

EVAPOTRANSPIRATION AND GROWTH ANALYSIS ON TOBACCO

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(Soil & Water Conservation)**

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C E R T I F I C A T E

This is to certify that the work recorded in the thesis entitled "EVAPOTRANSPIRATION AND GROWTH ANALYSIS ON TOBACCO" submitted by Shri Manoranjan Saha, for the award of the Degree of Doctor of Philosophy in Agriculture (Soil and Water Conservation) of the Bidhan Chandra Krishi Viswa-vidyalaya, is a faithful and bonafide research work carried out under my personal supervision and guidance. The results of the investigation reported in the thesis have not so far been submitted for any other Degree or Diploma. The assistance and help received during the course of investigation are duly acknowledged.

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A B S T R A C T

Commercial tobacco is cultivated in most parts of the world under a variety of soil and climatic conditions mainly for Nicotiana tabacum L. and Nicotiana rustica L. Studies relate to lysimetric experiments in completely randomised design spread over two winter seasons of 1979-80 and 1980-81 at Kalyani (South Bengal) situated at 22.53°N latitude and at 89°E longitude.

The weekly rates of evapotranspiration (E_T) and weekly average values of four climatic factors viz., Temperature (T), wind velocity (W), sunshine hours (S) and vapour pressure deficit ($e_s - e_a$) were processed to obtain functional relationship between them. The influence of temperature on evapotranspiration was highest under moist regime (0.2 atm) irrespective of varieties but the rate of change of evapotranspiration gradually decreased with the increase in soil moisture tension. Evapotranspiration increased linearly with the increase in wind velocity irrespective of soil moisture tension, variety and season, it was higher with 0.3 atmosphere soil moisture tension, it increased in all treatments with differential rate with the increase in sunshine hours, it increased in all treatments with differential rate with the increase in ($e_s - e_a$) and that the influence of ($e_s - e_a$) was

higher on the N. rustica species. Multiple regression analysis for prediction of E_T under combined influence of climatic variables indicated significant result. It was observed that E_T vs M (soil moisture tension) relationship was curvilinear with higher total E_T under 0.3 atmosphere soil moisture tension. The relationship indicated that with the increase in soil moisture tension total E_T decreased. E_T vs N (nitrogenous fertiliser) relationship indicated that at any stage of growth higher E_T was associated with higher doses of nitrogen.

Comparison between E_T and E_0 (pan evaporation) indicated that lowest ratio (E_T/E_0) was associated with 0.9 atmosphere soil moisture tension irrespective of species and seasons and the ratio (E_T/E_0) gradually increased with the decrease in soil moisture tension mainly due to higher evaporation rate under decreased soil moisture tension.

Height of plant under N. tabacum was found greater over N. rustica at harvest stage in both the seasons and prediction equations can be used in predicting height at any stage of growth. The height decreased with the increase in soil moisture tension. The height decreased progressively with the decrease in application of nitrogen, and it increased in a non-linear manner with the advance in growth stage. Diameter of plant did not show any remarkable difference between the varieties towards the harvest stage of the crop. It increased significantly with the decrease in soil moisture tension and increased rate of nitrogen caused a significant increase in diameter throughout the growth period.

Green weight of plant increased with the advance in growth stage for both the varieties, similarly irrespective of soil moisture tension and with increase in nitrogen level. Dry weight of plant increased for both the varieties with the advance in growth stage, it increased in all levels of soil moisture tension and also with the increase in levels of nitrogen. Leaf area index (LAI) increased with the advance in growth stage irrespective of variety with the decrease in soil moisture tension and increase in the nitrogen level. Leaf area coefficient indicated in general higher values for smaller leaves.

Yield (leaf) varied significantly with varieties, the higher rate of yield in N. tabacum might be due to the genetic characters of the variety, it decreased significantly with the increase in soil moisture tension in both the varieties, it increased significantly with the increase in nitrogen level in both the varieties. Yield (stalk) varied significantly for both the varieties during the two seasons, it decreased significantly with the increase in soil moisture tension and increased significantly with the increase in nitrogen level.

Quality character of tobacco leaf is judged from its nicotine content, the influence of variety on it was significant in both the seasons, with a significantly high per cent of nicotine with N. rustica indicating variation in nicotine content probably due to the genetic characters of the variety. It

increased with the increase in soil moisture tension and it increased significantly with the increase in nitrogen level.

With the increase in total evapotranspiration, leaf yield increased in a linear manner for both the varieties.

Prediction equation for evapotranspiration under climatic variables, soil moisture tensions and nitrogen levels showed high values of F.

Combined influence of soil moisture tension and nitrogen on leaf yield indicated high values of F.

C O N T E N T S

I.	INTRODUCTION	
1.1	Influencing Factors	3
1.2	Problem	3
II.	REVIEW OF LITERATURE	
2.1	Introductory Remarks	7
2.2	Evapotranspiration	8
2.2.1	Factors influencing evapotranspiration	9
2.2.1.1	Climate	9
2.2.1.1.1	Temperature	9
2.2.1.1.2	Wind velocity	10
2.2.1.1.3	Sunshine hours	11
2.2.1.1.4	Radiation	12
2.2.1.1.5	Vapour pressure deficit	13
2.2.1.2	Soil moisture tension	14
2.2.1.3	Nitrogen	17
2.2.1.4	Crop	18
2.2.1.4.1	Height of plants	18
2.2.1.4.2	Dry matter	18
2.2.1.4.3	Leaf area index	19

2.3	Influence of Soil Moisture Tension and Nitrogen on growth characters	19
2.3.1	Soil moisture tension	19
2.3.2	Nitrogen	22
2.4	Co-efficients for Estimating Leaf Area	24
2.5	Growth Function and Prediction Equation for Yield and Evapotranspiration	27
2.6	Influence of Soil moisture tension and Nitrogen on Yield	31
2.6.1	Soil moisture tension	31
2.6.2	Nitrogen	35
2.7	Influence of Soil Moisture Tension and Nitrogen on Nicotine Content of Tobacco	40
2.7.1	Soil moisture tension	41
2.7.2	Nitrogen	42
III. MATERIALS AND METHODS		
3.1	Location and Season	45
3.1.1	Location	45
3.1.2	Climate	45
3.2	Design of the Experiment	47
3.2.1	Soil	47
3.2.2	Design	48
3.2.3	Treatments	48
3.2.3.1	Soil moisture tension	48
3.2.3.2	Nitrogen levels	49
3.2.3.3	Variety	49
3.3	Agronomic Practices	49
3.3.1	Nursery for seedling raising	49
3.3.2	Manuring	49

3.3.3	Fertilizer application	50
3.3.4	Transplanting	50
3.3.5	Plant protection measures	51
3.3.6	Inter-cultural operations	51
3.3.7	Biometric observations	51
3.3.7.1	Pre-harvest observations	51
3.3.7.2	Post-harvest observations	51
3.3.8	Harvesting	52
3.4	Techniques of Measurements	52
3.4.1	Soil moisture tension	52
3.4.2	Irrigation	54
3.4.3	Measurement of evapotranspiration	54
3.4.4	Study of growth characters	55
3.4.4.1	Height of the plant	55
3.4.4.2	Diameter of the plant	55
3.4.4.3	Green weight of the plant	56
3.4.4.4	Dry weight of plant	56
3.4.4.5	Leaf area index (LAI)	56
3.4.4.6	Co-efficient for tobacco leaf area	56
3.5	Nicotine estimation	57
3.6	Statistical analysis	58
IV.	RESULTS AND DISCUSSION	
4.1	Evapotranspiration	59
4.1.1	Influencing Factors	59
4.1.1.1	Climate	59
4.1.1.1.1	Temperature	60
4.1.1.1.2	Wind Velocity	64

4.1.1.1.3	Sunshine hours	69
4.1.1.1.4	Vapour pressure deficit	73
4.1.1.1.5	Combined influence of climatic variables	78
4.1.1.2	Soil moisture tension	79
4.1.1.3	Nitrogen	87
4.1.1.4	Interaction	95
4.1.1.5	Crop factors	98
4.1.1.5.1	Leaf area index	98
4.2	Comparison Between Evapotranspiration And Pan Evaporation	101
4.2.1	Soil moisture tension	101
4.2.2	Nitrogen	103
4.3	Growth Characters	103
4.3.1	Height of plant	104
4.3.1.1	Variety	104
4.3.1.2	Soil moisture tension	108
4.3.1.3	Nitrogen	110
4.3.1.4	Interaction	111
4.3.2	Diameter of plant	113
4.3.2.1	Variety	114
4.3.2.2	Soil moisture tension	114
4.3.2.3	Nitrogen	114
4.3.2.4	Interaction	116
4.3.3	Green weight of plant	116
4.3.3.1	Variety	118
4.3.3.2	Soil moisture tension	118
4.3.3.3	Nitrogen	120

4.3.4	Dry weight of plant	120
4.3.4.1	Variety	120
4.3.4.2	Soil moisture tension	122
4.3.4.3	Nitrogen	122
4.3.5	Leaf area index	123
4.3.5.1	Variety	123
4.3.5.2	Soil moisture tension	126
4.3.5.3	Nitrogen	129
4.3.6	Co-efficient for estimating leaf area	130
4.3.6.1	Leaf area and product of length and maximum width	130
4.3.6.2	Variety	131
4.3.6.3	Soil moisture tension	133
4.3.6.4	Nitrogen	133
4.4	Yield	136
4.4.1	Leaf yield	136
4.4.1.1	Variety	136
4.4.1.2	Soil moisture tension	136
4.4.1.3	Nitrogen	140
4.4.1.4	Interaction	143
4.4.2	Stalk yield	143
4.4.2.1	Variety	143
4.4.2.2	Soil moisture tension	143
4.4.2.3	Nitrogen	145
4.5	Nicotine Content of Tobacco Leaf	146
4.5.1	Variety	147
4.5.2	Soil moisture tension	147
4.5.3	Nitrogen	149

4.6	Influence of Evapotranspiration	149
4.7	Development of Equation for Evapotranspiration	151
4.8	Combined Influence of Soil Moisture Tension and Nitrogen on Leaf Yield	154
V.	SUMMARY AND CONCLUSION	
5.1	Summary	156
5.2	Conclusion	164
VI.	FUTURE SCOPE OF RESEARCH	167
VII.	BIBLIOGRAPHY	i-xxii

LIST OF TABLES

3.1	Variation in meteorological data	46
3.2	Mechanical composition of soil	47
3.3	Physical properties of soil	47
3.4	Chemical properties of soil	47
3.5	Dates of sowing, transplanting and harvesting of tobacco	50
4.1	Analysis of variance	79
4.2	Variation in total evapotranspiration under different soil moisture tensions	86
4.3	Variation in total evapotranspiration under different level of nitrogen	92
4.4	Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on total evapotranspiration (cm) during 1979-80	96
4.5	Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on total evapotranspiration (cm) during 1980-81	97
4.6	Variation in E_T/E_0 under different soil moisture tension and nitrogen	102
4.7	Variation in plant height under different soil moisture tension and nitrogen level	107
4.8	Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on plant height (cm) during the season 1979-80 (90 days after transplanting)	112
4.9	Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on plant height (cm) during the season 1980-81 (60 days after transplanting)	113
4.10	Variation in plant diameter under different soil moisture tension and nitrogen level	115

4.11	Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on the plant diameter (cm), at 30 days after transplanting	117
4.12	Variation in plant green weight under different soil moisture tension and nitrogen level	119
4.13	Variation in dry weight of plant under different soil moisture tension and nitrogen level	121
4.14	Variation in leaf area index under different soil moisture tension and nitrogen level	128
4.15	Variation in co-efficient under varieties at different stages of development	133
4.16	Variation in co-efficients for leaf area under different soil moisture tensions	134
4.17	Variation in co-efficients for leaf area under different nitrogen level	135
4.18	Variation in leaf and stalk yield (q/ha) under different soil moisture tension and nitrogen level	139
4.19	Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on leaf yield (q/ha) during the season 1979-80	144
4.20	Variation in nicotine content of tobacco leaves at harvest under different varieties, soil moisture tension and nitrogen level	148
4.21	Values of regression co-efficients	152
4.22	Analysis of variance	153
4.23	Analysis of variance	155

LIST OF FIGURES

3.1	Soil moisture content and moisture tension, moisture resistance	53
4.1	Relationship between evapotranspiration rate and temperature	61
4.2	Relationship between evapotranspiration rate and temperature	62
4.3	Relationship between evapotranspiration rate and temperature during two seasons	63
4.4	Relationship between evapotranspiration and wind velocity	65
4.5	Relationship between evapotranspiration rate and wind velocity	66
4.6	Relationship between evapotranspiration rate and wind velocity during two seasons	67
4.7	Relationship between evapotranspiration rate and sunshine hours	70
4.8	Relationship between evapotranspiration rate and sunshine hours	71
4.9	Relationship between evapotranspiration rate and sunshine hours during two seasons	72
4.10	Relationship between evapotranspiration rate and vapour pressure deficit	74
4.11	Relationship between evapotranspiration rate and vapour pressure deficit	75
4.12	Relationship between evapotranspiration rate and vapour pressure deficit during two seasons	76
4.13	Mean evapotranspiration rate as a function of days after transplanting under different soil moisture tension	80

4.14	Mean evapotranspiration rate as a function of days after transplanting under different soil moisture tension	81
4.15	Mean evapotranspiration rate as a function of days after transplanting under different soil moisture tension during two seasons	82
4.16	Relationship between total evapotranspiration and soil moisture tension	84
4.17	Relationship between total evapotranspiration and soil moisture tension during two seasons	85
4.18	Mean evapotranspiration rate as a function of days after transplanting under different nitrogen levels	88
4.19	Mean evapotranspiration rate as a function of days after transplanting under different nitrogen levels	89
4.20	Mean evapotranspiration rate as a function of days after transplanting under different nitrogen levels during two seasons	90
4.21	Relationship between total evapotranspiration and nitrogen level	93
4.22	Relationship between total evapotranspiration and nitrogen level during two seasons	94
4.23	Relationship between evapotranspiration rate and leaf area index under different soil moisture tension during two seasons	99
4.24	Relationship between evapotranspiration rate and leaf area index under different nitrogen level during two seasons	100
4.25	Relationship between height of plant and days after transplanting under different variety, soil moisture tension and nitrogen levels	105
4.26	Relationship between height of plant and days after transplanting under different variety, soil moisture tension and nitrogen levels during two seasons	106
4.27	Relationship between height of plant and (A) Soil moisture tension, (B) Nitrogen	109

4.28	Relationship between leaf area index and days after transplanting under different variety, soil moisture tension and nitrogen levels	124
4.29	Relationship between leaf area index and days after transplanting under different variety, soil moisture tension and nitrogen levels during two seasons	125
4.30	Relationship between leaf area index and (A) Soil moisture tension, (B) Nitrogen	127
4.31	Relationship between leaf area measured and product of length and maximum width	132
4.32	Relationship between leaf yield and soil moisture tension	137
4.33	Relationship between leaf yield and soil moisture tension during two seasons	138
4.34	Relationship between leaf yield and nitrogen level	141
4.35	Relationship between leaf yield and nitrogen level during two seasons	142
4.36	Relationship between leaf yield and total evapotranspiration	150

S Y M B O L S

ALAI	Active Leaf Area Index
atm.	Atmosphere
cv.	Cultivar
e_a	Saturated vapour pressure of the atmosphere, mm Hg
e_s	Vapour pressure on the crop surface, mm Hg
E_T	Evapotranspiration rate, mm/day
E_T/E_0	Ratio of evapotranspiration and pan evaporation
$E_T(S)$	Total evapotranspiration, cm
ha	Hectare
kg m^{-2}	Kilogram per square metre
M	Soil moisture tension, atmosphere
S	Sunshine hours
T	Temperature

CHAPTER I

INTRODUCTION

I N T R O D U C T I O N

The information available on the origin and history of tobacco suffers generally from ambiguity and contradictions. It is said that tobacco was in existence in Asia even during the 12th century, A.D. when it was not known elsewhere. Some Asian communities considered it ^{as} a sacred plant. It was used not only as an intoxicant for producing an agreeable drugged state and as a cury for all kinds of ills but also for doing homage to deities. During the 17th century the habit of smoking spread rapidly in several countries.

In India mostly two species (Nicotiana tabacum L. and Nicotiana rustica L.) of tobacco are cultivated commercially. Although India occupies third position in tobacco production and fourth in its exports respectively, it would be also worthwhile to mention that it is the second largest exporter of flue-cured virginia tobacco. During 1981-82 India earned foreign exchange worth of Rs. 214 crores which was approximately 58 per cent higher than that was gained during 1980-81.

Among the traditionally grown cash crops in West Bengal, Motihari tobacco (N. rustica) is important for its characteristic strong flavour, colour, pungency, taste etc. Out of total area

of 14.9 thousand hectares with an annual production of 15 thousand tonnes of cured leaf in the State, Motihari tobacco alone accounts for 11.9 thousand hectares with 12.4 thousand tonnes of production of cured leaf. But the yield of this crop per unit area (965 kg leaf/ha) in India is very low in comparison with those of other countries like Japan, Canada, U.S.A., with an average yield of 2,290, 2,003 and 2,324 kg/ha respectively. The low yield of tobacco is mainly due to improper water management and fertilizer use. Water management is one of the important factors for assured crop production (Atkinson et al., 1969). It permits better utilization of all other production factors and leads to increased yield per unit of land and quality of the crop. Judicious estimation of quantity of water application, proper soil and crop management practices and scientific scheduling of irrigation according to the requirement of the plant are important aspects of efficient water management practices. It also requires a thorough study not only of soil properties but also of plant-water-relationship, climate, agronomic practices and economic assessment. The complexity of the factors chiefly governing the water relations of tobacco is of paramount importance, as a rule, in determining the type, grade, and quality of leaf produced, both, internal and external environmental factors contribute to the control of water relations.

Crop performance is best when both organic and inorganic fertilizers are applied to the crops in a balanced quantity. They have a positive effect on yield. Efficient use of nitrogenous fertilizer is one of the most important factors for the

commercial production of crop. From the seedling stage through final harvest, the soil nitrogen regime affects the process of plant development more than any other mineral elements. The role of nitrogen is of major importance with respect to time of absorption, concentration in the leaf at various stages of growth and numerous other aspects.

Therefore, for better growth and development of crop, application of balanced quantity of organic, inorganic fertilizer and maintenance of proper quantity of water is essential. The frequency and quantity of water, in turn, depend on the daily water use rate i.e., evapotranspiration of the crop. Evapotranspiration and growth analysis is, therefore, considered necessary.

1.1 Influencing Factors

The evapotranspiration rate (E_T) depends on the combined influence of several climatic factors, soil moisture tension (Maity, 1975), fertility level (Sinha et al., 1976) the stages of development of the crop and soil and crop management. All these factors influence the growth and development of tobacco.

1.2 Problem

The role of soil moisture tension and levels of nitrogen in regulating evapotranspiration of crops are not entirely clear although it is expected that with the increase of soil moisture tension with time, E_T will decrease. E_T is also influenced by the growth of crops which in turn depends on the fertility status

of the soil. It is expected that a well fertilized crop with its extensive root system will extract moisture from greater depth (Brown, 1971), but different view exists as to the influence of nitrogen on E_T . It is, therefore, necessary to examine the inter-relationship amongst measured E_T , climatic variables, soil moisture tensions ^{and} nitrogen levels.

In order to determine the frequency and quantity of irrigation water for a particular crop, irrigation studies are required. In absence of evapotranspiration study, recommendation for scheduling of irrigation may be made from a knowledge of soil and root system together with the estimate of evapotranspiration rate (Erie, 1968). An attempt has, therefore, been made to estimate evapotranspiration from pan evaporation data, mainly from the ratio between evapotranspiration and pan evaporation data.

Growth analysis (Height of plant, diameter of plant, green weight of plant, dry weight of plant and leaf area index) has become established as a standard method of estimating net photosynthetic production of plants and plant stands in many parts of the world. Growth analysis represents the first step in the analysis of primary production, being a link between merely recording plant production and analysing it by means of physiological methods. The primary values are measured in growing plants at certain time intervals, various indices and characteristics are calculated from them, that describe the growth of the plants. Growth characters are primarily designed to describe, in quantitative terms, the plants and plant stands as productive

system. From the practical point of view, growth characters are useful as indices of yield capacity. Statistically designed sets are considered for evaluation of growth analysis.

The low yield of tobacco is due to improper management of the most important inputs viz., irrigation and fertilizers. The condition is aggravated since the crop is grown mostly in winter (Rabi) season when soil moisture stress is maximum. The influence of the different soil moisture tensions and the nitrogen fertilization and their interaction on crop have not so far been investigated adequately. The growth characters of the crop at different growth stages as influenced by the proper and timely irrigation and nitrogen management called for detailed investigation.

Quality of tobacco leaves after curing is the most important character for market value. The assessment of leaf quality under different conditions of irrigation and nitrogen fertilizer is the most important criterion to be considered. Perhaps, the best known tobacco compound is the volatile base, nicotine. The strength of a smoke is a measure of its nicotine content and must be carefully controlled. An attempt has, therefore, been made to estimate nicotine content of tobacco varieties.

In view of the importance of tobacco crop and for increasing its yield per hectare, it is felt necessary to undertake an experimental study on the influence of soil moisture tensions and levels of nitrogen and their interaction on the growth of tobacco crop particularly under South Bengal condition, to explore the

possibility of its commercial cultivation in this part of the country.

The investigation was conducted with the following objectives :

To examine

1. a. The relationship between measured evapotranspiration rate and each of the ^{four} climatic variables, soil moisture tension, nitrogen levels and leaf area index,
- b. the relationship between evapotranspiration and pan evaporation data,
- c. the influence of different soil moisture tension and nitrogen levels on growth characters of tobacco,
- d. the influence of different soil moisture tension and nitrogen levels on leaf and stalk yield of tobacco,
- e. to estimate the nicotine content of tobacco under different soil moisture tension and nitrogen levels, and
2. a. to develop equations for estimating evapotranspiration from tobacco varieties, using four climatic variables, soil moisture tension and nitrogen levels,
- b. to develop equations for predicting leaf yield of tobacco varieties with different combinations of soil moisture tensions and nitrogen levels.

CHAPTER II

REVIEW OF LITERATURE

2.1 Introductory Remarks

Information on irrigation at different levels and times, its effect on growth and yield, quantity and water required for satisfactory growth and yield of tobacco, is at its minimum, in comparison to the work done on other crops. The experiments on water management of different crops carried out by many investigators showed that soil moisture stress at different stages had tremendous effect on the growth, development, maturity and production of crops. The experiments also indicated that timely supply of irrigation water to the crops increased yield. For maximizing yield of crops, judicious application of water at critical stages is regarded as a must in agricultural technology. Although much studies have been done on the water requirements of different crops, studies on the influence of soil moisture tension and the quantity of irrigation water on the different yield attributes and growth characteristics for tobacco are very limited in India. Attempts are made in this investigation to estimate evapotranspiration from free water surface evaporation. Attempt is also made from the practical point of view to establish relation between evapotranspiration and production of tobacco. Attempts have been made to correlate different climatic parameters with evapotranspiration and are also extended to estimate the quality of tobacco

leaves in response to varied soil moisture tension and nitrogen fertilization. The variation of water regimes as well as the application of nitrogen fertilizer to tobacco are the most important factors which influence the growth and yield attributes and characteristics to a great extent. It has been reported on the various factors influencing evapotranspiration, the influences of irrigation and nitrogen on the production of tobacco. The evapotranspiration and yield of tobacco predicted from nitrogen, soil moisture tension and various climatic variables with the help of different formulae are reviewed here.

