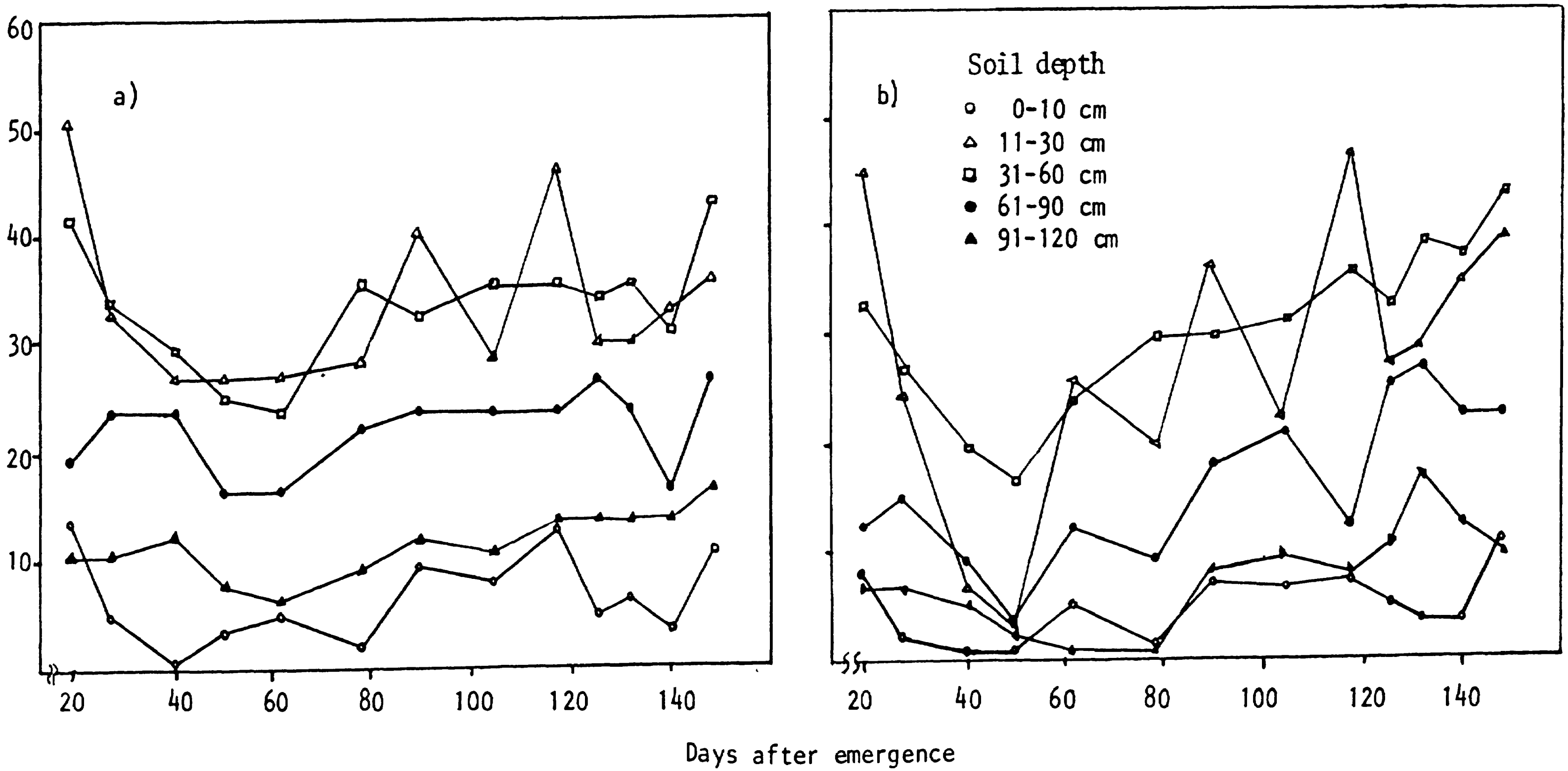
In Trt.1 (Fig.21) more available soil water was observed at 11-60 cm depth in the plots at 592 mm of ET than at 611 mm ET level. Extraction of available soil water was more from 11-30 cm soil depth at both ET levels.Very little variation in the available soil water content was noticed at soil depth of 61-90 cm and 91-120 cm.More fluctuations in the available soil water at 0-10 cm depth were noticed at both ET levels.

In Trt.2, the available soil water at the two levels of ET (Fig.22) was less up to about 55 DAE since the plots were under moisture stress during this period. After the release of stress, the available soil water in the soil profile started increasing.

In Trt. 2 (Fig.22), the available soil water was more in the plots at 576 mm ET level than at 494 mm ET level. At the higher ET level extraction of water from profile depth of 11-30 cm was more and to a less extent from 0-10 cm depth. The seasonal variation in the available soil water at 61-120 cm depth was not quite distinct at higher ET level. In the case of 494 mm ET level extraction of water occurred at all depths down to 120 cm.



igure 21. Seasonal changes in the available soil water at different soil depths in treatment 1 at a) 592 mm and b) 611 mm of ET levels during the 1982-83 postrainy season.



igure 22. Seasonal changes in the available soil water at different soil depths in Treatment 2 at a) 576 mm and b) 494 mm ET levels during the 1982-83 postrainy season.

In Trt.3 (Fig.23), the available soil water in general decreased up to 90 DAE at both levels of ET since the plots were under moisture stress during this period. After the release of water stress,the available soil water in the soil profile started increasing. During the moisture stress period, available soil water was more in the soil depth of 11 to 60 cm at 546 mm ET level than at 401 mm ET level. Extraction of water from profile depth from 11-60 cm was more at both ET levels. At 401 mm ET level, extraction of water was observed from the deeper depths of soil profile.

In Trt.4 (Fig 24), the available soil water content was quite high, expectedly, in the 11-60 cm soil profile at the 687 mm ET level as compared to the 47 mm ET level. At the high ET level of 687 mm, there was little extraction of water from profile depth below 90 cm. At 47 mm ET level, the extraction of water occurred at all depths.

4.3.1.3 Evapotranspiration

The net amount of water applied and evapotranspiration computed are presented in Table 17.

4.3.2 Plant Measurements

The response of plants to irrigation, be it dry matter production, grain yield, leaf area, etc. can be studied by applying different amounts of irrigation. These responses to irrigation will be modified by available soil water, rain and irrigation efficiency. The plant

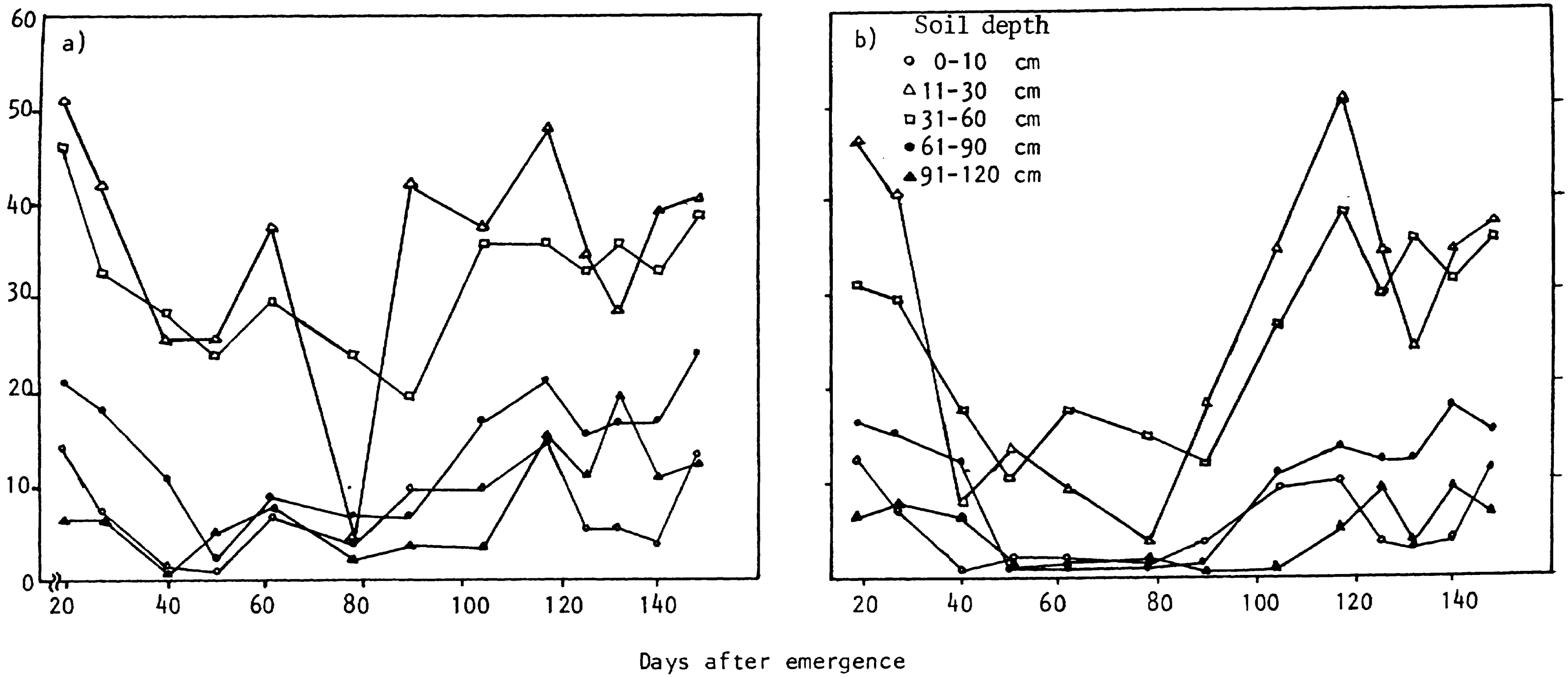


Figure 23. Seasonal changes in the available soil water at different soil depths in Treatment 3 at a) 546 mm and b) 401 mm ET levels during the 1982-83 postrainy season.

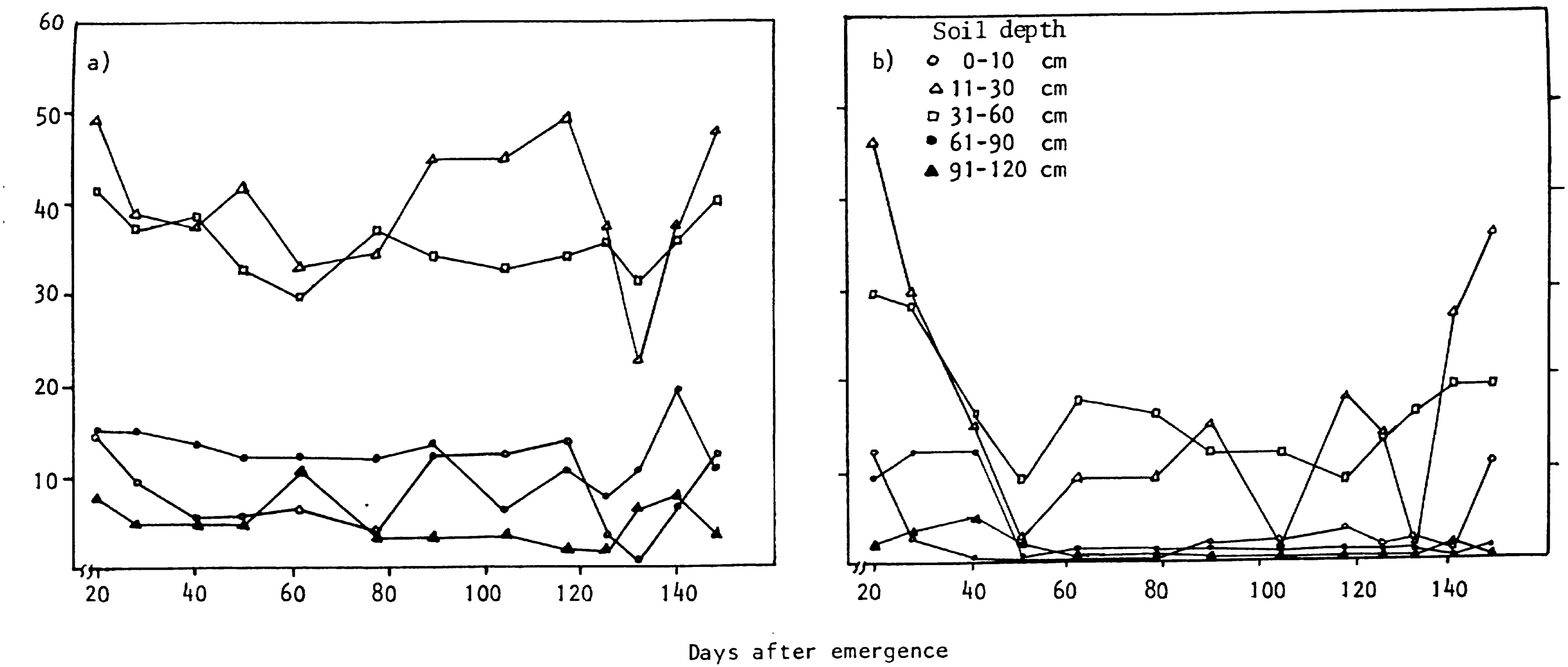


Figure 24. Seasonal changes in the available soil water at different soil depths in Treatment 4 at a) 687 mm and b) 47 mm ET levels during the 1982-83 postrainy season.

Table 17. Amount of water applied and ET in different treatments during the 1982-83 postrainy season.

Treatment	Distance from the line source (m)	Net amount of water applied (mm)	ET (mm)
1	3	665	592
	9	657	603
	15	623	611
2	3	630	576
	9	589	546
	15	522	494
3	3	603	546
	9	553	515
	15	477	401
4	3	739	687
	9	409	386
	15	27	47

responses to ET are more stable because ET includes all the sources of water to plant (soil water, rain and irrigation). All three sources of water are considered equally efficient (Stewart and Hagan, 1973; Stewart et al., 1977). Furthermore, no application efficiency is involved in the case of ET as with irrigation. Thus it is concluded that the discussion on plant responses to ET is much more valuable in understanding the effects of limited water than the responses to irrigation.

4.3.2.1 Phenology

The number of days taken for each specific reproductive stage (Boote, 1982) at different ET levels at different phenological stages of groundnut crop during 1982-83 postrainy season is presented in Table 18.

R1: In the reproductive stage R1 (beginning bloom), flowering occurred early in Trt.1 while at an ET level of only 41 mm in Trt.4, this was delayed by 9 days. The rest of the treatments did not differ in the initiation of flowers.

R2: Pegging occurred early in Trt.1. In the other 3 treatments peg initiation was delayed by about 4-6 days with decreasing ET.

R3: The duration of R3 was short in Trt.1. At an ET level of 494 mm in Trt.2, this duration was extended by 4 days and in Trt.3 by 10-13 days at different ET levels. In Trt.4, pod formation was delayed by 8-12 days with the decreasing ET.

Table 18. Days after emergence at different ET levels for different treatments during the 1982-83 post rainy season.

R.S.	TREATMENT 1			TREATMENT 2			TREATMENT 3			TREATMENT 4		
	592 mm	546 mm	611 mm	576 mm	546 mm	494 mm	546 mm	515 mm	401 mm	687 mm	386 mm	47 mm
R1	29	29	29	34	34	35	33	33	35	33	33	38
R2	46	46	46	46	50	50	54	54	56	50	50	56
R3	60	60	60	60	60	65	70	70	73	62	70	74
R4	70	70	70	70	71	78	80	80	82	72	80	85
R5	72	72	72	72	73	80	82	82	84	74	82	89
R6	87	87	87	87	87	97	96	96	104	86	99	107
R7	107	107	112	107	107	112	120	124	130	112	114	119
R8	134	134	141	141	134	141	141	148	148	141	134	148

R.S.: Reproductive Stage
R1 : Beginning Bloom
R2 : Beginning Peg
R3 : Beginning Pod
R4 : Full Pod
R5 : Beginning Seed
R6 : Full Seed
R7 : Beginning Maturity
R8 : Harvest Maturity

R4: The same trend as noticed in stage R3 was observed in all the four treatments.

R5: Trt.1 and Trt.2 did not differ except at an ET level of 494 mm in Trt.2 where seed formation was delayed by 8 days. In Trt.3, seed formation was further delayed as it took 82-84 days as against 74 days taken by Trt.4 with 687 mm of ET. The longest period for seed initiation occurred at a low ET level of 47 mm in Trt.4.

R6: Similar trend as noticed in stage R5 was observed.

R7: Trt.1 and Trt.2 were earliest to begin maturity while Trt.3 was very late in this regard. In Trt.4 the duration was 112 to 119 days in different ET levels.

R8 (Harvest maturity): Trt.1 and Trt.2 took 134-141 days to mature while the maturity was much delayed in Trt.3 and Trt.4.

4.3.2.2 Leaf area index

Leaf area index (LAI) as a function of time for all the four treatments is shown in Figure 25.

Marked differences in LAI at different ET levels were observed in Trt.3 and Trt.4 only, while they were not quite distinct in Trt.1 and Trt.2. In all the four treatments, maximum LAI was recorded at 90 DAE except at the ET levels of 515 and 401 mm in Trt.3 where maximum LAI was recorded between 100 to 110 DAE.

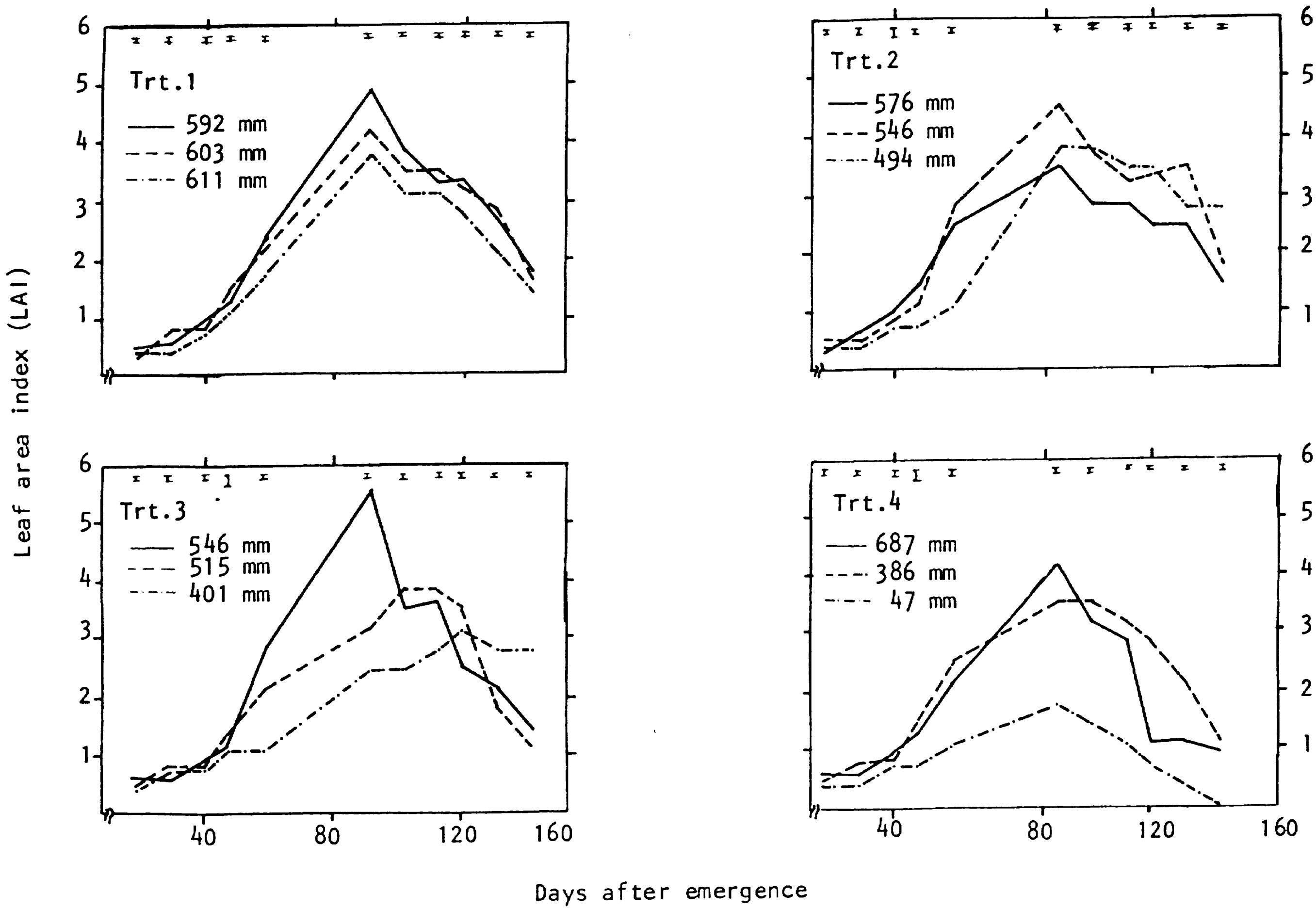


Figure 25. Leaf area index (LAI) as a function of time at different ET levels for different treatments during the 1982-83 postrainy season.

In Trt.1, 592 mm of ET resulted in significantly higher LAI from 60 DAE when compared to the higher ET values of 603 and 611 mm. In Trt.2 also at the lower ET levels of 546 and 494 mm the plants maintained higher LAI over the ET level of 576 mm from 100 DAE.

In Trt.3, significant differences in LAI were observed among the different ET levels from 60 DAE. From 110 DAE these differences were less discernable.

For Trt.4 at all the ET levels LAI increased up to 90 DAE at which time the differences were maximum. The plots with 687 mm of ET recorded the maximum LAI of 4.4 while the ET level of 47 mm resulted in an LAI of only 1.7. From 100 DAE, at an intermediate ET level of 386 mm the plants maintained a higher LAI over the other two ET levels.

4.3.2.3 Number of pegs

The number of pegs per plant as a function of time at different ET levels for different treatments during the 1982-83 postrainy season are presented in Table 19.

In Trt.1, the number of pegs was differed significantly with ET. The peg number was lowest with the ET level of 592 mm. In Trt.2 however the number of pegs increased with reduction in ET. A similar trend was observed in Trt.3.

The number of pegs at all ET levels occurred in Trt.4. At an ET level of 687 mm the groundnut plants produced less number of pegs as compared to the highest ET levels in the other treatments. The least number of pegs was obtained at the ET level of 47 mm.

Table 19. No. of pegs/plant as a function of time at different ET levels for different treatments during the 1982-83 post rainy season.

DAE	TREATMENT 1				TREATMENT 2			
	592 mm	546 mm	611 mm	SE $\pm$	576 mm	546 mm	494 mm	SE $\pm$
20	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-
60	4.96	4.14	2.39	0.15	6.85	6.94	4.61	0.12
90	10.83	14.49	8.19	0.14	16.53	12.07	12.22	0.14
100	12.07	15.20	9.79	0.24	16.52	16.52	20.78	0.22
110	13.30	26.74	33.28	0.13	21.62	18.89	32.69	0.09
120	23.05	40.04	33.65	0.36	32.84	31.24	48.26	0.21
130	20.60	52.23	43.62	0.01	37.49	35.06	53.82	0.08
140	42.64	44.05	50.04	0.10	47.02	33.66	47.92	0.23

DAE	TREATMENT 3				TREATMENT 4			
	546 mm	515 mm	447 mm	SE $\pm$	687 mm	386 mm	47 mm	SE $\pm$
20	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-
60	6.00	4.14	2.39	0.15	4.94	2.71	6.71	0.12
90	14.38	14.49	10.58	0.14	6.45	9.87	4.62	0.14
100	14.54	15.20	9.79	0.24	8.93	9.30	2.99	0.22
110	18.70	26.74	33.47	0.13	13.17	11.32	3.42	0.09
120	20.39	40.04	33.65	0.36	17.67	15.35	2.42	0.21
130	33.89	52.23	43.62	0.01	19.51	13.70	3.61	0.08
140	40.73	44.05	50.44	0.10	15.83	12.37	2.55	0.23

4.3.2.4 Number of pods

The number of pods per plant as a function of time at different ET levels for different treatments during the 1982-83 postrainy season is presented in Table 20.

In Trt.1, significant differences were observed in the pod number among the ET levels. There was however no consistency in the differences in pod number at different ET levels. In Trt.2, the low ET level of 494 mm resulted in higher pod number over the other two levels from 110 DAE onwards. In Trt.3 also the low ET levels of 515 and 401 mm resulted in more pods per plant over the higher level of 546 mm.

In Trt.4, the number of pods was significantly different among the ET levels. Pod number was expectedly more at the 687 mm ET level compared to 386 and 47 mm levels.

4.3.2.5 Dry matter distribution

Dry matter distribution among various plant parts for all the four treatments at two ET levels during the 1982-83 postrainy season is shown in Figures 26 to 29 and Table 21. Although data were collected at all ET levels, for the sake of comparison only data at the high and low ET levels in each treatment are presented.

In Trt.1, maximum dry matter accumulation was noticed at 120 DAE with more partitioning to the stems at 592 mm of ET. At 611 mm of ET, the dry matter accumulation was maximum at 130 DAE and higher partitioning into pods and kernels occurred.

Table 20. No.of pods/plant as a function of time at different ET levels for different treatments during the 1982-83 post rainy season.

DAE	TREATMENT 1				TREATMENT 2			
	592 mm	546 mm	611 mm	SE ±	576 mm	546 mm	494 mm	SE ±
20	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-
60	0.79	1.93	1.16	0.08	4.76	4.49	0.35	0.15
90	8.14	7.97	5.78	0.08	13.71	8.80	5.20	0.13
100	8.98	9.00	3.09	0.46	14.06	11.97	6.18	0.25
110	8.13	8.90	8.04	0.03	16.30	13.42	19.61	0.23
120	10.91	9.15	14.41	0.11	19.06	18.62	32.09	0.12
130	9.62	13.43	17.93	0.06	16.84	23.48	40.49	0.25
140	32.62	25.04	18.42	0.36	19.94	26.63	41.44	0.24

DAE	TREATMENT 3				TREATMENT 4			
	546 mm	515 mm	401 mm	SE ±	687 mm	386 mm	47 mm	SE ±
20	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-
60	2.74	0.61	0.00	0.06	0.83	0.13	0.18	0.06
90	10.47	10.18	2.77	0.07	4.05	5.98	0.74	0.06
100	10.02	10.51	3.61	0.14	6.17	6.05	0.43	0.20
110	10.81	13.65	10.90	0.09	9.89	7.47	0.68	0.09
120	10.72	14.31	14.33	0.34	10.80	11.97	0.25	0.24
130	18.82	34.70	26.87	0.03	13.63	9.86	1.46	0.01
140	30.38	33.09	39.75	0.47	13.69	9.07	1.08	0.37

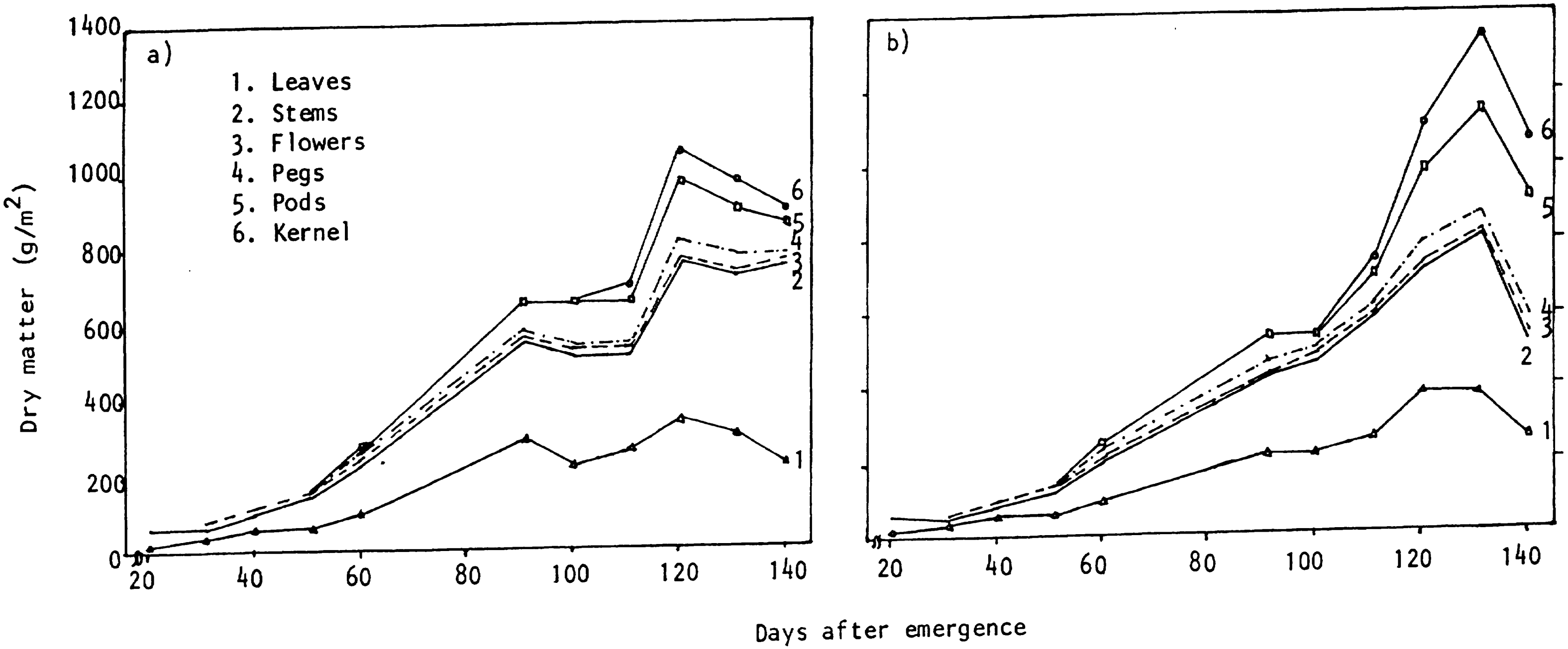


Figure 26. Dry matter distribution in groundnut at two levels of ET a) 592 mm and b) 611 mm in Trt.1 during the 1982-83 postrainy season.

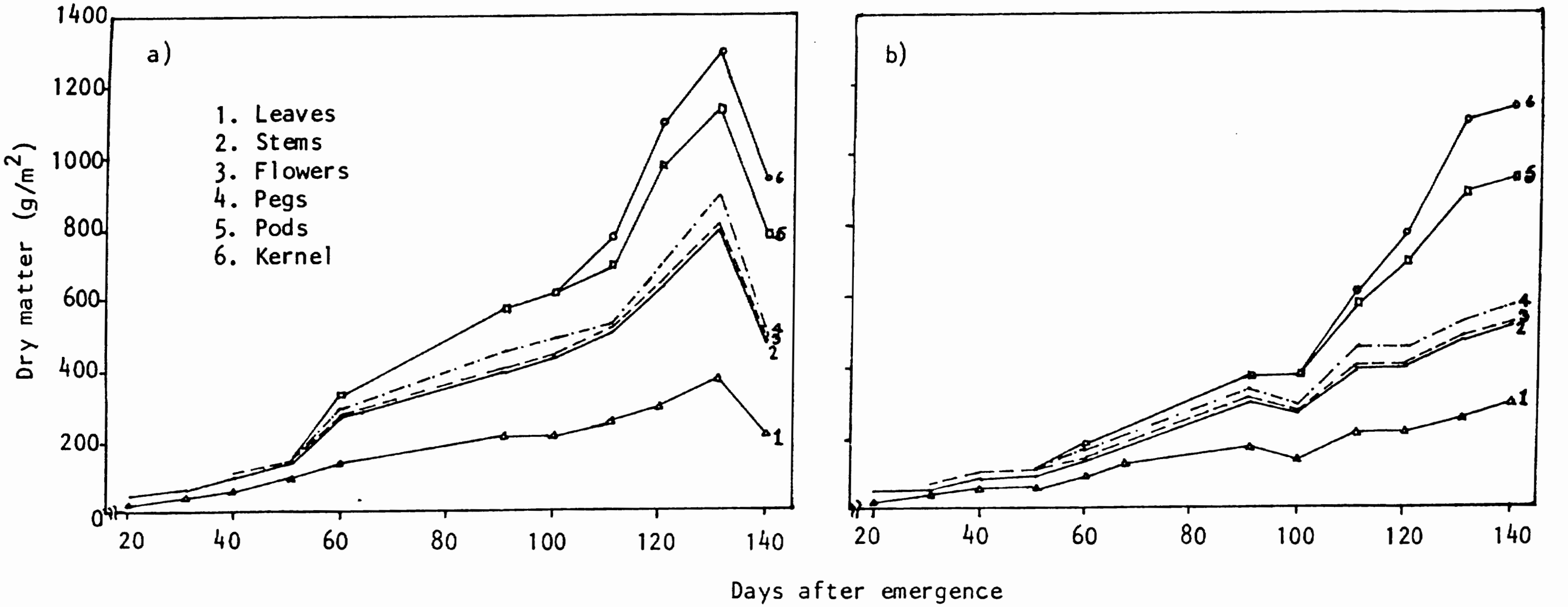


Figure 27. Dry matter distribution in groundnut at two levels of ET a) 576 mm and b) 494 mm in Trt.2 during the 1982-83 postrainy season.

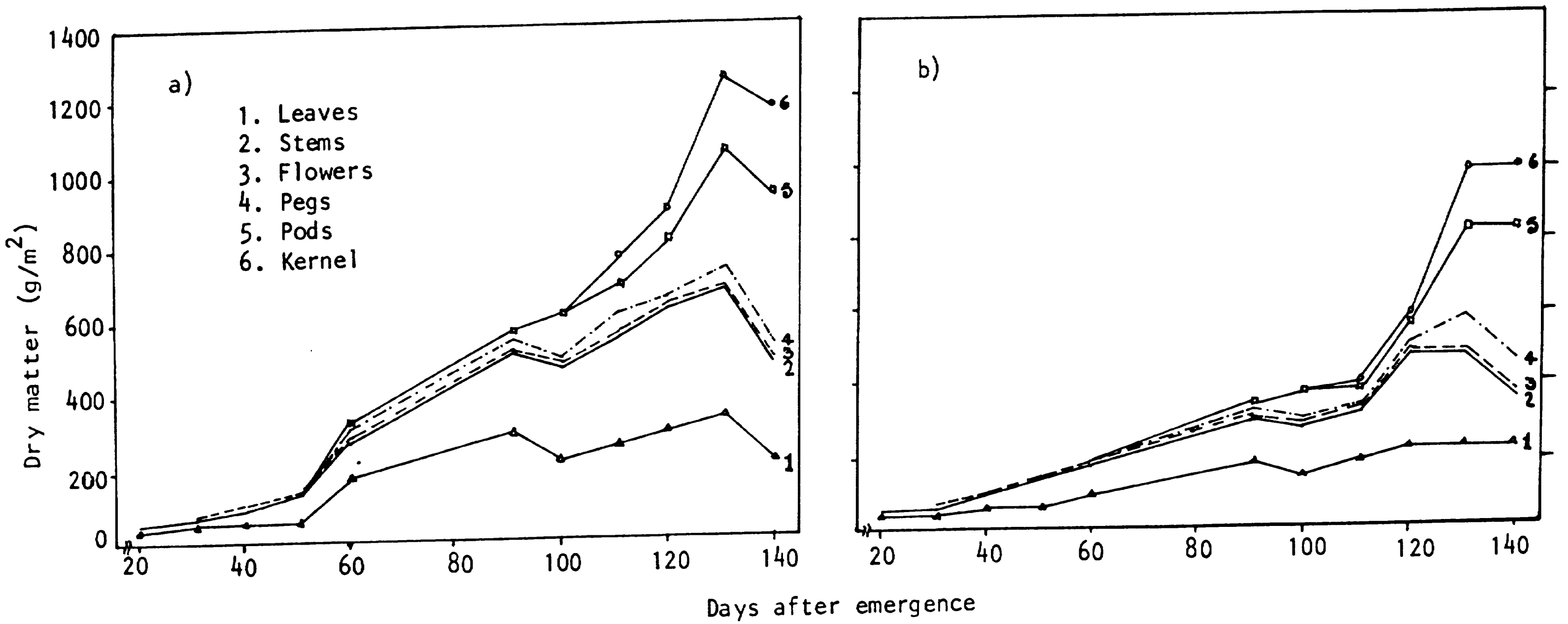


Figure 28. Dry matter distribution in groundnut at two levels of ET a) 546 mm and b) 401 mm in Trt.3 during the 1982-83 postrainy season.