2.2 Evapotranspiration

The rate at which water is lost from the soil by evaporation and from the plant by both transpiration and evaporation is termed as evapotranspiration rate (E_T). Thornthwaite (1948) used the term "potential evapotranspiration" to express the combined effects of evaporation and transpiration occurring from plant and soil. It is defined as the amount of water which will be lost from surface completely covered with vegetation if there is sufficient water in the soil at all times for the use of vegetation. Penman (1956) prefers to call this as evaporation and points out that in both cases, the process involved is the same.

Zlatev (1966) studied that upto 30 days after transplanting, the total losses of water through transpiration and evaporation in tobacco fields were 20-30% of the maximum evapotranspiration observed for local meadows; water losses reached a maximum of 50% at 20-40 days later and then fell sharply with the beginning of

leaf harvesting.

Evapotranspiration is often predicted on the basis of climatological data. The approaches followed are to relate the magnitude and variation of evapotranspiration to one or more climatic factors such as temperature, day length, humidity, wind, sunshine, etc. Many formulae have been developed and used from time to time and have been critically reviewed by various workers (Singh et al., 1960; Israelsen and Hansen, 1962; Tanner, 1967; Chang, 1968; Dastane, 1972; Taylor and Aschroft, 1972; Doorenhos and Pruitt, 1975).

2.2.1 Factors influencing evapotranspiration

The rate of evapotranspiration (E_T) of different plants varies greatly under the same conditions (Hanks et al., 1968). Even the E_T of the same crop varies greatly according to the stages of growth and the period of the year in which it is grown. Of the various factors affecting E_T , climate, water management practices, levels of fertilizer and crop are most important.

2.2.1.1 Climate

2.2.1.1.1 Temperature

Since with the increase in air temperature, the saturated vapour pressure increases in a non-linear manner, a large vapour pressure gradient above the crop is expected with higher temperature, resulting in more rapid removal of water vapour (Jensen and Haise, 1963).

Wilcox (1963) considered temperature as best single weather element to use in estimating E_T . Jensen (1967) reported that when humidity was held constant at 50 per cent, both evaporation and evapotranspiration increase proportionately as temperature was varied approximately from 60°F to 105°F. A linear relationship between the temperature and E_T from potato crop was reported by Maity (1972). The results of the experiment conducted on the Kalyani University Farm at Haringhata on potato during 1964-65, 1966-67 and 1968-70, indicated a linear relationship between evapotranspiration and the mean air temperature (Maity and Pandya, 1975).

2.2.1.1.2 Wind velocity

It was observed by Frost and Schwalen (1960) that evapotranspiration losses from Clover, bermuda grass and sudan grass reach a peak near mid-day, increasing with vapour pressure deficit and wind velocity. The E_T from beans, sugarbeet and grass, sword increased with the increase of wind velocity (Pruitt, 1960). The E_T from sugarbeet exceeded that of a grass sword, apparently because of turbulence induced by the greater roughness of the sugarbeet crop (Pruitt, 1960). On moderate days, high wind velocities usually had the effect of increasing losses equal to that on hot dry days without wind (Frost, 1963). During the night when the plants are turgid and there is no other source of energy wind may be effective in supplying advective energy for E_T to continue (Abdel Aziz et al., 1964). The E_T from bean increased with the increase of wind velocity (Maticic, 1965).

According to the theory of turbulence, the upward flow of water vapour is equal to the product of the vertical gradient of the vapour pressure and the rate of mixing. The latter depends on the rate of change of wind speed with the height (Chang, 1968). The E_T from wheat increased with the increase of wind velocity (Ghosh, 1974). Maity and Pandya (1975) have also reported that the evapotranspiration increases with the increase of the wind velocity.

2.2.1.1.3 Sunshine hours

The evapotranspiration is much higher during the light period than that during the darkness period (Shah, 1961). The E_T of beans and evaporation (E_0) from pan under different light periods were measured by Hani (1966) when the other climatic components were kept constant. While the change in diurnal light period had little influence on E_0 , it had a marked influence on daily E_T for the 6 hours and 24 hours period (continuous light). Influence of sky condition on evapotranspiration is much greater than that of irrigation (Burman and Loudon, 1968). Burman and Loudon (1968) reported that when bright sunshine occurred, all energy balance components (including E_T) were high. The passage of clouds almost immediately reduced the magnitude of energy balance components. Although, duration of bright sunshine hours had very little effect on evapotranspiration of boro paddy (Sarkar, 1970), the effect of bright sunshine hours on evapotranspiration from wheat crop varied with moisture tension (Ghosh, 1974). The increased rate of evapotranspiration (E_T) with the increased hours of sunshine from potato crop at different soil

moisture regimes was obtained by Maity and Pandya (1974).

2.2.1.1.4 Radiation

Measurement of energy budget indicated that in the tropics and during the warm season in the middle latitudes, 80 to 90 per cent of the total net radiation was responsive for evapotranspirations in Ontario (Graham and King, 1961), North Carolina (Harris and vanBavel, 1958), Missouri (Gerber and Decker, 1960), Hawaii (Chang, 1961), California (Halstead, 1954) and England (House et al., 1960). Mukammal and Bruce (1960) found that relative importance of radiation, humidity, and wind velocity determining pan evaporation were in the ratio 80:6:14 respectively. Pruitt (1964) observed a quick response of evapotranspiration for rye grass with net incoming radiation, in a calm clear day in spring. Further, when E_T was compared with net radiation, air temperature, and saturation deficit, the air temperature and saturation deficit were more out of phase with E_T than net radiation.

According to Pelton (1964) solar radiation is the principal source of energy for evaporation. In the absence of advected energy, a close relationship between the potential evapotranspiration and net radiation usually exists. Much of the net radiation may be converted directly to latent heat and often account for as much as 80 per cent of the water evaporation loss.

While a significant correlation between solar radiation and evapotranspiration for the rice field was reported by

Thongtawee (1965), the latent heat of water from the flooded rice field was about 65 per cent (Thongtawee, 1965; Loyd Johnson, 1965). van de goar and Zijlstra (1968) are of the opinion that E_T of rice is governed by the amount of energy available. Vamadevan (1970) stated that the E_T per net radiation was considerably more pronounced in August and September than during the earlier periods of rice growth. E_T exceeded the day time net radiation by 42 per cent when the entire vegetative cycle of rice was considered. Ritchie (1971) found that daily net radiation to be divided primarily between evaporative flux and sensible heat flux. He observed that when crop canopies covered at least 45 per cent of the ground surface and the plant evaporation was not limited by soil water, daily net radiation was approximately equal to daily measured evaporation.

2.2.1.1.5 Vapour pressure deficit

Evaporation is proportional to the vapour pressure gradient ($e_s - e_a$) between the evaporating surface and the air. But, it occurs only when the temperatures of the air and the evaporating surface are equal. Though it is not practically possible, it will continue as long as the temperature of the evaporating surface remains above the air temperature (Mather, 1959).

Monteith (1959) observed that for E_0 to take place, there should be a vapour pressure difference between evaporating surface and air. Since vapour pressure deficit generally reaches a peak by 1400 hours, E_T losses are usually highest at mid-day, decreasing rapidly with the decrease of vapour pressure deficit.

Evapotranspiration is proportional to the vapour pressure gradient between the evaporating surface and the surrounding air. It is the relative dryness of air which counts for E_T , rather than the absolute dryness of the air (Slatyer and Mollory, 1961).

Pruitt (1964) concluded from a number of studies that under near constant conditions, E_0 is closely related to the difference in vapour pressure ($e_s - e_a$) between the surface and some height above. He suggested a linear relationship between these two parameters and that line should pass through the origin.

According to Woerner quoted by Jensen (1967) that when the temperature was held constant at 76°F both free water surface evaporation (E_0) and evapotranspiration of red kidney beans decreased proportionately as humidity varied from 20 to 90 per cent. With the increase in vapour pressure deficit ($e_s - e_a$), the evapotranspiration (E_T) from wheat and paddy crop increased in a linear manner (Ghosh, 1974; Sarkar, 1976). Similar result was observed by Maity and Pandya (1975) on potato crop.

2.2.1.2 Soil moisture tension

When water is amply available, the rate of evapotranspiration is dictated mainly by meteorological factors (Gardner and Ehlig, 1963). As evapotranspiration proceeds and soil water content is reduced, the resistance to the vapour path way progressively increases and evapotranspiration declines. The results of lysimeter experiments on potato conducted during five winter seasons indicated that higher evapotranspiration rates

were always associated with lower soil moisture tension (0.1 to 0.4 bar) level, and it gradually decreased with the increase of soil moisture tension upto 0.8 bar. The relationship between total evapotranspiration and soil moisture tension is curvilinear (Maity, 1975). Similar curvilinear relationship was observed by (Ghosh, 1974) on wheat crop.

Average daily use of water by tobacco cv. Hicks grown on well-drained loamy-sand was 0.18 - 0.20 inch when water was not limiting (Sparrow et al., 1966).

Sreedharan and Vamadevan (1976) observed that solar radiation, air temperature, pan evaporation and wind velocity were correlated with evapotranspiration of rice. The correlations were generally significant during the rabi season but not during the kharif season. Solar radiation and air temperature were the most important factors affecting evapotranspiration. Grabarczyk (1976) reported from field trials at Pozorty, Baleyny and Lezany, Poland in 1955-70, average daily water utilization in spring on medium soil (before shading of the soil) was 2.79 mm. During the period of intensive growth, the rate was 3.52 mm/day and at maturity 2.41 mm/day. The rate of water utilization on very light soil was lower but with irrigation approached the value of the potential evaporation. During periods of optimum soil moisture, field water utilization was strictly correlated with air evaporation capacity, measured over the plant stand, as well as with Relative Humidity (RH) deficit and air temperature.

Iruthayaraj (1978) stated that the evapotranspiration of rice Cv. Kannaki and Bala under five different water management systems was compared with evaporation measured by a USWB Class. A pan evaporimeter installed at a nearby meteorological observatory and with data from can evaporimeters placed in the crop canopy and raised to canopy level as the crops grew. The mean ratios, evapotranspiration : Pan evaporation, were higher in the monsoon season than in summer, 1.38 compared with 1.18 and 1.35 compared with 1.16, for the 2 cv. As these values were not greatly different from 1.0, the pan values could be used to indicate levels of evapotranspiration. Higher values were obtained from submerged rice than for rice in saturated soil. Liu (1978) studied the relationship between the leaf water potential of flue-cured tobacco leaves, soil moisture conditions and various meteorological factors, and to ascertain the degree to which leaf water potential serves as an integrator of these stress inducing factors. The soil moisture tension treatments were maintained to 0.25, 0.42, 0.96, 3.50 and 15 bars. The meteorological factors including radiation-level, ambient temperature and ambient vapour pressure deficit were measured daily. Soil water potential, incoming radiation, ambient temperature, and ambient vapour pressure deficit were selected as the factors most likely to affect the leaf water potential of the flue cured tobacco leaves.

The results showed that a linear correlation coefficient were calculated between leaf water potential, soil water potential and meteorological factors. A multiple curvilinear regression

analysis of the data resulted in an equation involving linear and squared terms for soil water potential and linear terms for radiation, temperature and vapour pressure deficit, and the co-efficient (R) was significant at 1% level.

2.2.1.3 Nitrogen

The evapotranspiration is regulated to a large extent by the evaporative demand of the atmosphere when soil water is not limiting and a crop covers the land completely. Viets (1962, 1965) reported that after comparing the ability of fertilized and unfertilized crops that even when the water is limited, a well fertilized crop with its extensive root system can extract soil water under high tension and deeper depth to contribute a significant increase in water use. On dry land culture, E_T was increased with the addition of nitrogen (Luebs and Laag, 1967, 1969). Luebs and Laag (1969) further observed that E_T for barley was 14 and 42 per cent higher with 45 and 90 kg N/ha respectively for a period of 18 days before and during tillering. During subsequent 26 days dry period, available soil water was depleted first at the highest nitrogen level. Pande and Mitra (1971) observed that medium and high levels of NPK increased the water requirement of aus and aman crops compared with low levels. Increase of E_T with the addition of fertilizer was reported by Olson et al. (1964) on corn and grain sorghum; Willatt (1969) on maize; Jensen and Sletten (1965) on winter wheat; Jaeger (1966) on oat; Singh and Bains (1971) on sorghum, and Bond et al. (1971) on winter wheat.

2.2.1.4 Crop

2.2.1.4.1 Height of plants

In the humid Congo, Bernard (1954), observed that the rates of potential evapotranspiration (PET) are identical for both tall and short grasses. But in Hawaii, where a moderate amount of advection occurs, the maximum PET of sugarcane is approximately 10 per cent higher than that of short grass. EI nadi and Hudson (1965) reported that in the arid Sudan under advective conditions, the E_T of tall vegetation is much accentuated. According to Mitchell and Kerr (1966) a large difference in E_T between tall and short crops have also been reported for rye grass and White Clover in Newzealand.

The potential evapotranspiration (PET) of a tall crop in humid climate may exceed that of a short crop because of the higher net radiation and roughness. Because of the increased roughness, the maximum PET of a tall crop could far exceed that of a short crop in areas of strong advection (Chang, 1968).

2.2.1.4.2 Dry matter

Dry matter production does increase linearly with E_T though the regression line seldom passes through the zero point as often is the case in the relationship between transpiration and yield (Viets, 1962). Matsuhima (1962) reported that independent of variety, season or soil type, transpiration, water requirement for rice was approximately 5 ml/gm of DM/day. The relationship of dry matter to transpiration and water requirement in

glass house and also in field was studied by Sugimoto (1973). In general water requirement increased gradually after transplanting to a peak during the ripening. He also found that there was a direct positive correlation between transpiration and daily dry matter production.

2.2.1.4.3 Leaf area index

The E_T of well watered safflower remains nearly constant after the crop reaches a leaf area index (LAI) of four and intercepts more than 80 per cent of radiation (Sterns, 1965). The E_T from soybean field was 6 cm more than from the sorghum field mainly because the LAI of soybean increased 1.5 times than that of sorghum (Teare et al., 1973). Sugimoto (1973) studied the relationship of transpiration of leaf area of rice crop and meteorological factors and showed that transpiration ratio ($Tr : E_0$, E_0 = free water surface evaporation from Pan) increased with LAI upto 5 and then remained steady except in variety "Taduka".

2.3 Influence of Soil Moisture Tension and Nitrogen on Growth Characters

Different growth characters of tobacco plants are greatly influenced by soil moisture tension and nitrogen levels.

2.3.1 Soil moisture tension

Experimental results reveal that soil moisture conditions affect the plant growth at different stages of growth.

A marked reduction in stem elongation while the plant was

expanding, due to soil moisture stress was obtained by both Slatyer (1957) and Deumead and Shaw (1960). Slatyer (1957) observed in wheat, a marked reduction in the stem elongation, occurred due to soil moisture stress under green house condition.

Seibert (1964) reported that the daily water needs to tobacco were 6 mm in June, 8 in July and 5 in August (6 to 8 mm for Cigar tobacco) and irrigation has become a necessity for yield and quality of tobacco. Ligon and Benoit (1966) determined the rate of growth, yield and quality for bushy tobacco plants grown under controlled soil moisture condition and observed significant decrease in growth and yield for plants subjected periodically to soil moisture levels of 0.96 atm or above and significant reduction in quality. During periods of high moisture tension, growth was markedly slowed, after irrigation, stressed plants generally grew no faster than previously unstressed one. Mehrotra et al. (1970) reported that a significantly high plant growth and yield of curable leaves was found at 50 per cent available moisture. With increase in soil moisture level, the total nitrogen and nicotine per cent decreased.

Papenfus (1970) stated that temperature and water supply are particularly important to the seedbed phase. High temperature increases growth rate and produce the possibility of premature floral initiation while restricted water supply during the final period of this phase delays floral initiation and conditions the plants for possible drier conditions in subsequent phases. Volodarsky (1975) stated that insufficient water at any stage of

vegetative phase leads to depression of growth processes. However, the character and the results of this depression differ, depending on the stage of ontogenesis (including the seedling period upto 80 days) for tobacco of the eastern type. He further stated that the growth processes considerably decreased for water deficiency during the juvenile period and also, when the dry matter accumulation was extensive, water deficiency leads to sharp and almost irreversible depression of growth process, to quick aging of the top meristem and decrease of leaf yields.

Bae and Kang (1976) studied with three levels of soil moisture conditions of 30% (damp), 45% (moist) and 60% (wet) to the maximum water holding capacity, found that leaf area had a tendency of damp > moist > wet and showed significant difference between the plot of damp and the plots of moist and wet. Dry weight of unit leaf area was low at the plot of damp and highest at the plots of moist and wet.

Takahashi et al. (1976) found in bushy tobacco Cv. burky 21 and Ky 10 grown at five different locations that the plant height, number of leaves/plant and dry weight increased rapidly in early growth stages and the period between setting and flowering was short. Plant height and dry weight was lowest at Okayama due to drought conditions. Liu (1977) observed that increased soil moisture tension resulted in decreased total leaf area development, rate of leaf area and stalk development and total dry weight of leaves with delay in flowering and maturity with increased growth rates which did not exceed the normal rates of continually

non-stressed plants except as the non-stressed plants approached maturity. He conducted this study with Vam-Hicks and TT 5 varieties under the soil moisture tension maintained at near 0.25 bars, and to return soil to field capacity when the moisture tension increased to 0.96 and 15 bars of tension which correspond to available water of 100, 50 and 0% respectively.

2.3.2 Nitrogen

In the production of each type of Tobacco under favourable conditions, growth was most noticeably affected by the supplies of available water and nitrogen in the soil.

When other factors are not limiting, there is an increase in the rate of growth as the level of available nitrogen increases from deficient to adequate. Growth rate as measured by increase in height was slow under deficient conditions but was rapid at a moderate level of nitrogen (Garner et al., 1934).

With adequate moisture, and increase in the supply of nitrogen from deficiency to excessive resulted in an increase in the area of the leaf but a decrease in the weight per unit area, the latter effect being due primarily to a decrease in the thickness of the leaf (Raper, 1966).

Except at extremely deficient leaves, the total number of leaves produced by a plant was not appreciably influenced by the level of available nitrogen (Garner et al., 1934).

In field experiments whereas nitrogen availability regime

was created so that the plant was subjected to a nitrogen stress less than required for acute deficiency, a slight yellow color indicated reduction in chlorophyll content and length and width measurements showed a reduction in leaf area (Raper, 1966).

Friis-Nielsen (1966) stated that maximum dry matter yields of perennial rye grass, barley, potatoes and fodder-beet, grown in lysimeters under assumed optimum conditions, were proportional to maximum active leaf-area index (ALAI, derived from the ratio of evapotranspiration to free-water evaporation), integrated over the growth period. The slope of the graph was steeper for potatoes than for rye grass, beet or barley, indicating that the integrated parameter expresses genetically determined differences between crops in utilization of this potential photosynthetic production capacity. ALAI appeared to be a better measure of production capacity of crops than LAI.

Matar (1977) reported that plant height and leaf area increased with increasing nitrogen application.

Gopalachari et al. (1978) observed that dry matter production and nutrient uptake (N, P, K, Ca, Mg, S and Cl) were maximum during the reproductive phase (60-90 days) followed by the active vegetative phase (30-60 days) of growth in both the light and heavy soil types.

Atkinson et al. (1977) studied above ground parts of commercial and reduced alkaloid Burley tobacco Cv. B₂₁ and LAB 21 respectively, were sampled periodically during the growing

season for dry weight and nutrient uptake determinations. During the first half of the growth period 18% of the total dry weight had accumulated and about 25% of the total N, P and K had been adsorbed. At harvest dry matter was nearly divided between leaf and stem but nutrient content was higher in the leaf than in the stem. Total dry weight for LA B₂₁ was 2.9% lower than for B₂₁, and nutrient accumulation patterns did not differ.

2.4 Coefficients for estimating leaf area

The measurement of leaf area is important in many investigations of growth, potentiality and productivity of many crops. It is particularly important as an index of growth for the intermediate stages in agronomical and physiological studies, both in pot experiments and in field (Williams, 1954).

However, these measurements are not often made, because the available methods, such as, the planimeter (David, 1940), the airflow planimeter (Jenkins, 1959), the photo-electric cell (Frear, 1935), the dry weight method (Millar, 1938), the linear measurement method and the matching method (Darrow, 1935), are tedious and time consuming, some of them are impracticable for large numbers of leaves or for very big leaves, and they usually make it necessary to destroy the plants. Several workers have calculated equations or coefficients to convert linear measurements of length (L) and width (W) of tobacco leaves to area (A).

Tejwani et al. (1957) studied 1157 leaves of Ciger tobacco and suggested that $A = 0.60 X + 4.2$ for leaves larger than 2581

cm^2 and $A = 0.66 X + 0.20$ for leaves smaller than 2581 cm^2 where X is the product $L.W.$

Suggs et al. (1960), working with four varieties, two spacings and eight soil moisture levels, suggested $A = 0.6345 L.W.$ with only small effects for variety and soil moisture level. For small leaves a coefficient of 0.7028 was suggested.

The relationship between the area of a leaf and its length and width was found to be best described by a linear regression of leaf area on the product of the length and width with the regression line passing through the origin of the coordinates (Suggs et al., 1960).

Estimation of leaf area from linear measurements is possible with both leaves and their images, almost always also without destroying the leaves. Images of small leaves must be enlarged before sufficiently accurate measurements can be taken (de Parcevaux and Massin, 1970). The most frequently used leaf and leaf breadth (B), either the maximum breadth or the breadth at a specific fraction ($1/2$; $2/3$ etc.) of the leaf length behind the leaf tip. The method can be applied to leaves of various shapes wherever these allow suitable and well-defined linear measurements to be taken.

Yocum and Mckee (1970a), working on five varieties of type-41 Pennsylvania broadleaf tobacco, suggested coefficient of 0.66 for leaves of Pennleaf 1, 0.65, 0.61 for leaves of Swarrltibshanan and Pennbel 69 respectively.

Farah (1974) reported in a study of leaf co-efficients of flue-cured tobacco (N. tabacum L.) variety Kntsago 51, that coefficients were significantly affected by position of leaf on the stalk whereas spacing and the interaction of spacing and position were not significant and that a mean co-efficient of 0.6518 and 0.6131 can be used for the top and middle or bottom leaves respectively.

The general form of relationship : $A = b \cdot LB$ has been found satisfactory by many authors where b is a co-efficient which requires checking from time to time especially when leaf shape changes with position on the plant and with plant age. A similar relationship derived by Lal and Subba Rao (1950a, b, 1951) for cereals, relates leaf area (A), length (L) and breadth (B) by $\log A = \log L + \log B - \log b$,

where,

B is measured at $L/2$ and the constant $b = LB/A$. The mean co-efficients of variation for b were 2.9, 3.3, 6.6 and 1.0% for barley, rice, maize and wheat respectively. Langer (1956) modified this relationship by taking B as the mean of breadths measured at $1/4$ and $3/4$ of L but the extra effort involved does not seem worthwhile. Anikiere & Kutuzov (1961) provide further mathematical treatment of the relationship between leaf length and breadth and leaf area. Kemp (1960), having reviewed the previous literature on the subject, examined the use of linear measurement for estimating leaf area in grasses and arrived at $A = 0.905 \cdot L \cdot B$ for Lolium perene, Dactylis geomerata, Festuca

pratensis and Phleum pratense with B taken at L/2. The variation accounted for by this value of b was over 99%. Tejawani et al. (1957) examined the use of linear measurements for estimating leaf area in tobacco and Suggs et al. (1960) found the relationship $A = b LB$ satisfactory with B the maximum breadth and b ranging from 0.613 to 0.675 in large leaves according to the tobacco variety and irrigation treatment. In small leaves, $b = 0.703$.

2.5 Growth, Function and Prediction Equation for Yield and Evapotranspiration

Yield of crops are generally influenced by the growth factors. Probable yield of crops may be described as a function of the complex system of productivity parameters.

The most important and acceptable formula for prediction of yield is that of Mitscherlich which describes the yield as a function of different growth factors. Growth factor is a complicated system of plant, soil and moisture parameters which largely influence the yield. According to Mitscherlich's idea the increase in yield with the unit increase in the growth factors bears an explicable plant physiological relation with the ecological properties and the activity constants in the formula should not be affected by any other magnitude than the nature of the productivity factor.

The pioneering work quantifying relationships affecting plant growth was done by E.A. Mitscherlich. His two principal

objectives were to estimate the level of a preplanted soil nutrient for comparison with laboratory analysis and to estimate crop response for fertilizer application (Briggs, 1925).

Variations of models developed by Mitscherlich in the early part of this century are periodically used for estimating input-output relationships for plants. Mitscherlich's work focussed on a single variable. While these experimental models incorporate features of theoretical appeal, the procedures for quantifying the models are relatively complex when two or more independent variables are included. In fits of Mitscherlich and polynomial forms to yield-water-fertilizer data for corn grown under experimental conditions in Colorado and Kansas, statistics for the polynomial forms are as good as or better than those for the more complex Mitscherlich models (Roger et al., 1976).

The yield is described by a fundamental equation which takes the shape of the differential equation i.e., a function of the yield and of the growth factor. The equation may be expressed by the following :

$$\frac{dq}{dx} = f(q.x)$$

where,

q = Yield factor.

x = growth factor.

On the basis of this equation three formulae are developed :

- i) The Mitscherlich equation,
- ii) The projective yield function and

iii) The equation for limiting factors.

The growth equations are able to handle any number of ecological variables and allow the description of complex productivity situations. It is, however, necessary to know, how these empirical productivity magnitudes should be inserted into the formula. There are only a restricted number of growth factors, but only seldom will it be possible to obtain quantitative observations of a theoretically correct, uncontaminated growth factor, for which alone the simple solutions of the differential equations are valid. The value of the theoretically correct growth factors has to be built up from the values for the relevant ecological parameters.

Chen et al. (1968) developed mathematical relationships between the rate of plant growth and various environmental factors for small tobacco plants, the growth curve for a single leaf was found to be S-shaped for the entire growth period. The growth curve for small plants was found not be a pure exponential of the form :

$$\frac{A}{a} = e^{kt}$$

where,

A = leaf area at time 't'

a = leaf area at time t = 0

k = a constant for the particular plant.

A large plant was found to have a smaller growth rate than a plant with small initial size. The growth rate parameter K_1 and the plant's initial size had the relationship

$$K_1 = \frac{C_1 - \ln a}{C_2} \quad (r = 0.99)$$

where,

C_1 and C_2 are constants.

The growth rate parameter K was a function of initial size and time and can be represented by -

$$K = k_1 - k_2 (t-1)$$

where,

k_1 = growth rate parameter at $t-1$ (day) and is a function of plant's initial size.

k_2 = the regression coefficient of growth rate parameter versus time.

The resulting plant growth equation can be expressed as

$$A = ae \left[k_1 - k_2 (t-1) \right]^t$$

Using this type of information together with weather temperature patterns, it may be possible to predict more closely the relationship between seedling time and time for transplanting with a more knowledge in use of temperature as control factor.

The growth curve of a tobacco plant, when plotted as total mass versus time, is a characteristic sigmoidal curve. Employing oriental type tobacco, Wolf (1947) found that the rate of growth of the stems or of expansion of leaves when plotted against time also become a sigmoidal curve.

Yield prediction using the model PLANTGRO (Hanks, 1974) was made from soil, crop and climatic data. Agreement between

prediction and measurements was better for relative dry matter yield (R^2 ranged from 0.91 to 0.99) than a relative grain yield (R^2 ranged from 0.93 to 0.97). The method for predicting grain yields could be improved but a relation involving seasonal estimates of relative transpiration gave good first-order predictions.

A strong linear correlation exists between evapotranspiration and yield (Arkley, 1963; Steward et al., 1977).

Wenda and Hanks (1981) stated that there was a strong linear relation between relative yield and E_T ($R^2 = 0.95$ for dry matter yield and $R^2 = 0.87$ for grain yield) where variable irrigation was applied throughout the season as well as where irrigation was applied only at the early part of the season.

2.6 Influence of Soil Moisture Tension and Nitrogen on Yield

The growth characters, yield and quality of tobacco crops are largely dependent on the soil moisture tension and the nitrogen. The frequency of irrigation and varying levels of nitrogen significantly influence crop yield.

2.6.1 Soil moisture tension

Kadam et al. (1953) working with flue cured tobacco in Andhra Pradesh found that supplementary light irrigations at proper time increased the yield without any deterioration in quality.

Miles (1957) found that irrigated flue-cured tobacco gave a highly significant increase in yield, price per hundred weight, and value over non-irrigated tobacco.

Systematic studies on water requirement of tobacco were done at I.A.R.I., New Delhi. Water requirement of hookah tobacco was found to vary between 600 to 650 mm during the growth from March to May. The optimum moisture regime for tobacco was from field capacity to 0.5 atmospheric soil moisture, tension measured at 22.5 cm soil depth (Singh and Awatramani, 1958; Singh and Murthy, 1960).

Jones et al. (1960) observed that two most important times to irrigate tobacco in a dry season are (1) at transplanting time to ensure good stand, and (2) when plants are about knee high to full bloom (or topping stage) to aid in rapid plant growth.

Patel et al. (1963) observed that one irrigation at either 40, 50 or 60 days after transplanting increased the yield significantly over no irrigation. Between the three irrigation intervals, there were no significant difference in yield as well as in quality.

In further studies, Patel and Awatramani (1963) concluded that, one irrigation of 38 mm at 7 weeks was the best practice for obtaining high yields of tobacco (var. Harison special). Patel (1964) also observed that for Delcrest variety, one irrigation of 33 mm at 40 days after transplanting increased the yield by 40% over no irrigation treatment. The yield of treatments of

irrigation at 40, 50 and 60 days were at par. Sparrow et al. (1966) reported that irrigation significantly increased yields only when rainfall was inadequate or poorly distributed; it also increased the market grading of the cured leaf. Walunjkar and Singh (1967) observed on cured tobacco (var. Delcrest) that the irrigation increased the yield, over no irrigation treatment, of green leaf by 37%, cured leaf by 21% and total bright leaf equivalent by 19 per cent.

Yang (1967) found that plant heights were higher and leaves were larger and vice versa.

Kincaid et al. (1967) examined that the yield grade index and the crop index were not significantly different among irrigation treatments, which received 8, 8 and 6 inches of irrigation respectively. These crop factors were slightly reduced with treatments which received 2 inches (39% of field capacity) and significantly reduced with treatment which received no irrigation. With decreasing irrigation, leaves were slightly smaller and flowering was greatly delayed. But yield and quality were obtained with irrigation applied when the mean moisture level was between 52% and 58% of the field capacity. Yield and quality of crops were affected by the soil moisture conditions through physiological and metabolic processes.

Okazov (1968) reported that the lightest irrigation (300 to 580 m³/ha) increased cured tobacco yield by 12 to 24% with respect to an unirrigated control; 1000 to 1650 m³/ha irrigation increased

yield by 50 to 100 per cent. Mehrotra et al. (1970) stated that significantly increased yield of curable leaves was always associated at 50 per cent available moisture.

Singh and Sharma (1971) reported that irrigation of tobacco (*N. rustica*) crop with brackish water was substantially increased the yield of cured leaf and dried stalk per hectare, and markedly improved the quality of leaf.

Gurbev (1972) found that a correct irrigation regime during the tobacco development affected the plant height, size of leaves and blooming phase, maintenance of optimum soil moisture in dry seasons increased the yield by 50 to 60 per cent in comparison with non-irrigated plants, while with the wet seasons the effect declined considerably.

Brown and Street (1972) reported that increased yield was always associated with irrigation. Vardabasso and Cutolo (1975) reported that irrigation when soil moisture reached 50, 30 or 10% of available water, Green leaf yields with 70 kg N/ha were 29.40 t/ha with irrigation at 50% available water, 28.4 t with irrigation at 30% available water and 25.03 t with irrigation at 10% available water; comparable yields with 140 kg N/ha were 31.40, 29.73 and 26.35 t/ha respectively.

Bae and Kang (1976) observed that the number of harvested leaves was high in order Samsun < Basma < Xanth Gaya < Bursa < Izmir and low in order Zichna > Samsun Holmun > Xanthi > Myrna, but there were little difference among the treatments.

Trybala (1976) investigated that the yield of sugarbeet, fodder maize, spring and winter wheat, fodder beet and red clover were dependent to a significant extent on the amount of water to the plants during critical periods of water utilization which is, therefore, a primary requisite for obtaining good yields.

Liu (1977; 1978) observed that increased moisture tension decreased yield and total leaf value and increased the unit price of leaves.

2.6.2 Nitrogen

The elements essential for the commercial production of tobacco, none has as pronounced an effect of the degree of attention as in nitrogen fertilizer practices. From the seedling stage through final harvest, the soil nitrogen regime affect the processes of plant development more than any other mineral element. The role of nitrogen in the development and properties of the tobacco leaf is of major importance. The influence of variation in nitrogen supply on growth of the plant and properties of the cured leaf has been reviewed in the following paragraphs.

Pal and Gopalachari (1953, 1954 and 1955) observed that, with increased supply of nitrogen there was an improvement in the dry weight of the plant and the weight of the cured leaf. As the curing quality was not affected, there was also a corresponding improvement in the weight of bright leaf equivalent.

Parikh and Shah (1954), observed that bidi tobacco plant

removed 95 lb nitrogen, 41 lb P_2O_5 , 120 lb K_2O per acre.

According to Ramakrishna Kurup (1956), tobacco crop required about 75 lb of nitrogen, 150 lb potassium and 14 lbs P_2O_5 per acre and about four-fifths of these amounts were taken up during the second half of its growth period.

Marsen et al. (1964) stated that sprinkler irrigation with applications of 25-50 kg/ha each of N and K_2O and 50-100 kg/ha of P_2O_5 increased tobacco yields by at least 30% and improved smoking quality, the combined effect of moisture and mineral nutrients improved the consistency of leaves and decreased nicotine content.

Bowling and Wilso (1964) working with Maryland tobacco varieties, found an increase in yield with an increase in nitrogen fertilization.

Atkinson (1966) found that, the addition of nitrogen without irrigation did not increase leaf yield, but with irrigation, increasing nitrogen from 100 to 200 lbs per acre increased yield by 21 per cent. Atkinson et al. (1969) observed that plant size and yield were increased by both Nitrogen and irrigation. Response to Nitrogen was greatest in the irrigated plots. According to Gurbev (1970), 80 kg N/ha given to irrigated tobacco increased leaf yields from 19.7 h kg/ha, unfertilized to 21.5 h kg/ha; leaf quality was also improved. The same effect was also obtained from 80 kg N + 50 kg P_2O_5 /ha.

Stocks (1970) reported that nitrogen affected the development

of the tobacco plant more than any of the other essential element. Too much or too little nitrogen can substantially affect yield and quality.

Atkinson et al. (1971) found from their experiment which was with 100, 200 and 300 lbs N/ac. on burley tobacco that, 200 lbs N/ac. gave significantly higher yields than 100 lb N/ac. in 2 years but 300 lb N/ac. did not increase yield further. Irrigation markedly increased yields.

Colyer and Pohlman (1971) observed the response to nitrogen and potassium fertilizer by burley tobacco (N. tabacum). Both yield and quality were affected by the level of fertilizer use, with the effects due to nitrogen more pronounced. Quality as measured by price is maximised with an average rate of 184 kg N/ha, a lower application rate than the 271 kg/ha required to maximise yield.

Brown et al. (1972) concluded that nitrogen fertilizer rates of 100.9, 134.5 and 168.1 kg/ha were gains in yield and total value under irrigated condition.

Sims et al. (1972) conducted an experiment on Cv. burley-21 tobacco with seven levels of nitrogen (0, 40, 80, 160, 240, 320 and 400 lb N/acre) found that cured leaf yields were increased by application of nitrogen.

Brown and Street (1972) investigated the effect of irrigation, nitrogen level, plant population, and two varieties on the yield

and value of Maryland tobacco. Increasing the nitrogen rate from 90 to 120 pounds per acre significantly increased the yield. A further increase in nitrogen rate from 120 to 150 pounds per acre increased significantly the yields in two years. Yield increased as nitrogen rate increased for irrigated and non-irrigated tobacco. When irrigation applied, the Wilson variety produced the greater yield as compared to Catterton variety.

Shoumarski (1973) observed that irrigation, fertilizer, density of transplanting and topping significantly raised the rate of growth and the size of the stem and leaves, and contributes to uniform crop stand, augmented the average yield and total produce by 13 to 45%.

Trials in West Bengal with N. tabacum variety Jati was given 0-20 tons F.Y.M. + 100-200 kg P_2O_5 + 100-200 kg K_2O /ha; increasing the rate of N from 0 to 100 kg/ha, increased yields of cured leaves from 0.24 to 1.44 tons/ha. The response curve obtained by fitting quadratic production functions showed that the maximum yield of 1.54 tons/ha would be obtained by applying 163.2 kg N per hectare, but the economic rate would be 144.8 kg N/ha with an expected yield of 1.53 tons per hectare (Panikar, 1974).

Sinha et al. (1976) reported that the response of nitrogen level 56 and 112 kg/ha on the yield of the crop was linear.

Prasanna Simha Rao (1977) studied on the effect of different levels of nitrogen (112 kg N/ha; 168 kg N/ha), spacing (90 cm x 60 cm; 90 cm x 90 cm) and topping (at 14 leaves; at 16 leaves) on

four chewing tobacco varieties viz. DP 401, HPF, HP 6-12 and HP 6-20 at the Tobacco Research Station, Pusa, Bihar, during 1965-66 and 1966-67. Higher dose of nitrogen, closer spacing and low level of topping were found better.

Mckee (1978) conducted trials in 1974-76, Maryland tobacco Cv. 872 was planted with (a) 50, 70 or (b) 90 lb N/ac. at (c) 3556, 4149, 4978 or (d) 6223 plants/ac. Average green leaf yields for 1974, 75 and 76 were 2019, 1734 and 1686 lb/ac, respectively. Leaf yields ranged from 1740 lb/ac for (a) to 1896 lb/ac. for (b) and from 1590 lb/ac. at (c) to 2039 lb/ac at (d). At (c) there was increased fresh wt/plant, percentage cured-leaf yield of fresh plant wt. and leaf contents of total alkaloids and N compared with (d).

Venkata Rao and Chakrapani (1978) reported that nitrogen is found to play a great role on the growth, yield and quality of leaf tobacco because of its high mobility in soil, its rapid uptake by the plant and its translocation within the plants. Nitrogen if applied in excess quantities adversely effects the quantity of the leaf with delayed flowering and ripening of leaf by prolonging the vegetative phase resulting in more out turn of lower grade leaf. The under-nitrogened crop again delays maturity, with small size leaves, yellowing of the plants, drying of the leaf to light brown colour, producing pale yellow coloured leaf after curing.

Jones and Tramel (1979) reported that yields were increased

as nitrogen rate was increased from 78 to 179 kg/ha.

Stutler et al. (1981) stated that four levels of irrigation were imposed using two application methods, furrow and trickle, in combination with four nitrogen fertilizer rates. Yields generally increased with higher levels of applied water and with higher nitrogen rates upto 200 kg N/ha.

Singh et al. (1981) concluded from an experiment conducted during 1968-69 to 1970-71 at the Tobacco Research Station, Pusa (Bihar) that with increasing levels of nitrogen from 0 to 168 kg/ha yields were enhanced progressively and in general data were found to be statistically significant in all the seasons of experiments. Application of high dose of nitrogen at 168 kg/ha in combination with three irrigations recorded the highest cured and first grade leaf yields.

Agarwal and Yadav (1978) observed that under conditions of limited water supply, four irrigations based on critical physiological growth stages with 80 kg N/ha gave high grain yields of 3.79 - 3.92 t/ha. The highest yield of 5.26 t was obtained with six irrigations and 120 kg N/ha.

2.7 Influence of Soil Moisture Tension and Nitrogen on Nicotine Content of Tobacco

Soil moisture tension and quantity of nitrogen have a great influence on the leaf quality of tobacco. The "strength" of a smoke is a measure of its nicotine content which is to be isolated high with high yielding lines.

2.7.1 Soil moisture tension

Sparrow et al. (1966) reported that irrigation increased the sugar content of cured leaf and decreased the content of nitrogen and nicotine.

Mehrotra et al. (1970) observed that with increase in soil moisture level, the total nitrogen and nicotine per cent decreased.

Sficas (1971) reported that the nicotine level was higher with topping and lower with close spacing.

Honda and Arakawa (1971) observed that when tobacco subjected to low soil moisture (30% of maximum water holding capacity) during whole period, total sugar in leaves decreased, while total alkaloid, total nitrogen, protein and ether extract increased as compared with those of optimum moisture condition (50% water level). In the treatment of drought at both early and mature period, it was observed that the contents of total nitrogen, protein and ether extract were higher while total sugar was lower than those of optimum moisture condition, though the weight of leaves were almost the same, and content of total alkaloid was low.

Avetyan (1973) showed that a 50 to 80% increase in soil moisture lowered the nicotine and carbohydrate contents of leaf. The level of nitrogen substances in leaves was lower in very moist or very dry soils than in moderately moist ones.

Mandy and Kiss (1975) investigated in 3 tobacco cv. grown in 1972, the leaf total alkaloid content increased as the water

supply decreased. A biochemical pathway in which the increase in nicotine content was related to the increase in free amino acid level and decreased protein synthesis brought about by drought stress.

Chang and Chou (1975) stated that in tobacco, subjected to water stress, growth was inhibited, especially in cv. Vam-Hicks, transpiration was controlled by leaf wilting, the percentage of closed stomata increased and the proportion of spongy mesophyll decreased. Stress also increased contents of reducing sugars and total alkaloids and decreased starch content.

Bae and Kang (1976) reported that damp (30% maximum water holding capacity) condition of the soil had a tendency towards low nicotine content in comparison to moist and wet conditions (45% and 60% maximum water holding capacity, respectively).

2.7.2 Nitrogen

Tobacco with a high total nitrogen content produces a strong pungent-tasting smoke whereas tobacco low in nitrogen has a flat insipid-tasting smoke. Nitrogen is considered to be a dominant factor which influences the level of strength in tobacco smoke. Nitrogen is an integral constituent of the nicotine molecule, and thus nitrogen is an important factor in nicotine synthesis. The accumulation of nicotine in the plant is regulated more by the nitrogen supply than by any other plant nutrient (McCants and Woltz, 1967).

Marsen et al. (1964) observed in an experiment with sprinkler

irrigation and applications of 25-50 kg/ha each of nitrogen and K_2O and 50-100 kg/ha of P_2O_5 increased tobacco yields by at least 30% and improved smoking quality, the combined effect of moisture and mineral nutrients improved the consistency of leaves and decreased nicotine content.

Sparrow et al. (1966) reported that increased nitrogen had increased the nicotine content and also increased the specific volume of the leaf and decreased its chlorine content.

Ling (1975) studied with flue cured tobacco cv. Vam-Hicks and was given 0, 25, 50, 75 or 100 kg N/ha with 50 kg P_2O_5 and 150 kg K_2O /ha. Yield and value data indicated that rates of Nitrogen 50 kg/ha were not economic. With increasing rate of applied N, contents of total Nitrogen and total alkaloids increased and contents of P decreased. K content increased with upto 50 kg N/ha.

Hsu and Hsich (1977) concluded from a study that the contents of total particulate matter in the smoke decreased with increasing amounts of nitrogen supplies but contents of nicotine in the smoke increased as amount of nitrogen supply increased.

Mckee (1978) stated that application of nitrogen increased the nicotine content of leaves.

Venkata Rao and Chakrapani (1978) reported that higher nitrogen application tends to increase the nicotine and chloride content, while contributing at lowering the sugar content in the leaf.

Jones and Tramel (1979) observed that there was a trend for total to alkaloids and total nitrogen increase as nitrogen rates increased.

CHAPTER III

MATERIALS AND METHODS

3.1 Location and Season

3.1.1 Location

Study on evapotranspiration and growth characters for tobacco (Nicotiana sp.) was conducted in lysimeter plots of the Department of Agricultural Engineering, Faculty of Agriculture, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, during the winter season of 1979-80 and 1980-81. The experimental site is situated at 22.53°N latitude and at 89°E longitude. The elevation above mean sea level is 6.00 metres.

3.1.2 Climate

While the maximum summer temperature of this area does not exceed 40°C during April-May, the minimum temperature normally remains above 10°C during December-January. The average annual rainfall is about 1422 mm almost all of which are received during June to October. The rainfall during winter is very scanty.

Daily readings of maximum and minimum temperature, wind velocity, bright sunshine hours, humidity, rainfall, vapour pressure readings and free water surface evaporation from USWB Class A pan, were recorded from the nearby meteorological observatory located at Chinsura Rice Research Station.