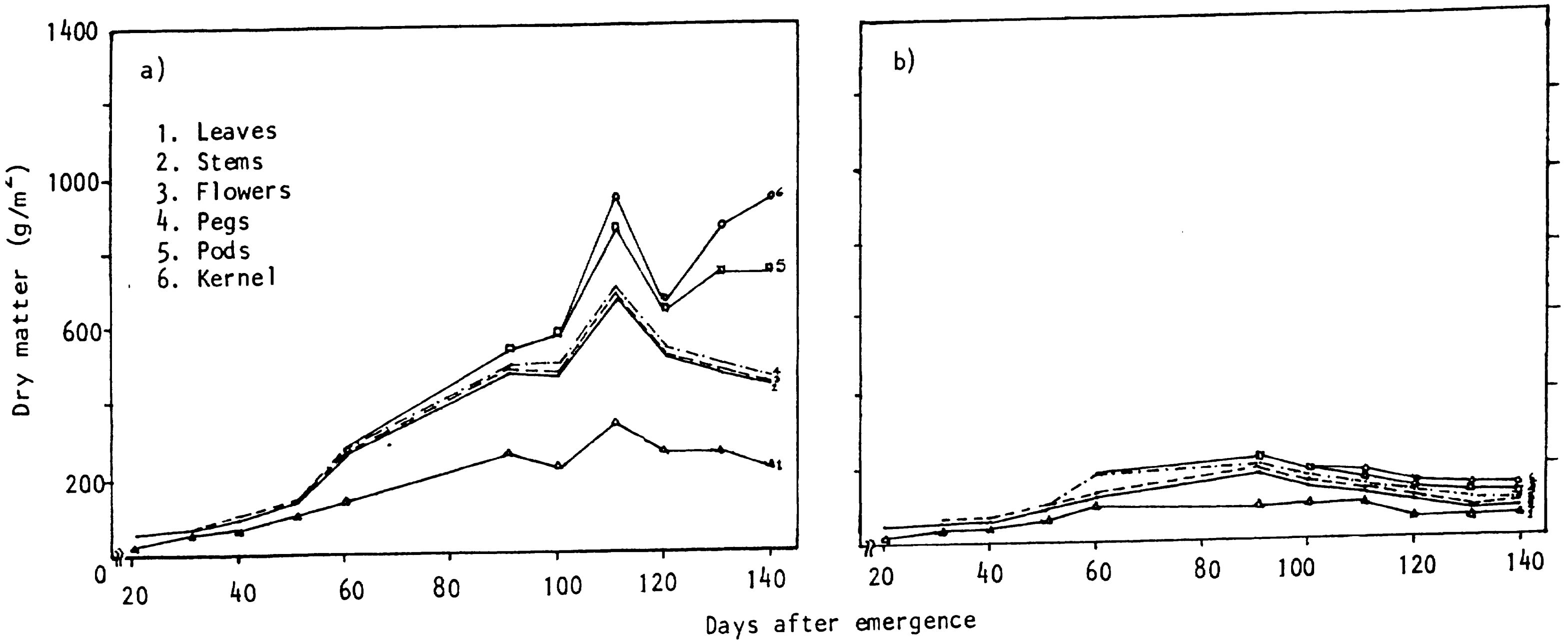


Figure 29. Dry matter distribution in groundnut at two levels of ET a) 687 mm and b) 47 mm in Trt.4 during the 1982-83 postrainy season.

Table 21. Dry matter partitioning at maturity expressed as percentage among the various plant parts at different ET levels for different treatments during the 1982-83 post-rainy season.

Plant Component	Drymatter distribution (%)							
	Trt. 1		Trt.2		Trt.3		Trt.4	
	592 mm	611 mm	576 mm	494 mm	546 mm	401 mm	687 mm	47 mm
Leaves	20.4	23.5	23.5	24.9	18.1	20.2	22.0	29.8
Stems	31.7	26.6	28.0	21.9	22.8	18.8	24.7	59.0
Flowers	0.1	0.1	0.5	0.1	0.1	0.1	0.1	0.8
Pegs	1.1	5.2	2.3	3.4	4.1	12.6	1.5	0.9
Pods	29.2	27.3	29.3	32.1	34.6	37.4	29.8	6.8
Kernels	17.5	17.3	16.4	17.6	20.3	15.8	22.0	2.7

In Trt.2, (Fig. 27) maximum dry matter accumulation was observed at 130 DAE with more partitioning to the stems and pods at 576 mm of ET, while at 499 mm ET level, a linear increase in the dry matter accumulation was noticed even up to 140 DAE. At the low level of ET, a greater proportion of dry matter was partitioned to the pods and kernels.

In Trt.3 maximum dry matter accumulation occurred at 130 DAE. Higher dry matter production as well as partitioning to stems, pods and kernels was observed at the ET level of 546 mm.

In Trt.4, highest total dry matter accumulation was observed at 110 DAE except for leaves and stems which continued up to 140 DAE with 687 mm of ET with greater partitioning of dry matter to pods. With a considerably less ET of 47 mm, total dry matter production was about nine times less when compared to the 687 mm of ET and the dry matter accumulation was mostly in the stems and leaves. Groundnut plots at maturity at the three ET levels in Trt.4 are shown in Plate 5.

4.3.2.6 <u>Pod Growth</u>

Pod growth as a function of time at different ET levels in different treatments during the 1982-83 postrainy season is shown in Figure 30.

In Trt.1, there was a mixed trend among the ET levels. The lowest ET level showed increased pod growth from 110 DAE while the intermediate ET level showed poor growth rates. In Trt.2 also increased pod growth rates were associated with low ET.

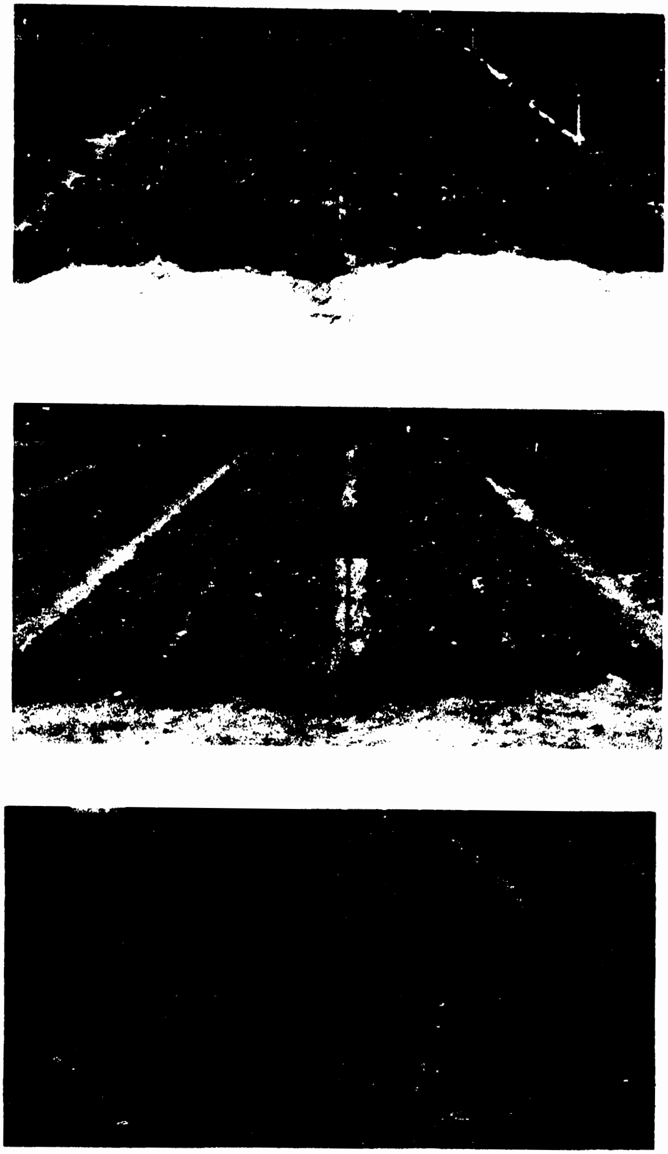


Plate 5. General view of the groundnut plants at maturity at a) 687 mm, b) 386 mm and c) 47 mm ET level in Trt.4 during the 1982-83 postrainy season.

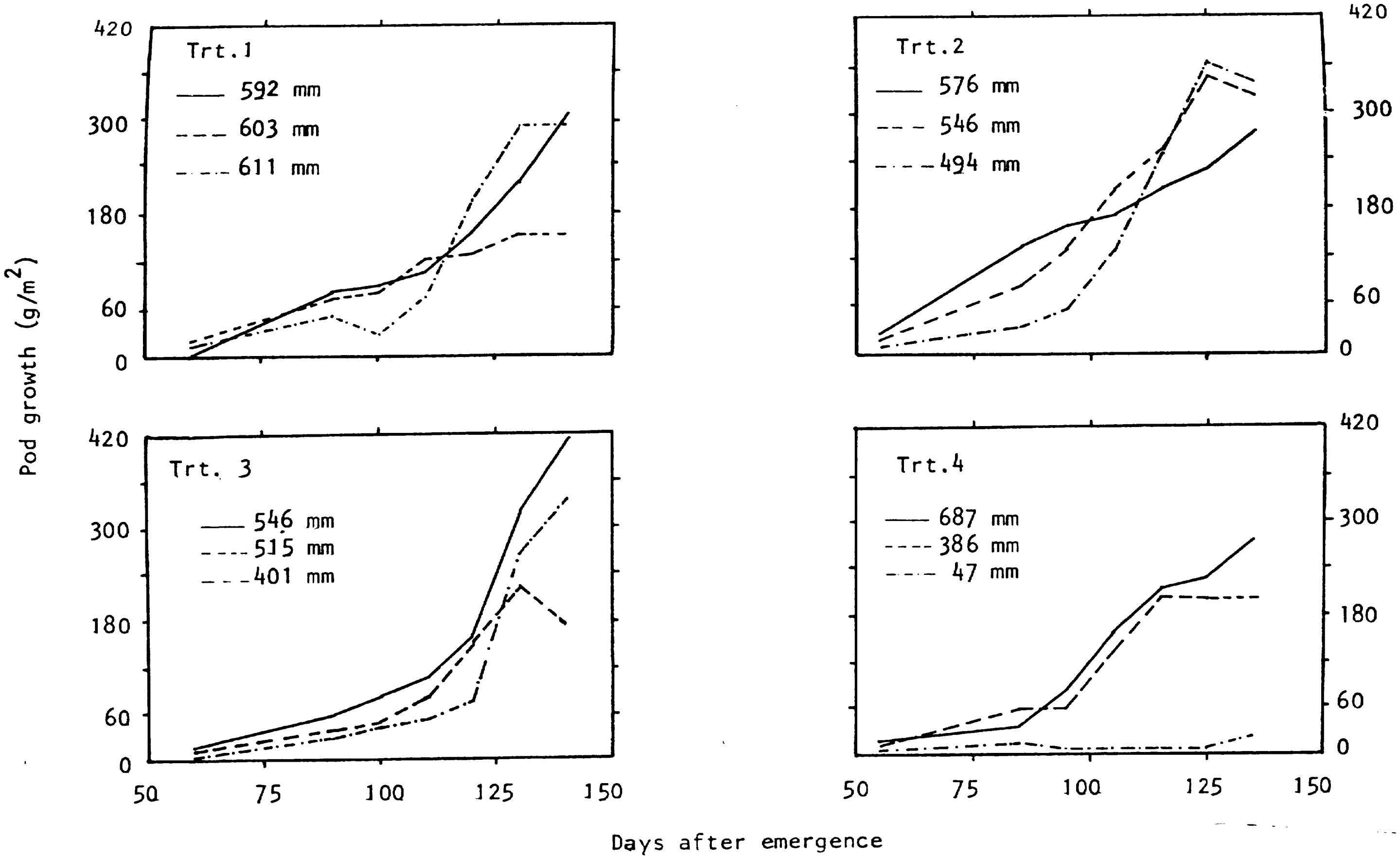


Figure 30. Changes in the pod growth at different ET levels for different treatments during the 1982-83 postrainy season.

In Trt.3, with maximum pod growth rates amongst all treatments, the high ET level (546 mm) promoted better growth rate. At the low ET level of 401 mm the plants showed poor growth rates initially, but substantially increased the pod growth from 120 DAE.

In Trt.4, pod growth was comparatively less even at the high ET level of 687 mm. The pod growth at this ET level was 274 g/m^2 while at 386 mm of ET the growth rate (237 g/m^2) was slightly lower. In the plots which were subjected to severe stress by reducing the ET to 47 mm, the pod growth was very much affected and the plots recorded about 7 g/m^2 of pod dry matter.

4.3.2.7 Kernel growth

Kernel growth at different ET levels in different treatments during the 1982-83 postrainy season is shown in Figure 31.

In Trt.1, kernel growth was similar to that of the trend observed in pod growth, with more pronounced differences in growth rates between 611 and 592 mm of ET levels. In Trt.2 also the pattern of seed growth was similar to that of pod growth with the low ET levels tending to promote better growth rates.

In Trt.3, kernel growth was maximum at the highest ET level of 546 mm followed by the 515 mm of ET level.

In Trt.4, marked differences were noticed in kernel growth among the ET levels. At an ET level of 687 mm the kernel dry matter at 140 DAE was 203 g/m^2 while at 386 mm of ET it was 131 g/m^2. At the lowest ET level of 47 mm, the kernels could accumulate only 2.7 g/m^2.

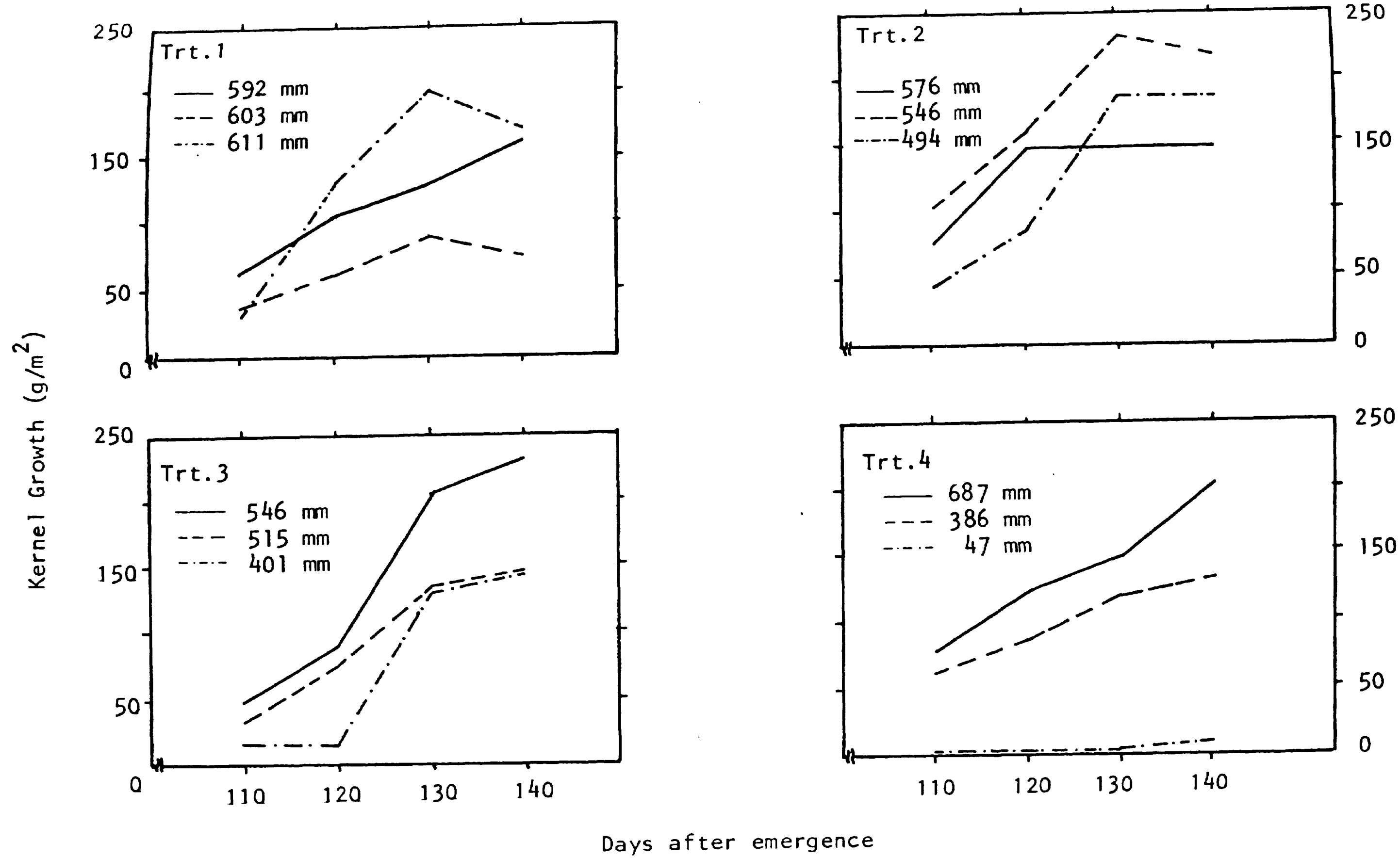


Figure 31. Changes in the kernel growth at different ET levels for different treatments during the 1982-83 postrainy season.

4.3.2.8 Dry matter production and evapotranspiration

The relationship between dry matter production and cumulative evapotranspiration (CET) is presented in Figur 32.

In Trt.1, with increasing cumulative ET, the dry matter production initially increased more rapidly at the 592 and 603 mm ET levels but the high ET levels of 611 mm showed a more linear increase in the later stages.

In Trt.2, however increase in dry matter production with ET was more pronounced at the lower ET levels of 546 and 494 mm than at 576 mm of ET. In Trt. 3 this trend was reversed with more dry matter production at the higher ET levels of 546 and 515 mm particularly at the later stages of crop growth.

In Trt.4, the intermediate level of ET (386 mm) promoted a higher dry matter production over the ET level of 687 mm. With a significantly lower ET of 47 mm the dry matter production was severely curtailed. The dry matter production at maturity was plotted against total evapotranspiration (TET) in Figure 33. There was a positive and highly significant correlation between dry matter production at maturity and TET.

4.3.2.9 Yield and Yield Components

The data on plant population and pod yield at different ET levels for different treatments during the 1982-83 postrainy season are presented in Table 22.

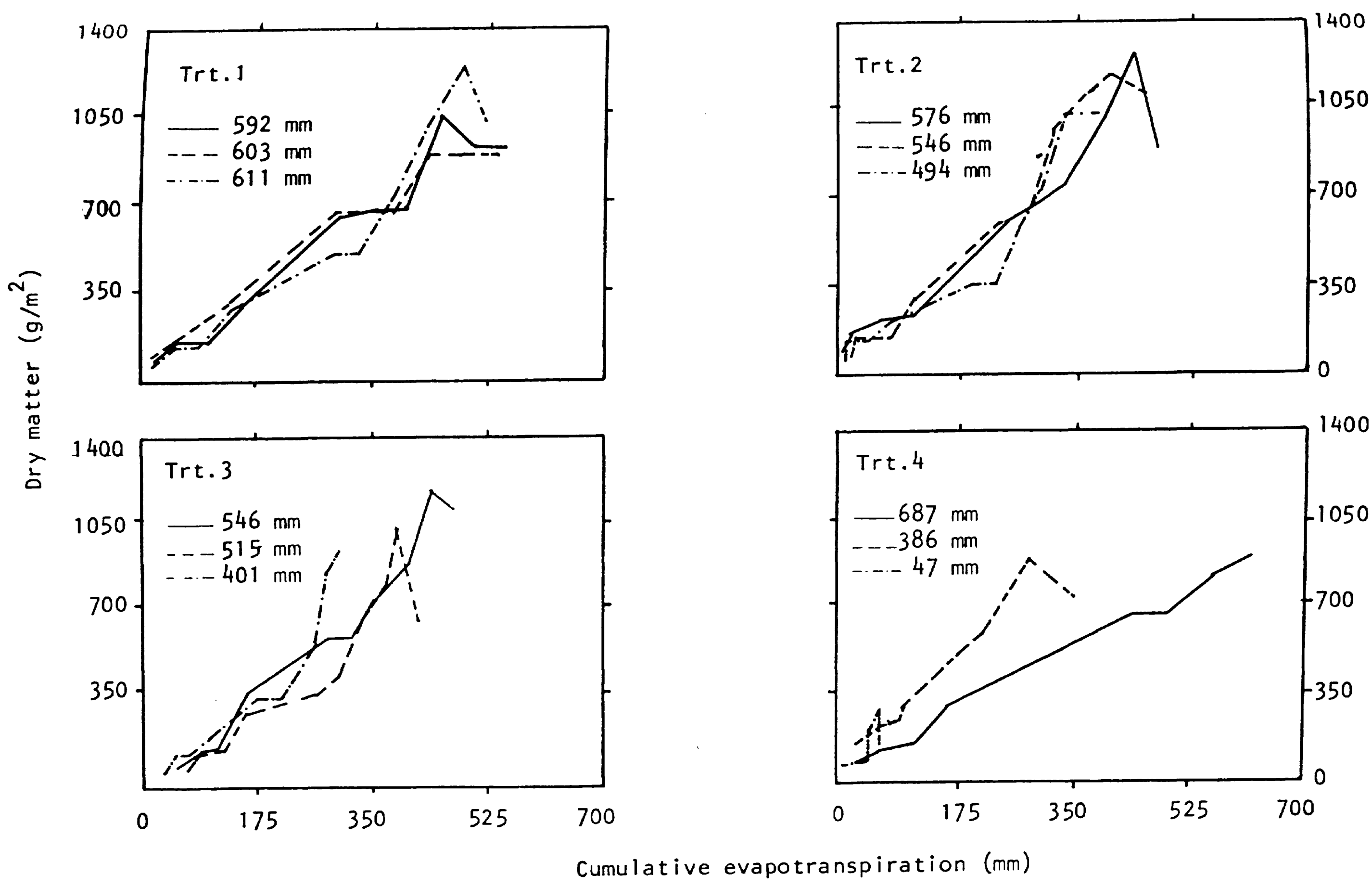
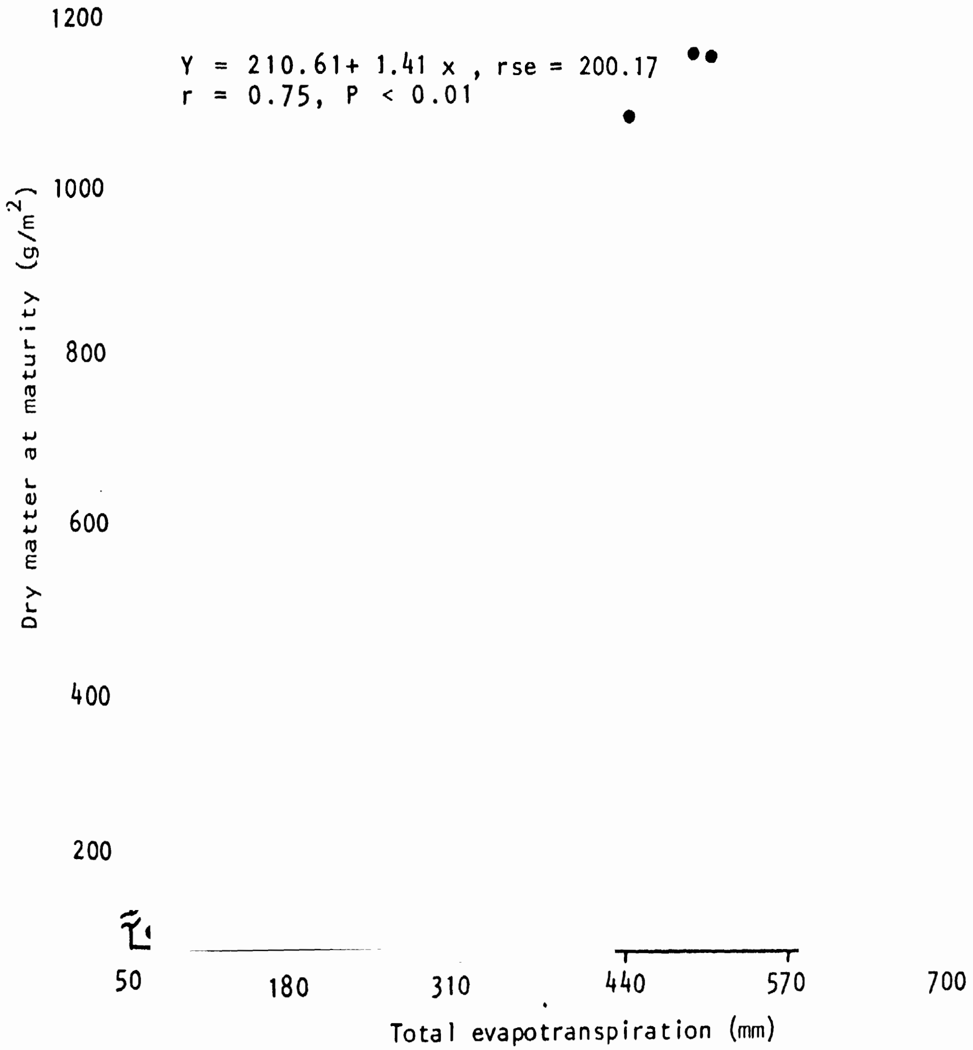


Figure 32. Relationship between dry matter production and cumulative evapotranspiration (CET) at different ET levels for different treatments during the 1982-83 postrainy season.



33. Dry matter production at maturity of groundnut as related to total evapotranspiration (TET) for different treatments during the 1982-83 postrainy season.

Table 22. Plant population at harvest and pod yield at different ET levels for different treatments during the 1982-83 post-rainy season.

Treatment	ET level	Plant Population per ha. ('000)	Pod Yield (kg/ha)
Treatment:1			
	592 mm	209.2	2949
	603 mm	207.2	2816
	611 mm	200.8	2701
Treatment:2			
	576 mm	201.9	3063
	546 mm	201.7	4743
	494 mm	219.2	4396
Treatment:3			
	546 mm	196.7	2998
	515 mm	207.2	2682
	401 mm	194.2	2438
Treatment:4			
	687 mm	213.9	3258
	386 mm	203.1	2259
	47 mm	216.7	503
SE ±		13.9	536

4.3.2.9.1 Plant population

The differences among the treatments pertaining to plant population at harvest were not significant.

4.3.2.9.2 Pod yield

Among the phenological stages, Trt.2 with a mean pod yield of 4067 kg/ha was significantly superior to Trt. 1, Trt.3, and Trt.4. Among the ET levels in Trt.1 and Trt.3 there were no significant differences. In Trt. 2, the lower ET levels of 546 and 494 mm recorded significantly superior pod yield over the higher ET level of 576 mm. In Trt.4, the yield at ET levels of 687 and 386 mm was significantly superior to that at 47 mm.

4.3.2.9.3 Kernel yield

Kernel yield is shown in Figure 34. for all the treatments. kernel yield showed the same trend as in the case of pod yield discussed above.

4.3.2.10 Shelling Percentage and Evapotranspiration (ET)

The results of the regression analysis of the shelling % at different ET levels during the 1982-83 postrainy season are shown in Fig 35.

The shelling % was significantly and positively correlated to the ET levels.

4.3.2.11 Water use efficiency and Harvest Index

Data on water use efficiency (WUE) and harvest index (HI) at different ET levels for different treatments are presented in Table 23.

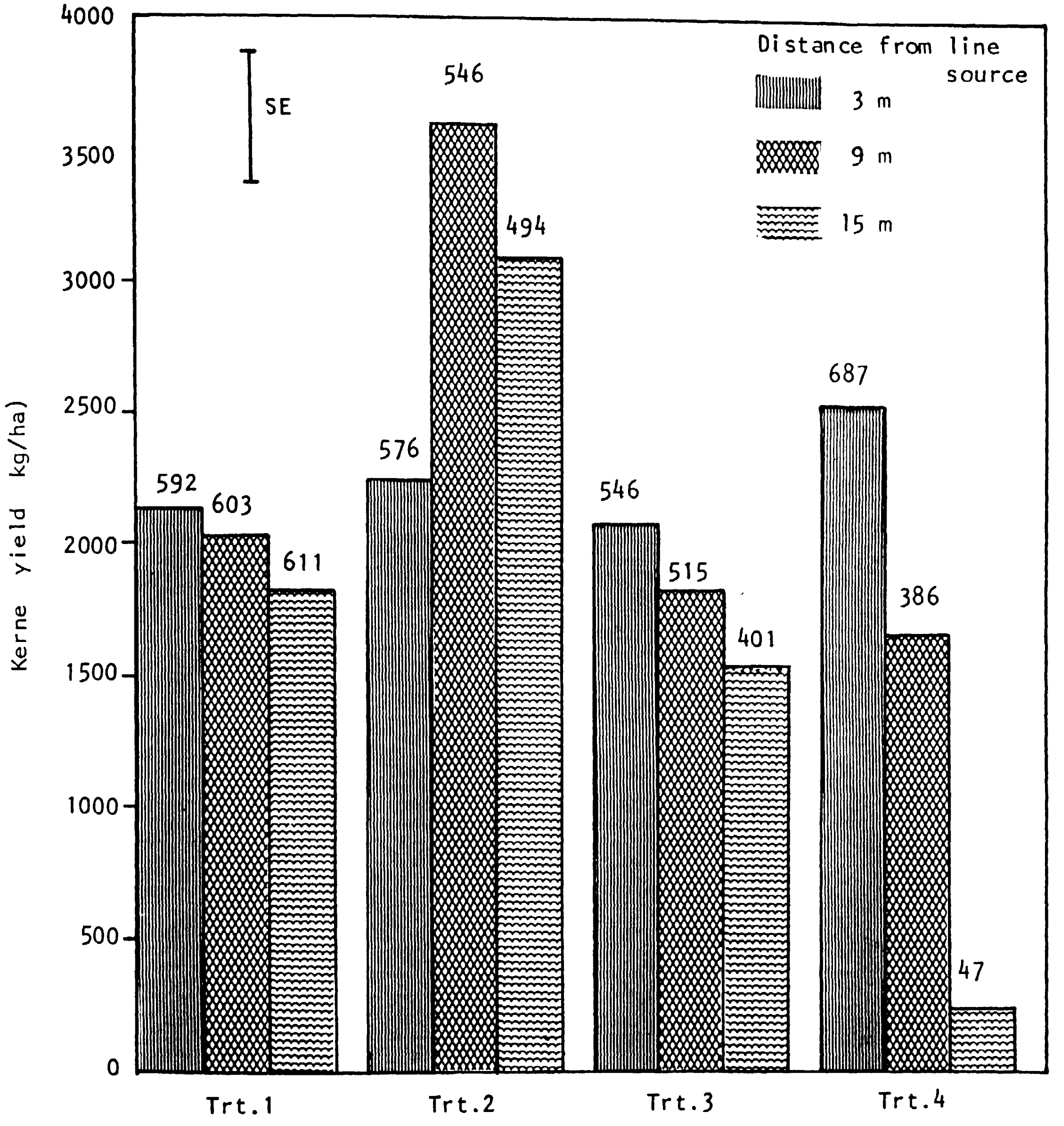


Figure 34. Kernel yield at different ET levels (given in mm) for different treatments during the 1982-83 postrainy season.

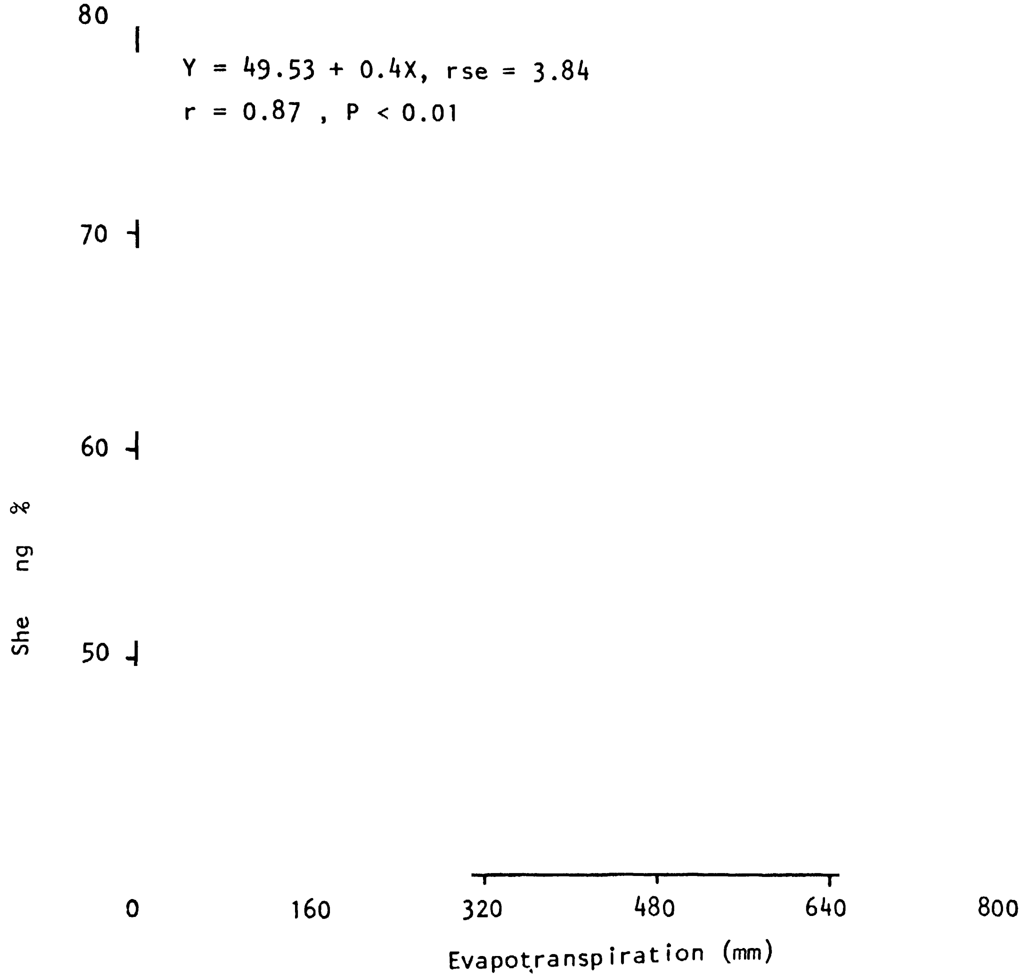


Figure 35. Groundnut shelling % as a function of evapotranspiration during the 1982-83 postrainy season.

Table 23. Water use effeiciency and harvest index at different ET levels for different treatments during the 1982-83 postrainy season.

Treatment	Water Use Efficiency (kg/ha/cm)	Harvest Index
Treatment: 1		
592 mm	162	22.3
546 mm	172	19.6
611 mm	149	20.0
Treatment: 2		
576 mm	143	47.3
546 mm	178	36.9
494 mm	186	33.7
Treatment: 3		
546 mm	152	25.2
515 mm	160	22.1
401 mm	204	18.9
Treatment: 4		
687 mm	113	32.7
386 mm	142	29.6
47 mm	491	10.4

4.3.2.11.1 Water Use Efficiency

In general WUE increased with decreasing ET level in all treatments. The lowest WUE was observed with the highest ET level of 687 mm in Trt.4 (Table 23).