TABLE 3.1 Variation in meteorological data

	Weeks	Mean air tempe- rature °C	Wind velo- city km/hr.	Sunshine hours	Vapour pressure deficit, mm Hg ($e_s - e_a$)	Pan eva- poration mm/day
Dec. 5-11, 1979	1	21.11	3.257	9.157	2.90	2.829
Dec. 12-18, 1979	2	19.99	2.043	9.486	3.51	2.757
Dec. 19-25, 1979	3	17.56	2.457	7.771	3.05	2.633
Dec. 26 '79-Jan. 1 '80	4	18.73	1.629	8.900	3.17	2.657
Jan. 2-8, 1980	5	17.86	4.971	7.96	2.69	2.357
Jan. 9-15, 1980	6	17.54	2.186	9.285	2.89	2.600
Jan. 16-22, 1980	7	21.14	1.629	7.971	8.33	2.486
Jan. 23-29, 1980	8	20.07	2.530	8.590	3.49	3.200
Jan. 30-Feb. 5, 1980	9	20.50	4.300	9.086	3.47	4.314
Feb. 6-12, 1980	10	18.96	2.843	9.529	3.34	3.871
Feb. 13-19, 1980	11	23.36	4.414	8.757	4.07	1.985
Feb. 20-26, 1980	12	24.86	2.790	9.086	5.02	4.48
Feb. 27-Mar. 4, 1980	13	24.82	5.800	7.557	4.49	4.31
Dec. 5-11, 1980	1	20.77	2.86	5.86	3.82	2.83
Dec. 12-18, 1980	2	18.04	2.66	9.17	3.21	2.97
Dec. 19-25, 1980	3	18.91	1.54	8.33	3.44	2.44
Dec. 26 '80-Jan. 1, 1981	4	18.89	2.63	8.41	3.35	2.83
Jan. 2-8, 1981	5	18.77	3.01	7.90	3.13	2.39
Jan. 9-15, 1981	6	15.91	4.34	5.89	2.37	2.11
Jan. 16-22, 1981	7	17.38	2.87	9.47	2.93	2.56
Jan. 23-29, 1981	8	19.85	3.96	7.90	3.34	3.19
Jan. 30-Feb. 5 '81	9	20.15	6.09	5.76	3.29	2.16
Feb. 6-12, 1981	10	19.34	7.17	3.56	2.93	2.30
Feb. 13-19, 1981	11	21.96	8.60	2.57	3.97	3.36
Feb. 20-26, 1981	12	22.26	9.73	2.90	4.19	4.53
Feb. 27-Mar. 4, 1981	13	25.34	5.84	7.66	4.89	5.71

3.2 Design of the Experiment

3.2.1 Soil

The soil from experimental plot upto 30 cm was collected for the study of physical and chemical properties and textural class. The soil of the lysimeter was found clay soil (Table 3.2). The analysis of physical and chemical properties of the soil are shown in Tables 3.3 and 3.4.

TABLE 3.2 Mechanical composition of soil

Sand (%)	Silt (%)	Clay (%)	Types of soil
25	24	51	Clay

TABLE 3.3 Physical properties of soil

Bulk density gm/cm ³	Particle density gm/cm ³	Pore space	Moisture content per cent by weight			Hydraulic conductivity cm/hr.
			Water holding capacity	Field capacity	Permanent wilting point	
1.33	2.65	49.90	57.79	24.00	5.99	0.65

TABLE 3.4 Chemical properties of soil

Organic matter %	Organic carbon %	Nitrogen %	P ₂ O ₅ ppm	K ₂ O ppm	pH
3.277	1.906	0.114	274	374	6.85

3.2.2 Design

The experiment was laid out in completely randomized design (C.R.D.) with twentyfour treatments allotted to forty-eight plots at random without breaking any group. The experimental plots were homogenous, fortyeight brick masonry lysimeters in four parallel rows. The soil surface in the lysimeter was level with surrounding ground level. The size of each lysimeter was one meter long, 50 centimeter wide and 75 cm deep. The bottom of each lysimeter was closed by concrete floor to avoid movement of water from and into the lysimeter. Each lysimeter was filled up with soil in such a way that the natural soil layer is maintained. Inside each lysimeter, a clear gap of 5-7 cm between the soil surface and top of lysimeter was left for water height during irrigation.

The plots were left fallow after harvesting first year's crop.

3.2.3 Treatments

Experiments were conducted on tobacco (Nicotiana sp.) with two varieties and four levels of nitrogen under three soil moisture tension. Twentyfour treatments were allotted in forty-eight plots.

3.2.3.1 Soil moisture tension

$M_1 = 0.1$ to 0.3 atmosphere

$M_2 = 0.1$ to 0.6 atmosphere

$M_3 = 0.1$ to 0.9 atmosphere.

3.2.3.2 Nitrogen levels

N_0 = No nitrogen

N_1 = 40 kg N/ha

N_2 = 80 kg N/ha

N_3 = 120 kg N/ha.

3.2.3.3 Variety

The latest most promising high yielding variety S-5 of N. tabacum and DD-437 of N. rustica were selected for experiment. The performance of these varieties are good in West Bengal condition.

3.3 Agronomic Practices

3.3.1 Nursery for seedling raising

The seeds were treated with Brassicol 2.0 gm/kg of seeds, Brestanol 3.0 gm/kg of seeds and BHC 10%, 3.0 gm/kg of seeds before placing the seeds in the nursery. The seeds were sown in the nursery on 5th October, 1979 and 1980 for first and second season respectively. The seedlings were raised in the seed bed with proper agronomic practices. The seedlings became ready for transplanting 8 weeks after sowing. Water of the nursery bed was reduced a week before transplanting to harden the seedlings.

3.3.2 Manuring

Organic matter in the form of farm yard manure was applied at the rate of 500 q/ha at the time of land preparation. The entire quantity was applied and mixed thoroughly with 0-25 cm layer of soil.

3.3.3 Fertilizer application

Fertilizers at the rate of 50 kg P_2O_5 /ha and 50 kg K_2O /ha and different levels of nitrogen were applied every season. While the entire amount of single superphosphate and muriate of potash mixed thoroughly was applied at the time of transplanting, urea was applied in two splits, half at the time of transplanting according to the different treatments for both the varieties and the remaining half at 30 days after transplanting.

3.3.4 Transplanting

The seedlings of tobacco were transplanted with a spacing of 90 cm row to row and 45 cm plant to plant. Dates of sowing and transplanting are given in the Table 3.5.

TABLE 3.5 Dates of sowing, transplanting and harvesting of tobacco

Particulars	Season	
	1970-80	1980-81
Sowing	October 5	October 5
Transplanting	December 5	December 5
Harvesting	March 5	March 5
Age of seedling (days)	60	60
Number of days from transplanting to harvest	90	90
Number of days from sowing to harvest	150	150

3.3.5 Plant protection measures

Rogor (Organo phosphate) at the rate of 0.04% (a.i.) was sprayed three times for the protection of the crop from pest as well as vectors of virus.

3.3.6 Inter-cultural operations

Hand weeding and hoeing were done at an interval of 15 days. Topping and desuckering were done both mechanically and by using coconut oil. The topping involves breaking of flower head and the top few leaves with the objective to improve the quality of leaves.

3.3.7 Biometric observations

3.3.7.1 Pre-harvest observations

The following parameters were taken into consideration for both the varieties.

- i) Height of the plant, cm
- ii) Diameter of the plant, cm
- iii) Green weight of the plant, kg m^{-2}
- iv) Dry weight of plant, kg m^{-2}
- v) Leaf area index,
- vi) Co-efficient for leaf area estimate.

Observations on the above parameters were taken by destructive sampling at an interval of 30 days after transplanting.

3.3.7.2 Post-harvest observations

Weight of the dry plants were taken after air curing.

3.3.8 Harvesting

The harvesting of plants were done from each lysimeter, when the normal green colour changes to yellowish green or to light yellow.

When visually it was found that chlorophyll partially degraded and a consequent predominance of yellow pigments developed, the harvesting started from the bottom and each time 2-3 leaves were harvested. The final priming was done at the end of 90 days after transplanting. The complete harvesting required four priming. After priming the leaves were kept on the ground upside down for a few hours for drying, after which they were tied into bunches of 4 to 5 leaves and air cured in sheds for 5 to 6 weeks. After curing thoroughly, the yield of tobacco leaves and stalk from each lysimeter was recorded separately.

3.4 Techniques of Measurements

3.4.1 Soil moisture tension

For recording soil moisture tension upto 0.6 atmosphere in each lysimeter a vacuum gauge tensiometer was used and for 0.9 atmosphere tension gypsum block was burried at 20 cm depth. The tensiometer and resistance block readings were taken daily at about 10 A.M. The irrigation water was supplied only when the soil moisture tension reached the predetermined value. On the basis of these readings, moisture present in the soil was estimated from the predetermined moisture tension and moisture resistance curve (Figure 3.1).

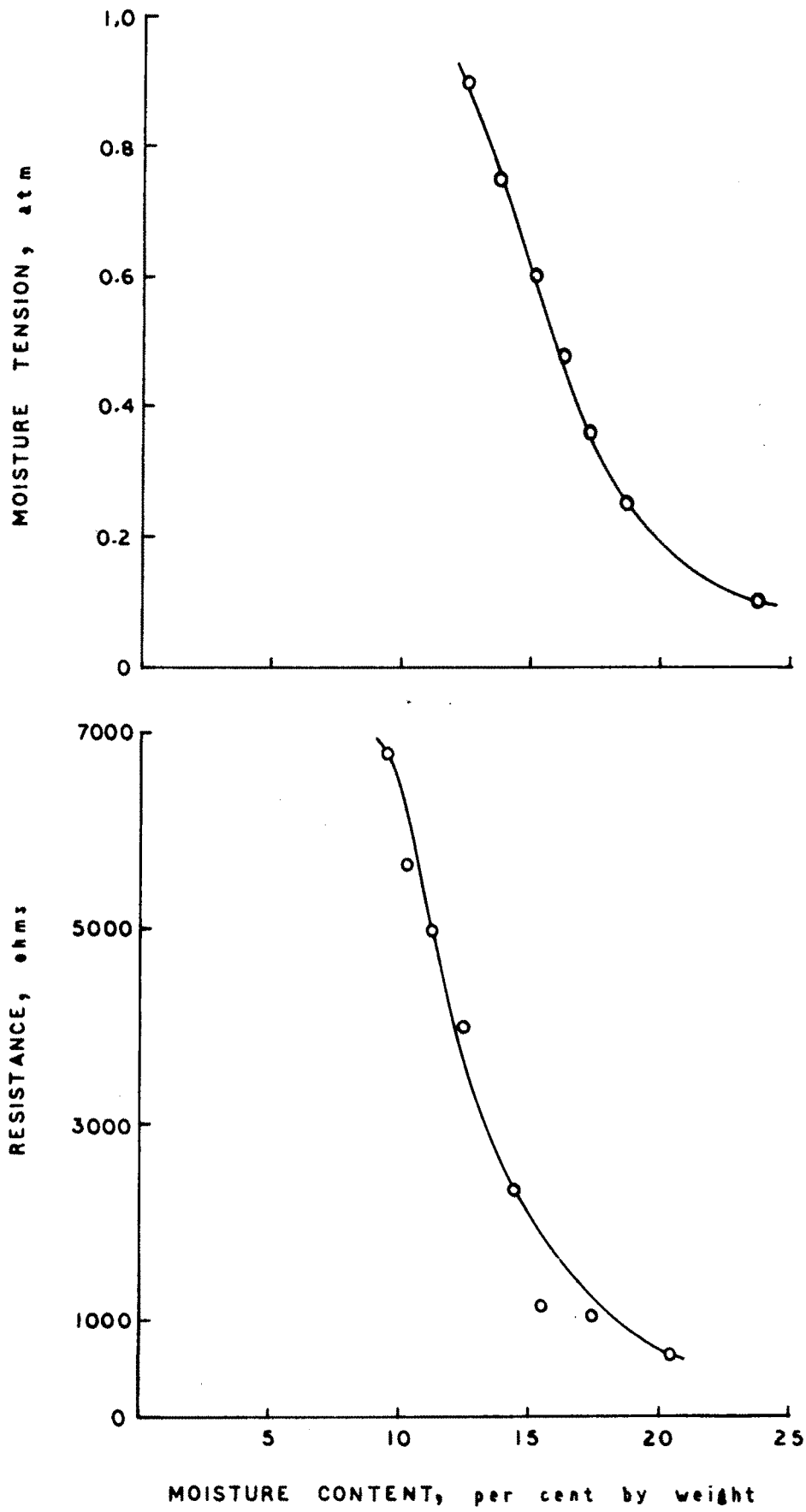


FIG. 3.1 SOIL MOISTURE CONTENT AND MOISTURE TENSION, MOISTURE RESISTANCE

3.4.2 Irrigation

For the first 10 days after transplanting, to establish the seedlings, measured quantity of equal amount of water was applied each time by a watering can to all lysimeters for the maintenance of uniform soil moisture tension. The actual irrigation treatment began after this period. Since, the lower limit of soil moisture tension was fixed at 0.1 atmosphere (field capacity) and since the corresponding moisture percentage present by volume was known, the calculated amount of moisture just sufficient to meet the deficit for 0-20 cm layer was applied each time to individual lysimeter. The soil moisture deficit was calculated from the following equation :

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

where,

- d = soil moisture deficit, in centimeter
- PV = soil moisture deficit in ith layer, in per cent by volume
- D_i = Depth of soil in cm of the ith layer
- n = Number of soil layers in the root zone.

3.4.3 Measurement of evapotranspiration

The daily rate of evapotranspiration (E_T) from the tobacco for both the varieties were measured by water balance method (Slatyer, 1967). The water balance method consists of measuring R, I, S, L and ΔW and E_T was calculated with the help of the formula :

$$E_T = R + I - S - L - \Delta W \quad (3.2)$$

where,

- E_T = Evapotranspiration rate, mm/day
 R = Rainfall, mm/day
 I = Irrigation, mm/day
 S = Runoff, mm/day
 L = Loss beyond rootzone, mm/day
 ΔW = Change in mean soil moisture storage (initial minus final) during the period of study, mm/day.

Since the experiment was conducted in specially designed lysimeter, the surface run off was controlled. There was no loss of water beyond rootzone as the bottom of lysimeter was sealed. Knowing daily the amount of rainfall, the irrigation loss below the root and also knowing the moisture present in the rootzone, the evapotranspiration was calculated for each day.

3.4.4 Study of growth characters

3.4.4.1 Height of the plant

Height of all the plants under different treatments was measured from the soil surface upto the apical bud of the stem in tobacco for both varieties.

3.4.4.2 Diameter of the plant

The diameter of the stem of plants under different treatments was taken at three different places (at the base, middle and at the top) by slide callipers and then the average of the diameters at three different places was considered as diameter of the stem.

3.4.4.3 Green weight of the plant

The fresh weight of the plant was determined immediately after destruction of the plant under different treatments. The quantity is expressed by kg m^{-2} .

3.4.4.4 Dry weight of plant

Dry weight of the plants under different treatments were taken by destructive sampling. The drying of plants was made at different stages of growth in the oven at 60°C kept for 3 days.

3.4.4.5 Leaf area index (L.A.I.)

Area of leaf blades per unit area of land surface is called Leaf Area Index. To determine the area of the leaf, the impression of the individual leaf of each plant was taken and the area was measured by using planimeter from the leaf impression. The length and breadth of each individual leaf was also measured to establish the relationship between leaf area and leaf length and breadth.

3.4.4.6 Coefficient for tobacco leaf area

The coefficient for tobacco leaf to determine leaf area from the leaf length and maximum leaf breadth was determined from each varieties. The leaf area considered was from the leaf area measured from planimeter for this study. The length and maximum breadth of leaf were measured individually from the same leaf.

The study was carried out to assess the appropriate coefficients for N. tabacum and N. rustica for the different stages of

its developments, under soil moisture tension and Nitrogen levels. The leaf materials were collected at different stages of its development. The leaves were collected from top, middle and bottom of the stalk from each treatment. The actual leaf area was determined from the impression of leaf traced on a plain paper and the areas were determined by planimeter. The corresponding length and maximum width were also measured.

The plant materials considered for correlation studies, 60 days after transplanting from each treatment are leaf length of < 15 cm from top leaves, 15.0 to 30.0 cm from middle and > 30.0 cm from bottom of the stalk. The leaf length, maximum width and area were taken from the average of 4 leaves and from the average of two seasons.

From the area measured (A) and the product of length (L) and maximum width (W), coefficient (C) was assessed by using the equation :

$$C = A/LW \quad (3.3)$$

3.5 Nicotine estimation

As nicotine is the major alkaloid present in tobacco, the total alkaloid estimation was done by following the standard procedure adopted from Cundiff and Markunas, 1955. The per cent of total alkaloid present in tobacco was determined with the objective to study its quality in response to different levels of nitrogen application and different levels of soil moisture tensions.

3.6 Statistical analysis

The seven day's moving average data of maximum and minimum temperature, °C, wind velocity, km/hr., bright sunshine hours and vapour pressure deficit in mm of Hg were used for calculating relationship between evapotranspiration rate and the climatic variables. Yield data of tobacco, total evapotranspiration, height of plant, diameter of stem, green weight of plant, dry weight of plant, leaf area index, nicotine content under different treatments, were analysed by analysis of variance for different stages of growth. Interactions which were significant are only reported.

Prediction equation for yield-water-nitrogen relationship was obtained by Bivariate Analysis.

Coefficients of correlation, regression, simple and multiple regression equations, polynomial equations were computed. The validity of all the computed equations were tested. Evapotranspiration as a function of days of growth and other relationship have been processed by least square method.

CHAPTER IV

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

4.1 Evapotranspiration

The functional relationship between the measured evapotranspiration (E_T) and each of four climatic variables like temperature, sunshine hours, wind velocity and vapour pressure deficit, soil moisture tension, nitrogen level and leaf area index has been considered.

4.1.1 Influencing Factors

4.1.1.1 Climate

The influence of four climatic variables, like temperature (T), wind velocity (W), sunshine hours (S) and vapour pressure deficit ($e_s - e_a$) on measured evapotranspiration rate (E_T) from tobacco crop during two seasons 1979-80 and 1980-81 has been considered. Since it was not possible to measure the radiation on the crop surface and since sunshine hours has a relation with radiation, the influence of sunshine hours on evapotranspiration has been considered. The evapotranspiration rates were measured on and from second week after transplanting. The weekly rates of evapotranspiration (E_T) and weekly average values of four

different climatic variables were processed by least square method to obtain the functional relationship between them.

4.1.1.1.1 Temperature

The relationship (Figures 4.1 to 4.3) between the mean air temperature (T) and evapotranspiration (E_T) indicates that with the increase in T , the E_T increases in a linear manner irrespective of soil moisture tensions and varieties, but the rate of change of E_T varies, as indicated by the regression co-efficients.

When the influence of temperature on E_T for two seasons is considered together (Figures 4.3) the following equations are obtained.

N. tabacum

$$E_T(M_1) = 0.289 T - 1.461, \quad r = 0.494 \quad (4.1)$$

$$E_T(M_2) = 0.186 T - 1.208, \quad r = 0.587 \quad (4.2)$$

$$E_T(M_3) = 0.080 T + 0.172, \quad r = 0.265 \quad (4.3)$$

N. rustica

$$E_T(M_1) = 0.254 T - 1.060, \quad r = 0.561 \quad (4.4)$$

$$E_T(M_2) = 0.218 T - 1.511, \quad r = 0.547 \quad (4.5)$$

$$E_T(M_3) = 0.163 T - 1.461, \quad r = 0.479 \quad (4.6)$$

where,

E_T = Evapotranspiration rate, mm/day and subscripts M_1 , M_2 and M_3 indicate soil moisture tension, atmosphere.

T = Mean air temperature, °C.

The influence of T on E_T is highest under moist regime

1979-80

—○— M₁
---Δ--- M₂
---●--- M₃

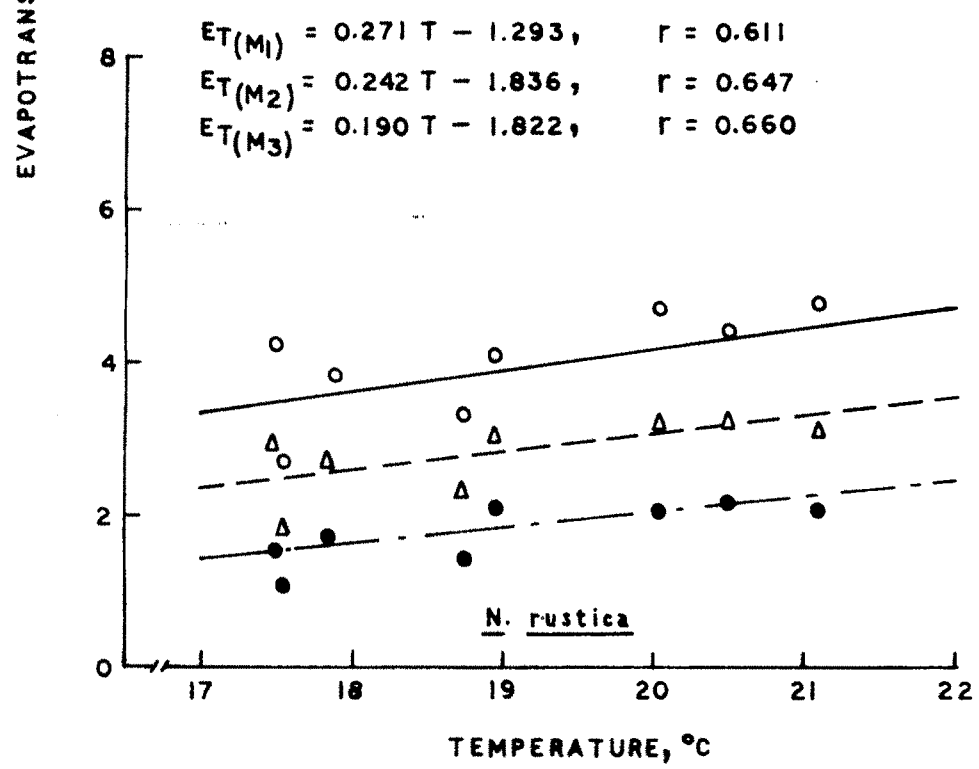
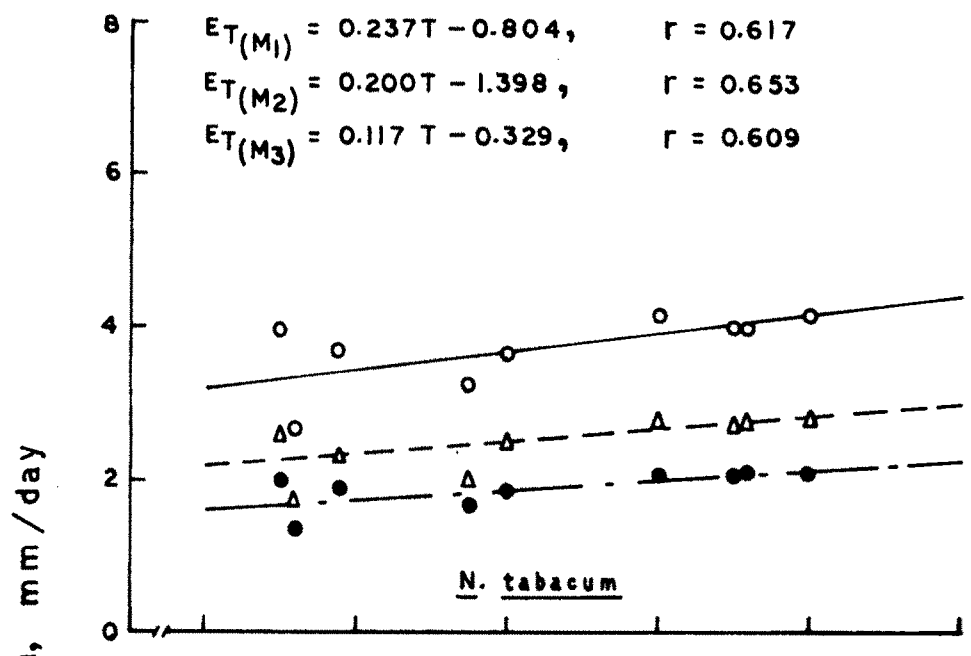


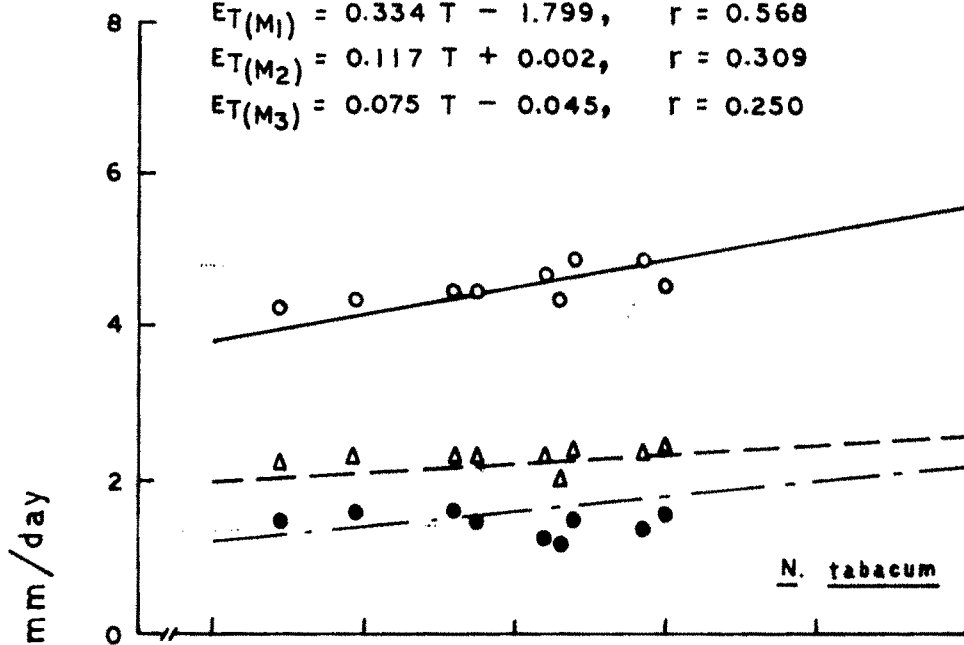
FIG. 4.1 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND TEMPERATURE

1980 - 81

62

—○— M₁
- - Δ - - M₂
- - ● - - M₃

$$\begin{aligned} ET(M_1) &= 0.334 T - 1.799, & r &= 0.568 \\ ET(M_2) &= 0.117 T + 0.002, & r &= 0.309 \\ ET(M_3) &= 0.075 T - 0.045, & r &= 0.250 \end{aligned}$$



$$\begin{aligned} ET(M_1) &= 0.198 T - 0.144, & r &= 0.385 \\ ET(M_2) &= 0.053 T + 1.438, & r &= 0.166 \\ ET(M_3) &= 0.031 T + 0.856, & r &= 0.074 \end{aligned}$$

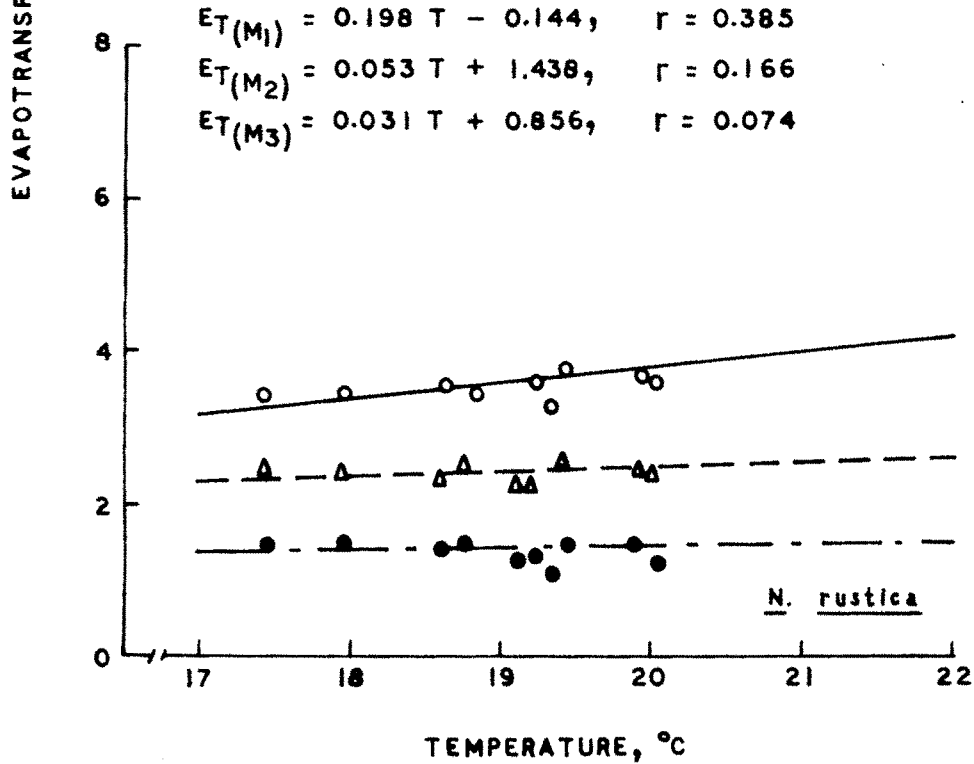


FIG. 4.2 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND TEMPERATURE

1979 - 1981

63
—○— M₁
- -Δ- - M₂
- -●- - M₃

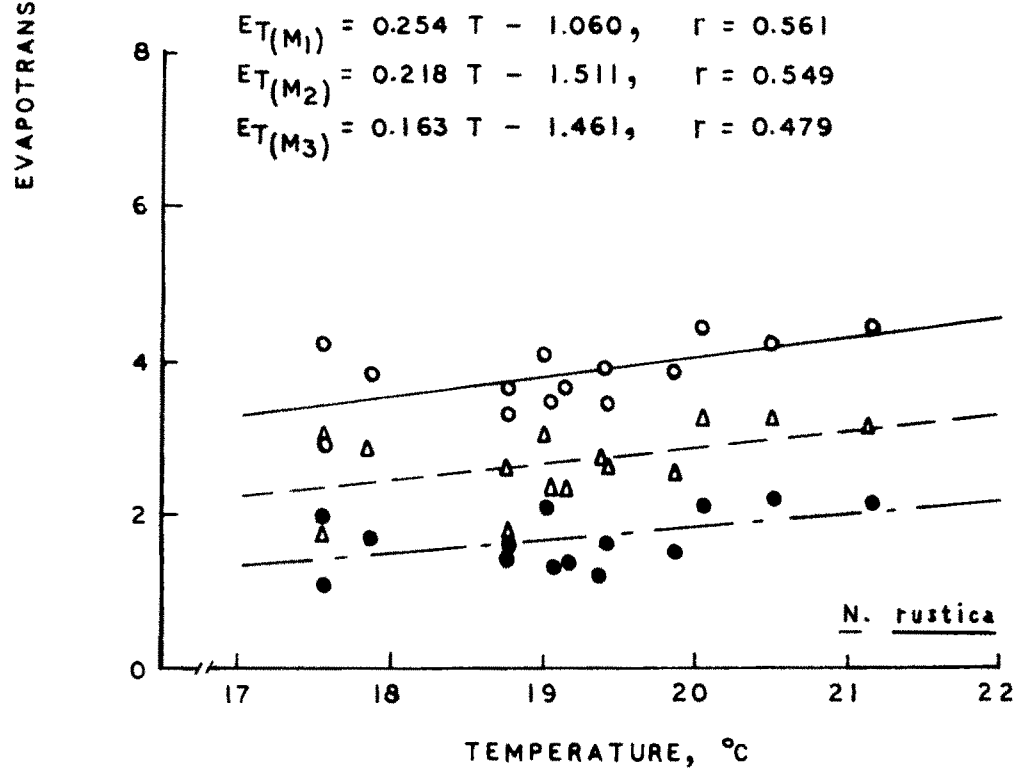
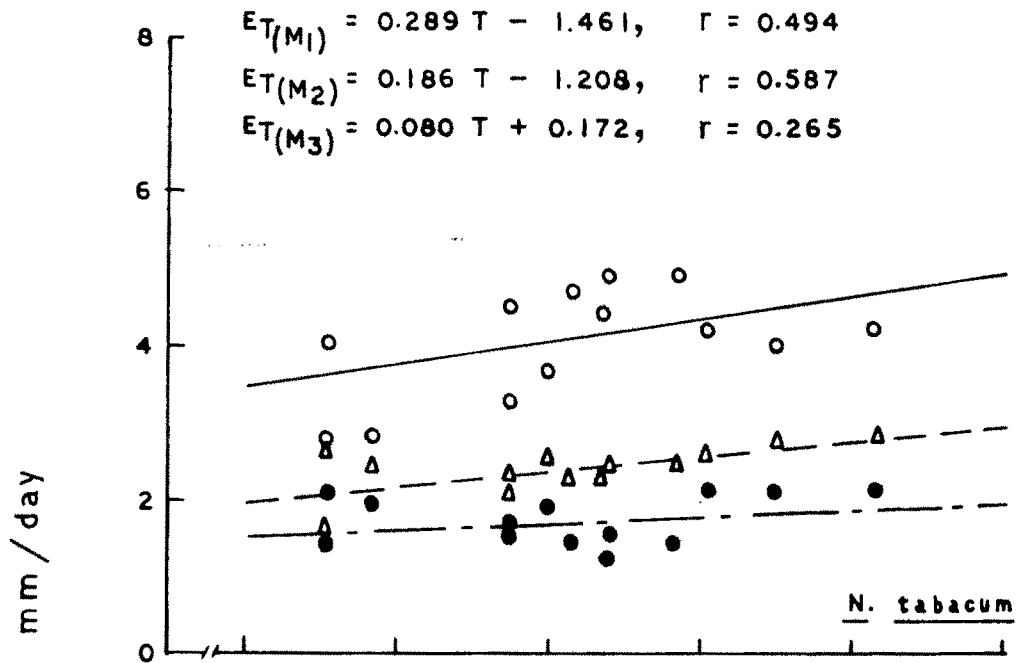


FIG. 4.3 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND TEMPERATURE DURING TWO SEASONS

(0.1 to 0.3 atm) irrespective of varieties. The rate of change of E_T gradually decreases with the increase of soil moisture tension.

Since, with the increase of air temperature, the saturated vapour pressure increases in a non-linear manner, a large vapour pressure gradient is expected above the crop surface (Jensen and Haise, 1963) with higher temperature, and since the vapour pressure deficit is the main driving force for diffusion of water vapour from the evaporating surface to the atmosphere, increase in E_T with the increase in temperature is logical.

It may be mentioned here that these results corroborate with those of Stearns and Carlson (1960) and Norum and Larsen (1960). Similarly, a high correlation between these two was found by Sharp (1958) and accepted by Pruitt (1964). Longacre and Blaney (1963), Pelton (1964), Baier and Robertson (1965) and Baker (1966) found that with the increase in temperature, transpiration rate also increased. Sarkar (1975) observed change in E_T with temperature on aman and boro paddy.

4.1.1.1.2 Wind velocity

The influence of wind velocity on evapotranspiration rates from tobacco has been presented in Figures 4.4 to 4.6.

When two seasons' data of E_T and W are considered together (Figure 4.6) the following equations have been obtained :

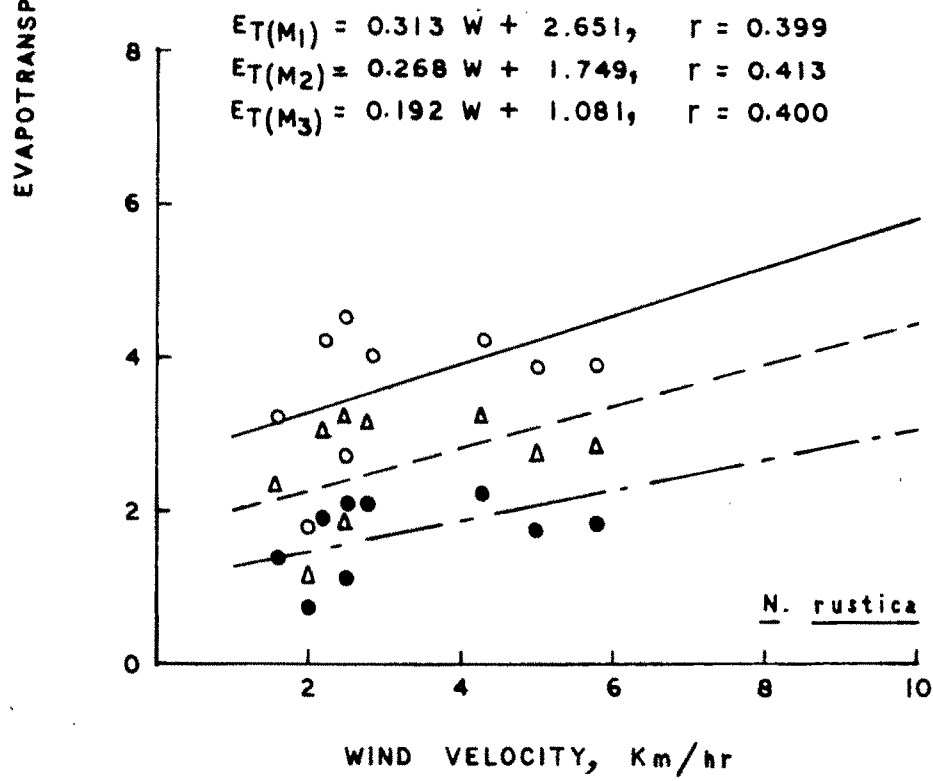
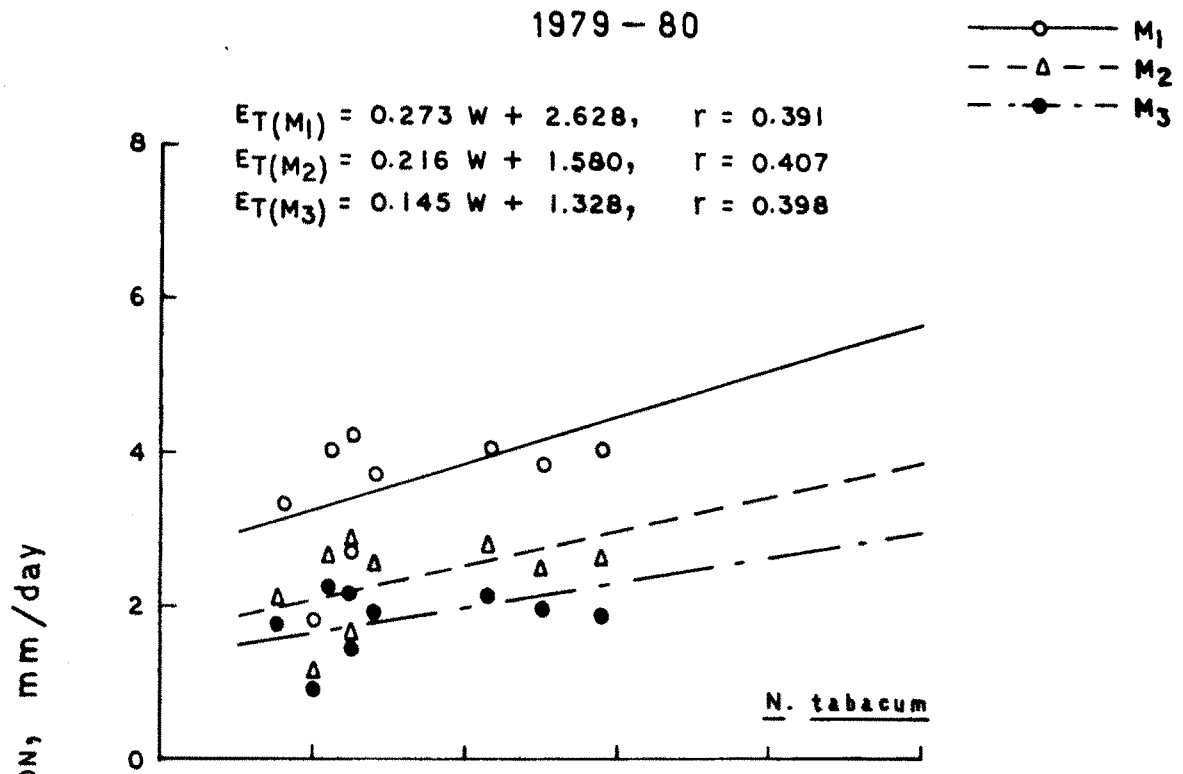


FIG. 4.4 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND WIND VELOCITY

1980 - 81

—○— M₁
 - -Δ- - M₂
 - -●- - M₃

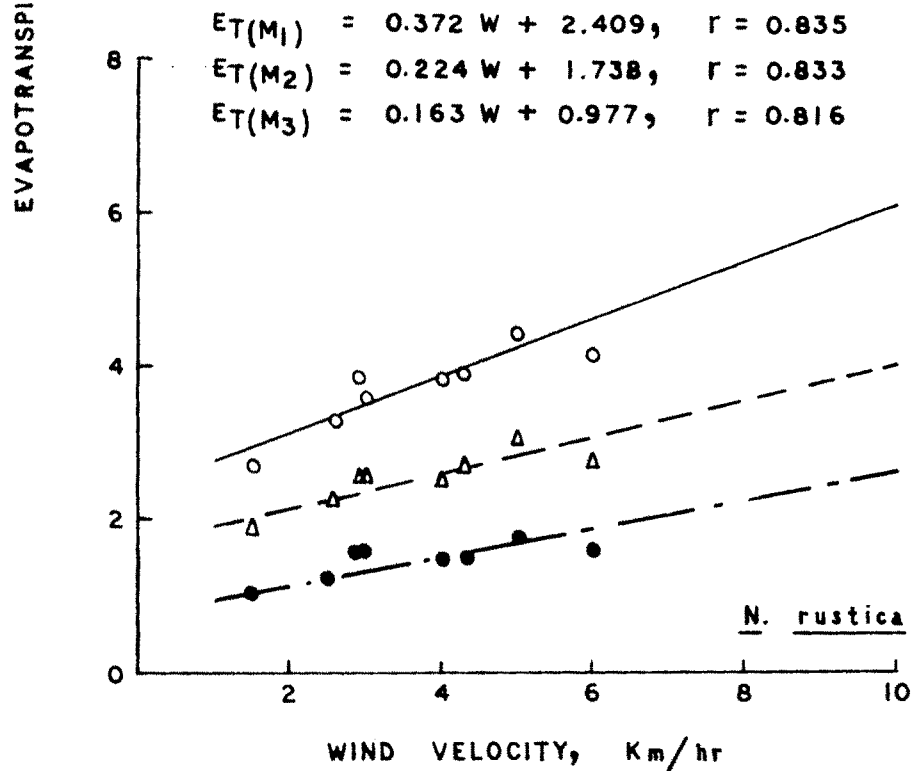
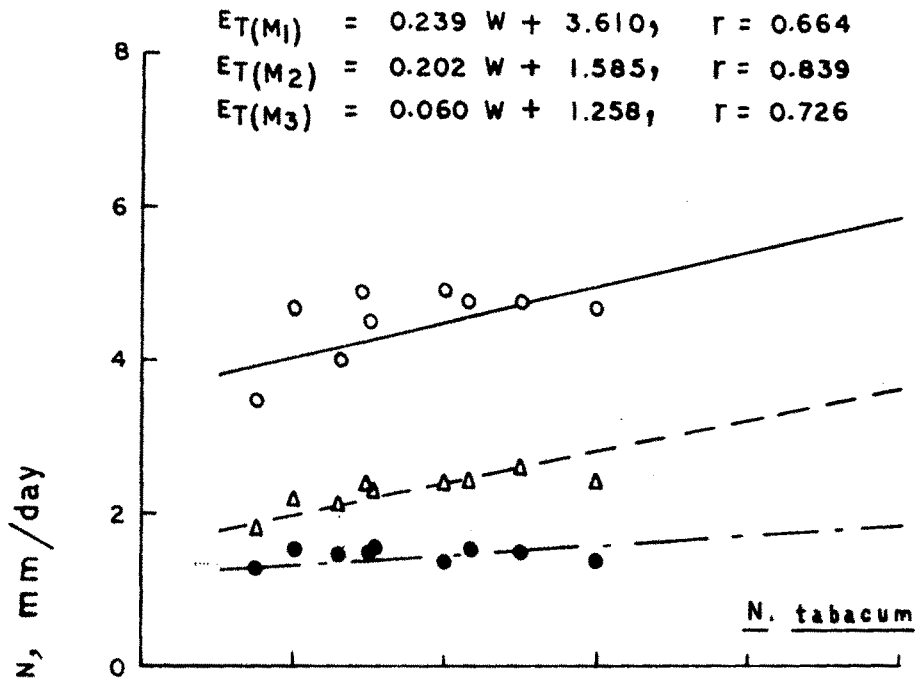
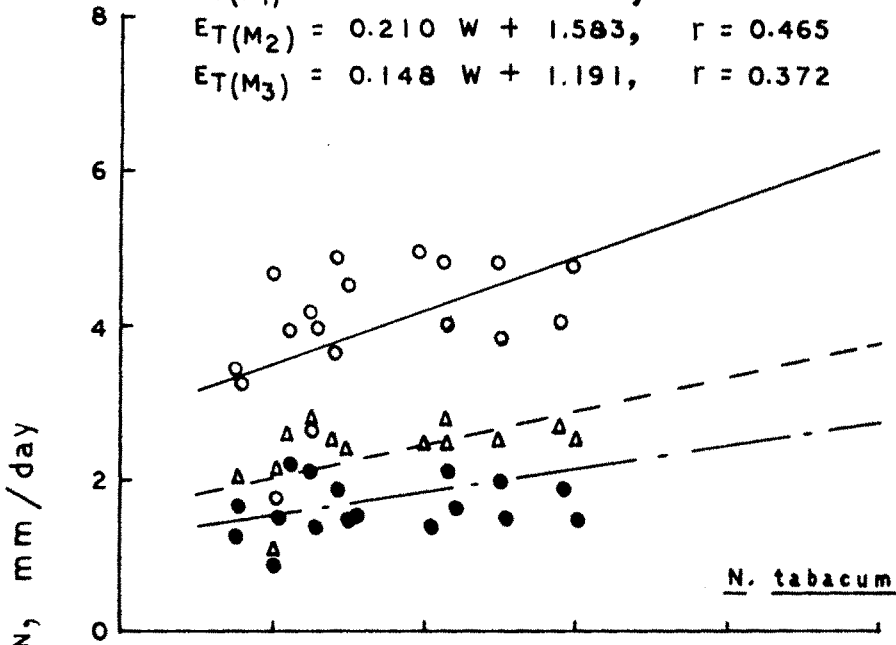


FIG. 4.5 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND WIND VELOCITY

1979 - 1981

- M₁
- -Δ- - M₂
- -●- - M₃

$$\begin{aligned} ET(M_1) &= 0.339 W + 2.823, & \Gamma &= 0.516 \\ ET(M_2) &= 0.210 W + 1.583, & \Gamma &= 0.465 \\ ET(M_3) &= 0.148 W + 1.191, & \Gamma &= 0.372 \end{aligned}$$



$$\begin{aligned} ET(M_1) &= 0.330 W + 2.573, & \Gamma &= 0.483 \\ ET(M_2) &= 0.246 W + 1.755, & \Gamma &= 0.447 \\ ET(M_3) &= 0.173 W + 1.053, & \Gamma &= 0.422 \end{aligned}$$

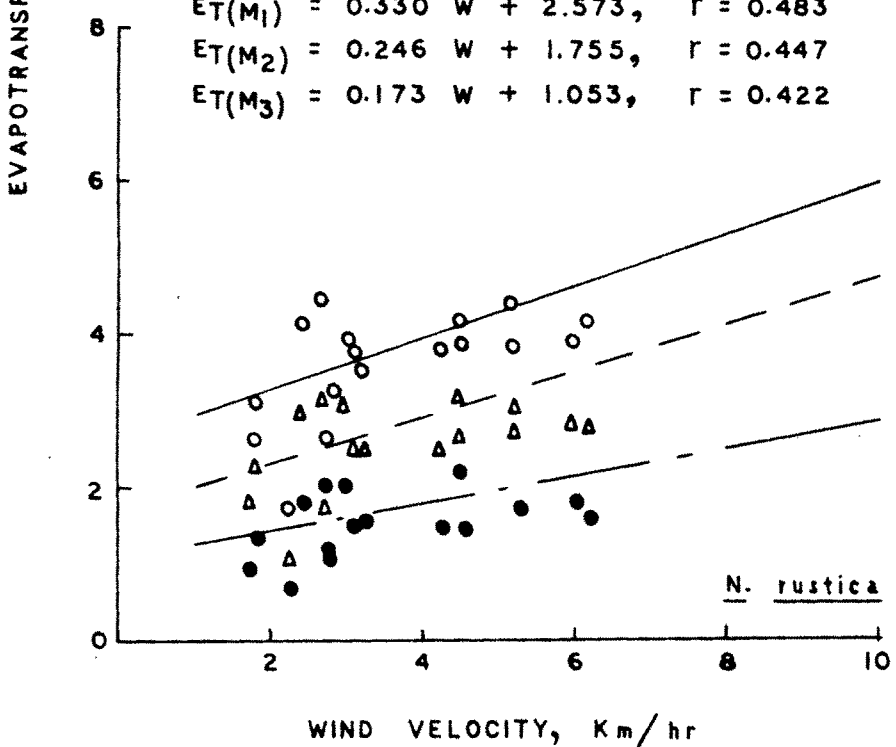


FIG. 4.6 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND WIND VELOCITY DURING TWO SEASONS

N. tabacum

$$E_T(M_1) = 0.339 W + 2.823, \quad r = 0.516 \quad (4.7)$$

$$E_T(M_2) = 0.210 W + 1.583, \quad r = 0.465 \quad (4.8)$$

$$E_T(M_3) = 0.148 W + 1.191, \quad r = 0.372 \quad (4.9)$$

N. rustica

$$E_T(M_1) = 0.330 W + 2.573, \quad r = 0.483 \quad (4.10)$$

$$E_T(M_2) = 0.246 W + 1.755, \quad r = 0.447 \quad (4.11)$$

$$E_T(M_3) = 0.173 W + 1.053, \quad r = 0.422 \quad (4.12)$$

where,

E_T = Evapotranspiration rate, mm/day and subscripts M_1 , M_2 and M_3 indicate soil moisture tension, atmosphere.