4.3.2.11.2 Harvest Index

The low ET levels of 546 and 494 mm in Trt.2 gave the highest HI values. In Trt.3 however, HI was higher with the higher ET levels. 47 mm ET level in Trt.4 gave the lowest HI (Table 23).

4.3.2.12 Covariate Analysis of Treatment Affects

The variation in the different treatments (phenological stages) by covariate analysis is presented in Table 24 in respect of leaf area index (LAI) at maturity, peg and pod numbers at maturity, pod yield and kernel yield, harvest index and water use efficiency.

1. Leaf area index: Treatments 1 to 3 were on par and were significantly superior to Trt. 4 in respect of LAI at maturity.

2. Number of pegs: Treatment 3 was significantly superior to the rest of 3 treatments as to the number of pegs at maturity, while Trt.1 and Trt.2 were on par. In Trt.4 the peg number was least and was significantly different from the other 3 treatments.

3. Number of pods. Pod number at maturity was significantly less in treatment.4 as compared to treatments.1 to 3 which were on par.

Table 24. Comparison of different parameters for different treatments (phenological stages) by covariate analysis method during the 1982-83 postrainy season.

Parameter	Trt.1	Trt.2	Trt.3	Trt.4	SE	F value
LAI at maturity	1.45	2.00	1.81	0.60	0.20	10.01**
No. of pegs at maturity	39.9	32.4	41.8	13.5	2.62	22.87**
No. of pods at maturity	24.4	25.6	31.3	11.1	2.64	10.59**
Pod yield	2453	3928	2754	2467	283	6.74**
Kernel yield	1685	2856	1830	1868	224	6.47**
Harvest index	16.8	37.9	22.6	29	1.75	14.91**
Water use efficiency	221	191	164	174	20.65	0.89 NS

**: Significant at $P < 0.01$
NS: Not significant

4. Pod yield. Trt.2 was significantly superior to the other three treatments in respect of pod yield.

5. Kernel yield. As in the case of pod yield, Trt.2 was significantly superior to the rest of the treatments.

6. Harvest index. Trt.2 was significantly superior to the rest of the 3 treatments. As compared to Trt.1, treatments 3 and 4 were significantly different.

7. Water use efficiency. The differences among the phenological phases were not significant as can be expected since the ET levels were used as covariates.

4.3.2.13 Root Studies

Data on root growth at two ET levels for different treatments are presented in Plate 6 and Table 25.

4.3.2.13.1 Length of Tap Root

The length of tap root decreased with decrease in ET in Trt.2 and Trt.3 while in Trt.4 (control) this trend was reversed. The groundnut plants which were subjected to severe moisture stress at the 47 mm ET level developed a deep root system going up to one meter deep as against 66 cm for the 687 mm ET level (Table 25).

4.3.2.13.2 Total length of roots

The total length of roots decreased with decreasing ET in all but

Table 25. Root components as affected by moisture stress at different ET levels for different treatments during the 1982-83 postrainy season.

Treatment	ET (mm)	Length of tap root (cm)	Total length of roots (cm)	Dry weight of total root system (g/plant)
1	592	82	1449	2.46
1	611	66	1107	1.73
2	629	51	1219	2.78
2	494	31	970	1.79
3	546	65	1361	2.03
3	401	15	888	0.76
4	687	66	1828	2.60
4	47	100	1303	1.77

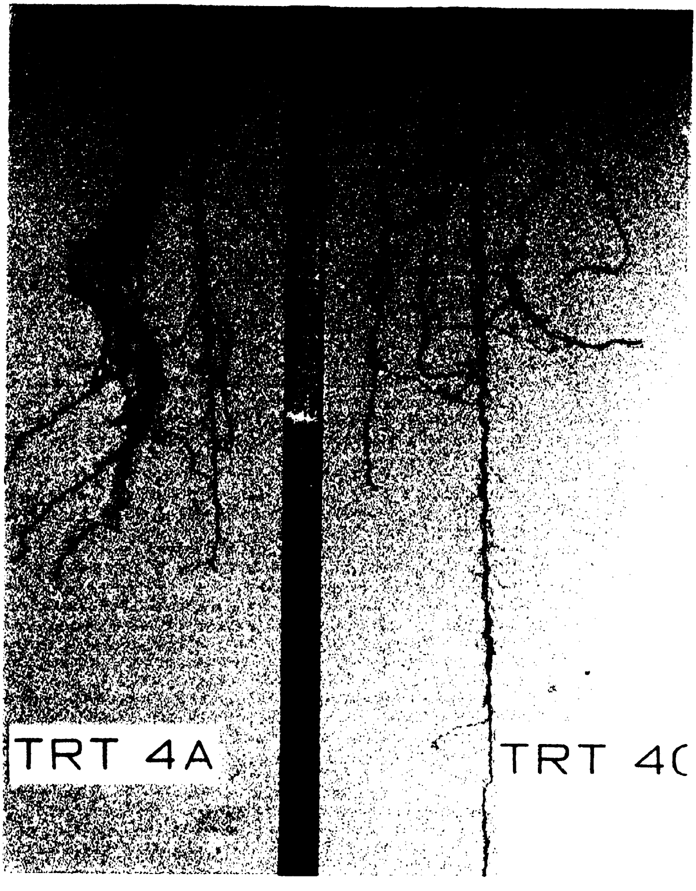


Plate 6. Root distribution of groundnut at a) 687 mm and c) 47 mm ET levels in Trt.4 during the 1982-83 postrainy season.

Trt.1. Maximum total root length was recorded at the highest ET level of 687 mm in Trt.4. Root length was severely affected at the low ET level in Trt.3.

4.3.2.13.3 Dry weight of total root system

The dry weight of total root system decreased with the decrease in ET in all treatments except Trt.1. Root dry weight was low at the lower ET level in Trt.3 (Table 25).

4.3.2.14 Seed quality

The 100 kernel weight, protein and oil contents at different ET levels for different treatments are presented in Table 26.

4.3.2.14.1 100 Kernel Weight

Among the phenological stages, Trt. 2 recorded the highest kernel weight followed by Trt.1, Trt.3 and Trt.4

Among the ET levels, the differences in the kernel weight were significant in all treatments. Except in Trt.1, the kernel weight decreased with decrease in ET. In Trt.3 with 401 mm of ET, a low kernel weight was recorded and the least weight was recorded at the lowest ET level of 47 mm (Table 26).

4.3.2.14.2 Protein Content

Trt.2 and Trt.4 recorded higher mean protein content than Trt.1 and Trt.3

Table 26. 100 Kernel weight, protein and oil contents at different ET levels for different treatments during the 1982-83 post-rainy season.

Treatment		100 Kernel weight (g)	Protein content (%)	Oil content (%)
Treatment: 1	592 mm	54.9	29.4	43.9
	546 mm	49.3	28.8	41.9
	611 mm	46.4	29.5	41.5
Treatment: 2	576 mm	59.5	34.0	43.8
	546 mm	58.1	29.7	42.4
	494 mm	50.8	29.8	41.5
Treatment: 3	546 mm	52.6	30.0	43.4
	515 mm	45.7	30.1	41.2
	401 mm	29.2	28.4	38.1
Treatment: 4	687 mm	57.7	31.0	41.4
	386 mm	55.9	33.7	40.1
	47 mm	22.3	30.8	39.3
	SE ±	0.17	0.17	0.18

Among the ET levels, Trt.2 with 576 mm of ET and Trt.4 with 386 mm of ET were on par and the protein contents were higher in these cases over other treatments (Table 26).

4.3.2.14.3 Oil Content

Trt.1 and Trt.2 recorded higher oil content over Trt.3 and Trt.4.

Among the degree of stress, the oil content decreased with the decrease in ET in all treatments except Trt.1. Trt.3 at 401 mm ET level recorded the lowest oil content followed by Trt.4 with 47 mm ET (Table 26).

4.3.3 Plant water stress measurements

4.3.3.1 Stomatal Conductance

4.3.3.1.1 Seasonal Variation

Seasonal variation in the stomatal conductance under field conditions during the 1982-83 postrainy season are shown in Figure 36. In examining the seasonal profile of stomatal conductance, careful consideration should be given to four factors (1) location of the measurement, (2) physiological stage of growth of the plant, (3) wet leaves and irrigation, and (4) evaporative demand.

Since the purpose is to examine the relative changes in stomatal conductance with changes in ET levels in different treatments, only mean values of plant measurements averaged over the day recorded on 16 sampling days over the growing period of the crop were used.

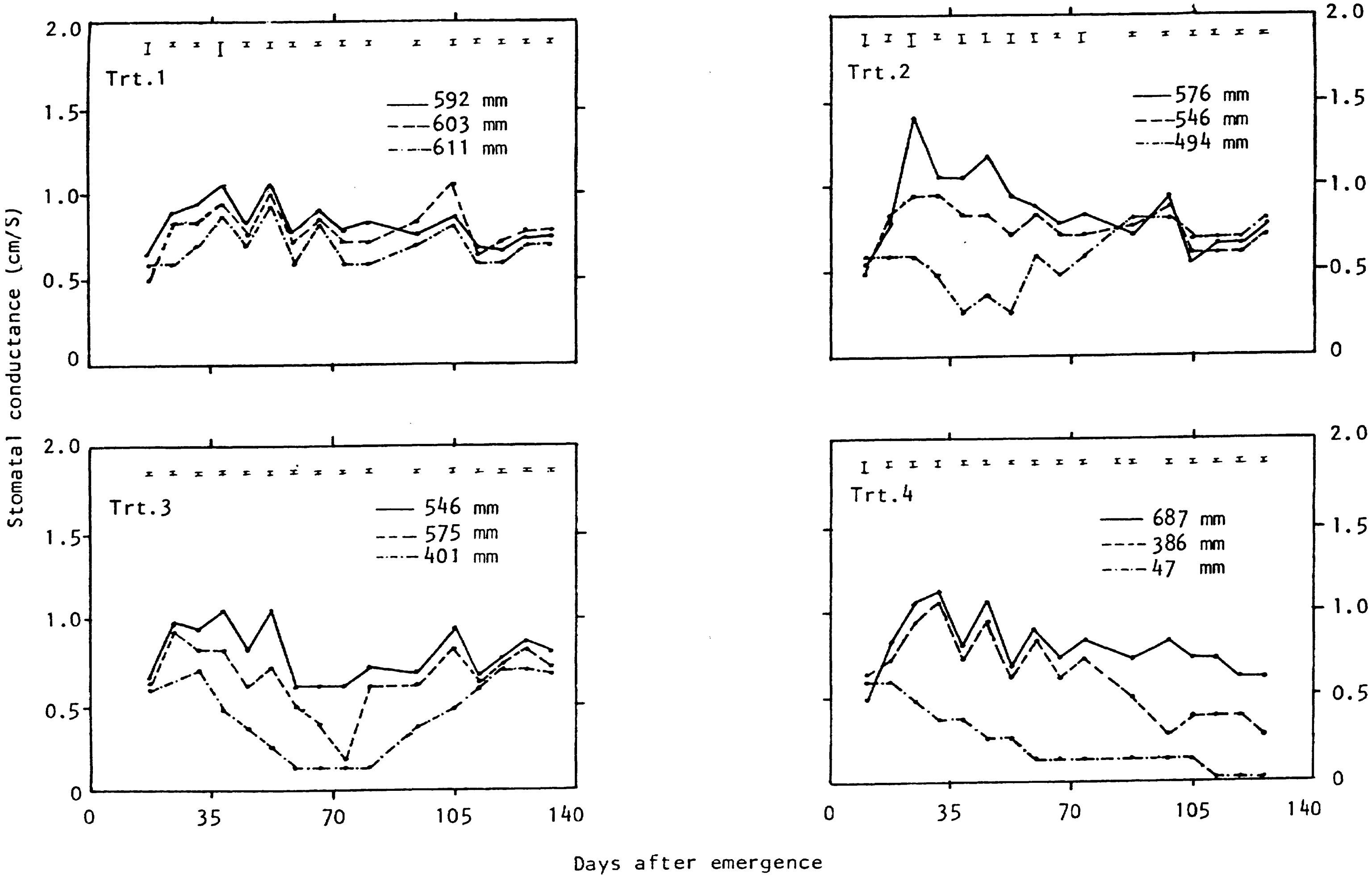


Figure 36. Seasonal variation in the stomatal conductance at different ET levels for different treatments during the 1982-83 postrainy season.

In Trt. 1, in general, conductance was higher at the lower ET level of 592 mm. In Trt.2 where moisture stress was imposed up to about 57 DAE, stomatal conductance was higher at the higher ET level. At the low ET level of 494 mm, the conductance was greatly reduced up to 57 DAE, but increased with water application steadily thereafter.

In Trt.3 where moisture stress was imposed from 29 to 92 DAE, the stomatal conductance values during this period among the three ET levels were different. The stomatal conductance reached a minimum mean value of 0.07 cm/s from 60 to 80 DAE in the plots with 401 mm of ET as against a value of 0.6 cm/s in the plots with 546 mm of ET. After the release of stress the stomatal conductance values improved.

In Trt.4 the stomatal conductance at 687 mm of ET was considerably higher over those at 47 mm of ET. The lowest value of 0.02 cm/s was recorded in the latter case at maturity as against 0.56 cm/s at 687 mm of ET. It is apparent that increasing soil dryness is associated with a decline in stomatal conductance. The stomatal conductance values with 687 and 386 mm of ET were very close up to 67 DAE and lateron the values were signifincatly different.

4.3.3.1.2 Diurnal variation

Under adequate water availability the stomates of most plants open when the sun rises and remain open until near sundown. But under moisture stress, when a imbalance develops between supply and demand for water, guard cells become less turgid and stomates begin to close. Two typical days, 75 DAE and 118 DAE, were selected to illustrate the diurnal pattern of stomatal conductance in groundnut. These days were selected to represent the R3 stage (beginning of pod) and R7 stage (beginning maturity) respectively.

Data at 75 DAE, (Fig.37) establish the fact that stomatal conductance was influenced by the time of the day and the stage at which stress was imposed. The influence of an adequate supply of water is well described by the greater stomatal conductance values in all the four main treatments, as opposed to the plots which were given less amount of water. This was more clear in Trt.3 and Trt.4 where the differences in the diurnal variation in the stomatal conductance with ET levels were large. Time of the day has a significant effect on stomatal activity. Stomata were open early in the morning and were open until 1300 hrs in Trt. 1 and Trt.4 and 1100 hrs in Trt.2 and Trt.3. With decreasing irradiance thereafter, stomatal conductance showed a rapid drop. The response of the crop at the low level of water availability at the 47 mm ET level in Trt.4 was to close the stomata rapidly by 1100 hrs. A similar response could be seen at the 401 mm ET level with Trt.3 also.

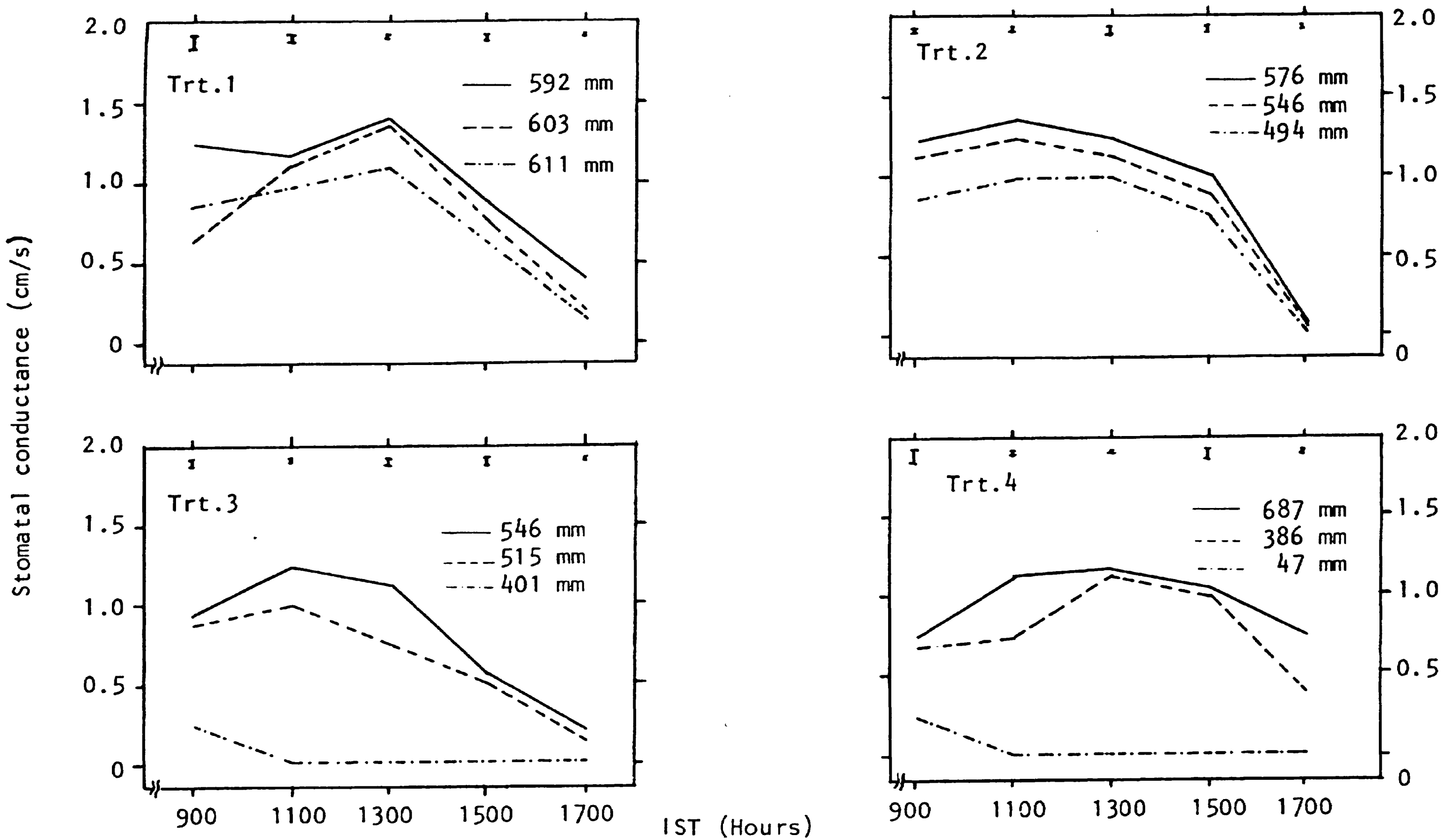


Figure 37. Diurnal variation in the stomatal conductance at different ET levels for different treatments on 75 DAE during the 1982-83 postrainy season.

The stomatal conductance values on 118 DAE present a different picture (Fig.38). A significant drop in conductance values as compared to 75 DAE in most of the treatments was noticeable. The differences are more perceptible in Trt.4 at different ET levels. Time of day at 118 DAE also has a significant effect on stomatal activity. In Trt.1, Trt.2 and Trt.4, stomata were open until 1300 hrs (IST) only and thereafter stomatal conductance started decreasing. But in Trt.3 where water stress was released on 92 DAE, the stomata were open until 1600 hrs and then closed. In Trt.4 at the low ET level of 47 mm, the stomata were closed all day.

4.3.3.1.3 Response to photosynthetic photon flux density (PPFD).

Stomatal conductance as a function of PPFD under field conditions is shown in Figure 39. To explain this relationship only the highest (687 mm) and the lowest (47 mm) ET levels in Trt.4 were chosen. At the high ET level (687 mm), the stomatal conductance increased with increasing PPFD, a response typical of a crop under adequate water availability. However at the low ET level of 47 mm, changing radiation levels had little influence on the stomatal conductance indicating thereby the controlling influence of water in this case.

4.3.3.1.4 Stomatal conductance as a function of Phoytosynthetic Photon Flux Density at three classes of Vapor Pressure Deficit

The data on stomatal conductance and PPFD recorded at the highest ET level of 687 mm in Trt.4 from 75 to 132 DAE were grouped into three

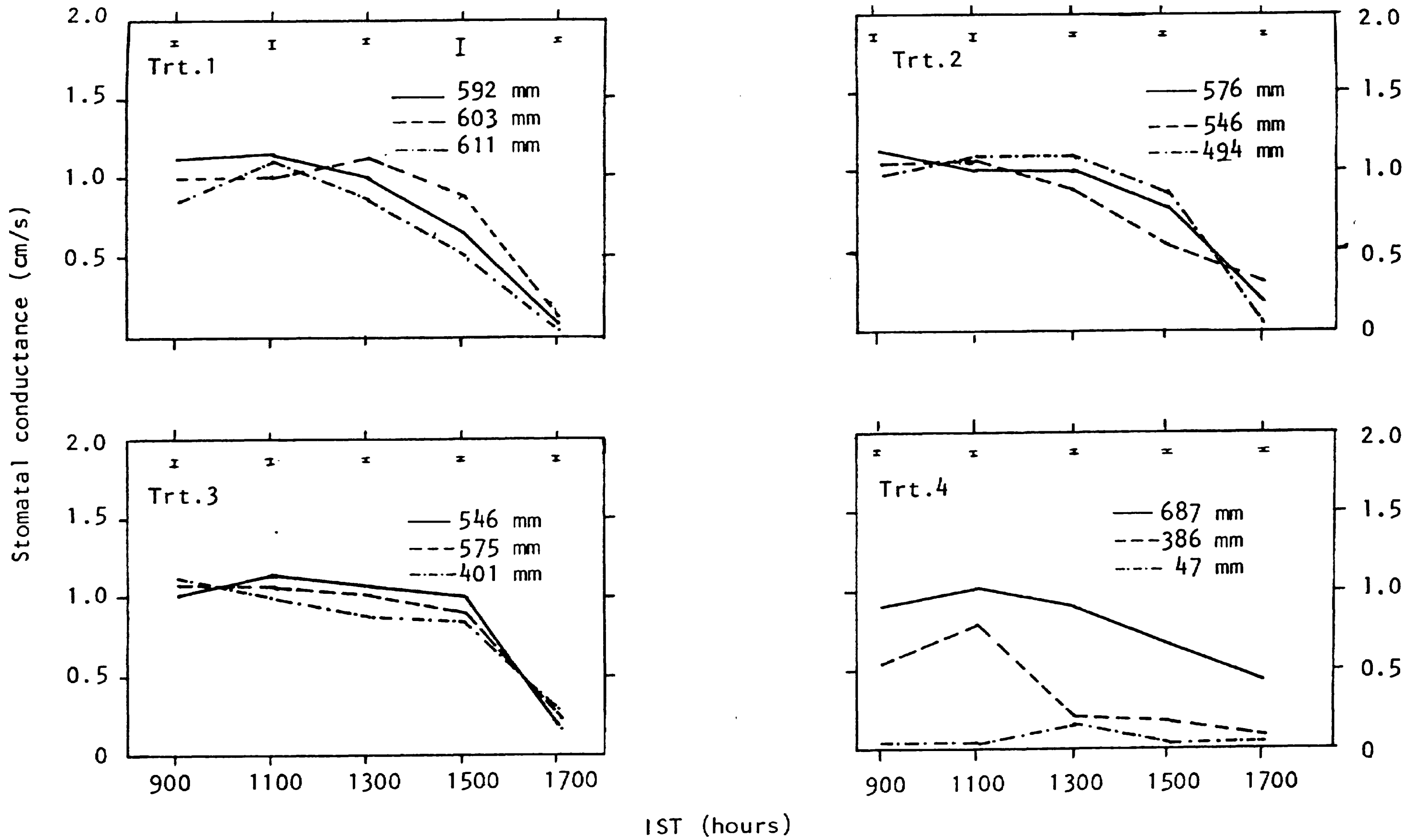
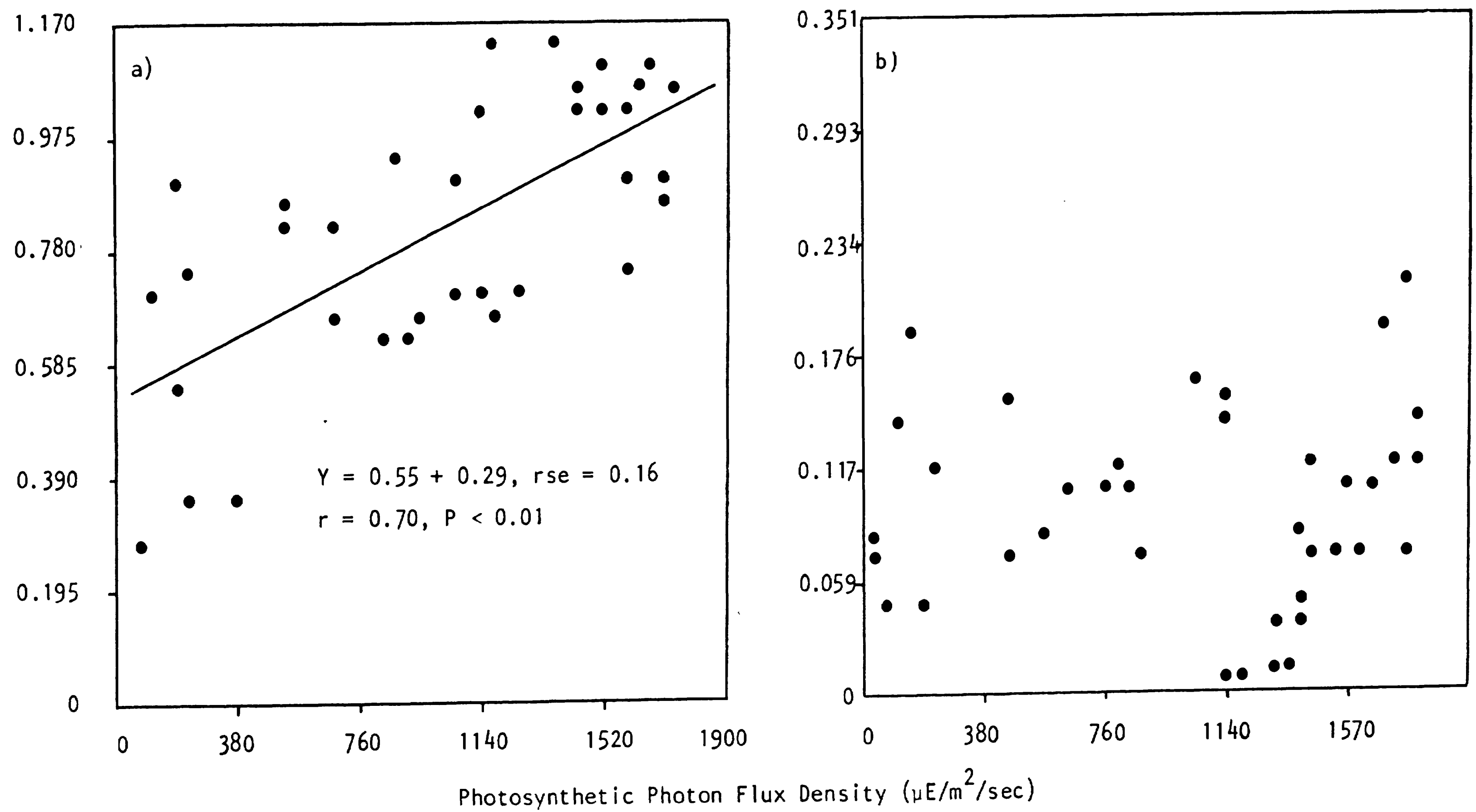


Figure 38. Diurnal variation in the stomatal conductance at different ET treatments on 118 DAE during 1982-83 postrainy season.



ure 39. Stomatal conductance as a function of photosynthetic photon flux density in Trt.4 at a) 687 mm and b) 47 mm ET levels during the 1982-83 postrainy season.

VPD classes viz., 1-4, 5-8, 9-12. The relationship between stomatal conductance and, Photonsynthetic Photon Flux Density (PPFD) at the three classes of Vapour Pressure Deficit (VPD) is shown in Figure 40.

At the low VPD range of 1-4 mb, the stomatal conductance was high and it increased with increasing photon flux density. In the VPD range of 5-8 mb, the stomatal conductance increase was slow at the low photon flux density but showed a greater increase at the higher values of 1700$\mu E/m^2/sec$.

4.3.3.2 Transpiration

4.3.3.2.1 Seasonal Variation

Seasonal changes in the transpiration under field conditions during the 1982-83 postrainy season are shown in Figure 41.

In Trt.1 up to 80 DAE transpiration was significantly higher in the plots with 592 mm of ET than in the plots with 611 mm of ET and the transpiration was similar at all the ET levels lateron. The maximum transpiration($18\ \mu g\ cm^{-2}\ s^{-1}$) was recorded on 33 DAE at 592 mm of ET against $11\ \mu g\ cm^{-2}\ s^{-1}$ at 611 mm of ET. In Trt.2 where moisture stress was imposed up to 57 DAE, the transpiration at 494 mm ET level was less up to 82 DAE as compared to those at ET levels of 546 and 576 mm. The crop recovered from the water stress lateron and the transpiration at different ET levels was almost similar during the rest of the crop growth period. At 546 mm of ET, transpiration values were close to those at 576 mm of ET at all sampling dates.

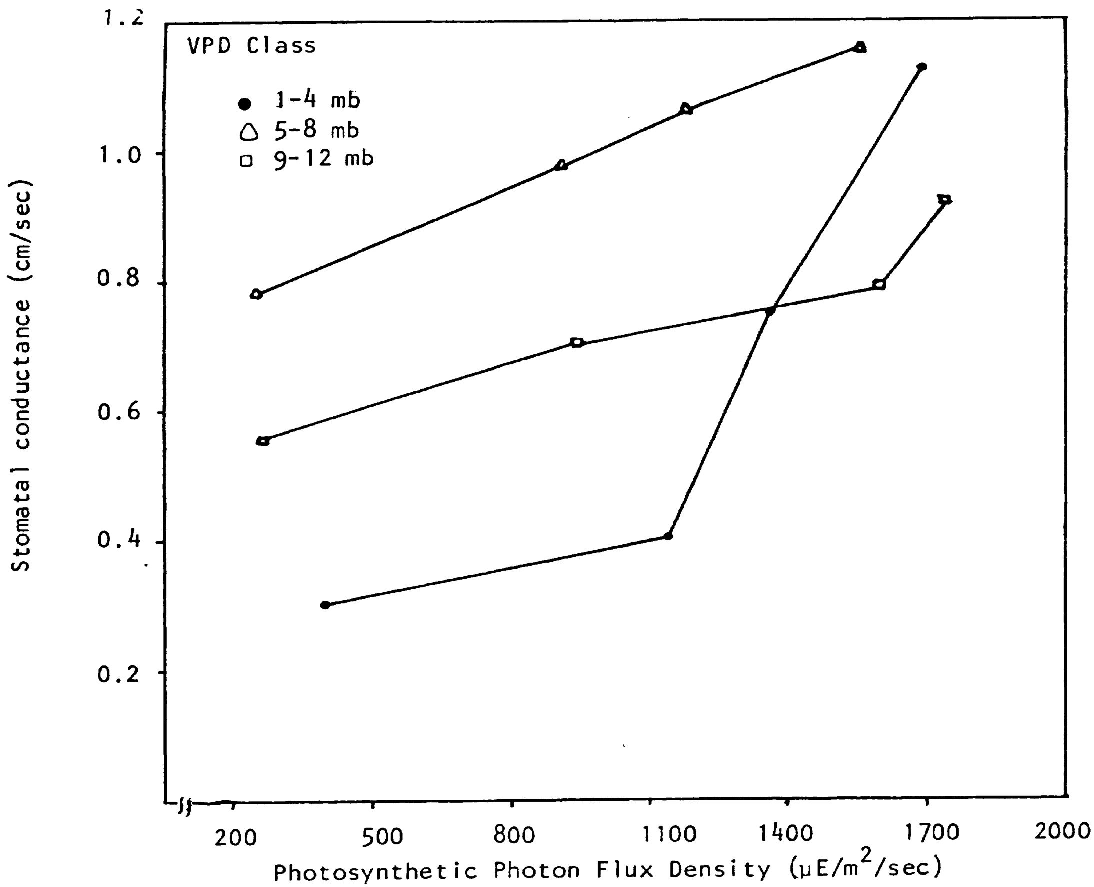


Figure 40. Stomatal conductance in Trt.4 at 687 mm ET level as a function of photosynthetic photon flux density (PPFD) in different vapor pressure deficit (VPD) class during the 1982-83 postrainy season.

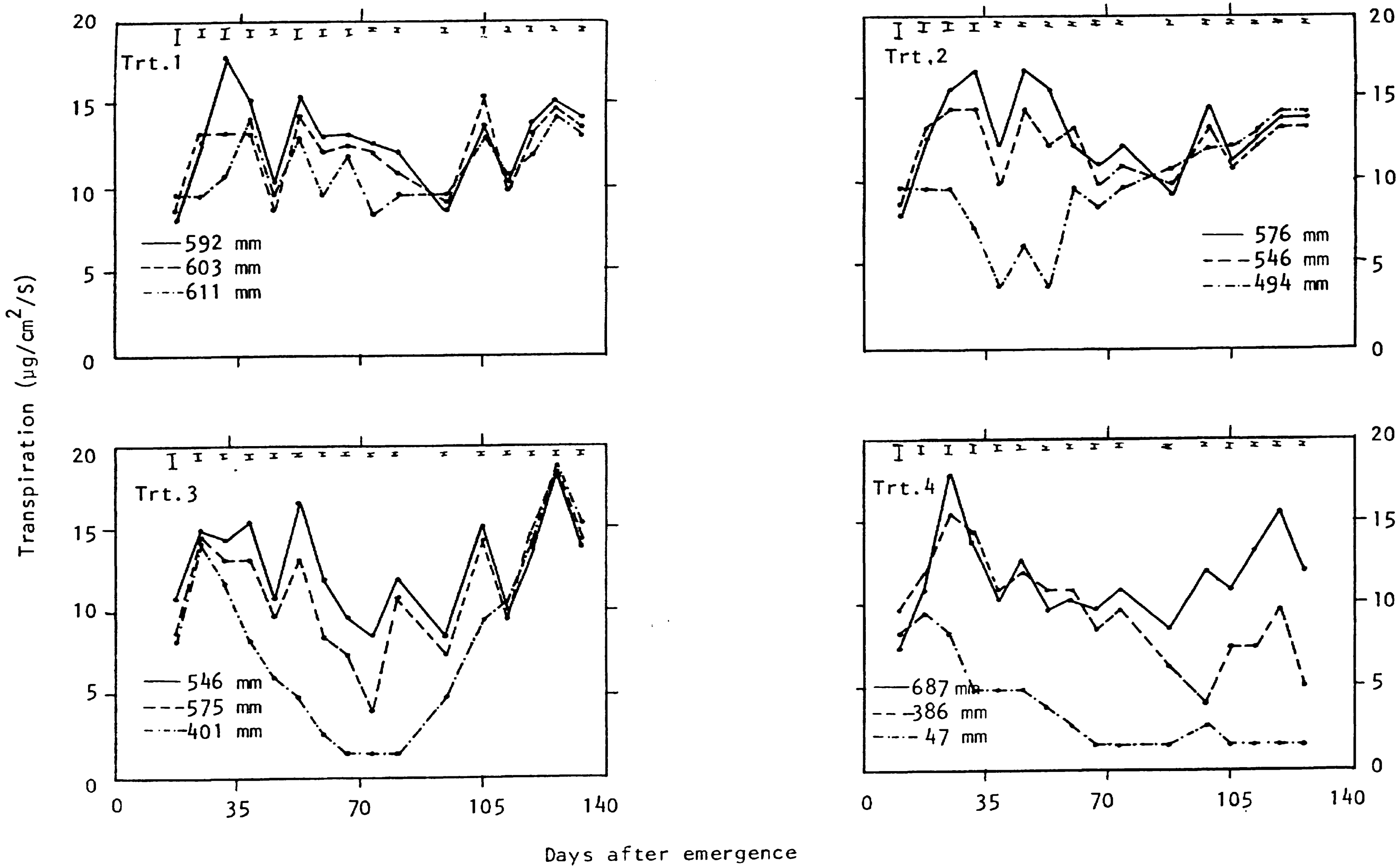


Figure 41. Seasonal variation in the transpiration at different ET levels for different treatments during the 1982-83 postrainy season.

In Trt.3 where moisture stress was imposed from 29 to 92 DAE, the differences among the 3 ET levels were large from 33 to 96 DAE. As low as 1.8 $\mu g\ cm^{-2}\ s^{-1}$ of transpiration was recorded during this period at the ET level of 401 mm while at 546 mm of ET the transpiration (16.5 $\mu g\ cm^{-2}\ s^{-1}$) was higher. The crop recovered from the water stress from 111 DAE onwards and the differences among the ET levels were not significant for the rest of the crop growth period.

In Trt.4 differences in the transpiration between the ET levels were large. The differences in transpiration between 687 and 386 mm ET levels were observed from 75 DAE. The lowest rates of transpiration ($0.7\ \mu g\ cm^{-2}\ s^{-1}$) were observed at the ET levels of 47 mm at 132 DAE against 11.8 $\mu g\ cm^{-2}\ s^{-1}$ at the ET level of 687 mm.

4.3.3.2.2. Diurnal Variation

Data at 75 DAE (Fig. 42) establish the fact that transpiration was influenced by the time of the day and the stage at which stress was imposed. The influence of an adequate supply of water is well described by the differences in the transpiration values in all the four treatments at different levels of ET. This was apparent in Trt.3 and Trt.4 wherein the differences in the diurnal variation in the transpiration observed at different ET levels were large. Time of the day has a significant effect on transpiration. These results were similar to those obtained in the diurnal changes of stomatal conductance. Transpiration was more until 1300 hrs in Trt.1 and Trt.4 while in Trt.2 and Trt.3 the increase was up to 1100 hrs only. With

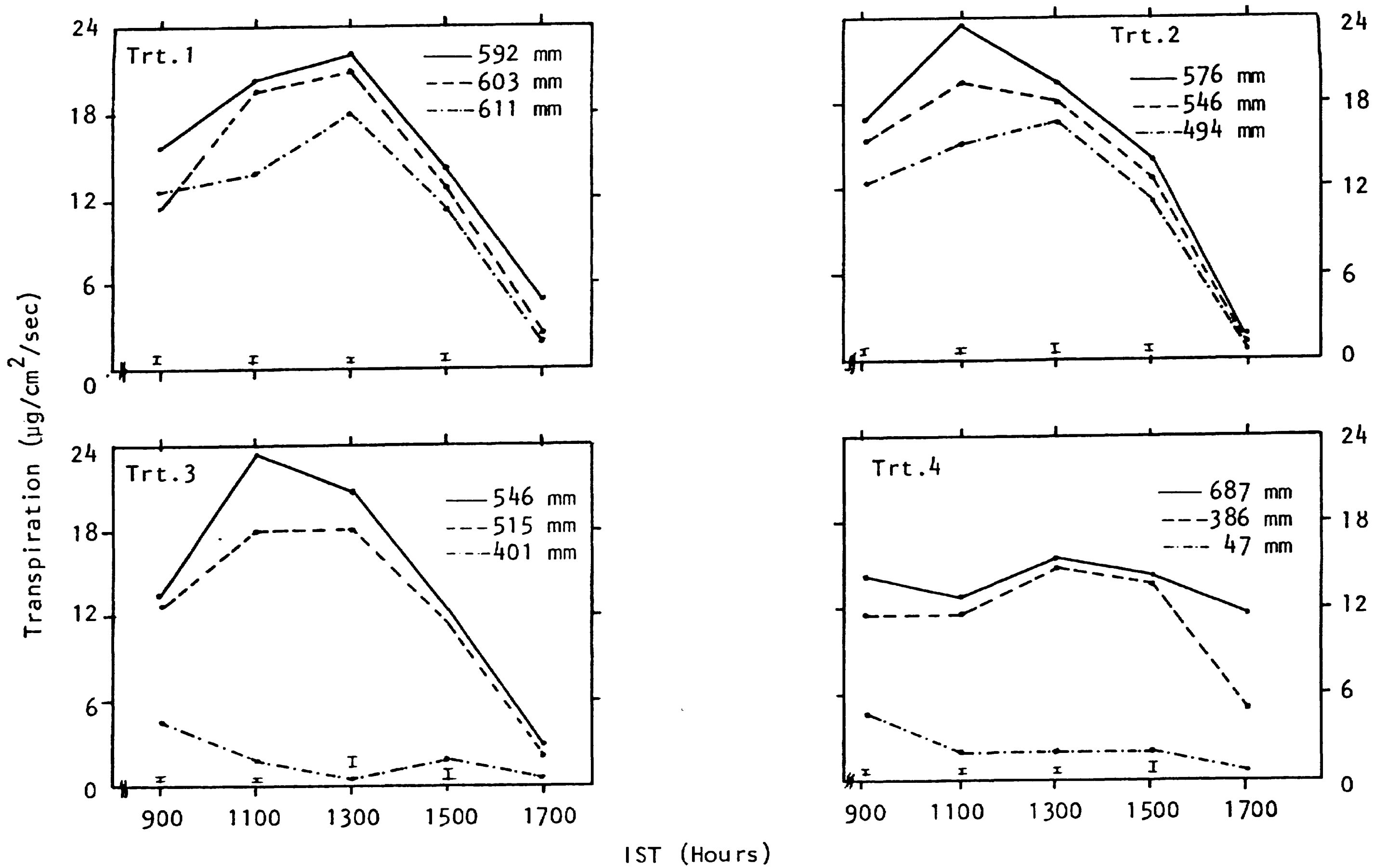


Figure 42. Diurnal variation in the transpiration at different ET levels for different treatments on 75 DAE during the 1982-83 postrainy season.

decrease in stomatal conductance with decreasing irradiance thereafter, transpiration showed a rapid drop. The diurnal changes in the transpiration at the low ET levels of 401 mm in Trt.3 and 47 mm in Trt.4 reflect the rapid stomatal closure described in Figure 37 earlier.

The transpiration values on 118 DAE (Fig.43) present a different picture. While changes in the diurnal pattern of transpiration at different ET levels were not well distinguished in Trt.1 to Trt.3, the differences were well defined in Trt.4. Time of day also has a significant effect on transpiration. In most of the treatments, transpiration increased upto about 1100 hrs and thereafter started decreasing. But in Trt.2 at 576 mm of ET and in Trt.4 with 687 mm of ET given, transpiration reached a maximum at 1300 hrs and thereafter started decreasing rapidly.

4.3.3.3 Leaf Water Potential

4.3.3.3.1 Seasonal variation

Seasonal variation in leaf water potential under field conditions during the 1982-83 postrainy season are shown in Figure 44.

Excepting Trt.1, it was observed that in the other three treatments the leaf water potential values decreased with decreasing ET.

In Trt. 3 which was under moisture stress from 29 to 92 DAE, the leaf water potential values reached a maximum of -24 bars at 401 mm of ET and the differences among the ET levels were large up to 104 DAE.

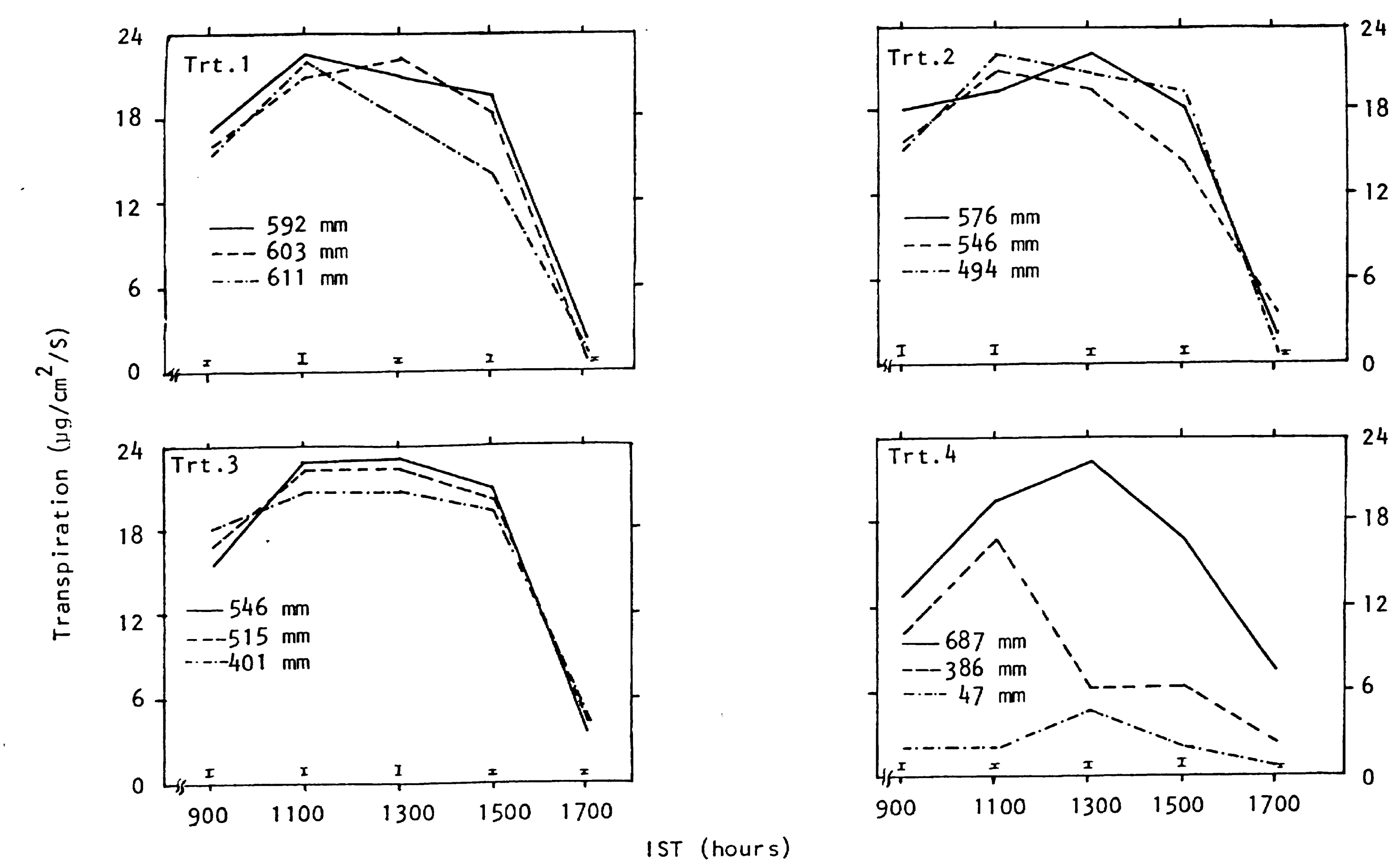


Figure 43. Diurnal variation in the transpiration at different ET levels for different treatments on 118 DAE during the 1982-83 postrainy season.

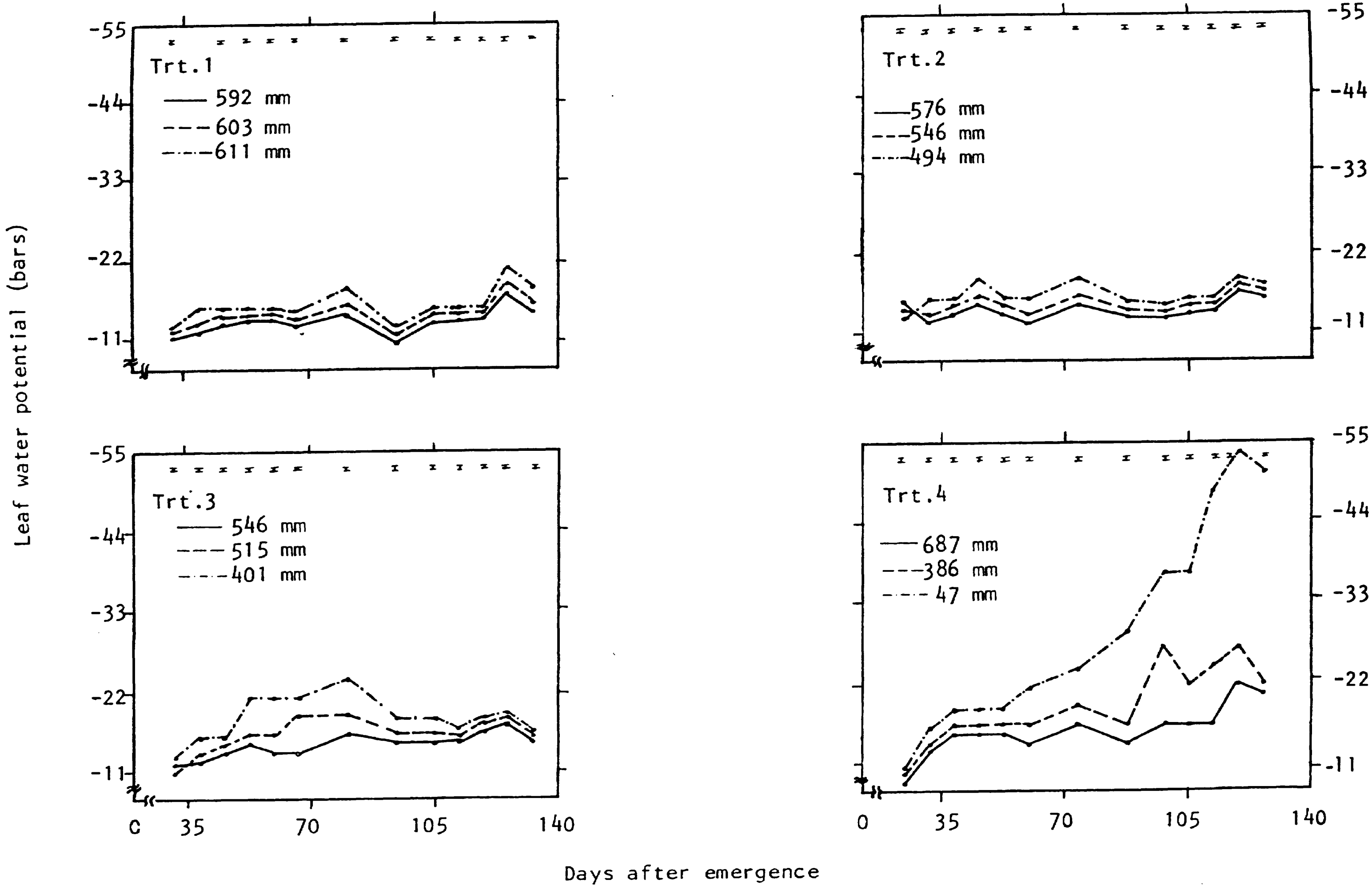


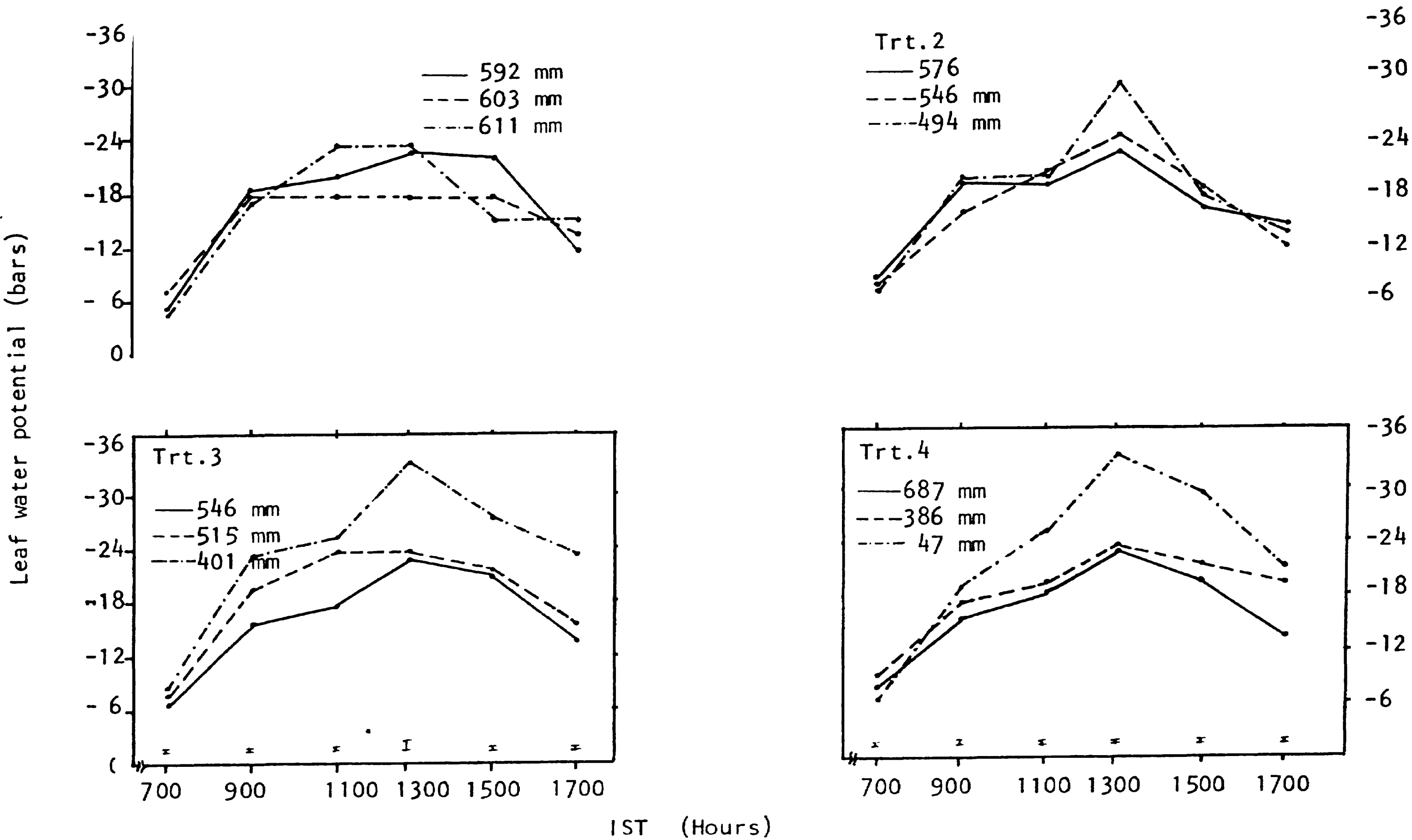
Figure 44. Seasonal variation in the leaf water potential at different ET levels of different treatments during the 1982-83 postrainy season.

With irrigations afterwards, the leaf water potential values have come down to about -15 bars.

In Trt.4 large differences were observed in leaf water potential among the ET levels, in particular between 687 mm and 47 mm of ET.The leaf water potential values at 687 mm of ET ranged from -8 to -20 bars while at 47 mm of ET, the values ranged from -10 to -54 bars on a seasonal basis which indicates the severe moisture stress conditions imposed in the latter case. In the case of ET level of 386 mm, the leaf water potential values ranged from -9 to -26 bars.

4.3.3.3.2 Diurnal Variation

Data at 75 DAE (Fig.45) establish the fact that leaf water potential was influenced by the time of the day and the stage at which the water stress was imposed. The influence of an adequate supply of water is well described by low leaf water potential in adequately watered plots as against high values obtained in the moisture stress plots. This was more clear in Trt.3 and Trt.4, where large differences in leaf water potentials were observed between the ET levels. In Trt.3 and Trt.4 it was observed that the leaf water potentials decreased with decreasing ET with the minimum values recorded at 1300 hrs (IST). In Trt.3 which was under moisture stress from 29-92 DAE, the diurnal changes in leaf water potential were very distinct on 75 DAE. The values in general increased with decreased ET and were different from 0900 to 1700 hrs at different ET levels. At 401 mm ET level, the leaf water potential values ranged from -7 to -36 bars.



igure 45 Diurnal variation in the leaf water potential at differe eve or er treatments on 75 DAE during the 1982-83 postrainy season

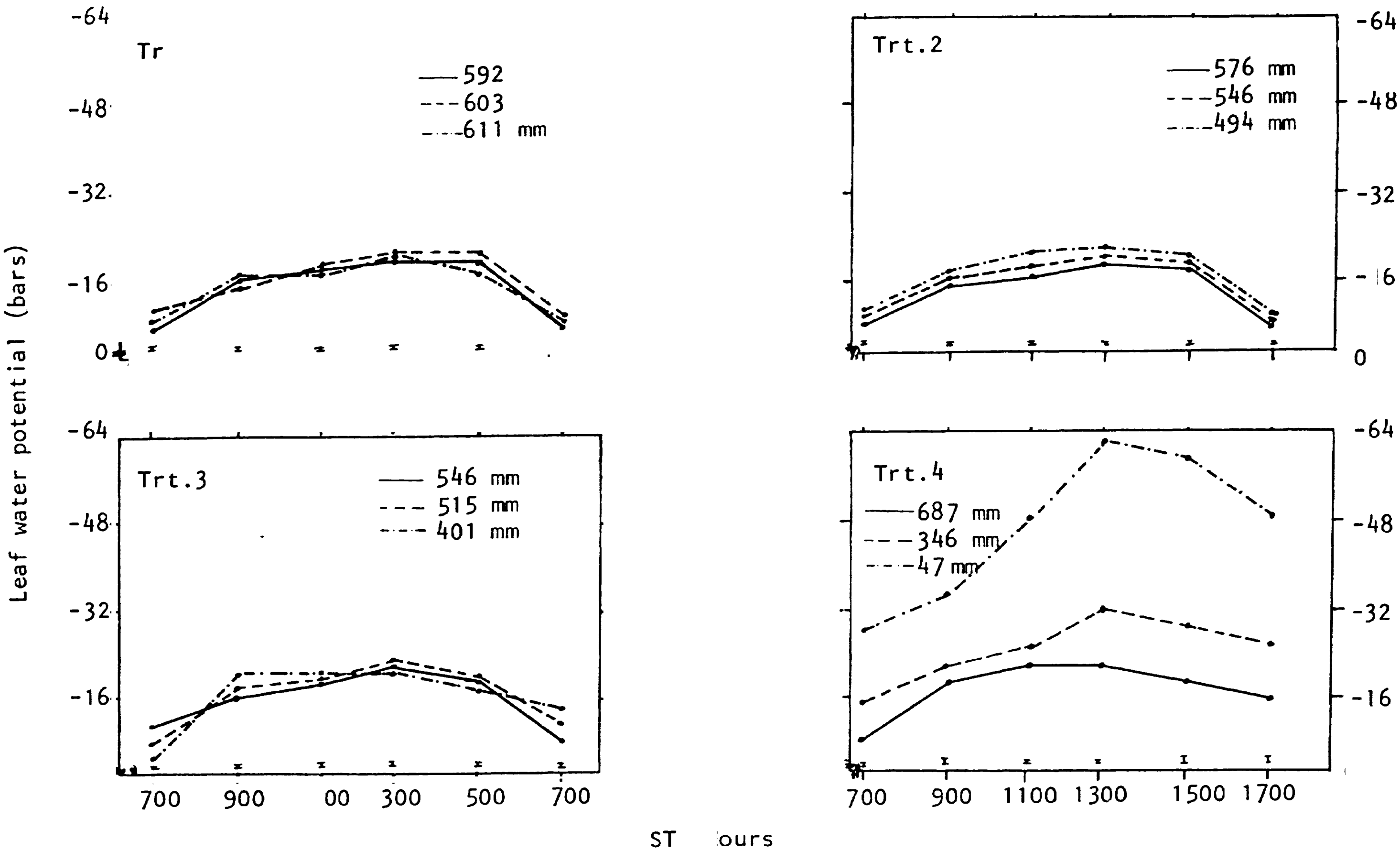
In Trt.4, the leaf water potential values were different at the high and low ET levels. But the values were almost similar at the 687 mm and 386 mm ET levels.

Diurnal changes in the leaf water potential at 118 DAE (Fig. 46) present a different picture from that observed on 75 DAE. Among the phenological stages, marked differences in diurnal changes of leaf water potential could be seen only in Trt.4 while the differences in Trt.1 to Trt.3 were very narrow. In Trt.4, the variation in the leaf water potential ranged from -7 to -63 bars.

At different ET levels,no marked differences were noticed in Trt.1 to Trt.3. But in Trt.4, the diurnal changes in the leaf water potential at 687 mm were not much since the range of variation was from -7 to -21.5 bars. At the ET level of 47 mm, the variation was large (-29 to -63 bars), reaching the peak water potential of -63 bars by 1300 hrs. The response of the crop at 386 mm of ET level was close to that at 687 mm of ET.

4.3.3.3.3 Leaf water potential as a function of stomatal conductance at three classes of vapour pressure deficit (VPD)

Observations on leaf water potential and stomatal conductance collected from 75 DAE were grouped into three VPD classes viz., 1-4, 5-8 and 9-12 mb and the relation between leaf water potential and stomatal conductance at the three classes of VPD is shown in Figure 47.



gure 46. Diurnal variation in the leaf water potential at differen eve or en treatments at 118 DAE during the 1982-83 postrainy season

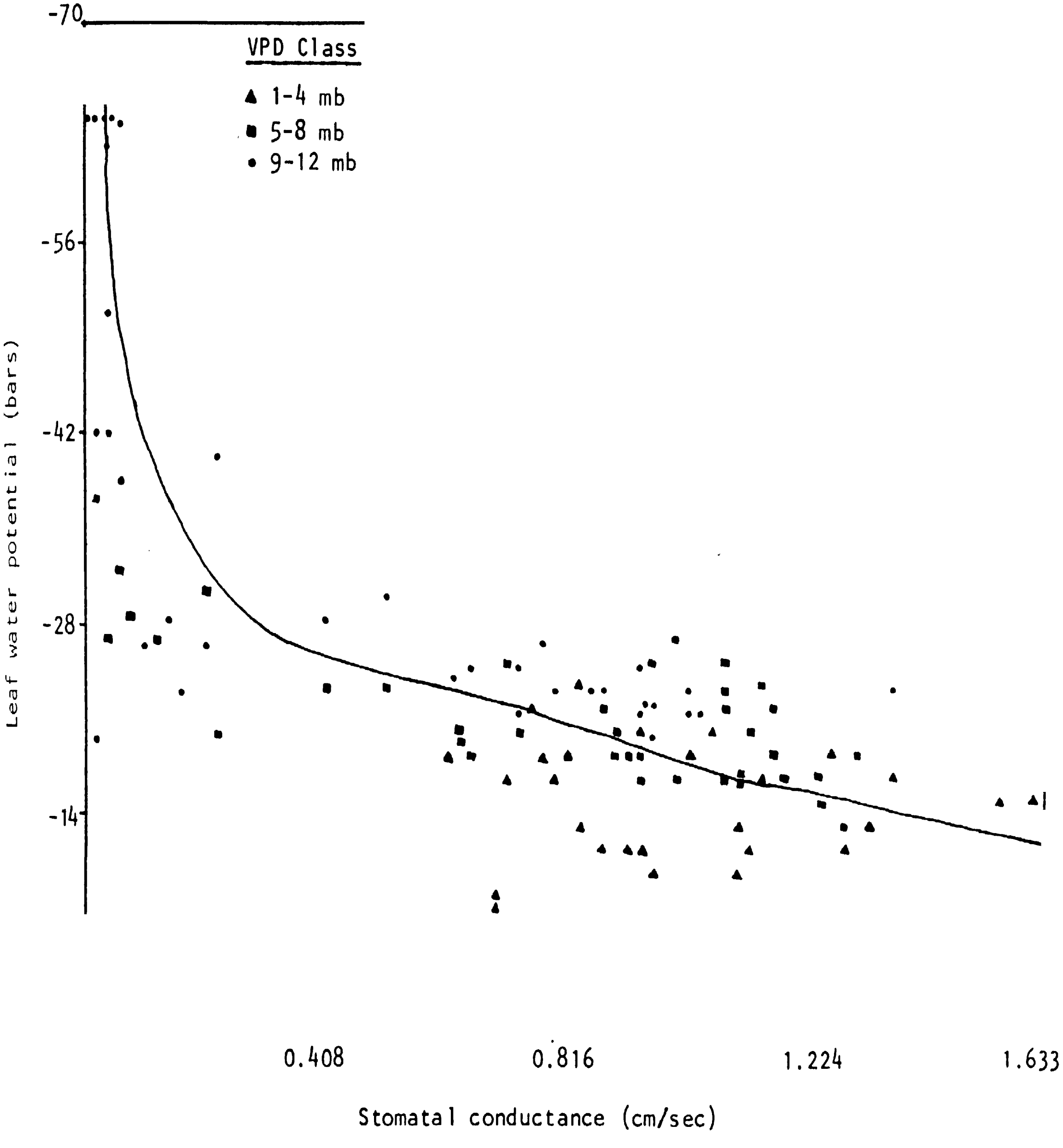


Figure 47. Leaf water potential as a function of stomatal conductance. Data pooled over 3 different classes of vapor pressure deficit (VPD) during the 1982-83 postrainy season.

In the VPD class 1-4 mb, with low values of leaf water potential stomatal conductance was higher. This is evident from the occurrence of many observations when the stomatal conductance was between 0.6 t0 1.4 cm/sec with leaf water potential of less than -15 bars. In the VPD class of 5-8 mb, the stomatal conductance values ranged from 0.6 to 1.2 cm/sec with leat water potential at -15 to -25 bars.

In the VPD class of 9-12 mb, stomatal conductance was very low (0-0.2 cm/sec) with the increase in the leaf water potential (-15 to -65 bars). In general, it is observed that stomatal conductance decreased with increase in leaf water potential especially in the VPD classes of 5-8 mb and 9-12 mb.

4.3.3.4. Canopy Temperature

4.3.3.4.1 Seasonal variation

Seasonal variation in the canopy temperature at different ET levels for different treatments are shown in Figure 48.

With the exception of Trt.1, it was observed that the canopy temperatures increased with decreasing ET and the differences were large especially in treatments 2 to 4.

Among the ET levels,no marked differences were noticed among the subtreatments in Trt.1 since the moisture stress was released at 29 DAE.

In Trt.2 which was under moisture stress from emergence to 57 DAE, the canopy temperatures were higher at 494 mm of ET when compared to 5/6 mm ET level. The groundnut crop was warmer in the former case by about 4 to 8 °C than in the latter. When the moisture stress was

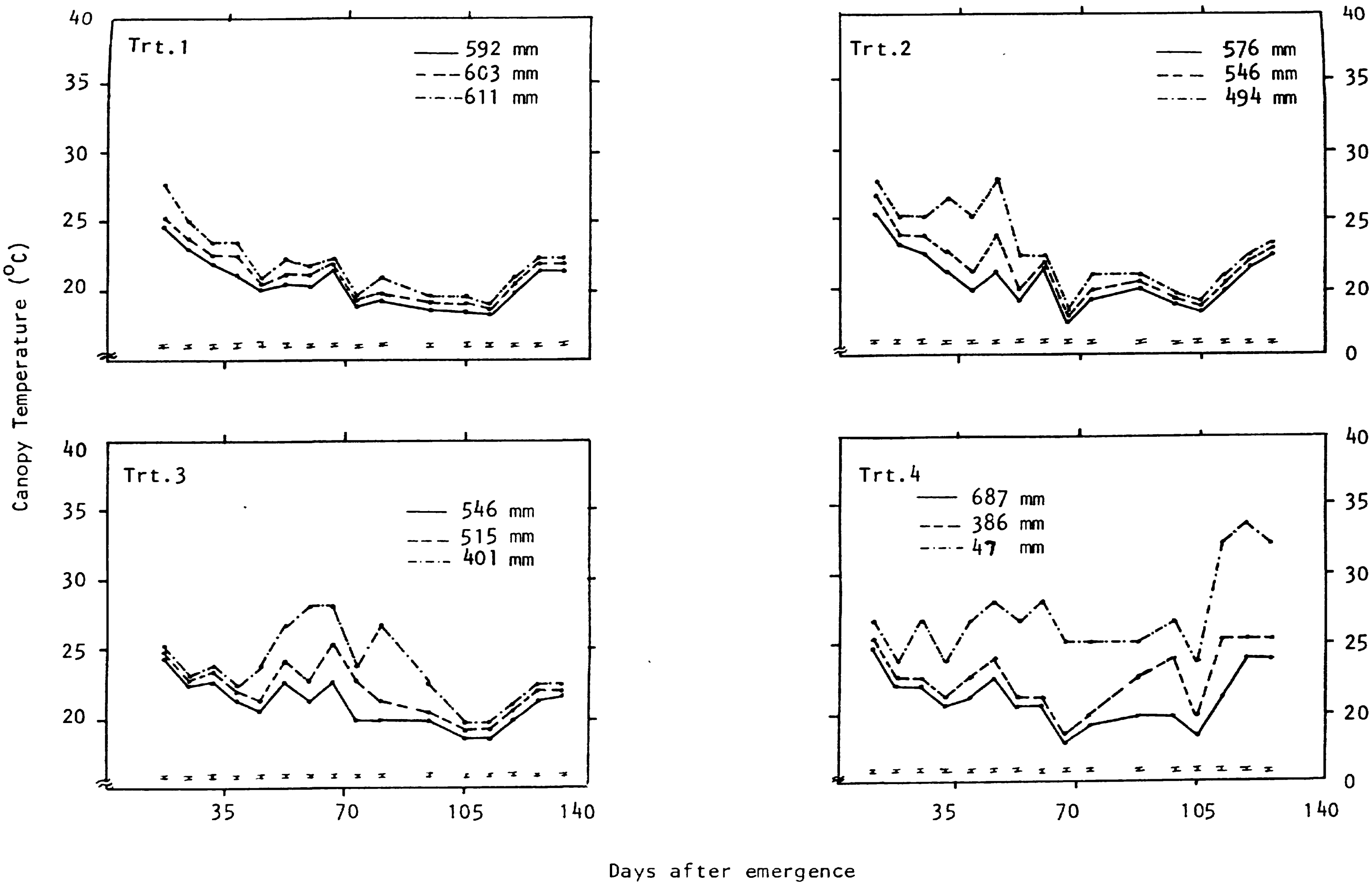


Figure 48. Seasonal variation in the canopy temperature at different ET levels for different treatments during the 1982-83 postrainy season.

released in this Trt., there was a 8-10 °C drop in the canopy temperature which could be attributed to evaporative cooling provided by increased transpiration flux.

In treatment 3 which was under moisture stress from 29-92 DAE, there were apparent differences in the canopy temperature at different ET levels. The plants at 401 mm ET level were warmer by 8-10 °C than those at 546 mm ET level. While the maximum canopy temperature recorded in the former case was 29 °C, in the latter it was only 22°C. After the release of moisture stress in this treatment, there was a drop of about 9-10 °C in the canopy temperature due to transpirational cooling.

In Trt.4 the differences in canopy temperature between ET levels were large throughout the growing season. The plants at 386 mm ET level exhibited temperatures similar to those at 687 mm level up to 82 DAE. The maximum mean canopy temperature at 687 mm ET level was only 24°C while at 4/ mm it peaked to 35°C.