W = Average wind velocity, km/hr.

The relationship between the W and the E_T indicates (Figures 4.4 to 4.6) that with the increase in W , E_T increases in a linear manner irrespective of soil moisture tension, variety and season, although the rate of change varies with different soil moisture tensions and variety. The regression coefficient indicates that higher E_T is always associated with 0.3 atmosphere soil moisture tension. The E_T gradually decreases with the increase of soil moisture tensions. The lowest E_T is observed under 0.9 atmosphere irrespective of variety.

The reasons for increase in E_T with the increase of wind velocity may be explained as follows. The evapotranspiration is a diffusive process, partly turbulent and partly molecular. Except on a very thin layer over the evaporating surface, the

turbulent process is dominant. According to the theory of turbulence the upward flow of water vapour is equal to the product of vertical gradient of vapour pressure and rate of mixing which in turn depends on the rate of change of wind speed with height (Chang, 1968). If air around the leaves is perfectly still, the flow of water vapour will gradually increase, increasing the vapour pressure, and reducing the vapour pressure gradient and, therefore, E_T is reduced. However, in the presence of wind, the vapour pressure gradient is maintained, and within limits, an increase in wind speed will cause an increase in E_T (Angus, 1959).

4.1.1.1.3 Sunshine hours

The relationship between sunshine hours (S) and evapotranspiration (E_T) (Figures 4.7 to 4.9) indicates that with the increase of S, E_T increases in all treatments, though the rate of increase varies. The regression coefficients (Figure 4.7) indicate that the rate of change in E_T is always higher during 1979-80 in both varieties.

When two seasons' data are considered together (Figure 4.9) the following equations are obtained.

N. tabacum

$$E_T(M_1) = 0.133 S + 3.315, \quad r = 0.632 \quad (4.13)$$

$$E_T(M_2) = 0.121 S + 1.186, \quad r = 0.515 \quad (4.14)$$

$$E_T(M_3) = 0.118 S + 0.692, \quad r = 0.756 \quad (4.15)$$

1979 - 80

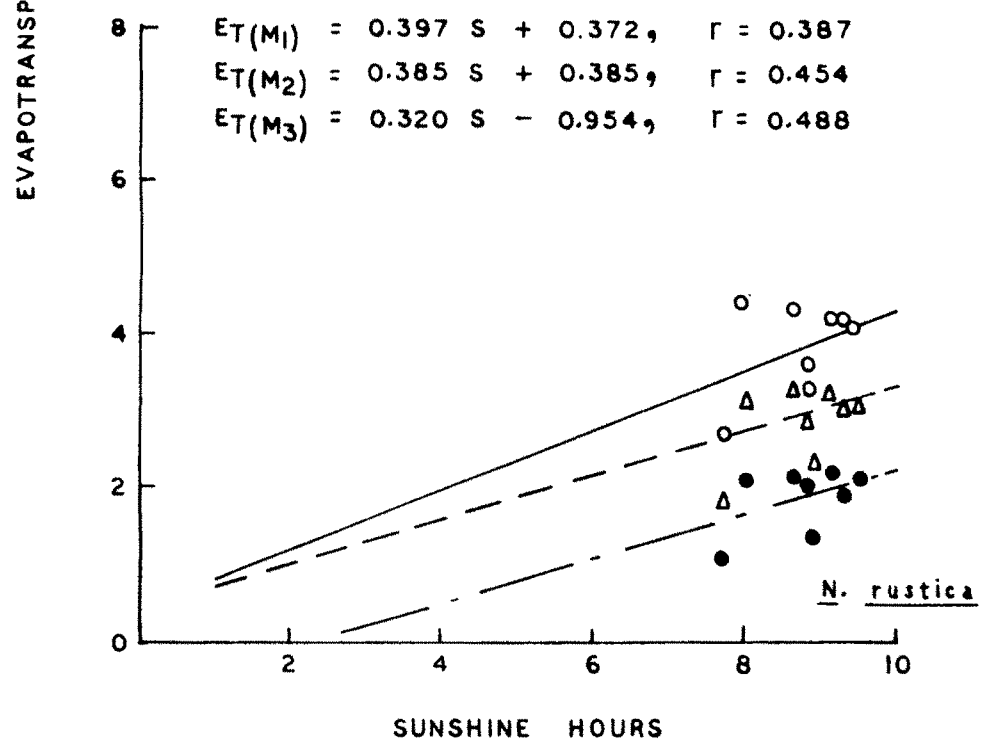
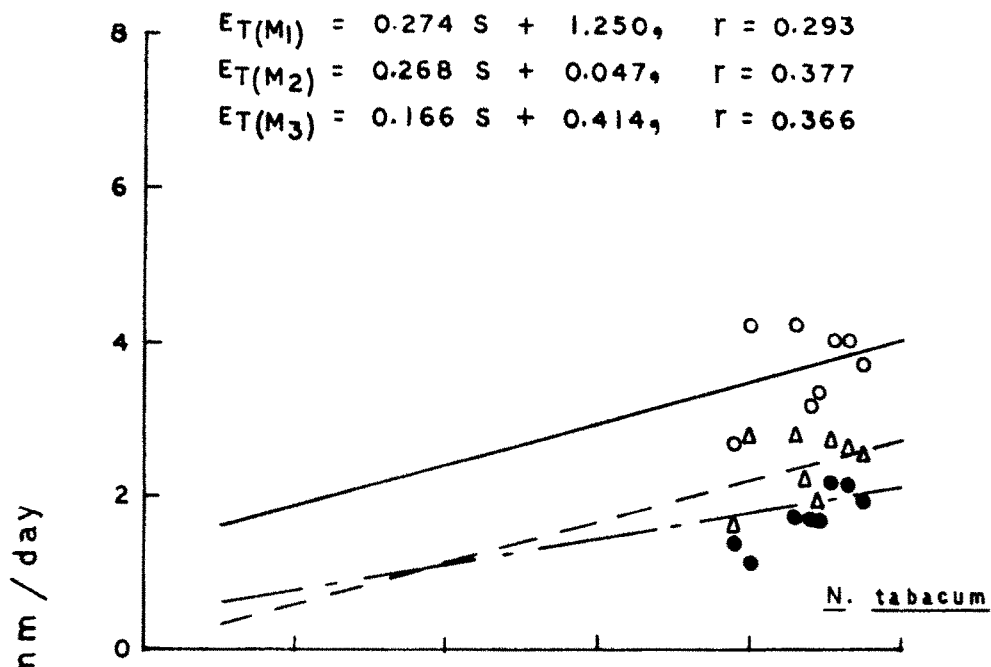


FIG. 4.7 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND SUNSHINE HOURS

1980 - 81

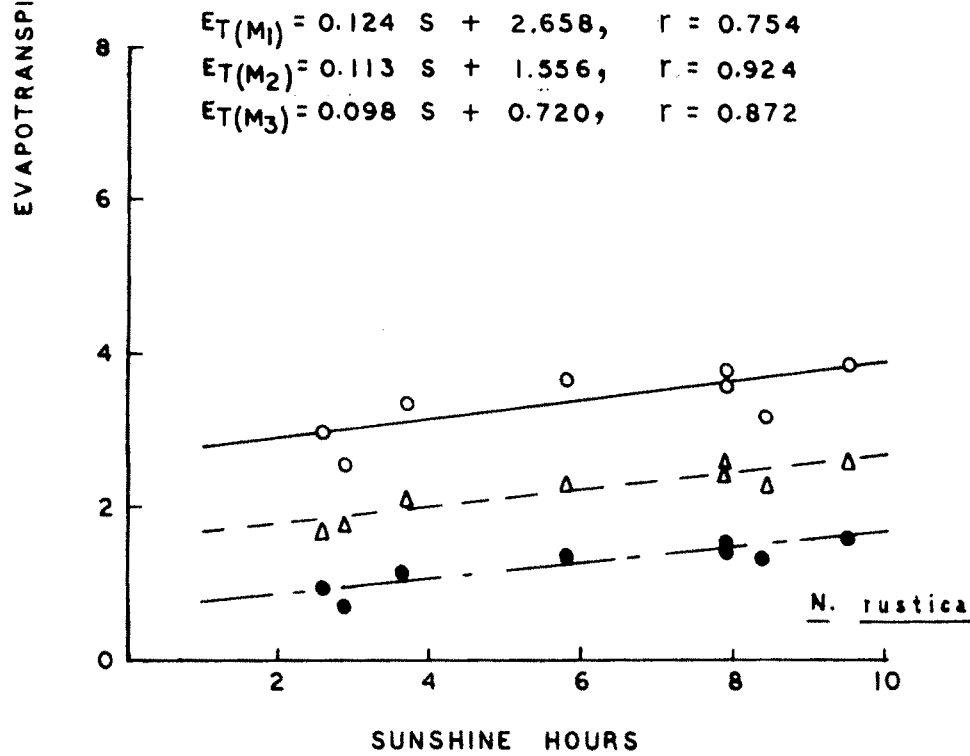
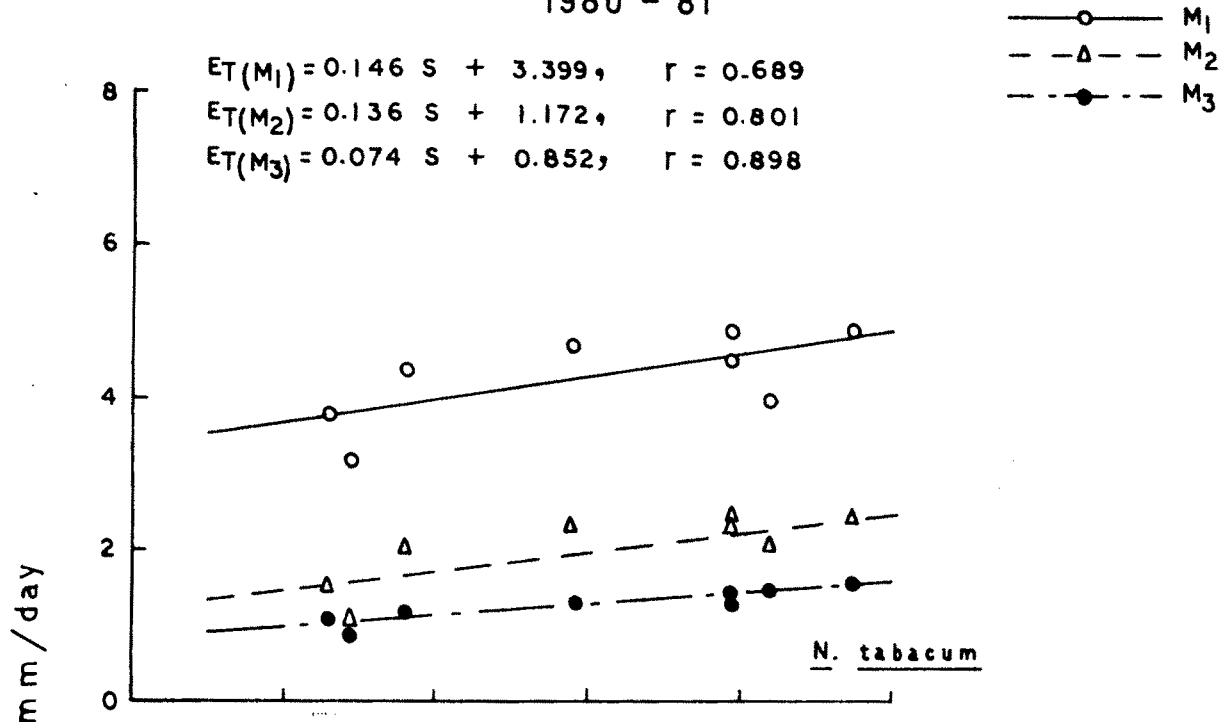


FIG. 4.8 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND SUNSHINE HOURS

1979 - 1981

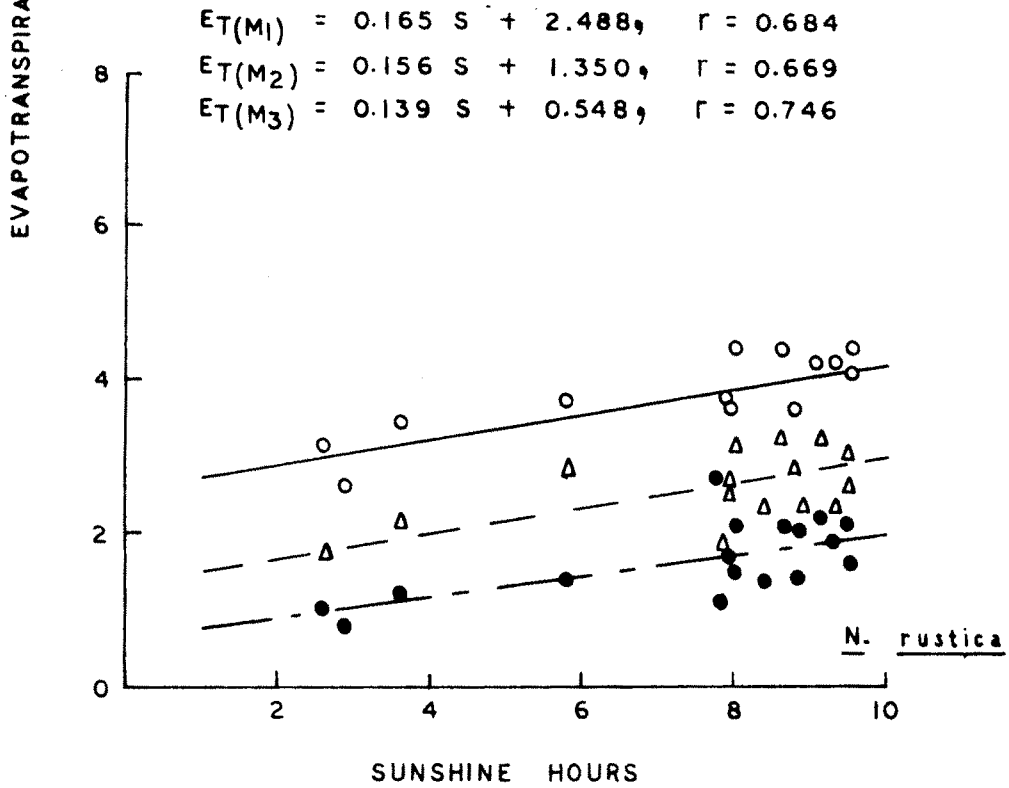
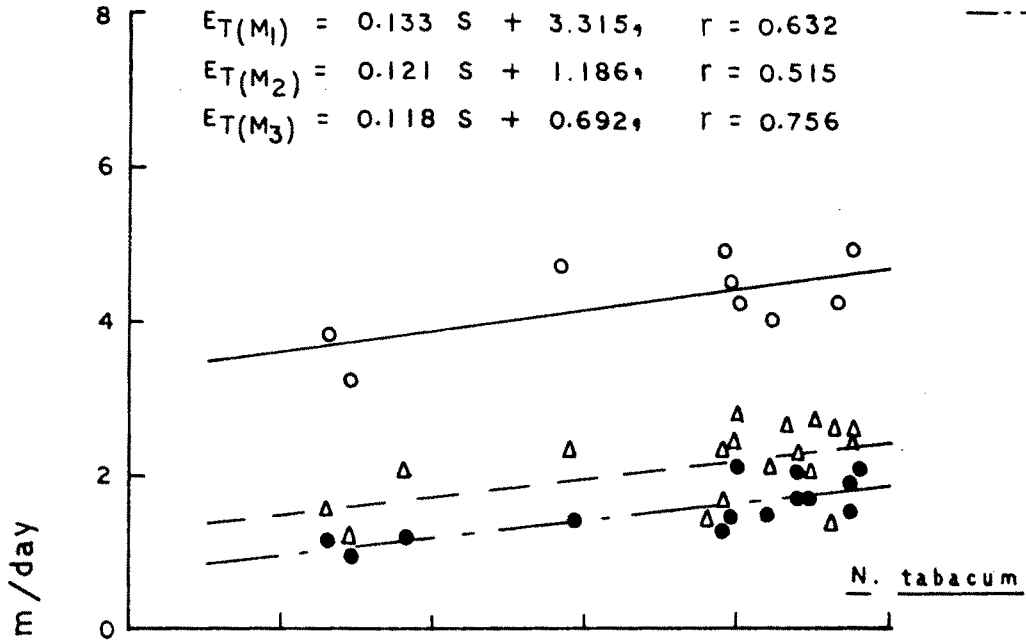


FIG. 4.9 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND SUNSHINE HOURS DURING TWO SEASONS

N. rustica

$$E_T(M_1) = 0.165 S + 2.488, \quad r = 0.684 \quad (4.16)$$

$$E_T(M_2) = 0.156 S + 1.350, \quad r = 0.669 \quad (4.17)$$

$$E_T(M_3) = 0.139 S + 0.548, \quad r = 0.746 \quad (4.18)$$

where,

E_T = Evapotranspiration rate, mm/day and subscripts M_1 , M_2 and M_3 indicate soil moisture tension, atmosphere.

S = Hours of bright sunshine.

The regression coefficients indicated that higher E_T was during the 1979-80 season. The equations (4.13 to 4.18) indicate that irrespective of the variety higher E_T is always associated with lower soil moisture tension and the rate gradually decreases with the increase of soil moisture tension.

The reason for the increase in E_T with the increase in sunshine hours may be due to the fact that, during bright sunshine hours all the energy balance components are high (Burman and Loudon, 1968) and since the thermal contact coefficient of the moist soil is relatively high, more of net radiation enters into the soil. As water is available, a large part of the radiation is used for evaporation. Therefore, the increase of E_T with the increase of bright sunshine hours is logical.