4.3.4.4.2 Diurnal Variation

Data at 75 DAE (Fig.49) establish the fact that canopy temperature was influenced by the time of the day and the stage at which the water stress was imposed. The influence of an adequate supply of water as against stress conditions is well described by low canopy temperatures at high ET levels as against high temperatures at the low ET levels. This was not that much evident in Trt.1 and Trt.2 due to the fact that in these treatments moisture stress was released

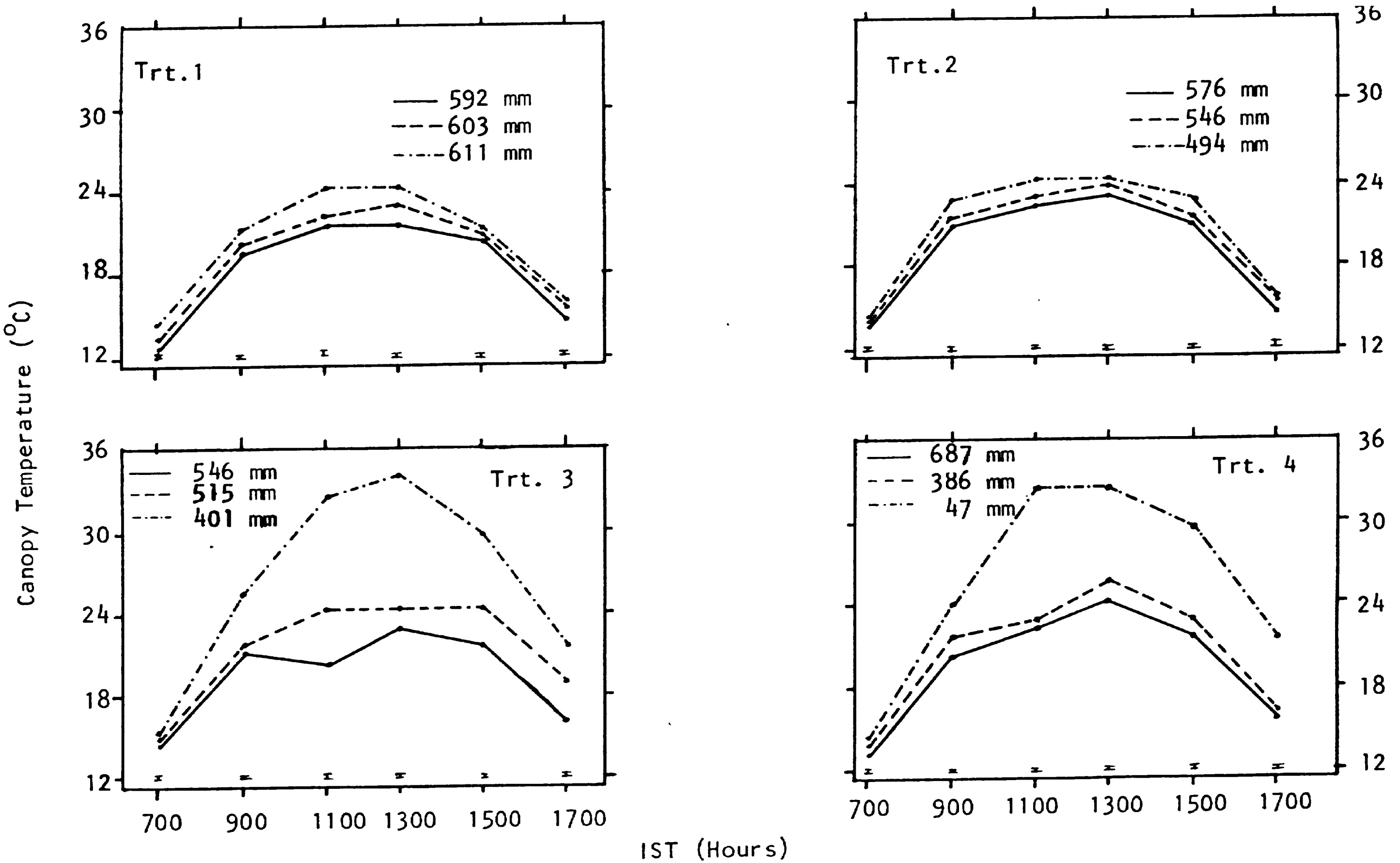


Figure 49. Diurnal variation in the canopy temperature at different ET levels at 75 DAE for different treatments during the 1982-83 postrainy season.

long before 75 DAE and normal irrigations were given. Trt.3 which was under moisture stress from 29 to 92 DAE, exhibited significant differences among ET levels in particular, at 401 mm. The canopy temperatures peaked to 35°C at 1300 hrs at 401 mm ET level while in the other two ET levels, the canopy temperatures reached 24°C at 1300 hrs. In Trt.4, at 47 mm ET level the canopy temperatures were much higher when compared to the other ET levels. Here the canopy reached a maximum temperature of 33°C by 1100 hrs and maintained the same until 1300 hrs and then the temperatures started decreasing. The maximum temperature recorded at the other two ET levels was 25°C.

Diurnal changes in the canopy temperature at 118 DAE (Fig.50) present a different picture from that observed at 75 DAE. Among the treatemnts, marked differences in the canopy temperature could be seen in Trt.4 only while the treatments 1 to 3 did not show much differences and also among the different ET levels. In Trt.4, the diurnal changes were significantly different among the three ET levels. At 47 mm of ET, maximum canopy temperature of 41.4 °C was recorded by 1300 hrs while at the other two ET levels maximum canopy temperatures were 31.4 °C and 35.6°C.

4.3.3.4.3 Relationship Between Stress Degree Days and Total Evapotranspiration

Relationship between Stress Degree Days (SDD) and Total Evapotranspiration (TET) of differentially irrigated groundnut during the 1982-83 postrainy season is shown in Figure 51.

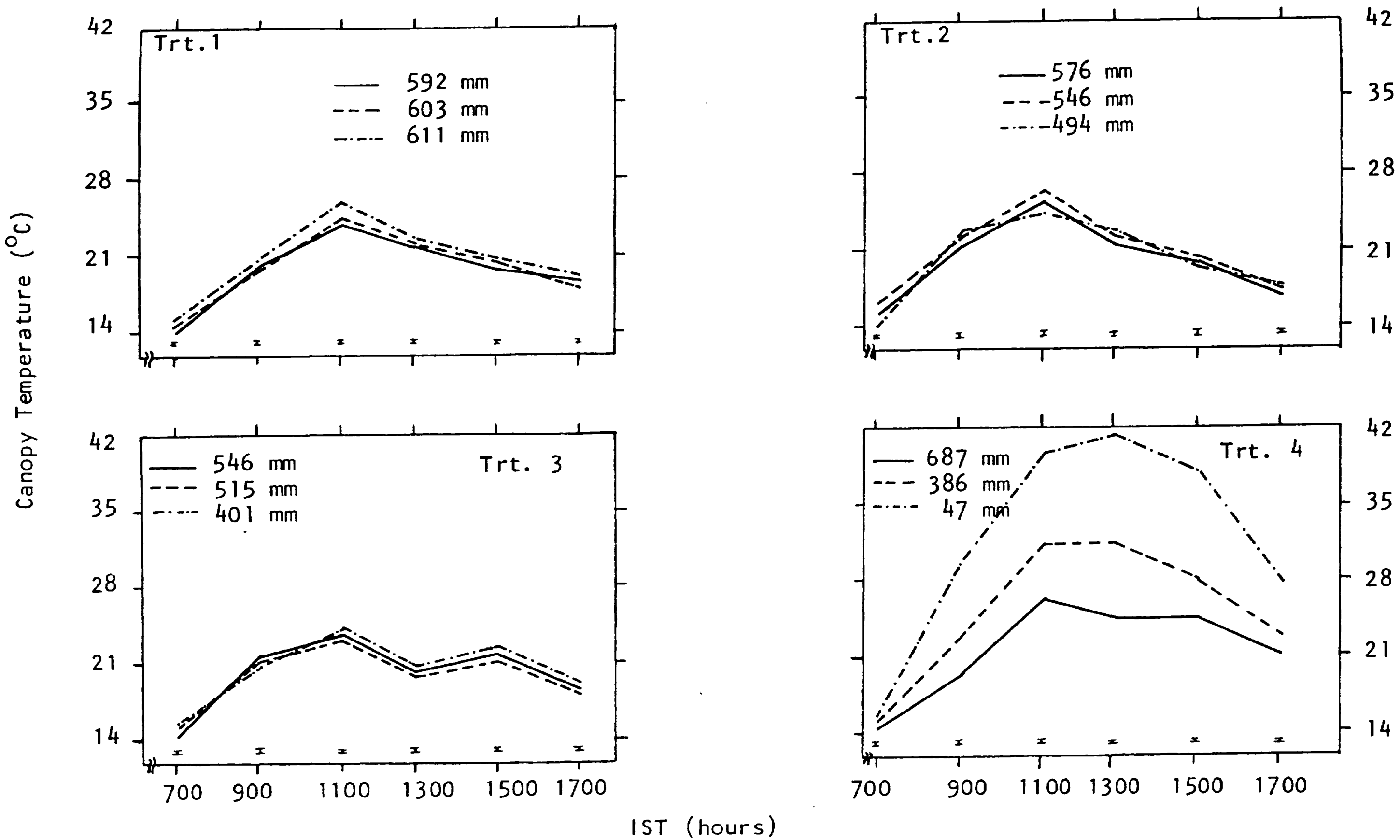


Figure 50. Diurnal variation in the canopy temperature at different ET levels for different treatments on 118 DAE during the 1982-83 postrainy season.

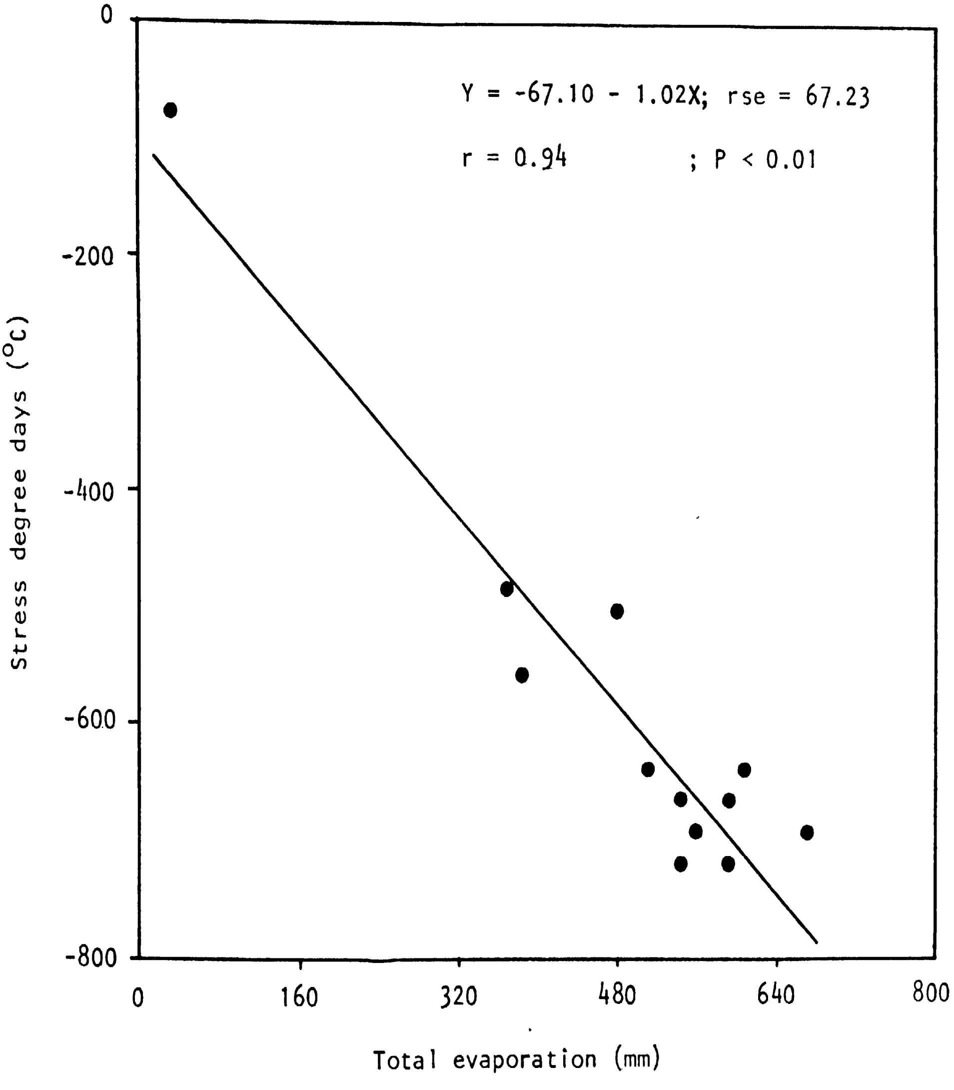


Figure 51. Relationship between stress degree days and total evapotranspiration for different treatments during the 1982-83 postrainy season.

The relationship between SDD and TET was highly significant and negatively correlated (r=0.94). At low values of TET, the SDD values were high while at high TET, the SDD values were quite low.

4.3.3.5 Canopy-air temperature differential (CATD)

4.3.3.5.1 Seasonal Variation

The seasonal variation in the canopy-air temperature differential are presented in Figure 52 for all the treatments.

Among the treatments, the differences in CATD were quite distinct in Trt.2 to Trt.4 while in Trt.1, the differences were not distinct.

In the case of Trt.2 which was under moisture stress up to 57 DAE, the CATD values were very low (1.9 to -2.9°C) at 494 mm of ET while at 576 mm the CATD values were from -1.3 to -5.3°C. After the release of moisture stress, the CATD values were not much different among the three ET levels.

In Trt.3 which was under moisture stress from 29 to 92 DAE, the CATD values were quite low (2.0 to -3.7°C) during the period of moisture stress at 401 mm ET level while at 546 mm of ET the the CATD values ranged from -2 to -6.7°C. The CATD values obtained at 515 mm ET level were close to those with 546 mm of ET.

In Trt.4 large differences in CATD values were noticed between the ET levels of 687 mm and 47 mm while the values at 386 mm were close to those obtained at 687 mm. The CATD values ranged from -2 to -8.8°C at 687 mm while the values were very low at 47 mm (1.9 to -

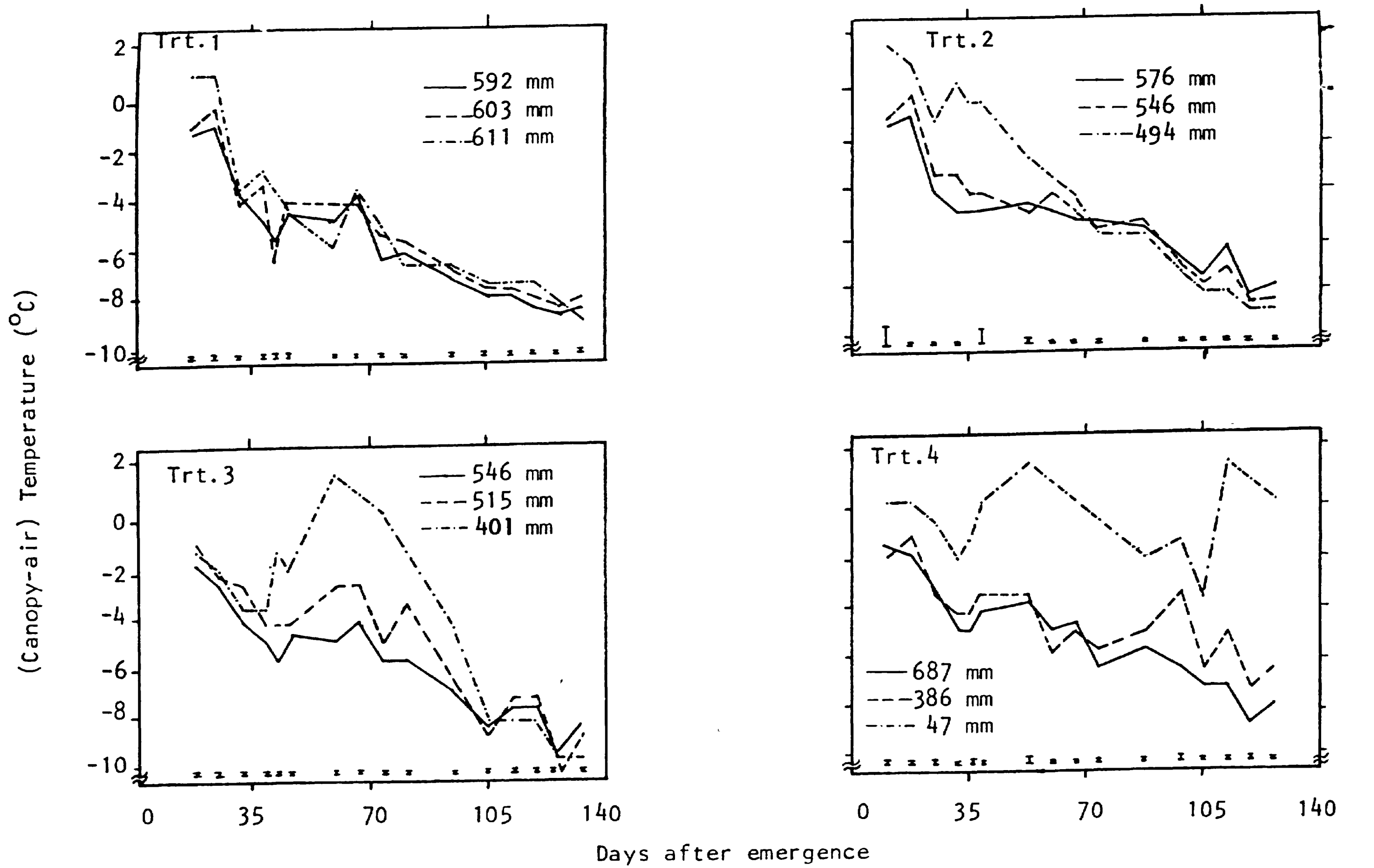


Figure 52. Seasonal variation in the (canopy-air) temperature at different ET levels for different treatments during the 1982-83 postrainy season.

3.7°C) indicating the severity of moisture stress in the latter case.

4.3.3.5.2 Diurnal Variation

Data at 75 DAE (Fig.53) establish the fact that CATD values were influenced by time of the day and the stage at which the moisture stress was imposed. The differences in CATD values were not much distinct in Trt.1 and Trt.2 where the crop recovered fully from the moisture stress by 75 DAE. But in the case of Trt.3 and Trt.4, marked differences were noticed among the ET levels. In Trt.3, which was under moisture stress from 29 to 92 DAE, significant differences in the diurnal values of CATD were observed between 546 and 401 mm ET levels while the values at 515 mm were close to those at 546 mm. At 401 mm of ET, CATD values were positive between 1100 to 1500 hrs (1.5 to 3.4 °C) while at 546 mm, the values were in the range of -1 to -10.8°C.

In Trt.4 large differences in the diurnal values of CATD were observed between 687 and 47 mm of ET while the values at 386 mm were close to those at 687 mm. The CATD values were positive (1.4 to 3.4°C) at 47 mm of ET between 1100 to 1500 hrs while at 687 mm CATD values ranged from -4.4 to -7.2 °C.

Data at 118 DAE (Fig. 54) on diurnal variation in CATD values present a different picture. As with transpiration, leaf water potential and canopy temperatures marked differences could be seen in only Trt.4 while the differences were very narrow in Trt.1 to Trt.3.

4.3.4 Soil temperature

4.3.4.1 Seasonal Variation

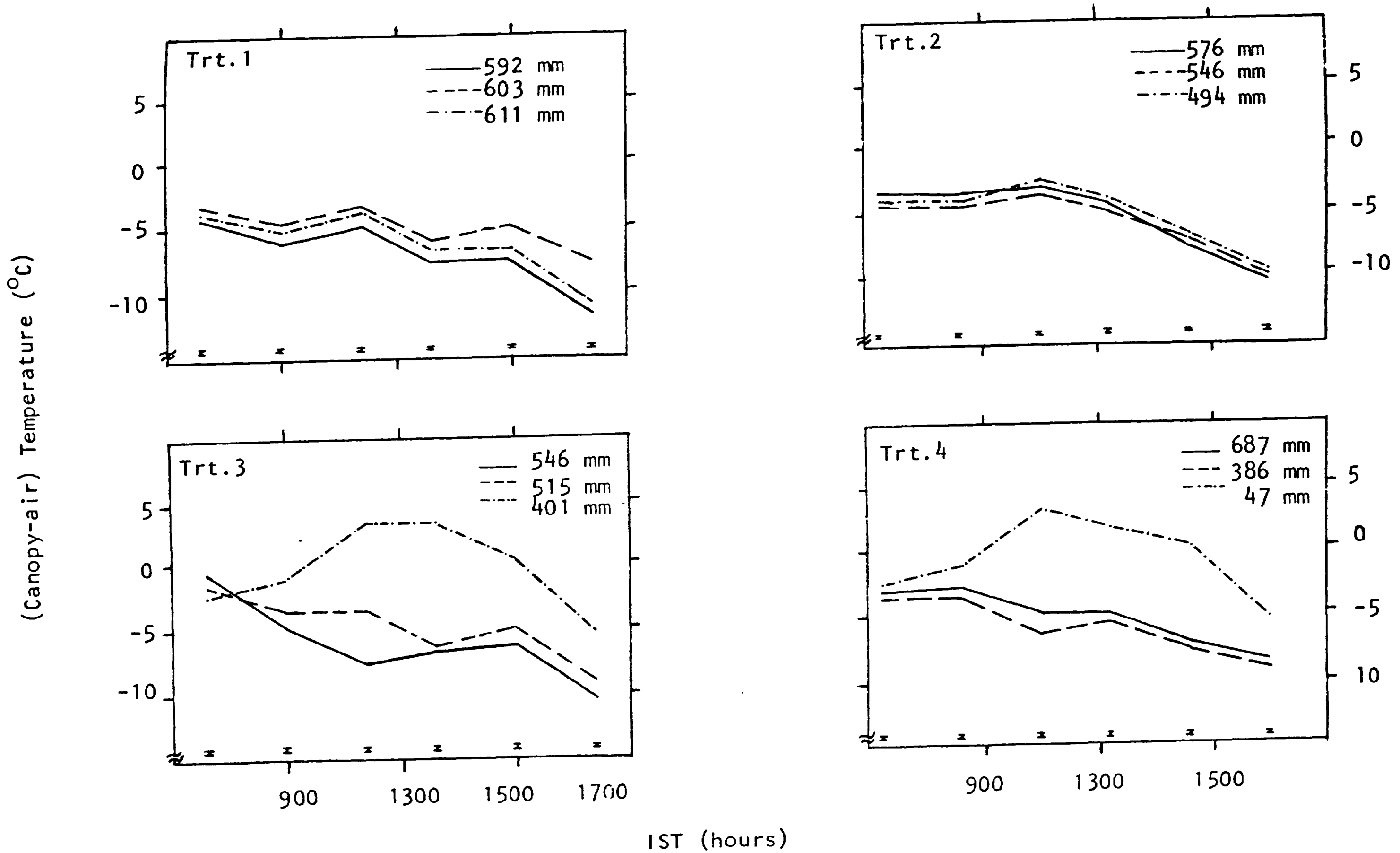


Figure 53. Diurnal variation in the (canopy-air) temperature at different ET levels for different treatments on 75 DAE during the 1982-83 postrainy season.

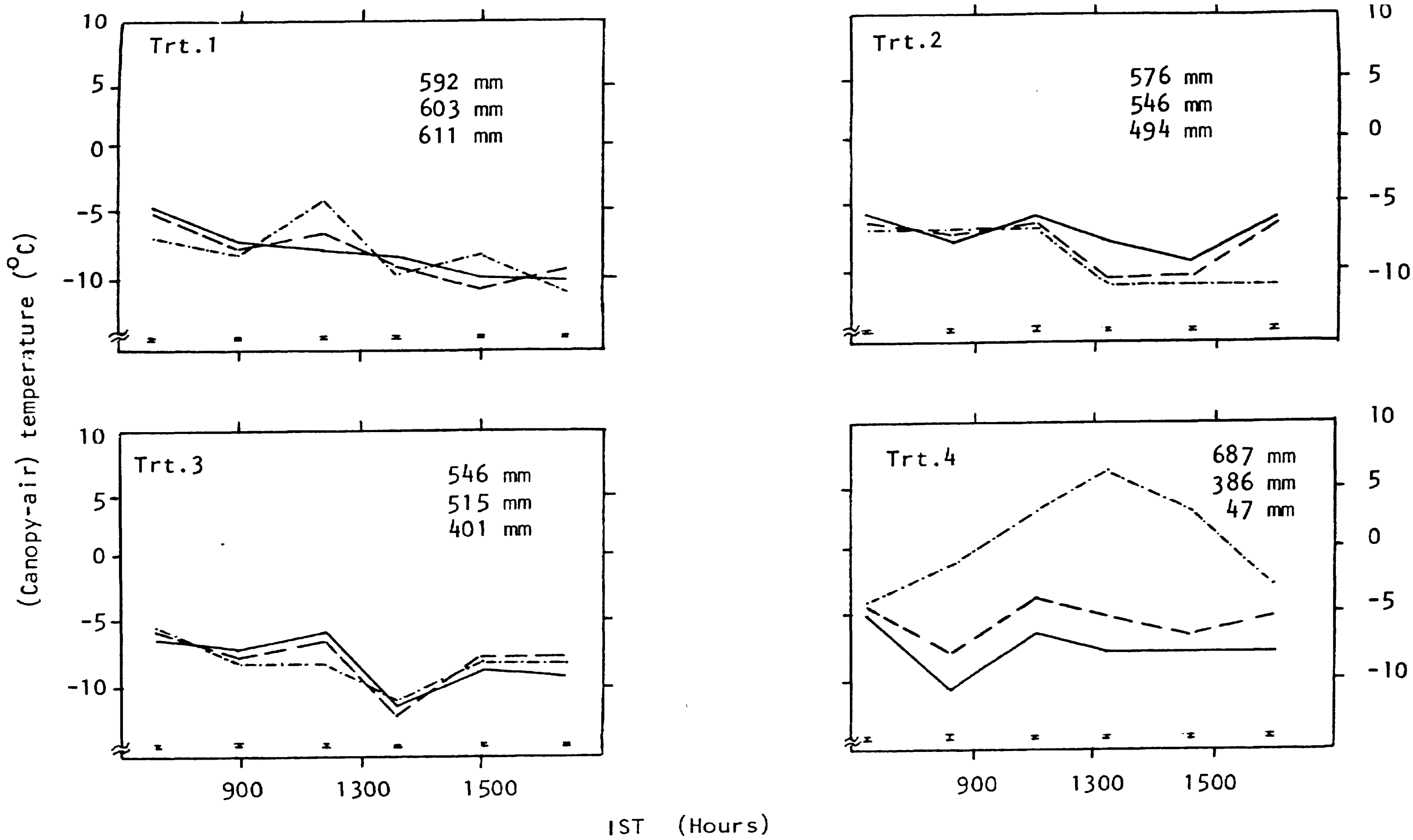


Figure 54. Diurnal variation in (canopy-air) temperature at different ET levels for different treatments on 118 DAE during the 1982-83 postrainy season.

Seasonal variation in the soil temperature at 10 cm dpeth at 687 and 47 mm ET levels in Trt.4 as compared to air temperature are shown in Figure 55.

Soil and air temperatures were recorded from 24-148 DAE. Up to about 60 DAE, the soil temperature exceeded air temperature at both the ET levels and lateron, the soil temperature at the high ET level was consistently below the air temperature. At the low ET level, the soil temperature exceeded the air temperature by 2-4°C.

4.3.4.2 Diurnal Variation

The diurnal variation in the soil temperature at the two ET levels of 687 and 47 mm in Trt.4 on 75 and 118 DAE are presented in Figures 56 and 57 respectively.

At 75 DAE, soil temperature at both the ET levels was above air temperatures up to 0800 hrs. With increasing energy flux thereafter, the air temperatures increased more rapidly compared to the soil temperatures up to 1600 hrs. Soil temperatures at the low ET level of 47 mm were below air temperatures from 0900 to 1400 hrs but were above air temperatures afterwards. At the high ET level however from 0800 hrs onwards soil temperatures were below the air temperature. The difference in the peak soil temperature between the high and low ET levels was 8°C.

By 118 DAE, the air temperatures were much higher compared to those at 75 DAE. The pattern of variation in soil temperature at the low ET levels was similar to that described above for 75 DAE. At the

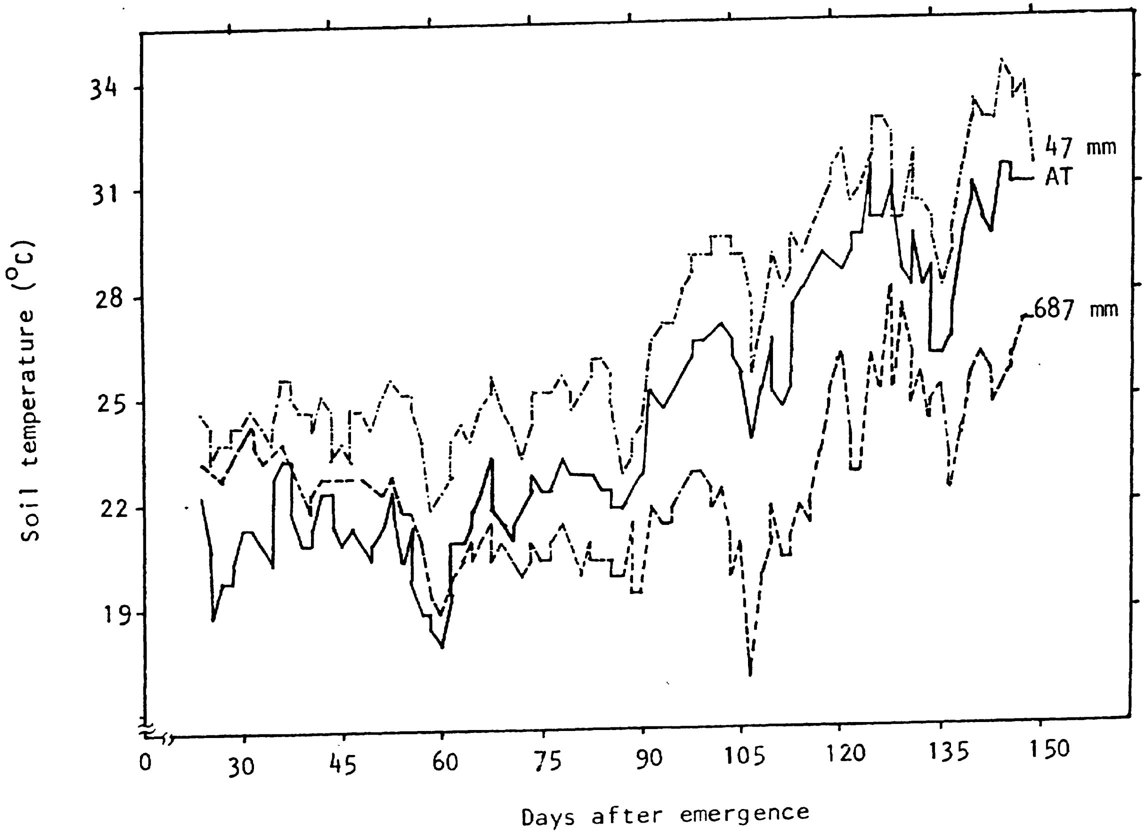


Figure 55. Seasonal variation in the soil temperature at 10 cm depth at 687 and 47 mm ET levels in Trt.4. Air temperature (AT) is shown ______ during the 1982-83 postrainy season.

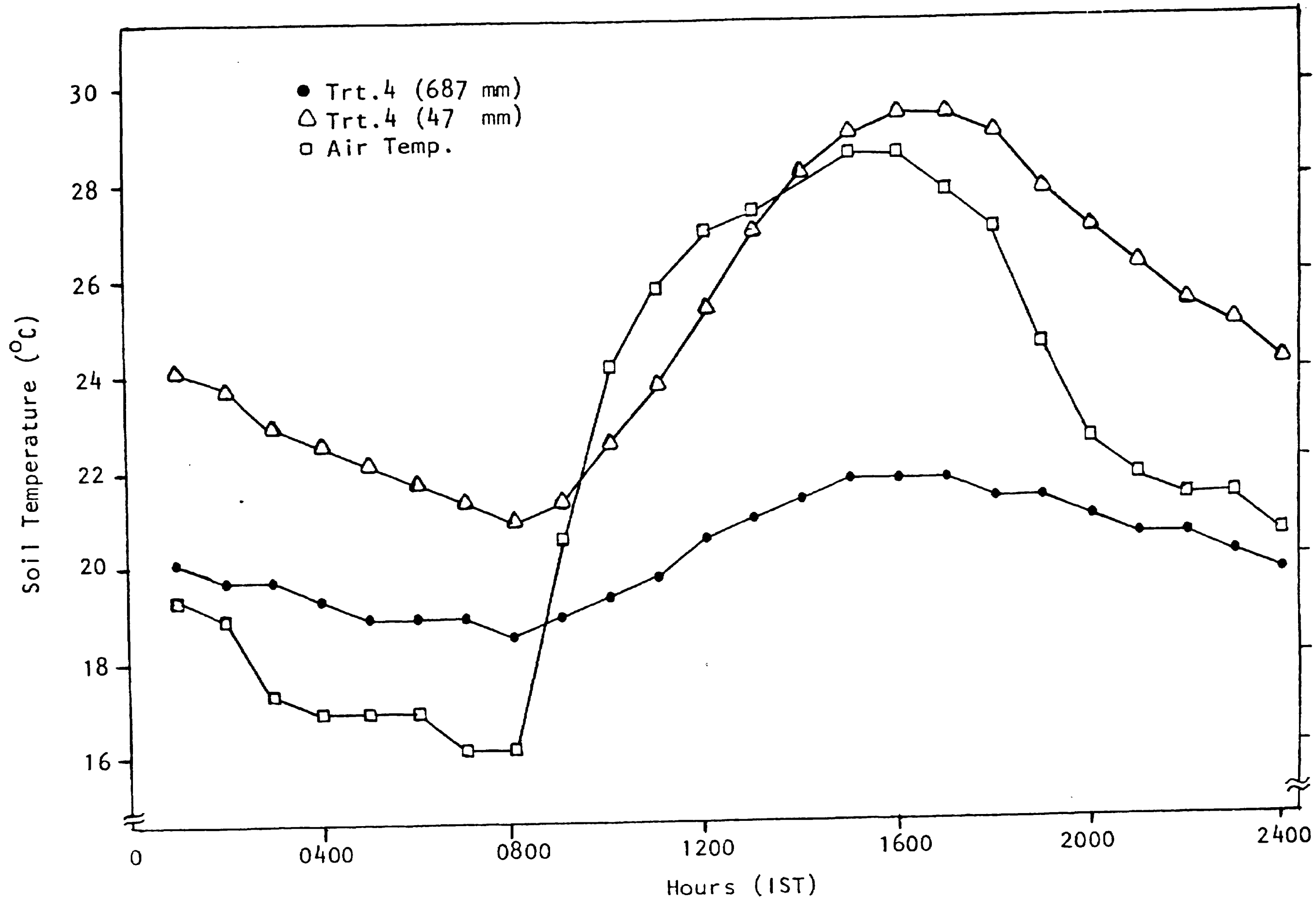


Figure 56. Diurnal variation in the soil temperature at 10 cm depth at 687 mm and 47 mm ET levels in Trt.4 at 75 DAE during the postrainy season (1982-83).

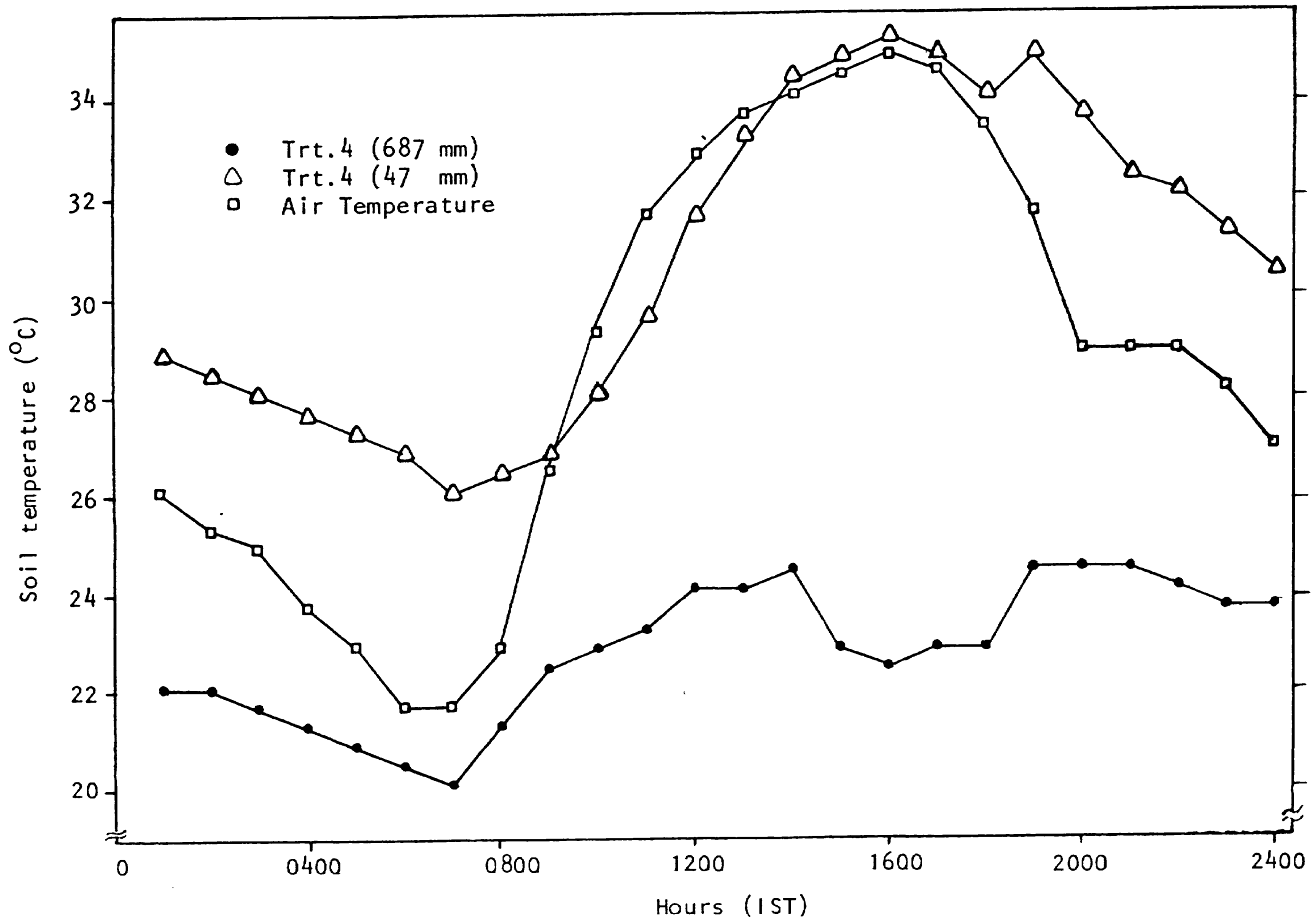


Figure 57. Diurnal variation in the soil temperature at 10 cm depth at 687 mm and 47 mm ET levels in Trt.4 at 118 DAE during the 1982-83 postrainy season.

high ET level however the soil temperatures were below the air temperatures throughout the 24 hr period.The variations in the soil temperatures between the two ET levels ranged from 20 to 35°C.

4.3.4.3 Seasonal Variation in (soil-air) temperature

Seasonal variation in the (soil-air) temperatures for the three ET levels in Trt.4 are shown in Figure 58.

At the high ET levels of 687 and 386 mm, the (soil-air) temperatures were below 0°C from 60 DAE with the differences at 687 mm level more negative than at 386 mm. At the low ET level of 47 mm, the (soil-air) temperatures varied between 1 to 5°C indicating the severe stress under which plants grew in this treatment.

4.3.4.4 Diurnal Variation

The diurnal variation in the (soil-air) temperature at the three ET levels in Trt.4 are presented in Figure 59 for 75 DAE and Figure 60 for 118 DAE.

Diurnal changes on 75 DAE revealed that the (soil-air) temperature differential values started decreasing from 0800 hrs at all the three ET levels but at the higher ET levels (687 and 386 mm), the differential was -6°C by 1000 hrs while at the low ET level of 47 mm, it was -2°C. In the former case, the value of (soil-air) temperature started increasing from 1600 hrs while in the latter, the increase started from 1100 hrs itself. The variation between the high and low ET levels ranged from -7°C to 5°C.

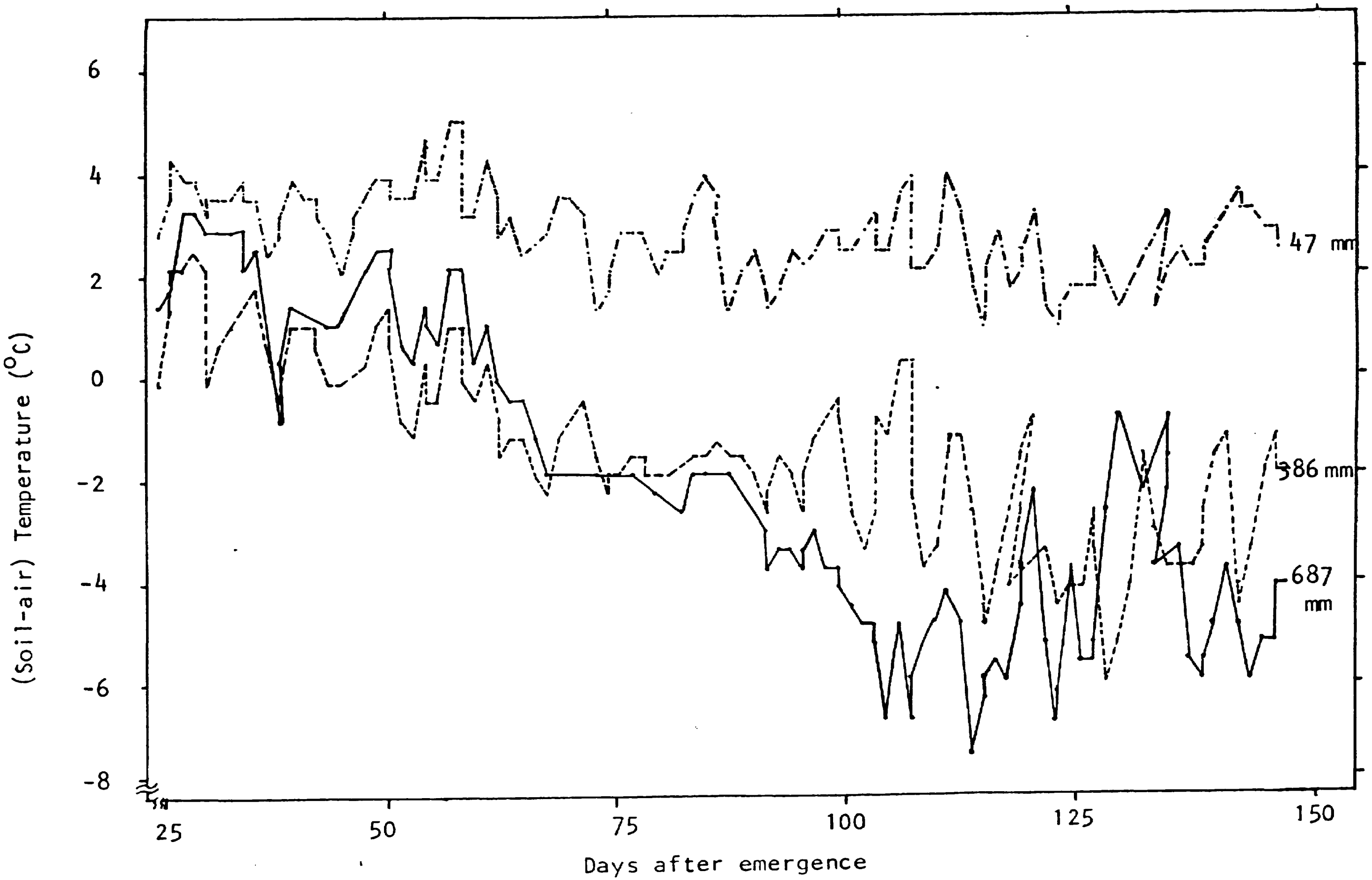
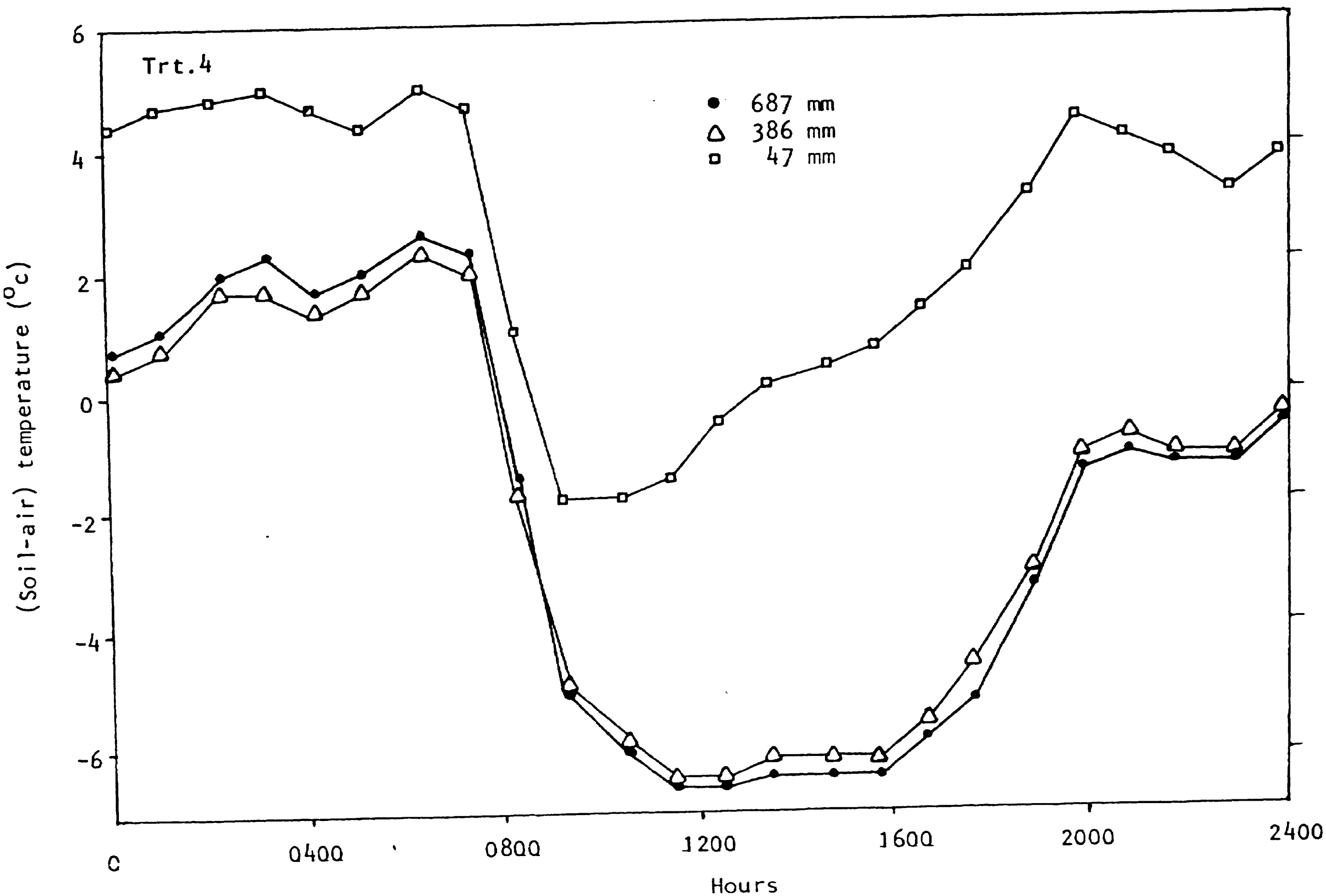


Figure 58. Seasonal variation in (soil-air) temperature at the three ET levels in Trt.4 during the 1982-83 postrainy season.



gure 59. (Soil-air) temperature hree eve in Tr 4 a 75 DA during he 982-83 postrainy season.

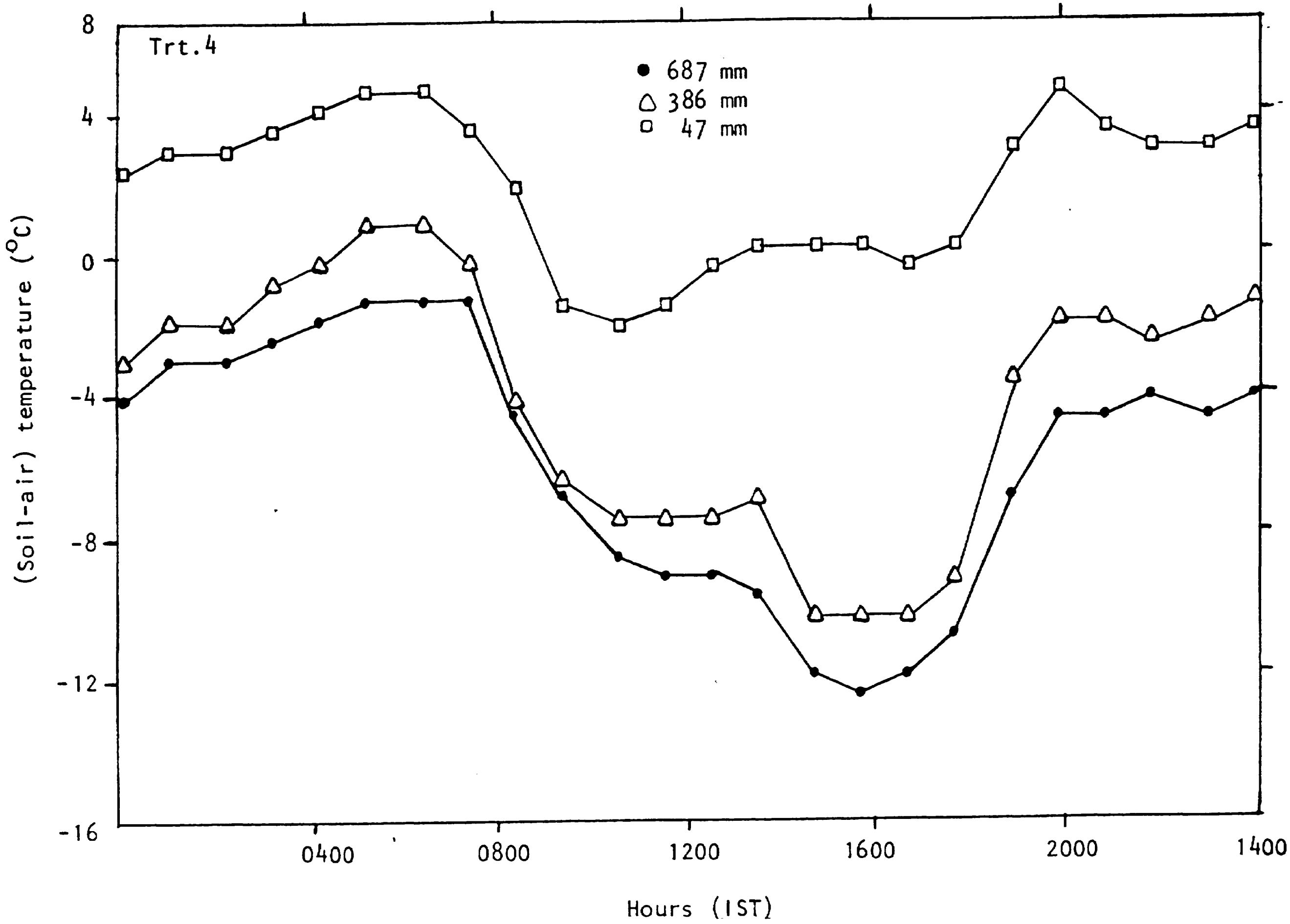


Figure 60. (Soil-air) temperature at the three levels in Trt.4 at 118 DAE during the 1982-83 postrainy season.

At 118 DAE, the diurnal variations in the (soil-air) temperature were larger at the high ET levels than at 47 mm. The values started increasing up to 0700 hrs, decreased from about 0800 hrs to 1600 hrs and then increased. The variation between the ET levels ranged from -11°C to 7°C.

4.3.5 Soil penetration resistance

4.3.5.1 Seasonal Variation

Seasonal variation in soil penetration resistance (SPR) at different ET levels in different treatments are shown in Figure 61. The SPR measurements were made beween 44 to 107 DAE (pod development period).

A wide variation in the SPR was observed in all the four treatments depending on the intensity and duration of water stress imposed.

Among the ET levels in Trt.1 the differences were marginal up to 58 DAE only. In Trt.2, the SPR values were different among the ET levels and in particular between 576 and 494 mm ET levels.

In Trt.3, which was under moisture stress from 29 to 92 DAE, the SPR values increasd steadily up to 92 DAE particularly at the low ET level of 401 mm. Highest SPR (64 kg/cm^2) was recorded at 86 DAE at this level. The SPR values increased with the decreasing level of ET.

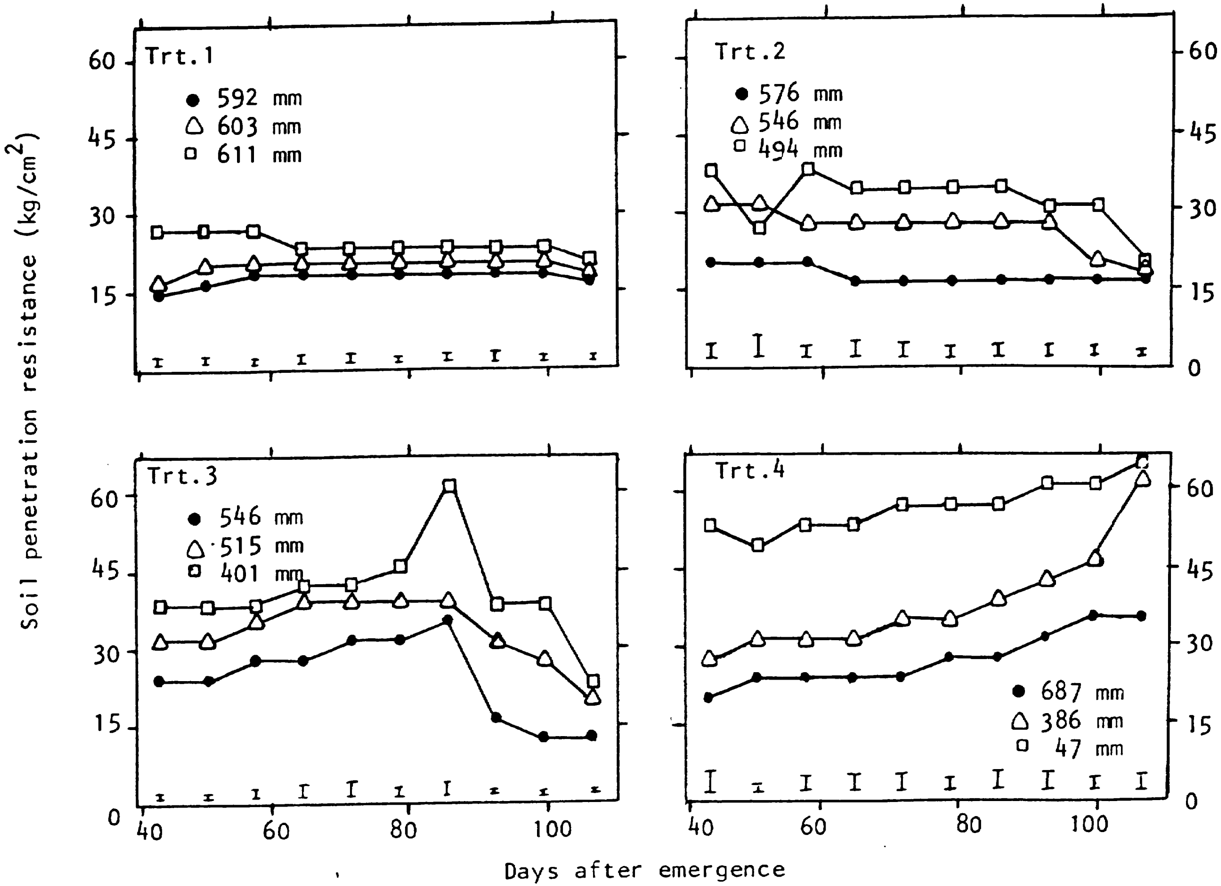


Figure 61. Seasonal variation in soil penetration resistance at different ET levels for different treatments during the 1982-83 postrainy season.

In Trt.4, differeces in the SPR values among the ET levels were larger from 51 to 107 DAE. The SPR values ranged from 19 to 37 kg/cm^2 at the high ET level of 687 mm while they ranged from 56 to 67 kg/cm^2 at the 47 mm ET level during the pod development period. The SPR values at the 386 mm ET level were close to the 687 mm level.

4.3.5.2 Soil Penetration Resistance and ET levels

Mean seasonal soil penetration resistance (SPR) as a function ET during the 1982-83 postrainy season is shown in Figure 62. The relationship between SPR and ET was highly significant and negatively correlated.

4.3.5.3 Soil Penetration Resistance and Kernel Yield

Kernel yield as a function of mean seasonal SPR at different ET levels for different treatments is shown in Figure 63.

The relationship between the kernel yield and SPR was significant ($r = 0.62$) and negatively correlated. Higher kernel yield was obtained at the lower end of SPR.

4.3.6 Radiation Balance

4.3.6.1 Albedo

Seasonal variation in the daily mean albedo at the 687 and 47 mm ET levels in Trt.4 are shown in Figure 64.

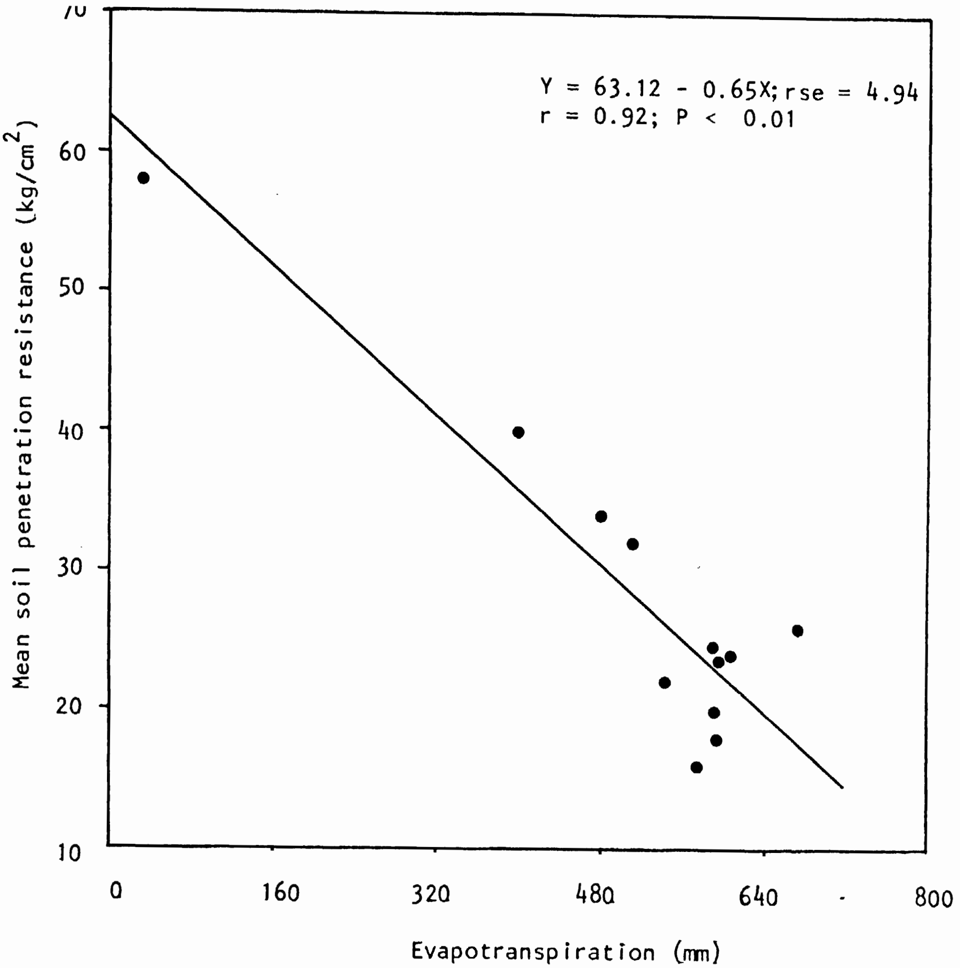


Figure 62. Mean soil penetration resistance from 44 to 107 DAE as a function of evapotranspiration during the 1982-83 postrainy season.

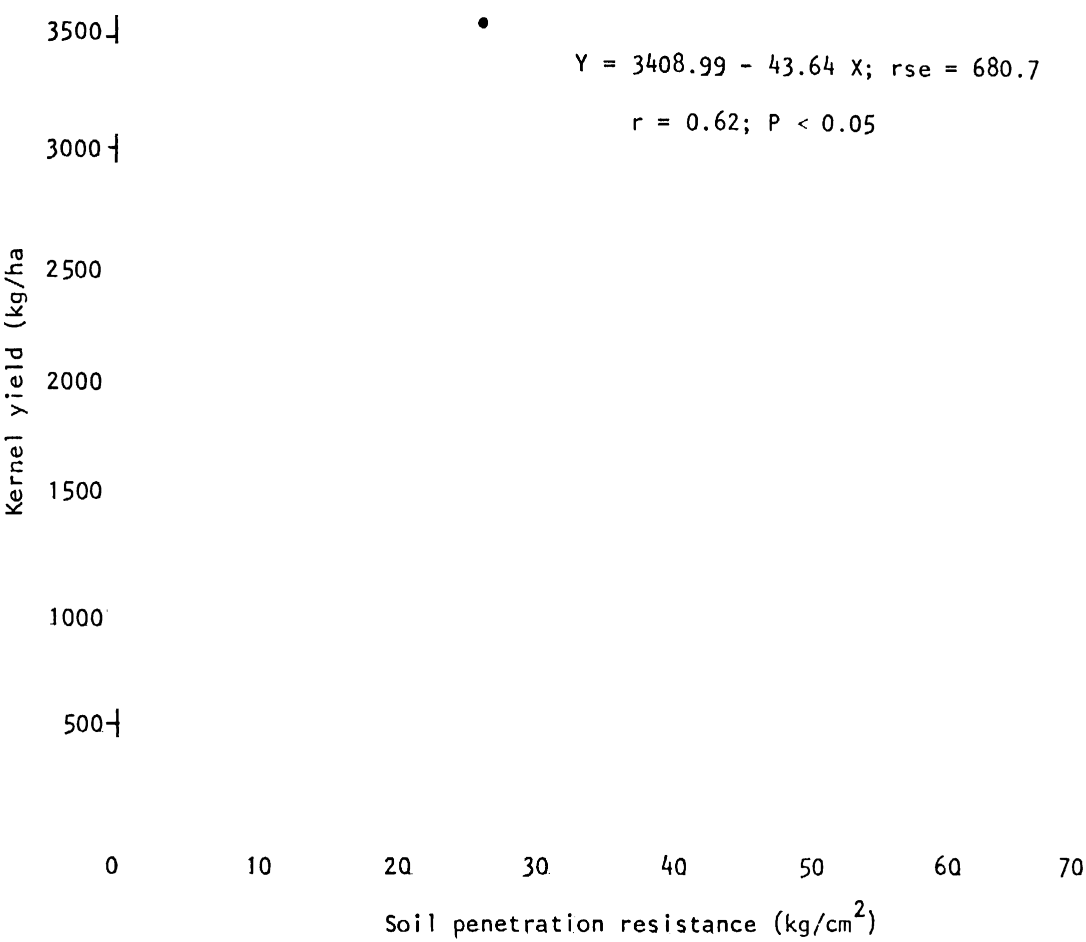


Figure 63. Kernel yield as a function of mean soil penetration resistance from 44 to 107 DAE at different ET levels during the 1982-83 post rainy season.

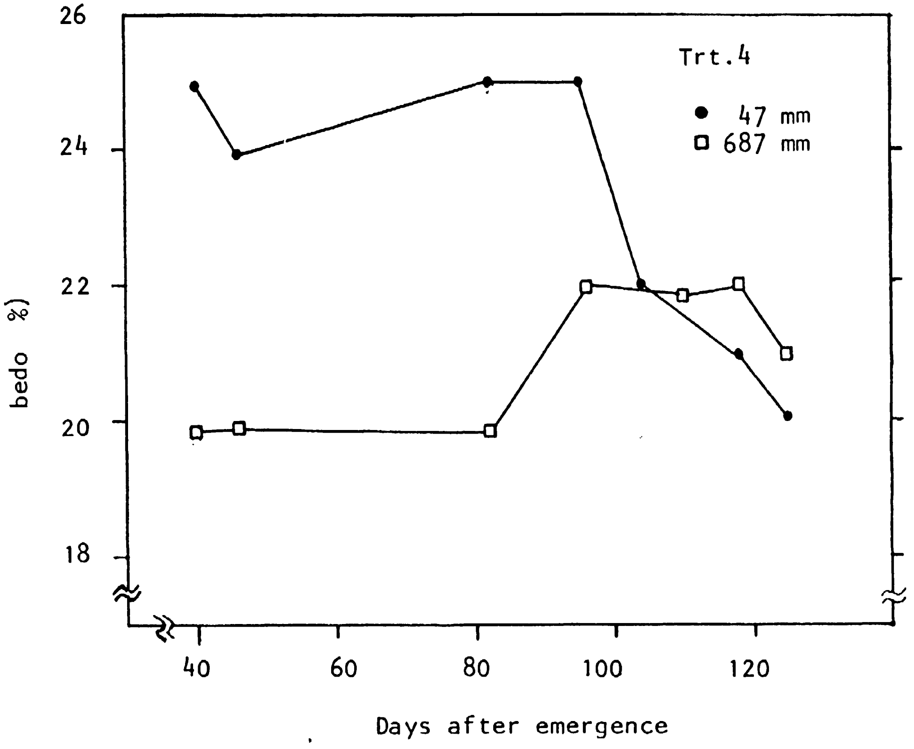


Figure 64. Seasonal variation in the daily mean albedo in Trt.4 at two ET levels (687 mm and 47 mm) during the 1982-83 postrainy season.

The albedo (percent of reflected radiation) was more in the dry crop at the low ET level of 47 mm as compared to the adequately watered crop (ET = 687 mm) up to 104 DAE and lateron the differences were small.

4.3.6.2 Net Radiation

Seasonal variation in the daily mean net radiation at the 687 and 47 mm ET levels in Trt.4 are shown in Figure 65.

The net radiation was low at the low ET level than at the high ET level (687 mm). In general, the net radiation showed an increase from 46 DAE up to 125 DAE.

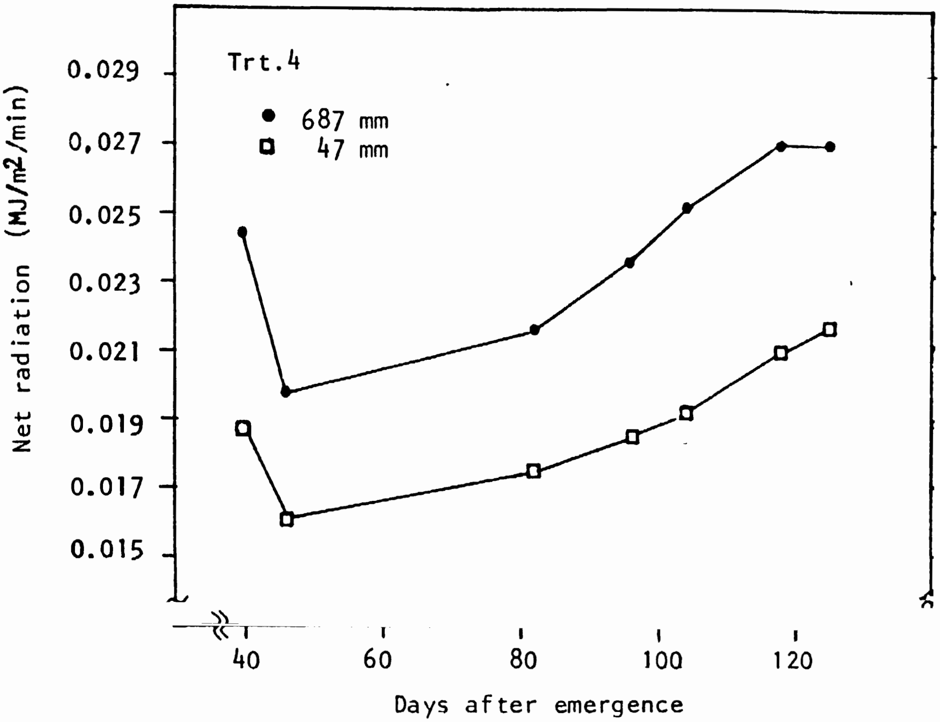


Figure 65. Seasonal variation in the daily mean net radiation in Trt.4 at two levels (687 mm and 47 mm) during the 1982-83 postrainy season.

DISCUSSION AND CONCLUSIONS

5. DISCUSSION AND CONCLUSIONS

The performance of crop plants under moisture stress is highly dependent on the maintenance of favourable plant water status. Information on the nature of development of crop water deficits and the growth stages most sensitive to water stress resulting from interactions between soil, plant, and atmospheric factors, would assist in developing agronomic practices for increased water use efficiency. Drought conditions are implicated in causing low yields, poor grades (Davidson et al. 1973, Stansell et al. 1976), decrease in subsequent germination (Pallas et al. 1977) and an increase in the incidence of aflatoxin (Diener and Davies, 1977) in groundnut. Several reports are available on the general effects of water stress on groundnuts (Pallas et al., 1979; Boote and Hammonds 1981; Krishna Sastry et al., 1980). However, studies on plant response to a range of water deficits occurring at different stages of crop growth are limited in literature to understand the soil-plant-atmospheric relations in groundnut.

Work has been done on the effects of soil-water stress during germination (Hadas and Russo, 1974). Pallas et al. (1977) reported with their investigations on the problem of seed germination with groundnut in Georgia that germination of all varieties was obtained when the average soil water tension in the surface 30-cm was maintained at less than 0.6 bars. On the other hand, allowing Florigiant variety to reach a soil water tension greater than 15 bars during the growing season lowered its percentage of sound mature kernels by 34%. The large seeded virginia type peanut, Florigiant, was found to be the most susceptible to droughty soil conditions. The effect of a previous history of moisture stress on the early seedling vigor of groundnut has not been fully studied.

In the present set of three experiments, the response of groundnut to early moisture stress (EMS) as well as to stress imposed at different phenological stages was studied during the rainy season as well as the postrainy season. In order to study the effect of a previous moisture stress history on the seedling vigor and yield of a current crop of groundnut, seed samples from a previous experiment in which water stress of different intensities was imposed on the groundnut crop at different stages of growth were collected.

The results of the proximate analysis of the kernels with a previous moisture stress history (Table 6) indicated that early moisture stress helped increase the oil and sugar content with a slight increase in the protein and the decrease in the starch content. Among the seed samples that were used in this experiment, the seeds were poorly filled in the treatment where the water stress was imposed from flowering to last pod set.