4.1.1.1.4 Vapour pressure deficit

The influence of vapour pressure deficit ($e_s - e_a$) on E_T varied with variety and season. The relationship (Figures 4.10 to 4.12) indicates that with the increase in ($e_s - e_a$), the E_T

1979 - 80

- M₁
- -Δ- - M₂
- -●- - M₃

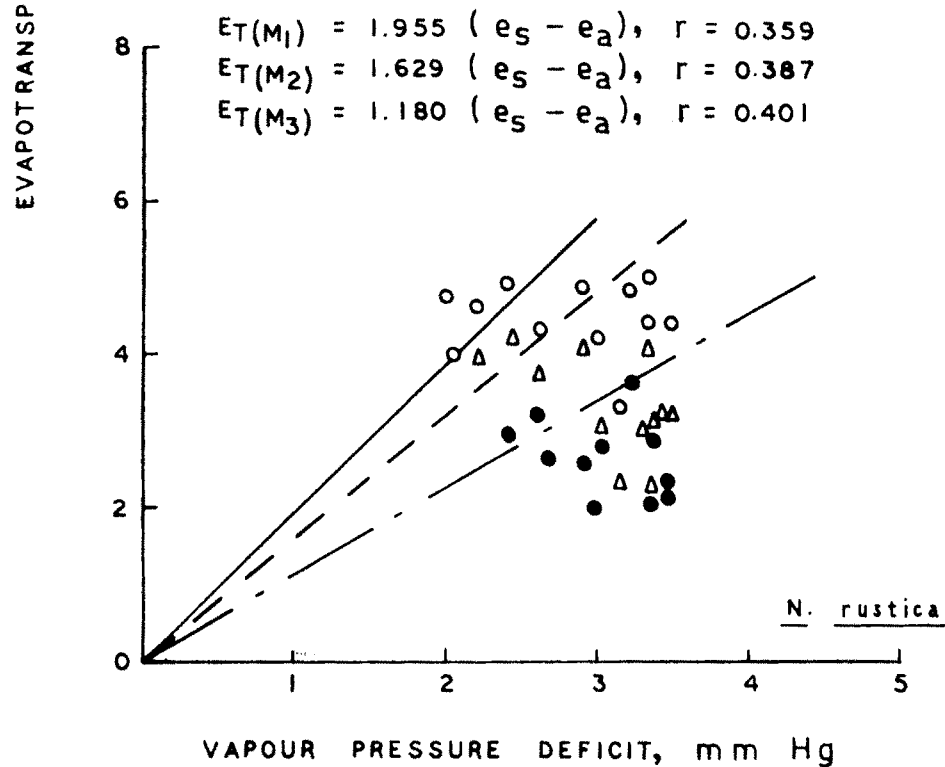
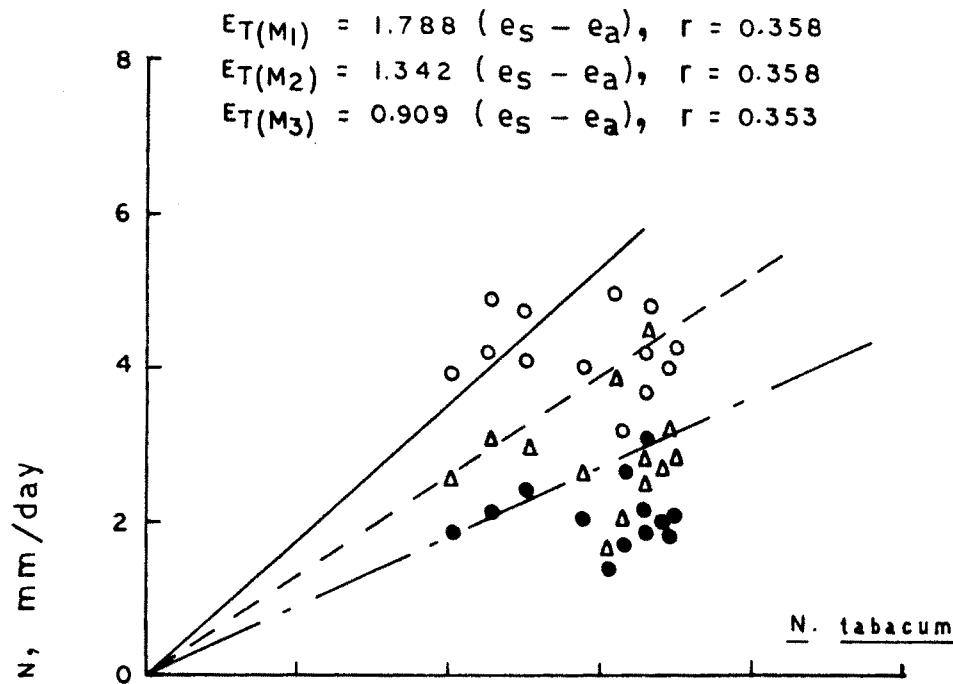


FIG. 4.10 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND VAPOUR PRESSURE DEFICIT

1980 - 81

- M₁
- -Δ- - M₂
- -●- - M₃

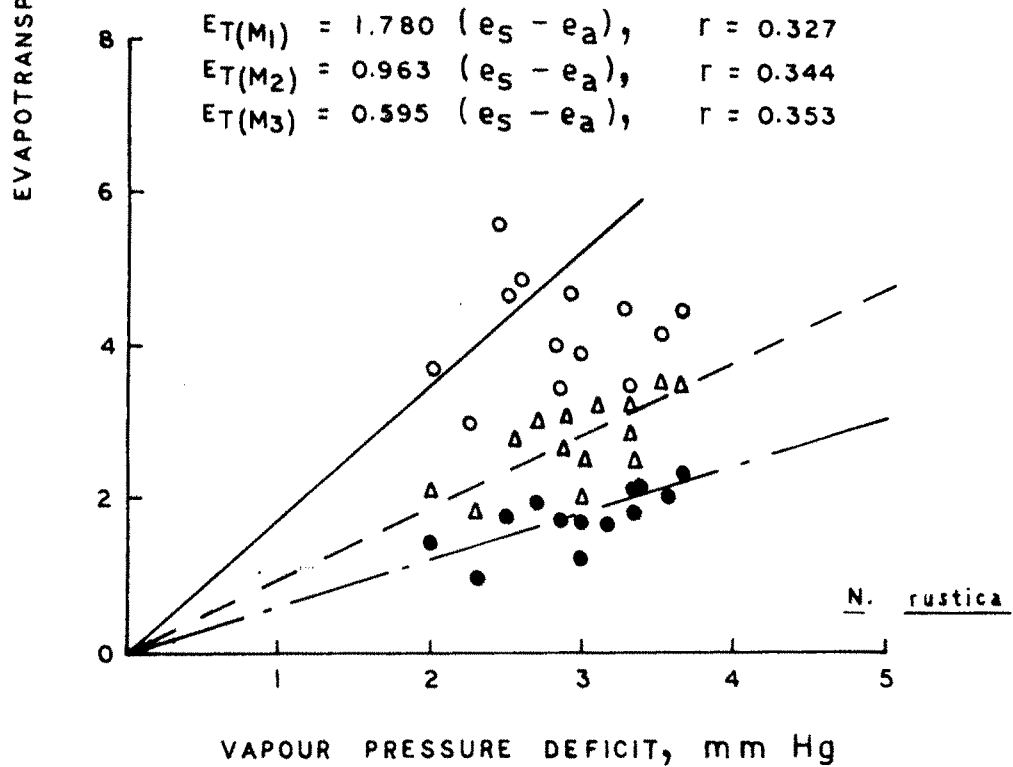
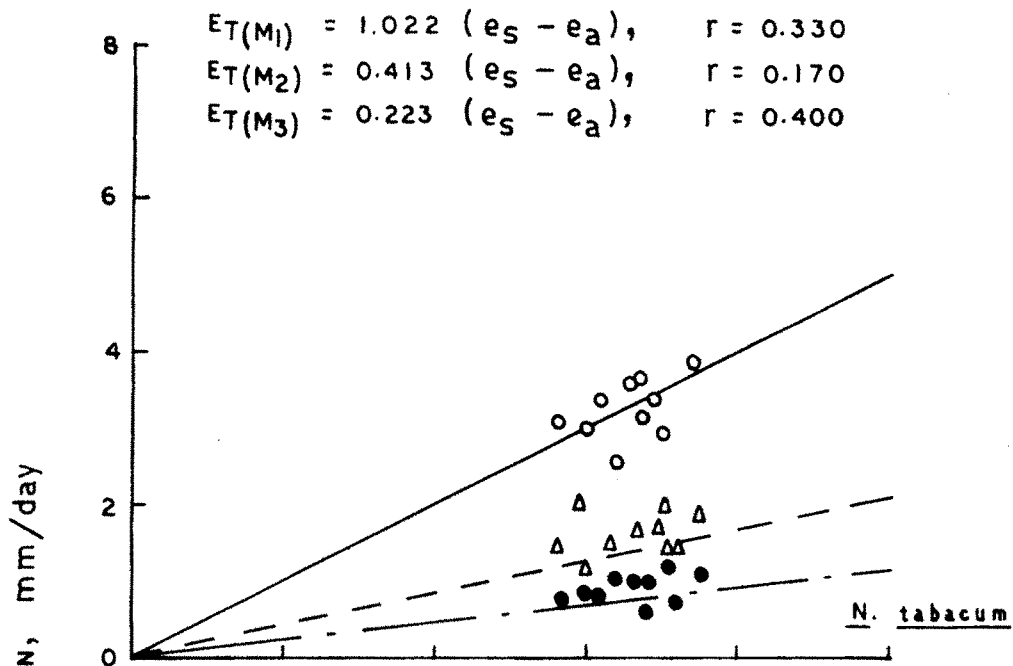


FIG. 4.11 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND VAPOUR PRESSURE DEFICIT

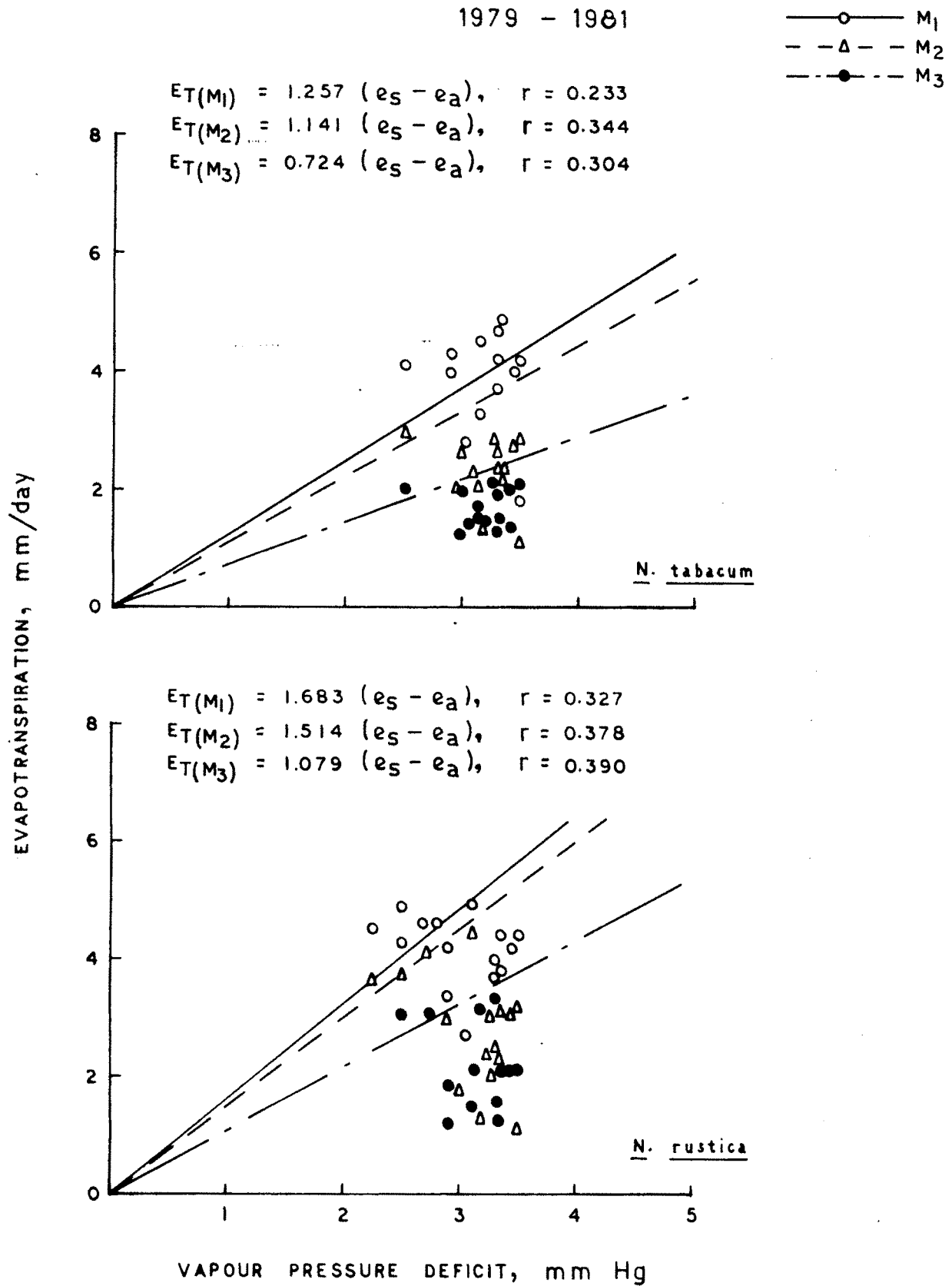


FIG. 4.12 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND VAPOUR PRESSURE DEFICIT DURING TWO SEASONS

increases in all treatments, though the rate of change varies. The higher rate is always associated with lower soil moisture tension.

Considering two seasons data together (Figure 4.12) the following regression equations are obtained.

N. tabacum

$$E_{T(M_1)} = 1.257 (e_s - e_a), r = 0.233 \quad (4.19)$$

$$E_{T(M_2)} = 1.141 (e_s - e_a), r = 0.344 \quad (4.20)$$

$$E_{T(M_3)} = 0.724 (e_s - e_a), r = 0.304 \quad (4.21)$$

N. rustica

$$E_{T(M_1)} = 1.683 (e_s - e_a), r = 0.327 \quad (4.22)$$

$$E_{T(M_2)} = 1.514 (e_s - e_a), r = 0.378 \quad (4.23)$$

$$E_{T(M_3)} = 1.079 (e_s - e_a), r = 0.390 \quad (4.24)$$

where,

E_T = Evapotranspiration rate, mm/day and subscripts M_1 , M_2 and M_3 indicate soil moisture tension, atmosphere.

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

The regression coefficient indicates that the influence of $(e_s - e_a)$ is higher on the N. rustica variety. The regression lines pass through the origin (Figures 4.10 to 4.12) indicating that when $(e_s - e_a)$ is zero, the E_T is zero.

Since, the rate of diffusion of water vapour from the evaporating surface to the atmosphere is controlled by vapour pressure gradient between these surfaces, higher evapotranspiration with higher vapour pressure deficit is reasonable.

These results are in conformity with those of Maity and Pandya (1975) and Ghosh (1974).

4.1.1.1.5 Combined influence of climatic variables

The weekly average data of air temperature (T), wind velocity (W), bright sunshine hours (S), vapour pressure deficit ($e_s - e_a$) and measured values of evapotranspiration (E_T) for both the varieties have been considered for prediction of evapotranspiration. Two equations have been developed through multiple regression analysis. Two seasons' data are considered together for the following equations :

N. tabacum

$$E_T = 5.278 - 0.3377 (T) + 0.4540 (W) + 0.2643 (S) - 0.0139 (e_s - e_a) \quad (R = 0.51) \quad (4.25)$$

N. rustica

$$E_T = 4.2124 - 0.3371 (T) + 0.5632 (W) + 0.3607 (S) - 0.0356 (e_s - e_a) \quad (R = 0.53) \quad (4.26)$$

where,

E_T = Evapotranspiration rate, mm/day.

T = Mean air temperature, °C.

W = Average wind velocity, km/hr.

S = Hours of bright sunshine.

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

The high value of F in the analysis of variance indicates that the regression equations (4.25 and 4.26) account for the major portion of the variations of the dependent variables and hence the relationship fits the data reasonably well.

TABLE 4.1 Analysis of variance

Source of variation	Degrees of freedom	Sum of square	Mean square	Variance ratio	Level of significance
<u>N. tabacum</u>					
Regression equation	4	19.98	4.995	7.43	P < 0.001
Error	86	57.81	0.672		
Total	90	77.79			
<u>N. rustica</u>					
Regression equation	4	19.62	4.905	8.54	P < 0.001
Error	86	49.34	0.574		
Total	90	68.96			

4.1.1.2 Soil moisture tension

The influence of soil moisture tension on evapotranspiration of two varieties was studied during two seasons (1979-80 and 1980-81). Daily evapotranspiration rate was measured on and from two weeks after transplanting. Weekly average E_T values are plotted against days of growth (Figures 4.13 to 4.15) and best fit lines are drawn to represent their relationship.

The curves (Figures 4.13 to 4.15) indicate that E_T gradually increases till the peak is reached at about 50th day after transplanting under all soil moisture tension in both varieties. The E_T then gradually decreases. It may be mentioned that the flowering started during 55-60 days in both the varieties.

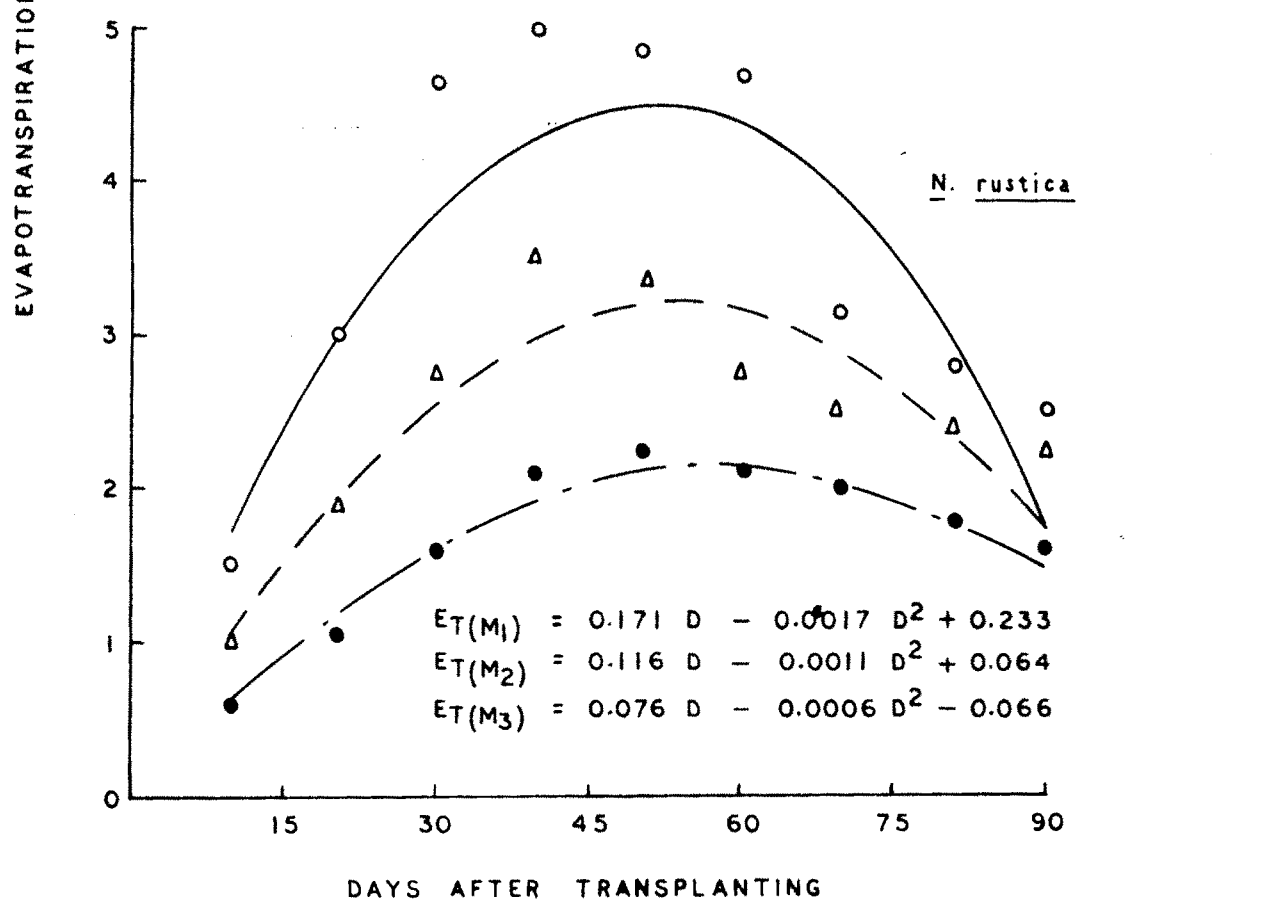
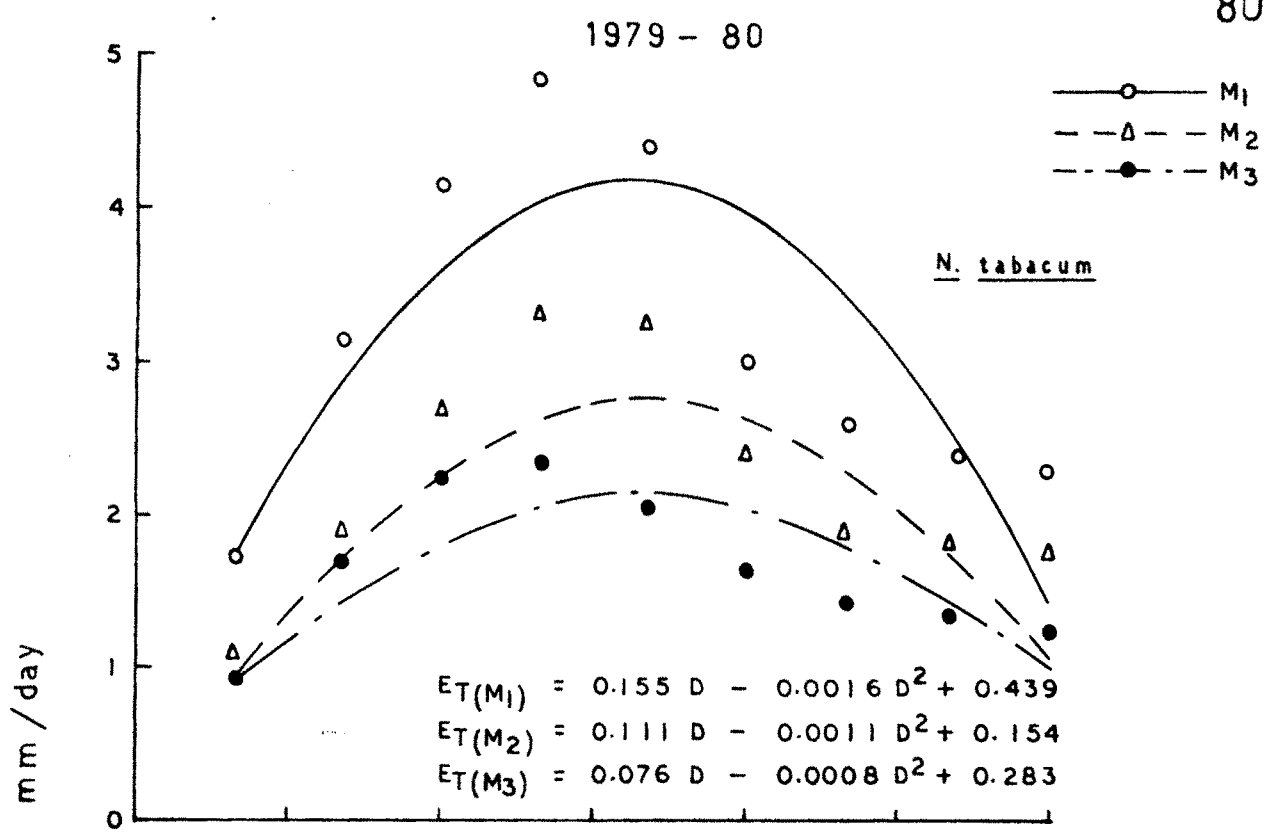


FIG. 4.13 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF DAYS AFTER TRANSPLANTING UNDER DIFFERENT SOIL MOISTURE TENSION