The seeds with a previous moisture stress history from emergence to initiation of pegs (early moisture stress) had better seed filling (Table 6) and gave higher field emergence (Fig. 4) than other treatments. Greater seed weight resulting from early moisture stress was due to higher oil and sugar contents as found by Unchiev (1941).

These results emphasised that germination vigor is a most important seed quality factor in the efficient production of crops (Spain, 1976; Sivasubramanian and Ramakrishna, 1974; Reddy, 1978). The higher field emergence resulted in a higher plant population in the case of groundnut from seed with a stress history during early stages of crop growth than those at other stages (Table 9).

The seedling vigor was analysed in terms of rate of germination (Fig.4), leaflet number and area and dry matter production from samples taken every 3 days from emergence to 26 DAE. In the treatment with early moisture stress history the crop produced higher leaf area per leaflet (Fig.6) and also on a plant basis (Fig.7). The leaflet production was also better in this treatment (Fig.5). It was considered that synchronisation of seed growth with a large leaflet area (Williams et al. 1975) and early development of the leaf canopy and maintenance of maximum leaf number (Maeda, 1970) were important for higher yield. The final dry matter production was also superior in crop grown from seed that had been early stressed than for others (Fig.8). The seeds with an early moisture stress history recorded maximum pod and kernel yields and higher shelling percentage (Table 8 and Fig. 9) which might be due to higher partitioning of dry matter into the seeds (Naidu and Narayanan, 1981). In this treatment. the seeds were larger and better filled and the yield appeared to be determined by the size of seed sink (Williams et al. 1975; Gorbet, 1977).

In order to study in detail the response of groundnut to early moisture stress two experiments were designed, one during each of the rainy and the postrainy seasons. During the rainy season EMS was induced by covering the experimental plots with black polyethylene film in two cultivars TMV2 and Robut. The presence of the polyethylene film between the crop rows prevented the seepage of rain water into the soil and the polyethylene cover was removed at 44 DAE i.e. at the time of peg initiation. During the postrainy season, treatment 2 was comparable to the treatment imposed during the rainy season.

The efficacy of the techniques used in this experiment to induce early moisture stress on the groundnut crop was reflected in the very low levels of evapotranspiration possible both in the rainy as well as in the postrainy season. Rainfall to an extent of 233 mm out of 656 mm received during the rainy season was prevented from entering the soil by covering the plots with the black polyethylene film. As a result the evapotranspiration in the covered plots was only 10 mm as compared to 60 mm in the uncovered plots during the period when the black polyethylene film was on the ground. Even after the removal of the polyethylene film, the evapotranspiration in the groundnut crop was low. During the postrainy season in Trt. 2 the evapotranspiration ranged from 494-576 mm depending upon the distance from the line source as against 687 mm in the irrigated control treatment in Trt. 4. By the use of the line source irrigation technique varying levels of ET were also achieved in the other treatments where stress was imposed at different phenological stages.

As to the available soil water, during the postrainy season, in the Trt. 2, which was comparable to the early stress treatment imposed during the rainy season, the extraction of water was more from the 11-30 cm profile depth at 576 mm ET level while at an ET level of 494 mm the extraction of water occurred at all depths down to 120 cm (Fig.22). In Trt. 1 during the postrainy season the available soil water was more at 11-60 cm depth while there was little variation at depths below 60 cm. At the ET level of 546 mm in Trt.3, the available soil water in the soil depth of 11-60 cm was more when compared to the ET level of 401 mm where the plants extracted more water from deeper depths of the soil profile (Fig.23). In the irrigated control treatment of Trt.4 where the available water was quite high in the 11-60 cm depth, there was little extraction of water below the 90 cm profile depth. At the lowest ET level of 47 mm in Trt.4, the crop extracted water from all soil depths. Stansell et al. (1976) reported that water extraction occurred up to a depth of 106 cm in peanuts. Mantell and Goldin (1964) reported evapotranspiration for groundnut of 403-687 mm with an optimum around 515 mm. Anand Reddy et al. (1980) observed the highest ET requirement of 560 mm for groundnut as compared to the other crops.

The early moisture stress resulted in higher LAI in particular in cv Robut during the rainy season. The same phenomenon was also observed at the ET levels of 546 and 494 mm in Trt.2 during the postrainy season (Fig.25). The early stress delayed flower initiation (Ochs and Wormer, 1959) and suppressed vegetative growth by inhibiting the leaf expansion rates. The release of water stress at this stage resulted in reproductive flush leading to synchrony in flowering and subsequent pod filling which increased the ratio of filled pods to the total number of pods. Although one would expect this to happen when vegetative phase was drought stressed followed by release of water stress, there are no reports in literature quantifying this phenomenon. Billaz and Ochs (1961) also observed a considerable stimulus in leaf growth after the release of water stress during the early stages of crop growth. The resulting advantage in the dry matter production of groundnut was observed both in the rainy season as well as during the postrainy season, particularly at the lower ET levels of 546 and 494 mm (Fig. 32). EMS also appeared to have increased the root growth through an increase in the length of the tap root as well as the total length of the root system (Table 11). Higher soil temperatures (4°C) during the EMS period could have helped in better root and shoot growth leading to increased dry matter production during the two growing seasons. Dry matter production was higher in the EMS plots (Fig.17) with more efficiency for cv Robut during the rainy season. During the postrainy season also the advantages of EMS were more pronounced at the lower ET levels (Fig. 32).

For both the cvs tested during the rainy season, WUE was almost double with the EMS treatment. Imposition of EMS on the crop appears to have increased the peg as well as pod production for both the cvs during the rainy season and at all ET levels during the postrainy season. The relative dry matter production (DM/DMmax) in relation to relative evapotranspiration (ET/ETmax) of the two groundnut cvs TMV-2 and Robut presented in Figure 66 show the advantage in dry matter production relative to water extracted in EMS treatment (covered

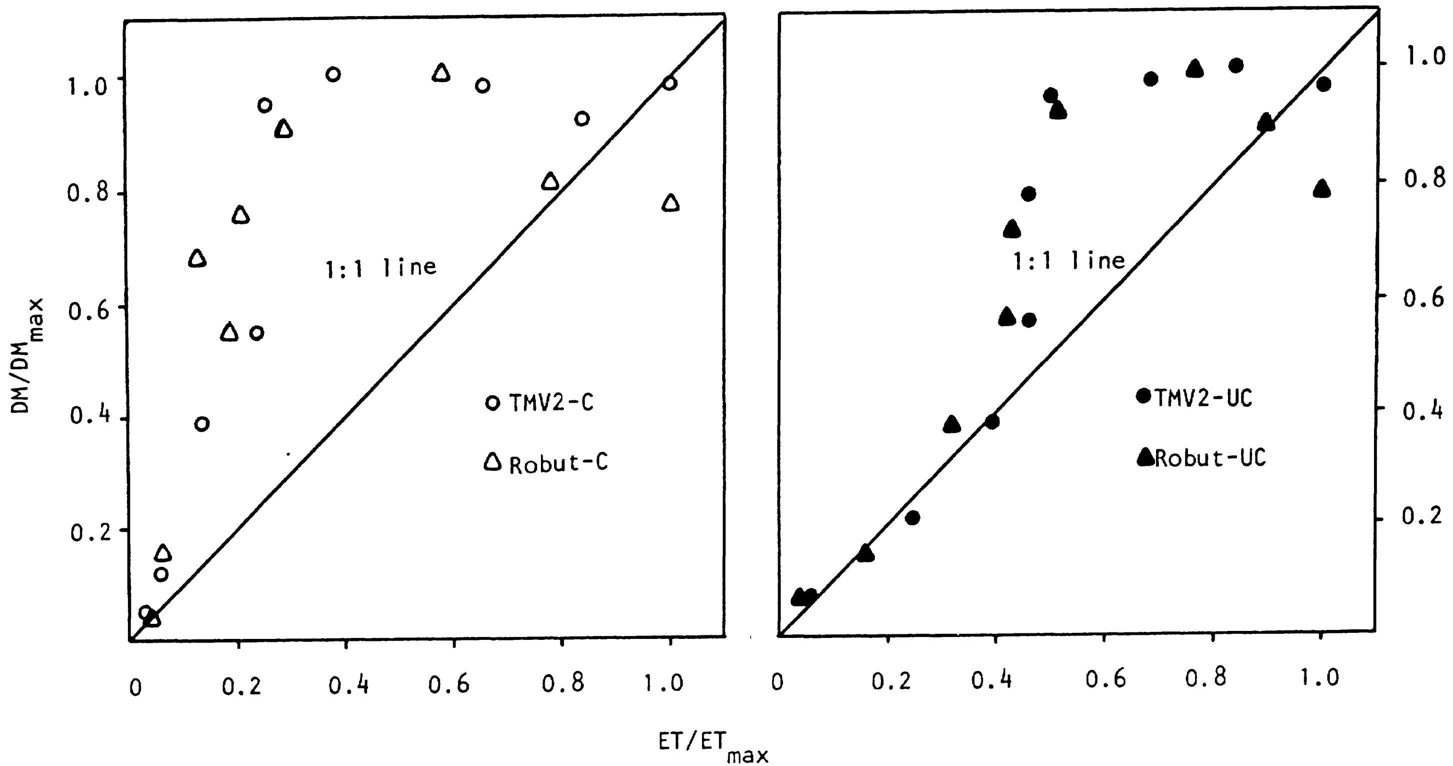
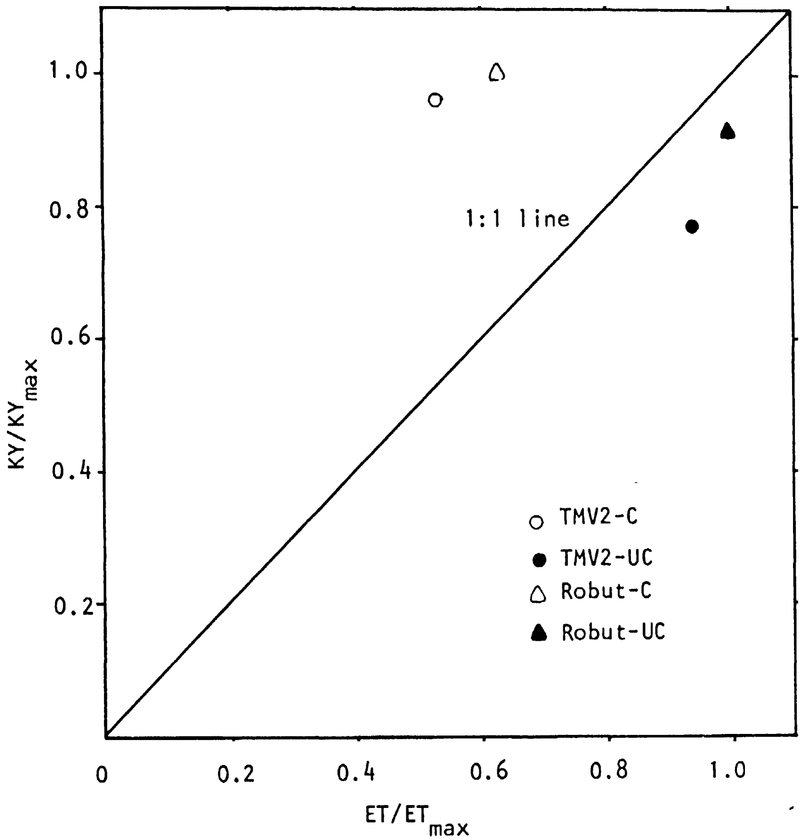


Figure 66. Relative dry matter production (DM/DM_{max}) in relation to relative evapotranspiration (ET/ET_{max}) of two groundnut cvs Robut and TMV2 under two moisture treatments (C - covered; UC - uncovered) in the 1982 rainy season.

plots) particularly at the low levels of relative ET (ET/ETmax). The resulting yield advantage can be seen in Figure 67 where the relative kernel yield was higher for both cultivars at a low relative level. An increased pod yield of 21 to 28% was observed with EMS during the rainy season while during the postrainy season significantly superior pod and kernel yield were obtained in Trt.2 over the other three treatments (Table 22 and Fig. 34). The lower levels of ET in Trt.2 gave higher pod and kernel yields during the postrainy season. A plot of the relative kernel yield (KY/KYmax) in relation to relative ET (ET/ETmax) show the yield advantage at these two ET levels in Trt.2 compared to all other treatments (Fig. 68). The favourable partitioning of total biomass into reproductive structures contributed to the observed yield advantages. This appears to be an important mechanism of adaptation to drought of groundnut where rainfall or irrigation are barely sufficient.

Early water stress also appeared to have contributed to improved quality of the seed in terms of increased seed weight as well as oil and protein contents. This was confirmed by the proximate analysis of the seed samples.

With regard to the effects of water stress at the other growth stages it was observed that during the postrainy season in Trt.1, the reproductive growth stages were observed earlier as compared to other treatments. In Trt.3 because of water stress at a critical stage, i.e., from flowering to last pod set, (29-92 DAE), the reproductive growth phases were delayed. These results were in agreement with the findings of Billaz and Ochs (1961), Joshi and Kabari (1972), Subramaniam et al. (1974), Su et al. (1964), Williams et al.



igure 67. Relative kernel yield (KY/KY_{max}) in relation to relative evapotranspiration (ET/ET_{max}) of two groundnut cvs Robut and TMV2 under two moisture treatments (C - covered, UC - uncovered) in the 1982 rainy season.

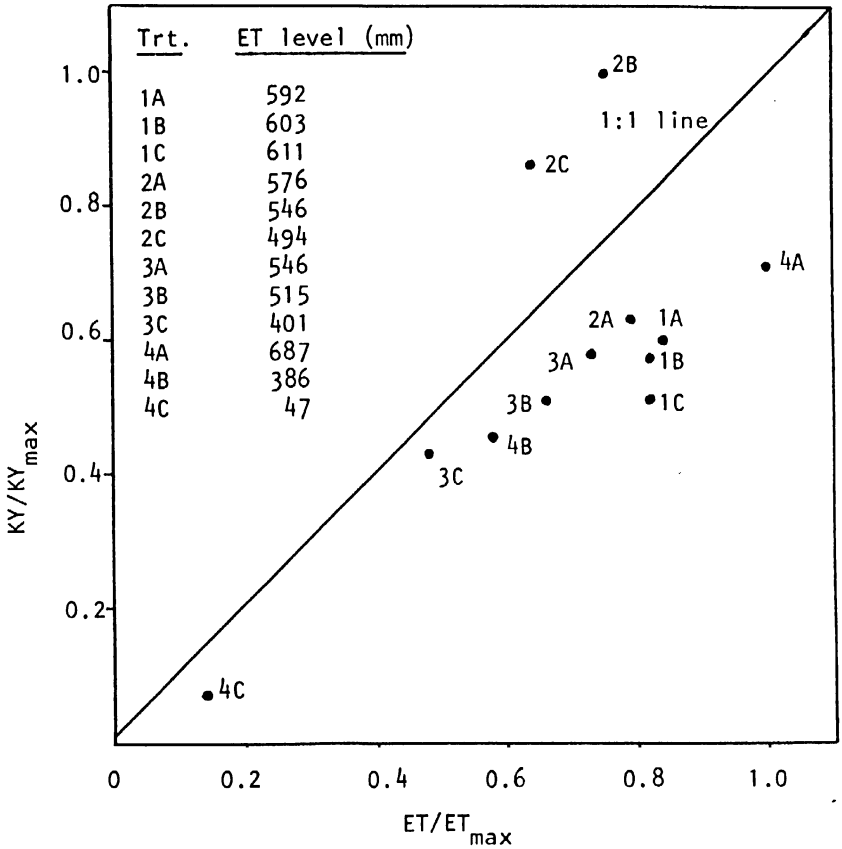


Figure 68. Relative kernel yield (KY/KY_{max}) in relation to relative evapotranspiration (ET/ET_{max}) for different treatments during the 1982-83 postrainy season.

(1978), and Boote and Hammond (1981). In Trt.4 delayed pod formation and harvest maturity was noticed while at the lowest ET level of 47 mm the pod initiation was delayed the longest (89 DAE).

Maximum LAI was obtained at the highest ET level of 687 mm in the irrigated control treatment in Trt.4 while the LAI was significantly lower at the lowest ET level of 47 mm where the continuous soil-water deficit caused production of fewer and smaller leaves. That water deficit affects the leaf enlargement of groundnut was also shown by Il'ina (1968) and Lin et al. (1963). The rate of daily leaf production was also shown to have been reduced because of water deficits at several stages of growth of groundnut (Ochs and Wormer, 1959; Billaz and Ochs, 1951; Vivekanandan and Gunasena, 1976).

Peg and pod production was observed to have been more in Trt. 3 during the postrainy season which was due to profuse flowering observed after the release of moisture stress at 92 DAE. Groundnut plant was reported to have the mechanism to compensate for flower reductions because of early water deficit (Lin et al. 1963; Ono et al. 1974; Boote et al. 1976) by producing a flush of flowers and fruit when the water stress is relieved (Billaz and Ochs, 1961; Pallas et al. 1979). However the majority of the pods remained immature at 148 DAE. The effect of soil water deficit in Trt. 3 could also have been on peg penetration as well as pod development. Measurements of soil penetration resistance made from 44 to 107 DAE in this treatment also revealed that during the period when the surface moisture content was very low the penetration resistance was considerably larger in Trt. 3 than in other treatments. Cox (1962), Underwood et al. (1971) and Boote et al. (1976) observed that pegs frequently failed to effectively penetrate into air-dry soil thus preventing fruit growth. Skelton and Shear (1971) also reported that adequate root zone moisture will keep pegs alive until pegging zone moisture content is sufficient to allow penetration and initiation of pod development. Adequate pegging zone moisture was critical for peg development into pods and adequate soil moisture in the root zone was reported not to compensate for the requirement for pegging zone moisture for the first 30 days of peg development (Ono et al. 1974).

The reduction in the yield of groundnut because of stress during Trt. 3 is not unexpected since the period of pod formation and pod addition is the period when peanut plants were reported by (Sandhu et al. 1972; Subramaniam et al. 1978; Reddy and Reddy, 1977) to be most sensitive to water deficit. The yield reduction in Trt. 3 was due to low shelling percentage. Stan (1968) reported that shelling percentage was commonly lower under stress conditions. The seed weight and oil content were also decreased with decrease in ET levels except in Trt. 1. The lowest 100 seed weight was obtained at the ET level of 47 mm in Trt. 4 while the lowest oil content was observed in Trt. 3 at 401 mm ET level which was due to poor filling of pods as the moisture stress was imposed during pod filling stage (Table 26).

The root length as well as the root dry weight were higher in both treatments 1 and 2 at the higher levels of ET when compared to the maximum stressed treatments at the ET level of 47 mm in Trt.4. In the latter treatment the maximum root length was observed (100 cm). During drought stress periods, lower roots were reported to continue to grow downwards into unrestricted moist soil zones even though top growth may appear to stop (Allen et al. 1976). Great rooting depth for water stressed groundnut was also reported by Lin et al. (1963), Linka and Misra (1973), and Narasimham et al. (1977).

The water stressed plants also showed lower leaf water potentials and lower stomatal conductance as well as low transpiration rates. Pallas and Samish (1974) and Pallas et al. (1974) also showed that under water stress peanut plants show significant changes in the stomata. The diurnal patterns of stomatal opening in peanut leaves were also reported by Vivekanandan and Gunasena (1976). Reduced stomatal conductance under severe water stress is a plant adaptation to drought stress which was also reported by Bhagsari et al. (1976) with peanuts where the relative water content was reported to decrease below 80%. At all ET levels in both treatments 1 and 2 the seasonal patterns in stomatal conductance indicated considerable recovery in the stomatal activity of the leaves after the water stress was released. In Trt. 3 however, where the stress duration was much longer, the level of decrease in stomatal conductance during the period of water stress was considerably higher compared to treatments 1 and 2. At the lowest ET level of 47 mm in Trt. 4 the stomatal conductance steadily decreased from 0.5 cm/sec at 19 DAE to as low as .01 cm/sec around 120 DAE. Stomatal closure in groundnut plants was reported to reduce the net photosynthesis (Bhagsari et al. 1976). Diurnal variation in the stomatal conductance as well as the response of stomatal conductance to varying levels of PPFD during the growing season indicated the strong relationship between stomatal opening and closure and irradiance when peanut was under adequate water supply as opposed to the severe effect of water stress on the stomatal conductance at ET level of 47 mm in Trt. 4.

Atmospheric vapor pressure deficit (VPD) also had a strong influence on the stomatal conductance of groundnut. At the same level of PPFD, a lower VPD caused low stomatal conductance in peanut plants but with increasing levels of PPFD the increase in stomatal conductance at the low VPD level of 1-4 millibars was initially small but increased rapidly with increasing PPFD level beyond 1100 $\mu E/m^2/sec$. At the high level of VPD of 9-12 millibars however this rapid increase in the stomatal conductance was not observed with increasing irradiance. At the lowest level of ET of 47 mm, the stomatal closure was most significant with the complete depletion of soil water. Allen et al. (1976) also reported that when soil water is completely depleted groundnut plants reduced further water loss by folding their leaflets which reduced the exposed evaporative surface area. At this very limited level of ET, leaf water potentials of up to -64 bars were obtained. In literature however, water stressed groundnut plants were reported to reach leaf water potentials of -30 to -45 bars (Bhagsari et al. 1976; Pallas et al. 1977, 1979).

Decreased stomatal activity apparently affected the transpiration rates from the groundnut plant as indicated by both the seasonal variation as well as the diurnal variation in transpiration for different treatments during the growing season. The atmospheric evaporative demand combined with the soil water deficit exerted a strong influence on the variability in the transpiration rates of the groundnut plants. It is understood that any reduction in transpiration is usually accompanied by decreased photosynthetic rate and as a result decreased dry matter production. The yield advantages obtained because of the EMS in Trt. 2 could be attributed towards the rapid recovery in the stomatal conductance as well as the transpiration rates from the leaves upon the release of moisture stress. Because of the presence of good ground cover in this treatment upon the release of stress, the transpiratin component of evapotranspiratin from the plant was significant. In the absence of plant ground cover, average evaporation from the soil surface was reported to be 30 to 40% of pan evaporation (Goldberg et al. 1967, Kassam et al. 1975). After establishment of full ground cover, Kassam et al. (1975) reported that the ratio of evapotranspiration to open pan evaporation remained very stable under adequate soil water supply until the leaf area began to decline. Hence it can be surmised that in Trt. 2 because of the higher LAI and higher transpiration rates, the groundnut plants were able to maintain higher rates of net photosynthesis.

The changes in the canopy temperature of groundnut during the growing season as well as on a diurnal basis at different ET levels in different treatments also showed that the lack of transpirational cooling at the lower ET levels contributed to increased canopy temperature. With other crops Wiegand and Namken (1966), Ehrler and Van Bavel (1967) and Bartholic et al. (1972) showed that leaf temperatures and leaf air temperature differences were related to plant water stress and could be used to differentiate treatments undergoing stress and no stress.When soil moisture becomes limited, stomatal closure occurs resulting in reduced transpiration, increased heat load on the canopy and a consequent rise in leaf temperatures sometimes by as much as 10°C above the air temperature (Pearcy et al. 1971). At the ET level of 47 mm in Trt. 4 the canopy temperatures rose to 35°C while at 687 mm ET level it was only 24°C when the crop was at 82 DAE. SDD of groundnut plants showed a linear decrease with increasing evapotranspiration. This pattern is in line with the observations of Idso et al. (1977). These data indicate that measurements of canopy temperature as well as the difference between the canopy and the air temperature facilitate comparison of the effect of water deficit on the groundnut plants.

Under water deficit the soil temperatures are reported to increase and the diurnal variations in the soil temperatures under different treatments show that at significantly decreased level of ET the soil temperatures is very much in phase with the air temperature and could exceed the air temperature for a considerable portion of the day after mid afternoon. However at a higher ET level the soil temperatures were consistently below the air temperature.

The advantage in dry matter production enjoyed by the groundnut plants with recovery from water stress was apparent from the relationships between the dry matter production and cumulative evapotranspiration of the plant (Fig. 32). The slopes of the lines indicated that in Trt. 2 specially at the lower levels of ET with increasing evapotranspiration the plants produced more dry matter as compared to the higher level of ET. It is significant to notice that the slope of the line in Trt. 2 was significantly improved over the irrigated control treatment in Trt. 4 where the ET level was 687 mm. A plot of the relative dry matter production to relative ET for different treatments indicated the obvious advantages of dry matter production in treatments 2B and 2C as well as in Trt. 3A (Fig. 69). The advantage at the lower ET levels of Trt. 2 was also apparent in a

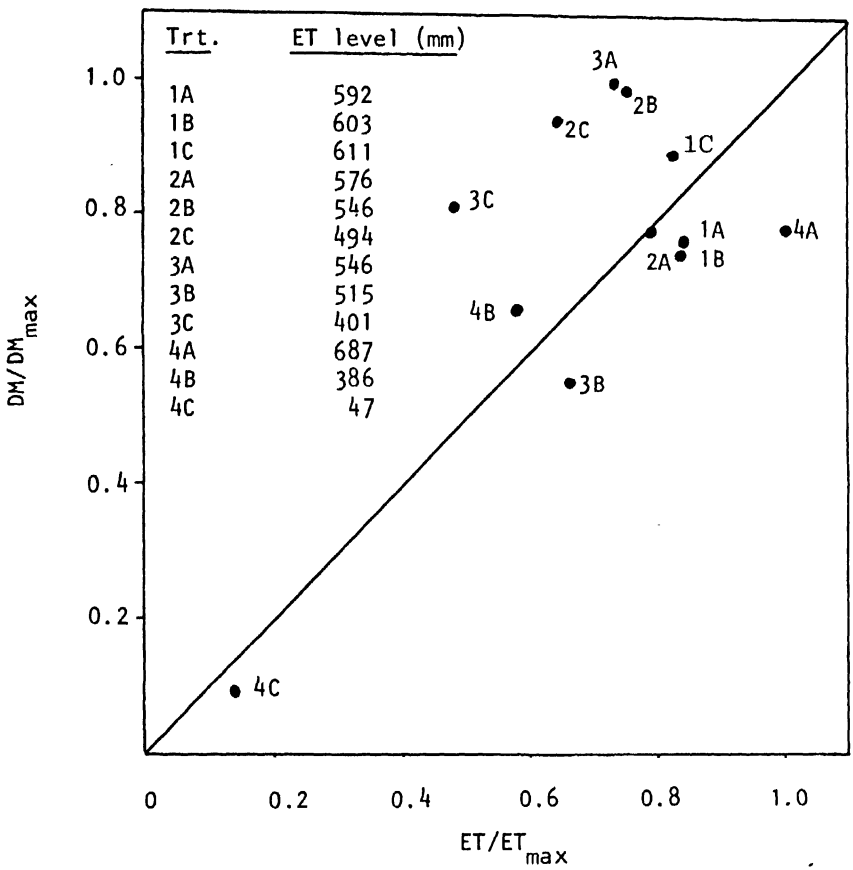


Figure 69. Relative dry matter production (DM/DM_{max}) in relation to relative evapotranspiration (ET/ET_{max}) for different treatments during the 1982-83 postrainy season.

plot of the relative kernel yield in relation to relative evapotranspiration (Fig. 68). At the comparative ET levels in the other treatments , the lower ET levels of 546 mm and 494 mm in Trt. 2 gave higher water use efficiency as compared to the efficiencies of water use observed at similar ET levels in other treatments.

Based on the above discussion on the three experiments given above, the following conclusions are drawn:

Response of Groundnut to Early Moisture Stress (EMS)

1. As a result of EMS, irrigations can be skipped off which will save considerable amount of irrigation water.
2. The probable drought periods in the crop season can be arrived by analysing the climatic data in that region and the date of sowing can suitably be adjusted so that the early drought coincides with the EMS stage in groundnut.
3. Considerable reduction in the ET was achieved with the imposition of EMS both in the rainy and postrainy seasons.
4. In the EMS treatment during the postrainy season, the extraction of water was more from the 11-30 cm profile depth at 576 mm ET level while at a lower ET level, the extraction of water occurred at all depths down to 120 cm depth.
5. EMS resulted in higher LAI, more pegs and pods during the rainy season as well as the postrainy season, particularly at the low ET levels of 546 and 494 mm.
6. Higher dry matter production in both rainy and postrainy seasons was obtained in the EMS treatment, probably due to higher soil

temperature which might have resulted in better root and shoot growth.

7. Pod and kernel growth were enhanced in both the cultivars in the EMS treatment during the rainy season while the same trend was observed in the postrainy season also at the low ET levels.

8. Increased pod yield (21 to 28%) was obtained during rainy season with the EMS treatment. During the postrainy season, significantly superior pod and kernel yields were obtained when stress was imposed from emergence to pegging. This might be due to preferential partitioning of photosynthates to pods and kernels.

9. EMS improved the seed quality in terms of increased seed weight, oil and protein contents.

10 Water use efficiency was almost double with the EMS treatment during the rainy season. Harvest index was better in the rainy season while the same was highest at the low ET levels of 546 and 494 mm during emergence to peg initiation during the postrainy season.

Effect of Moisture Stress History During Previous Season on Current Season Productivity

11. The seeds with a previous moisture stress history from emergence to initiation of pegs (early moisture stress) produced crop with better seed filling, higher oil and sugar contents with a slight increase in the protein and decrease in starch and gave higher field emergence resulting in higher plant population.

12. Seedlings with EMS history were more vigorous in terms of leaf number, leaf area, and superior dry matter production.

13. Maximum pod and kernel yields besides higher shelling percentage were obtained using seeds having an EMS history.

Response of Groundnut to Water Stress (ET Levels) at Different Phenological Stages

14. Moisture stress imposed during reproductive stages R1 to R6 delayed the duration in almost all the reproductive stages.

15. At the lowest ET level, the crop extracted water from all soil depths.

16. Maximum LAI was obtained with the highest ET level of 687 mm while at the lowest ET level of 47 mm the LAI was very low.

17. Highest peg production and more partitioning of dry matter to pods, kernels and stems were observed at low ET levels when moisture stress was imposed from flowering to last pod set. At a very low ET of 47 mm in the continuously stressed treatment, pod number was least and dry matter production was nine times less when compared to 687 mm ET in the continuously irrigated treatment and was partitioned to mostly stems and leaves.

18. Pod and kernel growth were more when moisture stress was imposed from flowering to last pod set while the same were very much reduced with a very low ET level of 47 mm in the continuously stressed treatment.

19. There was a positive and highly significant correlation between the dry matter production and total ET at maturity.

20. Pod and kernel yields were reduced when stress was imposed from emergence to flowering, flowering to last pod set and continuously stressed treatment. Water use efficiency was lowest with the highest ET level of 687 mm in the continuously stressed treatment while the HI was lowest at 47 mm ET level. Shelling %

was very much affected when moisture stress was imposed from emergence to last pod set.

21. Groundnut plants which were subjected to severe moisture stress at the 47 mm ET level in the continuously stressed treatment developed a deep root system going up to one meter deep.

22. Moisture stress from flowering to last pod set affected the seed filling, protein and oil contents.

23. The stomatal conductance increased with increasing PPFD at the highest ET level of 687 mm while at 47 mm ET level, radiation levels had little influence on the stomatal conductance.

24. At the low VPD range of 1-4 mb, the stomatal conductance was high and it increased with increasing PPFD while it was low at 5-8 mb range of VPD.

25. At the lowest ET level of 47 mm, the leaf water potential reached a peak value of -63 bars.

26. The soil penetration resistance (SPR) values increased with the decreasing level of ET. At the lowest ET level of 47 mm, the SPR values ranged from 56 to 67 kg/cm^2 as against 19 to 37 kg/cm^2 at 687 mm ET level. At lower values of SPR, higher kernel yield was obtained.

27. Seasonal pattern in the stomatal conductance in the treatments subjected to moisture stress from emergence to flowering and emergence to peg initiation indicated considerable recovery in the stomatal activity of the leaves after the moisture stress was released. The decrease in the stomatal conductance in the treatments with stress imposed from flowering to last pod was considerably higher. The least stomatal conductance was seen in the continuously moisture stressed plots at 47 mm ET level.

28. The transpiration rates were affected due to the decreased stomatal activity by both the seasonal variation as well as the diurnal variation for different treatments.

29. Increased canopy temperatures were observed in all the treatments during the growing season as well as on a diurnal basis at lower ET levels because of lack of transpirational cooling. In the continuously moisture stressed plot, at the ET level of 47 mm, the canopy temperatrues peak to 35°C while at 687 mm ET level, it was only 24°C when the crop was at 82 DAE. At low values of total evapotranspiration, the stress degree day values were high and vice versa.

30. The seasonal and diurnal variations in the soil temperatures under different treatments show that at low ET, the soil temperature was very much in phase with the air temperature and exceeded the air temperature for a considerable portion of the day after mid afternoon.

31. More albedo and low net radiation were observed at low ET level of 47 mm.

SUMMARY

6. SUMMARY

Studies were undertaken to investigate the effect of using seeds with a moisture stress history in the previous season on the current season productivity and to examine the effects of moisture stress at different phenological stages of groundnut during the 1982 rainy season and the 1982-83 postrainy season at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh.

In the experiment usig seeds with a previous moisture stress history, early seedling vigor in terms of rate of seed emergence, leaflet number, leaf area per leaflet and plant, and dry matter production was evaluated at 3-day intervals from emergence up to 26 DAE. Quality of the seed samples with moisture stress history during the previous season and also of the seed obtained from the subsequent crop was analysed.

The seeds with moisture stress history from emergence to peg initiation during the previous season gave higher seedling vigor in terms of leaf number, leaf area and superior dry matter production besides maximum pod and kernel yield.

In the investigations on the effect of water stress at different phenological stages, soil water, leaf area, plant growth and plant parameters of water stress such as stomatal conductance, transpiration, canopy temperature and leaf water potential and radiation measurements were measured at 7-10 day intervals. Soil temperature was monitored throughout the growing season. Soil

penetration resistance was measured from 44 to 107 DAE. Root studies were made at maturity besides seed quality estimation.

The results indicated that considerable reduction in ET was achieved by imposition of early moisture stress (EMS) both in the rainy and postrainy seasons. The extraction of water was more at 566 mm ET level from 11-30 cm soil profile and the soil water extraction occurred at all depths down to 120 cm depth at the lower ET level. Higher LAI, pegs and pods were obtained in the EMS treatment. Due to higher soil temperature in the EMS treatment higher dry matter production with better root and shoot growth was achieved besides enhanced pod and kernel growth. About 21-28% higher pod yield was obtained with the EMS treatment during the rainy season and significantly superior pod and kernel yield during the postrainy season due to preferential partitioning of photosynthates to pods and kernels. Higher water use efficiency, harvest index and improved seed quality in terms of increased seed weight, oil and protein contents were obtained with EMS treatment.

In the treatment where water stress was imposed continuously during the growing season the crop extracted water at all soil depths at the lowest ET levels. The highest ET level of 687 mm gave maximum LAI while in the severely stressed treatment the LAI was much reduced. In the latter treatment a 9-fold reduction in dry matter production occurred as compared to that at 687 mm of ET.

Pod and kernel yields were reduced when stress was imposed from emergence to flowering and from flowering to last pod set. The groundnut plants showed significant adaptation to the lowest ET level by extending the roots to deeper soil depths.

Moisture stress imposed from flowering to last pod set was a critical period since it affected the seed filling, protein and oil contents.

The seasonal and diurnal variations in the soil temperatures under different treatments show that at low ET, the soil temperature was very much in phase with the air temperature and exceeded the air temperature for a considerable portion of the day after mid afternoon.

Seasonal pattern in the stomatal conductance in the treatments subjected to moisture stress from emergence to flowering and emergence to peg initiation indicated considerable recovery in the stomatal activity of the leaves after the moisture stress was released. The decrease in the stomatal conductance in the treatments with stress imposed from flowering to last pod was considerably higher. The least stomatal conductance was seen in the continuously moisture-stressed plots at 47 mm ET level.

The transpiration rates were affected due to the decreased stomatal activity by both the seasonal variation as well as the diurnal variation for different treatments.

Increased canopy temperatures were observed in all the treatments during the growing season as well as on a diurnal basis at lower ET levels because of lack of transpirational cooling.

LITERATURE CITED

7. LITERATURE CITED

Al-Ani, T.A., and J.F. Bierhuizen. 1971. Stomatal resistance and relative water content as influenced by soil moisture stress. Acta Bot., Neerl. 20:318-326.

Allen, L.H., Jr., K.J. Boote, and L.C. Hammond. 1976. Peanut stomatal diffusion resistance effected by soil water and solar radiation. Soil Sci.Soc.Am. Proc. 35:42-46.

Allerup, S. 1961. Stem cutting and water movement in young barley plants. Physiol. Plant.14:632-637.

Anand Reddy, K., A. Venkatachari, and P. Suryaprakash Rao. 1980. Evapotranspiration and water use efficiency of different crops. Indian J. Agron. 25:176-180.

AOAC. 1975. Official method No.47.021. Official methods of analysis of the Association of Official Analytical Chemist (Ed.). William Hart Witz 12th Ed.

AOCS. Official method Ab 3-49. 1981. In Official and tentative methods of American Oil Chemists Society Vol. I. 3rd ed.

Arie, D.R. 1980. Water relations in groundnuts, and implications for groundnuts grown at Katherine, Australia. M.Sc. dissertation submitted to the Univ. Read. Australia.

Asana, R.D. 1960. Investigations on water relations of some Indian crop plants - a review. Bull. Res. Coun. Israel (D):97-104.

Baker, D.N., and R.B. Musgrave. 1964. Photosynthesis under field conditions. V. Further plant chamber studies of the effect of light on corn (Zea mays L.). Crop Sci. 4:127-136.

Balasubramanian, V., and J.Y. Yayock. 1981. Effect of Gypsum on moisture stress on growth and pod full of groundnut (Arachis hypogaea L.). Plant and Soil 62:209-219.

Bartholic, J.F., L.N. Namken, and C.L. Wiegand. 1972. Aerial thermal scanner to determine temperature of soil and crop canopies differing in water stress. Agron.J.64:603.

Barrs, H.D. 1968. Determination of water deficits in plant tissues. p.235-268. In T.T. Kozlowski (ed.) Water deficits and plant growth. Vol.I. Academic Press, New York.

Bennett, J.M., K.J. Boote, and L.C. Hammond. 1981. Alterations in the components of peanut leaf water potential during desiccation. J. Exp. Bot.32:1035-1043.

Bhagsari, A.S., R.H. Brown, and J.s. Schopers. 1976. Effect of moisture stress on photosynthesis and related physiological characteretics in peanut. Crop Sci. 16:712-715.

Bhargava, P.N., A. Pradhan, and M.N. Das. 1974. Influence of rainfall on crop production. JNKVV Res. J. 8:22-29.

Billaz, R., and R. Ochs. 1961. Stages of susceptibility to drought. Ole'agineux 16:605-11.

Birajdar, J.M., V.N. Ingle, and V.G. Musande. 1979. Quality of groundnut as influenced by irrigation and fertilization. Res. Bull. Marathwada Agri.Univ. 3:49.

Black, C.R., and G.R. Squire. 1979. Effects of atmospheric saturation deficit on the stomatal conductance of pearl millet (Pennisetum typhoides) and groundnut (Arachis hypogaea L.). J. Exp. Bot. 30:935-945.

Boote, K.J., R.J. Varnell, and W.G. Duncan. 1976. Relationships of size, osmotic concentration, and sugar concentrations of peanut pods to soil water. Proc. Soil and Crop Sci. Soc. Florida 35:47-50.

-----------, and L.C. Hammond. 1981. Effect of drought on vegetative and reproductive development of peanut. Proc. Amer. Peanut Res.& Edn. Soc. 13:86. Abstr.

-----------. 1982. Growth stages of peanut (Arachis hypogaea L.). Peanut Sci. 9:35-40.

Boyer, J.S. 1967. Leaf water potential measured with a pressure chamber. Plant Physiol. 42:133-137.

-----------. 1968. Relationships of water potential of growth of leaves. Plant Physiol. 43:1056-1062.

-----------. 1969. Measurement of water status in plants. Ann. Rev. Plant Physiol. 20:351-364.

-----------. 1970b. Differing sensitivity of photosynthesis to low leat water potentials in corn and soybean. Plant Physiol. 46:236-239.

Brady, R.A., S.M. Goltz., W.L. Powers, and E.T. Kanemasu. 1975. Relation of soil water potential to stomatal resistance of soybean. Agron. J. 67:97-99.

Brix, H. 1962. The effect of water stress on rates of photosynthesis and respiration in Tomato plants and lolbolly pine seedling. Physiol. Plant. 15:10-20.

Brown, K.W. 1969. A model of photosynthesizing leaf. Physiol. Plant. 22:620-637.

Brown, K.W., and N.J. Rosenberg. 1970. Influence of leaf age, illumination and upper and lower surface differences on stomatal resistance of sugarbeet (Beta vulgaris) leaves. Agron. J.62:20-24.

Brown, K.W., and B.P. Van Haveran (Eds). 1974. Psychrometry in water relatios research. Utah Agric. Expt. Stn., Logan, Utah.

Charoy, J. 1974. Water dynamics in a tropical Ferruginous soil of dune origin at Tarna and application to millet, groundnut and bare soil. Agronomic Tropicale 29:821-830.

Cheema, S.S., H. Kundra, and J.S. Kaul. 1974. Response of groundnuts to various soil moisture regimes and methods of P application. Punjab Agric. Univ. 11:380-385.

Cheema, S.S., K.S. Minhas., H.P. Tripathi, and H.C. Kundra. 1977. The effect of applying phosphorus and nitrogen to groundnut under different regimes of soil moisture. J. Res. (Punjab) 14:9-14.

Chen, C.Y., and S.H. Chang. 1972. Studies on the relationship between several physiological functions of plants and DPD of leaves and soil moisture stress. J. Agric. Assoc. China 80:26-41.

Chen, Y., and J.A. Katan. 1980. Effect of solar heating of soils by transperent polyetheylene mulching on their chemical properties. Soil Sci. 130:271-277.

Clark, B.N., and E.A. Hiler. 1973. Plant measurements as indicators of crop water deficit. Crop Sci. 13:466-469.

Cowan, I.R. 1965. Transport of water in the soil-plant-atmospheric system. J. Appl. Ecol. 2:221-239.

Cox, F.R. 1962. The effect of plant population, various fertilizers, and soil moisture on the grade and yield of peanuts. Diss. Abstr. Intl. 22:3326-B.

Cox, F.S., G.A. Sullivan, and C.K. Martin. 1976. Effect of calcium and irrigation treatments on peanut yield, grade and seed quality. Peanut Sci. 3;81-85.

Dale, J.E. 1961. Investigations into the stomatal physiology of upland cotton. I. Effects of hour of day, solar radiation and leaf water content on stomatal behaviour. Ann. Bot. 25:39-51.

Davidson, J.M., J.E. Garton., R.s. Matlock., D. Scrwab., J.F. Stone, and L.D. Tripp. 1973. Irrigation and water use. In 'Peanuts, culture and uses.' A.P.R.E.A. (Stone, Virginia).

Denmead, O.T., and L.H. Shaw. 1962. Availability of soil water to plants as affected by soil moisture and meteorological conditions. Agron. J. 54:385-390,

Dhillon, G.S., D.S. Kler, and A.S. Walia. 1981. Further studies on seed vigour in groundnut. J. Res. (Punjab) Agric. Univ. 18:248-256.

Diener, U.L., and N.D. Davis. 1977. Aflatoxin formation in peanuts by Aspergillus flavus. Auburn Univ. Agric. Exp. Stn. Bull.493.

Duncan, W.G., D.E. McCloud.,R.L. McGraw, and K.J. Boote. 1979. Physiological aspects of peanut yield improvement. Oleaguinuex 34:523-530.

Dube, P.A., K.r. Stevenson, and G.W. Thurtell. 1974. Comparison between two inbred corn lines for diffusive resistances, photosynthesis and transpiration as a function of leaf water potential. Can. J. Plant Sci. 54:765-770.

Dubios, M., K.A.Gillus., J.H. Hamilton., P.A. Rebers, and F. Smith. 1956. Calorimetric method for determination of sugar and related substances. Analytical Methods. 28:350-356.

Ehlig, C.F., and W.r. Gardner. 1964. Relationship between transpiration and the internal water relations of plants. Agron. J. 56:127-130.

Ehrler, W.L., and C.H.M. van Bavel. 1967. Sorghum foliar responses to changes in soil water content. Agron. J. 59:243-246.

-----------, and -----------. 1968. Leaf diffusion resistance, illumination and transpiration. Plant physiol. 43:208-214.

Fischer, R.A., and R.M. Hagon. 1965. Plant water relations, irrigation management and crop yield. Expl. Agric. 1:166-177.

Forestier, J., and J.P. Raffaillac. 1980. Composition and yield of the groundnut. II. Photosynthesis and harvest. Cahiers ORSTOM, Serie Biologic. 42:87-109.

Food and Agricultural Organisation (FAO). 1981.

Fourrer, P., and P. Prevot. 1958. Influence of groundnuts of rainfall, chemical manuring, and steeping the seeds. Ole'agineux 13:805-809.

Gabriilides, S.T., and C.B. Akritidis. 1971. Soil pressure influence on some basic plant characteristics for groundnuts and sesame. Field Crop Abstr.24:35-88.

Gardner, W.R. 1970. Internal water status and response in relation to external water regime of plants. p.221-225. In R.O. Slatyer (ed) Plant response to climatic factors. Proc. Uppsala Symp., UNESCO, Paris.

Garrity, D.P., D.G. Watts., C.Y. Sullivan, and J.R. Gelley. 1982. Moisture defecits and grain sorghum performance: Evapotranspiration and yield relationships. Agron J. 74:815-820.

-----------, -----------, and -----------. 1982. Moisture deficits and grain sorghum performance. Effect of genotypes and limited irrigation strategy. Agron.J. 74:808-814.

Gates, C.T. 1968. Water deficits and growth of herbacious plants. P. 135-190. In T.T. Kozlowski (ed) Water deficits and plant growth. Vol.II Academic Press, New York.

Gorbet, D.W., and F.M. Rhoads. 1975. Response of two peanut cultivars to irrigation and kaylor. Agorn.J. 67:373-376.

-----------. 1977. Effect of seed size on the performance of "Florunner" peanuts. Peanut Sci. 4:33-36.

Gowda,A. 1977. Moisture stress and hormonal influence on the flowering and yield of groundnut (Arachis hypogaea L.) Mysore J. Agric. Sci.12:529-530.

Griever, B.J., and F.W. Went. 1965. An electric hygrometer apparatus for measuring water vapor loss from plants in the field. UNESCO Arid Zone Research Series. 25:247-257.

Hadas, A., and D. Russo. 1974. Water uptake by seeds as affected by water stress, capillary conductivity, and seed-soil water contact. I. Experimental Study. Agron.J.66:643-647.

Haise, H.R., and R.M. Hagon. 1967. Soil, plant and evaporative measurements as criteria for scheduling irrigations. In R.M. Hagon et al. (eds.) irrigation of Agricultural lands. Agronomy 11:577-565. Am. Soc. Agron., Madison, Wisconsin.

Hammond, L.C., K.J. Boote., R.J. Varnell, and W.K. Robertson. 1978. Water use and yield of peanut on a well drained sandy soil. APREA, 10:73.

Hanks, R.J., J. Keller., V.P. Rasmussen, and G.D. Wilson. 1976. Line source sprinkler for continuous variable irrigation - crop production studies. Soil Sci. Soc. Am. J.40:426-429.

Hansen, G.K. 1971. Photosynthesis, transpiration and diffusive resistance in relation to water potential in leaves during water stress. Acta Agr. Scand. 21:163-171.

Harris, D.G. 1973. Photosynthesis, diffusive resistance and relative water content of cotton as influenced by induced water stress.

Crop Sci.13:570-572.

Hatfield, J.L 1975. Relationship of photosynthetically active radiation to apparent photosynthetic distribution within soybean canopies. Unpublished Ph.D. dissertation. Library, Iowa State University, Ames, Iowa.

Hesketh, J.D. 1968. Effects of light and temperature during plant growth on subsequent leaf CO2 assimilation rates under standard conditions. Aust.J. Biol.Sci.21:235-241.

Holford, I.C.r. 1971. Effect of rainfall on the yield of groundnuts in Fiji. Tropical Agriculture (Trin). 48(2):171-175.

Holmes, J.W. 1950. Calibration and field use of the neutron scattering method of measuring soil water content. Aust. J. Appl. Sci.7:44-58.

Hsiao,T.c., E. Acevedo, and D.W. Henderson. 1970. Maize leaf elongation: continuous measurements and close dependence on plant water status. Science 168:590-591.

------------.1973. Plant response to water stress. Ann. Rev. Plant Physiol.24:519-570.

-----------. 1975. Variables affecting stomatal opening complicating effects. In measurement of stomatal aperture and diffusive resistance. Washington State University, Research Center, College of Agriclture Bull.809.

Hung, M.T. 1975. Effect of cultivar and planting season on seed protein and oil contents of groundnuts (Arachis hypogaea L.). J. Agric. Res. China 24:24-31.

Idso, S.B., R.D. Jackson, and R.J. Reginato. 1977. Remote sensing of crop yield. Science.196:19-25.

Il'ina, A.I. 1959. Definition of the periods of high sensitivity of peanut plants to soil moisture. Soviet Plant Physiol. 5:253-258.

-----------.1959a. Study of periods of high susceptibility of groundnuts in Fiji. Trop.Agri. (Triny) 48:171-175.

-----------.1959b. Etude des P'erodes de hante sensibilite' de larachide aux differences d' humidite'du sol.Ole'agineux 14:89-92.

-----------.1959. Study of the periods of high susceptibility of groundnuts to different soil moisture conditions. Ole'agineux 14(2):89-92.

International Irrigation Information Centre. 1976. Publication No.1.

International Crops Research Institute For Semi Arid Tropics (ICRISAT). 1981. Progress Report-8 of Agroclimatology, Patancheru, A.P. pp:55(a).

International Crops Research Institute (ICRISAT). Annual Report. 1982. p:189.

Iyama,J. and Y.Murata. 1961a. 1. Studies on the photosynthesis in upland field crops 2. Relationships between the soil moisture and photosynthesis of some upland crops and rice plant. Proc. Crop. Sci. Soc. Japan. 29:350-352.

Jarvis, P.G. 1976. The interception of the variations in leaf water potentials and stomatal conductance found in canopies in the field. Phil. Trans.R. Soc. Lond. B. 273:593-610.

Jenson, M.E. (ed.) 1973. Sources of evapotranspiration data. p.63. In Consumptive use of water and irrigation water requirements. American Society of Civil Engineers, 345 East 47th Street, New York, N.Y.10017.

Johnson, R.R., N.M.Frey, and D.N.Moss. 1974. Effect of water stress on photosynthesis and transpiration of flag leaves and spikes of barley and wheat. Crop. Sci. 14:728-731

Joshi, S.W., and M.M.Kaharia. 1972. Effect of rainfall distribution on the yield of groundnut in Saurashtra. Indian J. Agric. Sci. 48:681-684.

Kanemasu, E.T., and C.B.Tanner. 1969. Stomatal diffusion resistance of snap beans. Influence of leaf water potential. Plant Physiol. 44:1547-1552.

-----------., An-Jen Cheu., W.L.Powers, and I.D.Teare. 1973. Stomatal resistance as an indicator of water stress. Trans. Kan. Acad. Sci. 76:159-166.

Kanitkar, N.O. 1968. Dry farming in India. ICAR, New Delhi. p.470.

Kanwar, J.S., H.L.Nijhawan, and S.K. Raheja. 1983. Groundnut nutrition and fertilizer responses in India. ICAR. New Delhi.

Kassam, A.H., J.M.Kowal, and L.Harkness.1975. Water use and growth of groundnuts at Samaru, Northern Nigeria. Trop. Agric. (Trin) 52:105-112.

Khan, A.R., and B.Datta. 1982. Scheduling irrigation for summer peanuts. Peanut Sci. 9(1):10-13.

Klepper, B. 1968. Diurnal patterns of water potential in woody plants. Plant Physiol. 43:931-934.

-----------. 1973. Water relations of peanuts plants. In peanuts culture and uses. A symposium. American Peanut Research and Education Association. Inc. Still water, Oklahoma. 740/4:265-269.

Kozlowski, K.K.(ed) 1968. Water deficits and plant growth. Vol I. Development, control and measurement. Academic Press, New York.

Kramer, P.J. 1963. Water stress and plant growth. Agron. J.

55:31-36.

-----------.,1969. Plant and soil water relationships: A modern synthesis. Mc Graw- Hill, New York.

-----------., and H.Brix. 1965. Measurement of water stress in plants. Arid Zone Res. 25:343-351.

-----------. 1974. Fifty years of progress in water relations research. Plant Physiol. 54: 463-471.

Krantz, B.A., J. Kampen and S.M. Virmani. 1978. Soil and water conservation and utilization for increased production in the semi-arid tropics. ICRISAT Journal Article 30.

Krishna Sastry, K.S., M. Udaykumar., J.S. Prasad, and V.R. Sashidar. 1980. Drought tolerant studies in groundnut and sunflower. Crop Physiol. Dept. Project Report 1975-80, UAS, Bangalore.

Kuiper, P.C.J. 1961. The effect of environmental factors on the transpirations of leaves with special reference to stomatal light response. Medeal. land bou who gesch. Wageningen, 61:1-49.

Lange, D.L., R. Losch., E.O. Schulze, and 1. Klepper. 1971. Responses of stomata to changes in humidity. Planta. 100:76-86.

Lee, T.A., D.L. Ketring, and R.D. Powell. 1972. Flowering and growth response of peanut plants (Arachis hypogaea L.var.star) at two levels of relative humidity. Plant Physiol. 49:190-193.

Lenka, D., P.K. Mishra. 1973. Response of groundnut (Arachis hypogaea L.) to irrigation. Indian J. Agron. 18:492-497.

Letey, J., and D.B. Peters. 1957. Influence of soil moisture levels and seasonal weather on efficiency of water use by corn. Agron. J. 49:362-365.

Lin, H., C.C. Chen, and C.Y. Lin. 1963. Study of drought resistance in the virginia and spanish types of peanuts. J. Agric. Assoc. China. 43:40-51 (Chinese English summary).

Lin, H., C.C. Chen, and C.Y. Lin. 1969. Study on fruit development of different types of peanut. Taiwan Agricultural Quarterly 5:45-64.

Liu, L.S. 1973. Effects of internal water content of plant on the growth and yield of peanuts. J. Taiwan Agri. Res. 22:47-53.

Maeda, K. 1970. Growth analysis on the plants type in peanut varieties (Arachis hypogaea L.) Proc. Crop. Sci. Soc. Japan 39:1/7-183.

Mantell, A., and E. Goldin. 1964. Influence of irrigation frequency and intensity on the yield and quality of peanuts. Israel J. Agric. 14:203-310.

Mc Cloud, D.S. 1977. Florida field crop yield trends with a changing climate. Proc. Soil and Crop Soc. Florida 36:200-204.

Mederski, H.J., R.B. Curry, and L.H. Chen. 1975. Effects of irradiance and leaf water defict on net carbon dioxide assimilation and mesophyll and transport resistances. Plant Physiol. 55:594-597.

Meidner, H. 1955. Changes in the resistance of mesophyll tissue with changes in the leaf water content. J. Exp. Bot. 6:94-99.

-----------., and T.A. Ransfield. 1968. Physiology of stomata. Mc Graw-Hill. New York.

Metelerkamp, R.R. 1972. The effect of planting date and irrigation on the development of a late maturing groundnut variety. Rhodesian Agric. J. 69:87-89.

----------. 1975. Irrigation scheduling by means of class A pan evaporation. Rhodesian Agric. J. Tech. Bull. No. 16.

Milthrope, F.L. 1945. Fibre development of flax in relation to water supply and light intensity. Ann. Bot., London. 33:31-53.

Mohamed Ali, A., J.C. Mohan, and R. Shanta. 1974. Responses of groundnut to different moisture regimes and farm yard manure. Madras Agric. J. 67:472-476.

Monteith, J.L., and P.C. Owen. 1958. A thermocouple method for measuring relative humidity in the range 95-100%. J. Sci. Inst. 35:443-446.

Naidu, T.C.M., and A. Narayanan. 1981. Utilization of seed reserves for seedling growth of groundnut. I. Effect of seed size in dry matter depletion. Seed Res. 9:6-11.

Narasimham, R.N., I.V. Subba Rao, and M. Singa Rao. 1977. Effect of moisture stress on response of groundnut to phosphate fertilization. Indian J. Agric. Sci. 47:573-576.

Neuman, H.H., G.W. Thurtell., K.R. Sterenson, and C.L. Beadle. 1974. Leaf water content and potential in corn, sorghum, soybean and sunflower. Can. J. Plant Sci. 54:184-195.

Ochs, R., and T.M. Wormer. 1959. Influence of the supply of water on the growth of groundnuts. Ole'agineux 14:281-291.

Ono, Y., and K. Ozaki. 1974. Effect of air temperature on pod development and yield of groundnut plants. Proc. Crop Sci. Soc. Japan. 43:242-246.

Padma Raju, A., G.H. Sankara Reddy, and T. Bapi Reddy. 1981. Studies on the productivity of rainfed groundnut under moisture stress using Neutron moisture Probe. J. Nuclear Agric. Biol. 10:131-133.

Pallas, J.E., Jr., and Y.B. Samish. 1974. Photosynthetic response of peanut. Crop Sci.14:478-482.

----------., ----------., and C.M. Wilmer. 1974. Endogenous rhythmic activity of photosynthesis, transpiration, dark respiration, and carbon dioxide compensation point of peanut leaves. Plant Physiol. 53:907-911.

Pallas Jr.J.E., J.R.Stamsell, and T.J.Koske. 1971. Effect of drought on florunner peanuts. Agron. J. 71:853-858.

-----------.,-----------., and R.R. Bruce. 1977. Peanut seed germination as related to soil water regime during pod development. Agron. J. 69:381-383.

-----------. 1980. An apparent anomaly in peanut leaf conductance. Plant Physiol. 65:848-851.

Panabokke, C.R. 1959. Water consumption patterns of crops in the dryzone environment of Ceylon. Trop. Agriculturist. Agron. J. 63:381-383.

Pearcy, R.W., D. Bjorkham., A.t. Harrison, and H.A. Mooney. 1971. Photosynthetic performance of two desert species with C-4 photosynthesis in death valley, California. Carnegie Inst. Wash Year Book 70:540.

Prevot, P., and M. Ollagnier. 1957. Le problima de le'au dans l'arachide. Ol'eagineux. 12:215-223.

Purseglove, J.W. 1968. 'Tropical Crops Dicotyledons'. (longmans Bristol).

Rao, P.V., and P.S. Rao. 1981. Chemical composition and fatty acid profile of high yielding varieties of oil seeds. Indian J. Agric. Sci. 51:703-707.

Raschke, K. 1960. Heat transfer between the plant and the environment. Ann. Rev. Plant Physiol. 11:111-126.

Rawlins, S.L., and P.A.C. Raats, 1975. Prospects for high frequency irrigation Science. 188:604-610.

Reddy, G.H.S., and M.N. Reddy. 1977. Efficient use of irrigation water for wheat and groundnut. Mysore J. Agric. Sci. 11:22-27.

Reddy, S.K. 1978. Effect of seed size on plant stand, growth, and yield of rainfed groundnut (Arachis hypogaea L.). Thesis abstracts 4:89-90.

Reddy, S.Ch.S., and S.V. Patil. 1980. Production potential of groundnut (Arachis hypogaea L.) in two different seasons under Dharwar Agro-climatic conditions. Food Farm Agric. J. 12:177-180.

Reddy, G.B., S.R. Reddy, and G.H.S. Reddy. 1980. Agricultural water management. 3:45-51.

Reicosky, D.C., R.B. Campbell, and C.W. Doty. 1975. Diurnal fluctuations of leaf water potential of corn as influenced by soil matric potential and micro climate. AGron. J. 67:380-385.

Richards, L.A., G. Ogata. 1958. Thermocouple bar vapor pressure measurement in biological and soil systems at high humidity. Science 128:1089-1090.

Ritchie, J.R. 1974. Atmospheric and soil water influences on the plant water balance. Agric. Mateorol. 14:183-198.

Robertson, W.K., L.C. Hammond, J.T. Johnson, and K.J. Boote. 1980. Effects of plant water stress on root distribution of corn, soybeans and peanuts in sandy soil. AGron. J. 72:548-550.

Rook, N. 1973. Effect of water stress on plant processes. Proc. Soil and Plant Water Symp. Palmerston. North. DSIR. Newzealand. 17-23.

Russell, M.B. 1980. Profile moisture dynamics of soil in Vertisols and Alfisols. Page 75-87. In Proceedings of the International Workshop on Agroclimatological Research Needs of the Semi-Arid Tropics, 22-24 Nov 1978, ICRISAT, Patancheru, India.

Sandhu, R.S., J.S. Saini, and T. Singh. 1972. The effect of irrigation and fertilizer levels on the yield and quality of groundnut C 501. J. Res. Punjab Agric. Univ. 9:535-540.

Scholander, P.F., H.T. Hammel., E.D. Bradstreet, and E.A. Hemmingsen. 1965. Sap pressure in vascular plants. Science. 148:339-346.

Schulze, E.D., O.L. Lange, U. Buschboom, L. Kappen, and M. Evanari. 1972. Stomatal responses to changes in humidity in plants growing in the desert. Planta 108:259-270.

Shinde, G.G., and K.R. Pawar .1982. Effect of irrigation on the pod yield of groundnut. Indian J. Agric. Sci. 52:576-578.

Shockley, D.G. 1966. Evapotranspiration and farm irrigation planning and management. In evapotranspiration and its role in water resources management ASAE. Canf. Proc. St. Joseph. Michigan. 3-5.

Sindagi, S.S., and B.S.G. Reddy. 1968. Effect of sowing date and rainfall distribution on the yield of groundnut crops. In Rao. B.V.V. (ed). Proc. Seminar Drought, Univ. Agric. Sci. Bangalore.

Singh, P., and M.B. Russel. 1979. Water balance and profile moisture loss patterns of an Alfisol. AGron.J. 71:963-966.

Sivakumar, M.V.K. 1978. Environmental factrors affecting plant productivity. Proceedings of Final INPUTS review meeting. Honolulu, Hawai.

---------., N. Seetharama., Sardar Singh, and F.R. Bidinger. 1979.

Water relations, growth, and dry matter accumulation of sorghum under postrainy season conditions. Agron. J. 71:843-847.

-----------., R.C. Sachan., A.K.S. Huda., Sardar Singh., N. Seetharama, and S.M. Virmani. 1982. Paper presented at the IRAT-ICRISAT workshop on watermanagement and crop production, Montpellier, France, 26 May 1982.

Siva Subramanian, S., and V. Ramakrishna. 1974. Effect of seed size on seedling vigour in groundnut. Seed. Sci. Tech. 2:435-441.

Skelton, B.J., and G.M. Shear. 1971. Calcium translocation in the peanut (Arachis hypogaea L.) Agron. J. 63:409-412.

Slatyer, R.O. 1955. Studies on water relations of crop plants grown under natural rainfall in North Australia. Aust. J. Agric. REs. 6:365-377.

-----------. 1967. Plant water relationships . Academic Press. London.

-----------. 1970. The effect of internal water stress on plant growth, development and yield. p. 177-191. In R.O. Slatyer (ed.) plant responses to climatic factors. Proc. of uppsale. Symp. UNESCO,Paris.

Slavik, B (ed.) 1965. Water stress in plants. Dr. W. Junk, N.V. Publ. The Hague.

Smart, R.E., and H.D. Barrs. 1973. The effect of environment and irrigation interval on leaf water potential of four horticultural species. Agric. Meteorl. 12:37-346.

Spain, G.E. 1976. Seed vigour, a seed control official's view point. J. Seed. Tech. 1:13-17.

Stalfelt, M.G. 1961. The effect of water deficit on stomatal movement in a carbon dioxide free atmosphere. Physiol. Plant.

14:826-843.

Stansell, J.R., B. Klepper, V.B. Browning, and h.M. Taylor. 1973. Plant water status in relation to clouds. Agron. J. 65:677-678.

-----------., J.L. Shepherd, J.G., Pallas, R.R. Bruce, N.A. Minton, D.K. Bell and L.W. Morgan. 1976. Peanut responses to soil water varialble in the south east. Peanut. Sci. 3:44-48.

-----------.,and Pallas, J.E:Jr. 1979. Peanut response to timing and duration of drought stress as reflected in kernel yield and quality. Proc. Amer. Peanut Res. Ed. Soc. 11:61.

Stern, W.R. 1968. The influence of sowing date on the yield of peanuts in a short summer rainfall environment. Aust. J. Exp. Agric. Anim. Aust. 8:594-598.

Stevenson, K.R., and R.H. Shaw. 1971. Diurnal changes in leaf resistance to water vapour diffusion at different heights in soybean canopy. Agron. J. 63:17-19.

Stewart, J.I., R.J. Janks, R.E. Denielson, E.B.Jackson, W.O. Pruitt, W.T. Franklin, J.P. Riley, and R.M. Hagan. 1977. Optimising crop production through control of water and salinity levels in the soil. Utah Water Research Lb. Report.

Stewart, J.I. and R.M. Hagan. 1973. Functions to predict effects of crop water deficits. Journal of the Irrigation and Drainage Division, ASCE 99 (IR 4):421-43. Proc. Paper 10229.

Stransky, J.J., and D.R. Wilson. 1964. Terminal elongation of loblolly and short leaf pine seedlings under soil moisture stress. Soil Sci. Soc. Am. Proc. 28: 439-440.

Su, L.C., and P.C. Lu. 1963. Effect of time of irrigation and amount of water irrigated on peanut yield. J. Agric. Assoc.

China. 41:43-51.

------------., T.R. Chen, S.C. Hsu, and M.T. Tseng. 1964. Studies on processing of water and economised irrigation of peanuts. J. Agric. Assoc. China. 45:31-40 (Chinese English Summary).

Subramanian, S., S.A. Sundersingh., K.P. Ramaswamy, S.P. Pakiraj, and K. Rajagopalan. 1974. Effect of moisture stress at different growth stages of groundnut. Madras Agric. J. 61:813-814.

Subramanyam, P.,C.S.K. Vijayakumar, and A.S. Rao. 1978. Transpiration in rust infected leaves of groundnut. Current Science 47:302-304.

Sullinan, J.P., and W.A. Brun. 1975. Effect of root genotype on shoot water relations in soybeans. Crop Sci. 15:319-322.

Tiwari, P.N., P.N. Gambhit, and T.S. Rajan. 1974. Rapid and nondestructive determination of seed oil by pulsed nuclear magnetic resonance technique. J. Am. Oil Chem. Soc.51:104/9.

Thivend, P., C. Mercier, and A. Guilbot. 1972. Determination of starch with glucoamylose. In Methods in corbohydrate chemistry (ed.) L. Whistler and J.N. Be Miller. Vol. VI. p.100-105. Academic Press. New York.

Troughton, J.H. 1969. Plant water status and CO2 exchange jof cotton leaves Aust. J. Biol. Sci. 22:289-302.

------------., and R.O. Slatyer. 1969. Plant water status, leaf temperature and calculated mesophyll resistance to carbon dioxide of cotton leaves. Aust. J. Biol. Sci. 22:815-827.

Turner, N.C. 1970. Illumination and stomatal resistance to transpiration in three field crops. p.63-63. In R.O. Proc. Uppsala Symp., UNESCO, Paris.

Turner, N.C., and L.S. Incoll. 1971. The vertical distribution of photosynthesis in crops of tobacco and sorghum. J. Appl. Ecol. 8:581-591.

Unchiv, N.D. 1941. Effect of irrigation and rain on the yield and quality in Arachis. Hort. Abst. 12:1013.

Under Wood, C.V., H.M. Taylor, and C.S. Hoveland. 1971. Soil physical factors affecting peanut pod development. Agron. J. 63:953-954.

Vaadia, Y., F.C. Raney, and R.M. Hagan. 1961. Plant water deficits and physiological processes. Ann. Rev. Plant. Physiol. 12:265-292.

Varnell, R.J., H. Mwandermere, W.K. Robertson., and K.J. Boote. 1976. Peanut yields affected by soil water, no till and gypsum. Proc. Soil and Crop Sci. Soc. Florida 35:56-59.

Vivekananda, A.S., and H.P.M. Gunasena. 1976. Lysimetric studies on the etfect of soil moisture tension on the growth and yield of maize (Zea mays L.) and groundnut (Arachis hypogaea L.). Beitr. Trop. Landwirtsch. Veterinarmed. 14:369-378.

Walker, W.M., and Hymowitz. 1972. Simple correlations between certain mineral and organic components of common bean, peanuts and cowpeas. Communications in soil science and plant analysis. 3:505-511.

Waring, R.H., and B.D. Cleary. 1967. Plant moisture stress. Evaluation by pressure bomb. Science. 155:1248-1254.

Watson, D.J. 1952. The physiological basis of variation in yield. Adv. Agron. 4:101-145.

Weatherly, P.E. 1950. Studies in the water relations of cotton plant. I. The field measurements of water deficits in leaves.

New physol. 49:81-97.

Wessling, W.H. 1966. Reaction of peanuts to dry and wet growing periods in Brazil. Agron. J. 58:23-26.

Wiegand, C.L., and L.N. Namken. 1966. Influence of plant moisture stress, solar radiation, and air temperature on cotton leaf temperature. Agron. J. 58:582.

Williams, R.F., and R.E. Shapter. 1955. A comparative study of growth and nutrition in barley and rye as affected by low-water treatment. Aust. J. Biol. Sci. 8:435-466.

Willams,J.H., J.H.Wilson, and G.C. Bate, 1975. The Growth and development of four groundnut (Arachis hypogaea L.) cultivars in Rhodesia. Rhodesian. J. Agric. Res. 13;131-144.

-----------., G.L. Hildebrand, and J.R. Tattersfield. 1978. The effect of weather and genotype x environment interation on the yields of groundnut (Arachis hypogaea L..) Rhodesian J. Agric. Res. 16:193-204.

Wormer, W.T., and R. Ochs. 1959. Soil moisture opening of the stomata and transpiration of oil palm and groundnuts. Ole'agineux 14:571-580.

Zamski. E., and M.Ziv. 1976. Pod formation and its geotropic orientation in the peanut (Arachis hypogaea L.) in relation to light and mechanical stimulus., Ann. Bot. 40:631-636.

V I T A

The author was born on 4th April 1941 at Kapileswarapuram, Andhra Pradesh. He obtained his B.Sc (Agr) degree from Andhra University, Waltair in 1962 and his M.Sc (Agr) degree (Plant Physiology) from the Sardar Patel University, Vallabh Vidyanagar, Anand, Gujarat, in 1972.

He served in the Department of Agriculture, Government of Andhra Pradesh and Andhra Pradesh Agricultural University from 1962 to 1983 as State Seed Farm Manager, Research Assistant in oilseeds, and sugarcane, Assistant Plant Physiologist, and Assistant Professor, Department of Plant Physiology, College of Agriculture, Rajendranagar, Hyderabad.