1980 - 81

81

- M₁
- -Δ- - M₂
- -●- - M₃

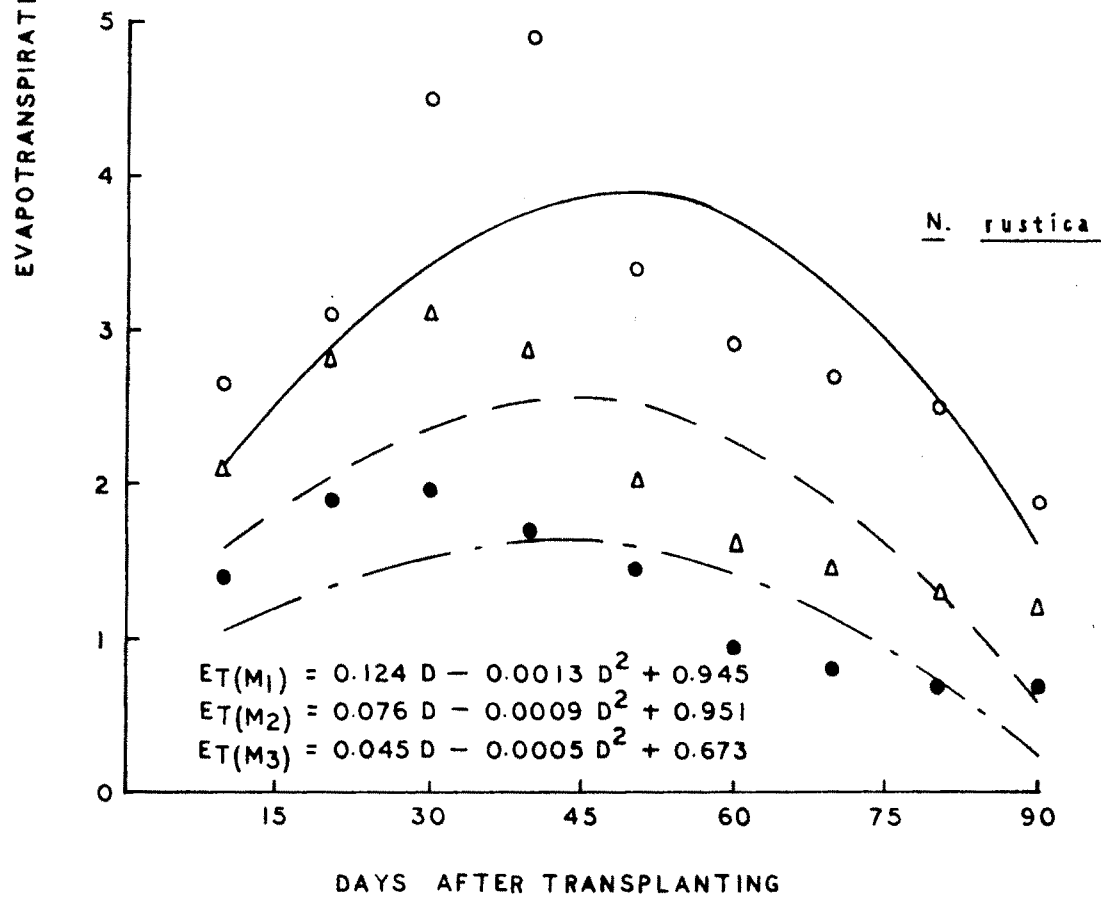
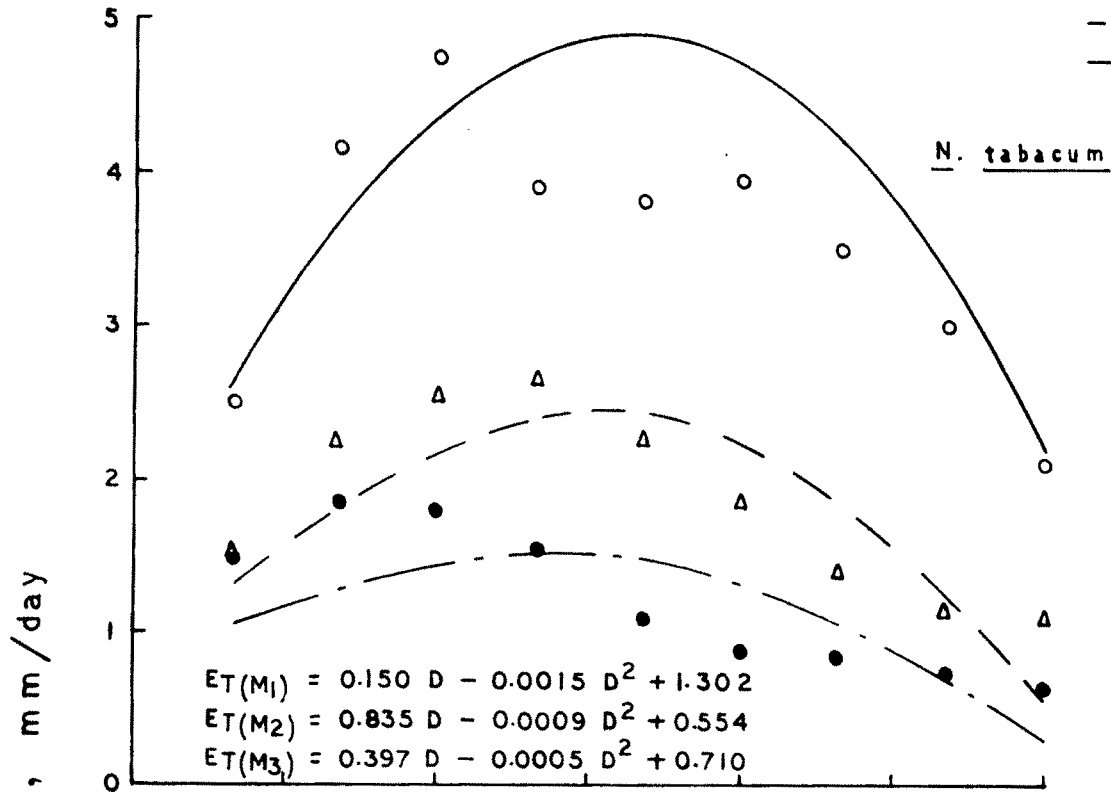


FIG. 4.14 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF DAYS AFTER TRANSPLANTING UNDER DIFFERENT SOIL MOISTURE TENSION

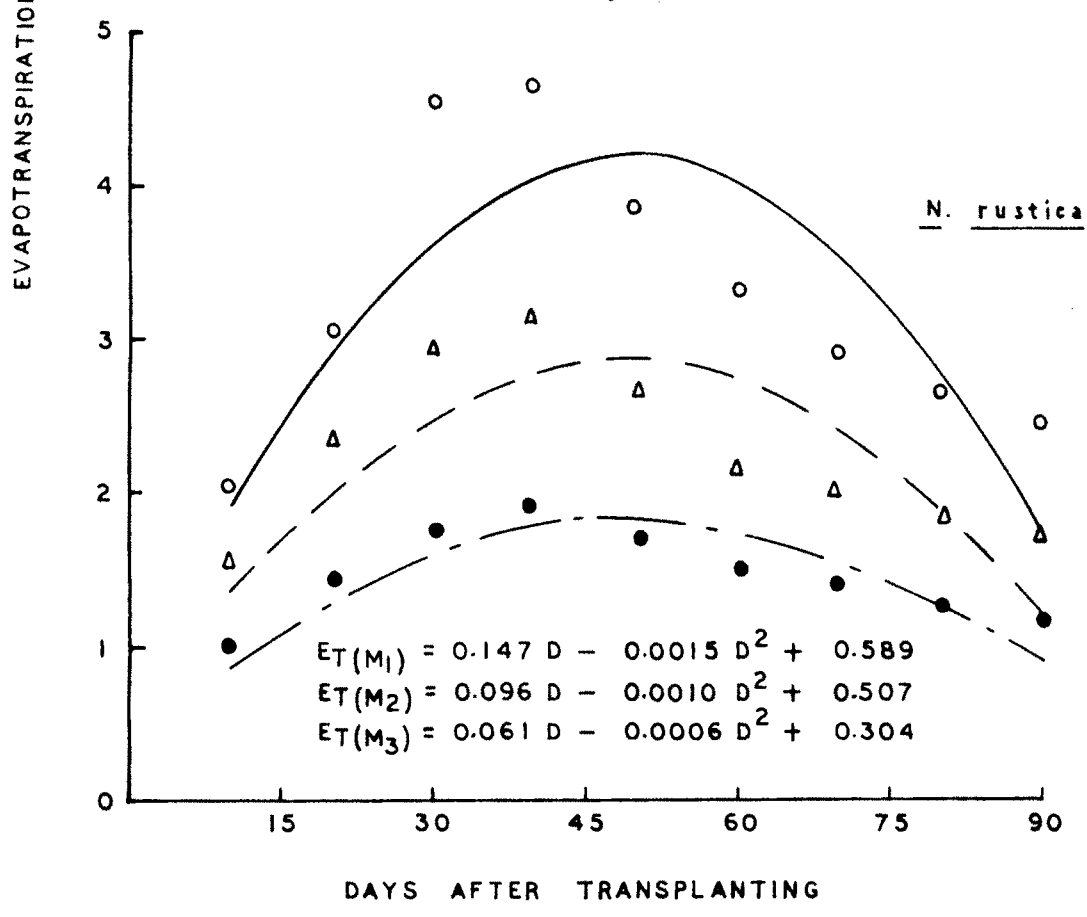
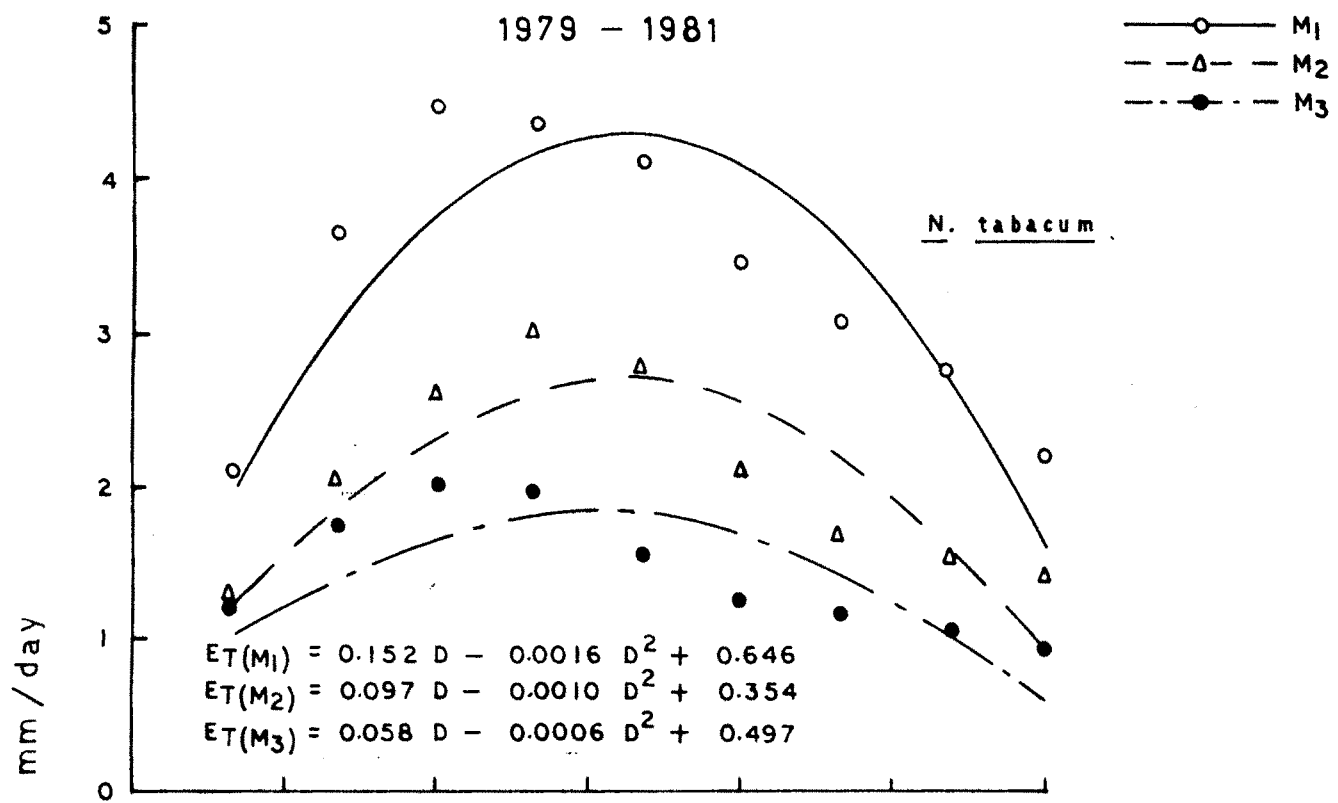


FIG. 4.15 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF DAYS AFTER TRANSPLANTING UNDER DIFFERENT SOIL MOISTURE TENSION DURING TWO SEASONS

It is also observed (Figures 4.13 and 4.14) that E_T at peak for N. rustica is 4.5 mm, 2.8 mm and 1.75 mm per day respectively under 0.3, 0.6 and 0.9 atmosphere soil moisture tension. In case of N. tabacum, peak E_T under 0.3, 0.6 and 0.9 atmosphere soil moisture tension is 4.25 mm, 2.70 and 1.80 mm per day respectively. Throughout the growth period the highest E_T was observed under 0.3 atmosphere soil moisture tension during 1980-81.

The relationship (Figure 4.15) between days after transplanting and evapotranspiration averaged over two seasons has been expressed by the following equations :

N. tabacum

$$E_{T(M_1)} = 0.152 D - 0.0016 D^2 + 0.646 \quad (4.27)$$

$$E_{T(M_2)} = 0.097 D - 0.0010 D^2 + 0.354 \quad (4.28)$$

$$E_{T(M_3)} = 0.058 D - 0.0006 D^2 + 0.497 \quad (4.29)$$

N. rustica

$$E_{T(M_1)} = 0.147 D - 0.0015 D^2 + 0.589 \quad (4.30)$$

$$E_{T(M_2)} = 0.0961 D - 0.0010 D^2 + 0.507 \quad (4.31)$$

$$E_{T(M_3)} = 0.061 D - 0.0006 D^2 + 0.304 \quad (4.32)$$

where,

E_T = Evapotranspiration rate, mm/day and subscripts M_1 , M_2 and M_3 indicate soil moisture tension, atmosphere.

D = Days after transplanting.

The total evapotranspiration rates, $E_{T(S)}$, have been plotted against three soil moisture tensions (Figures 4.16 and 4.17) and their relationship has been obtained.

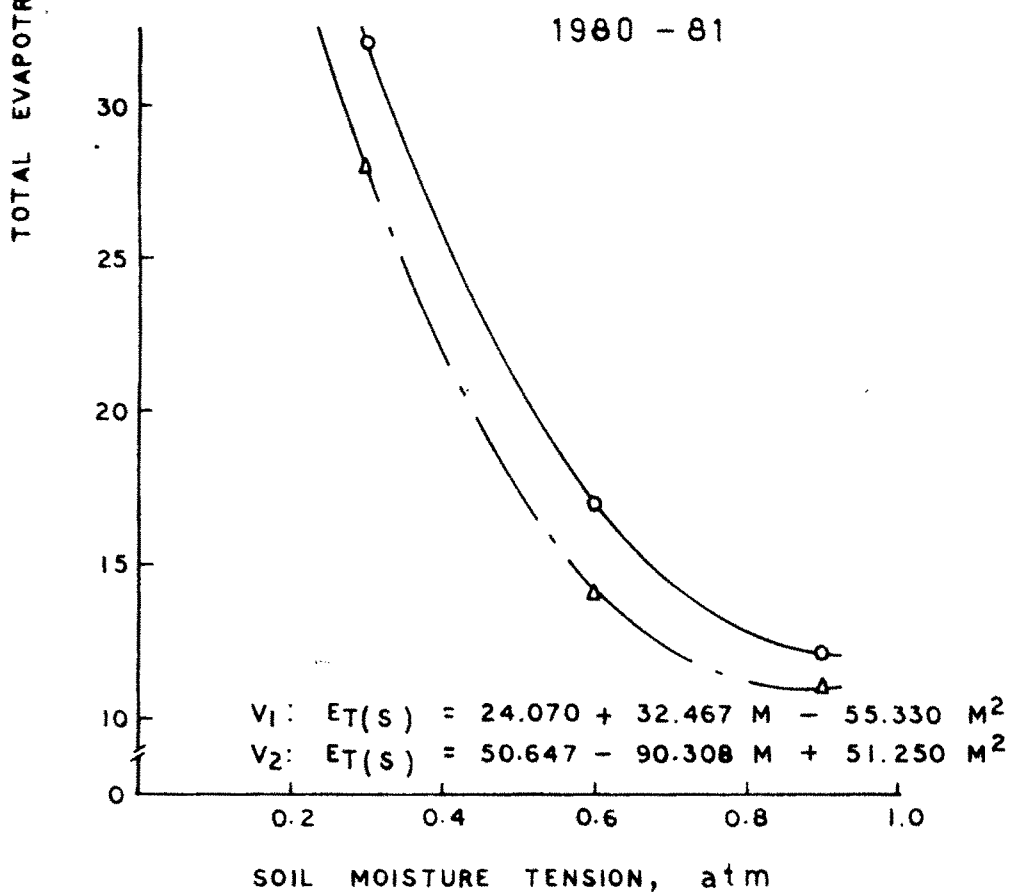
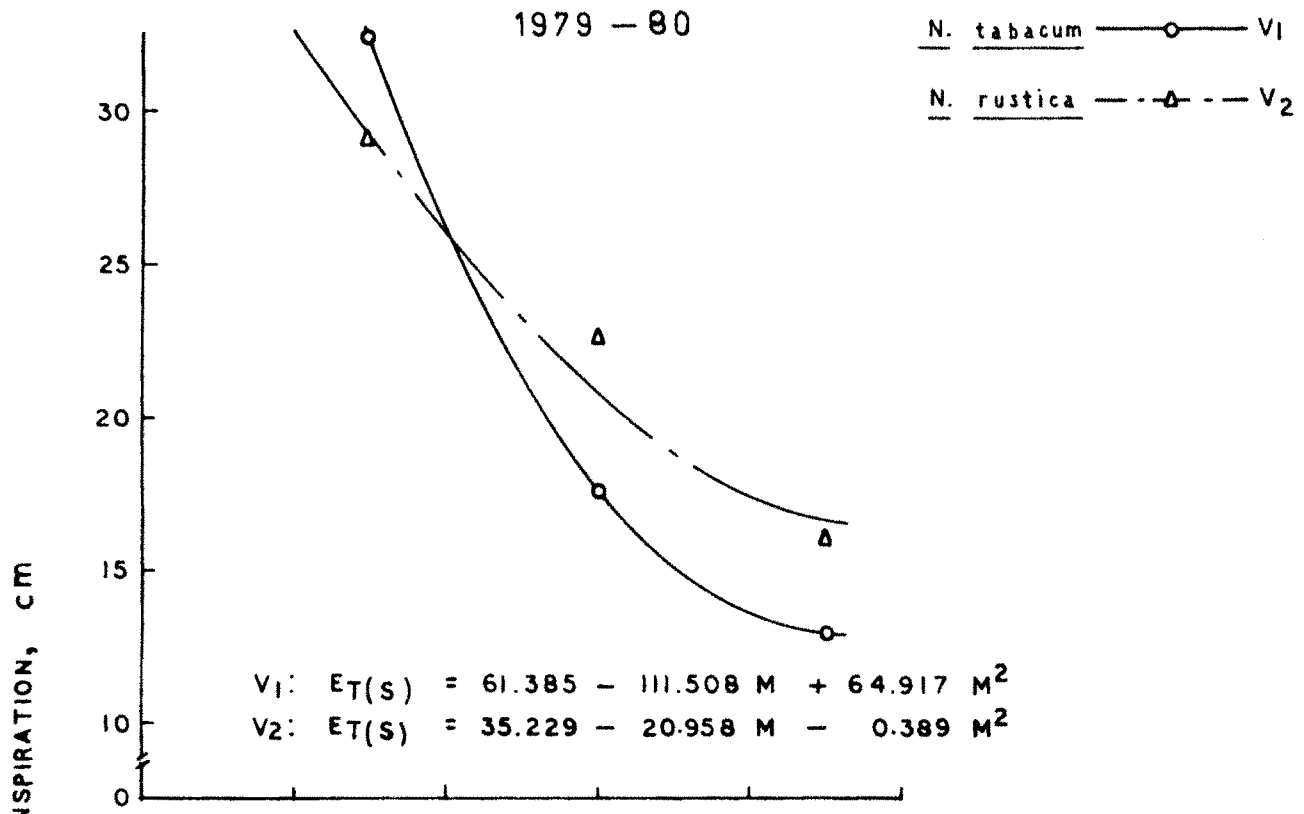


FIG. 4.16 RELATIONSHIP BETWEEN TOTAL EVAPOTRANSPIRATION AND SOIL MOISTURE TENSION

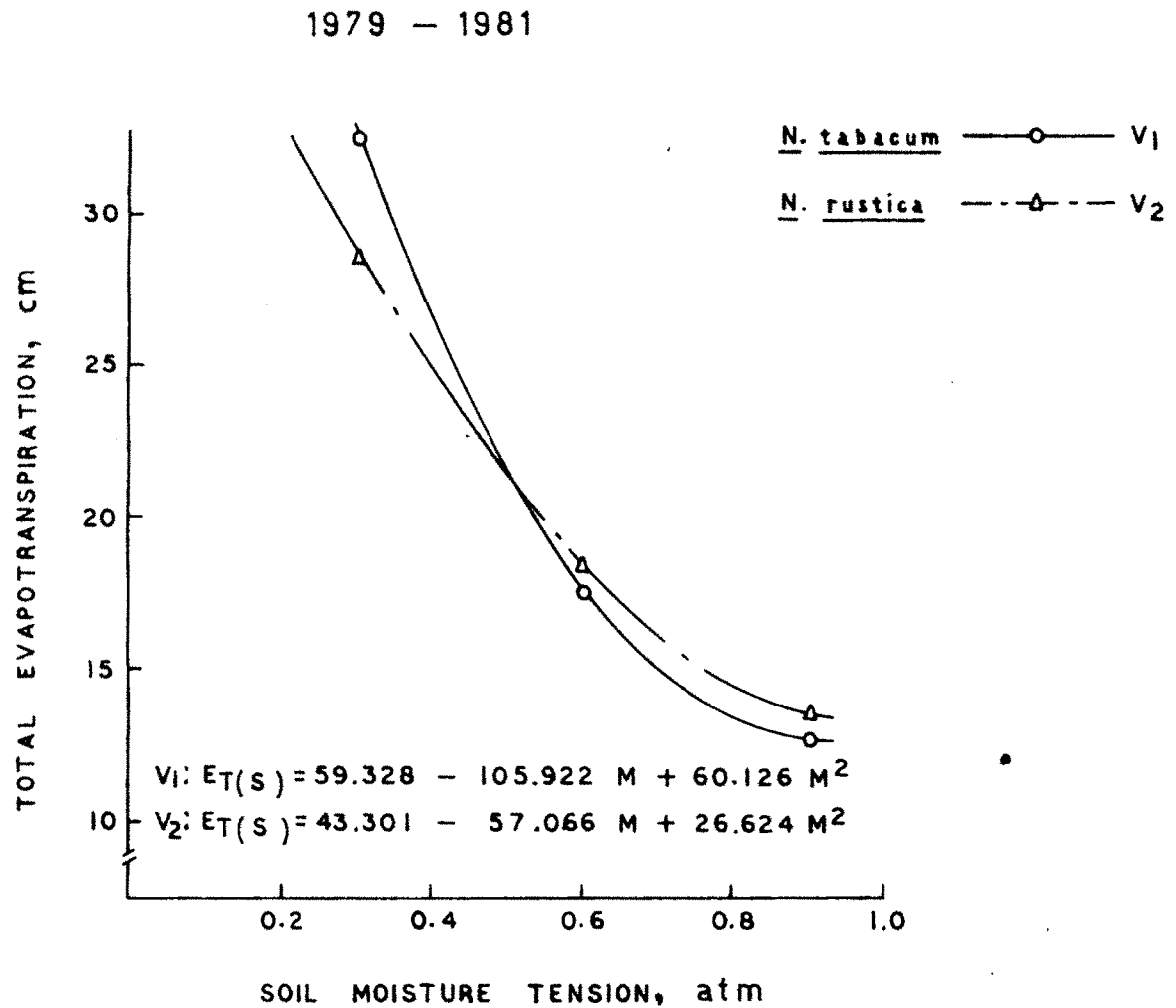


FIG. 4.17 RELATIONSHIP BETWEEN TOTAL EVAPOTRANSPIRATION AND SOIL MOISTURE TENSION DURING TWO SEASONS

It is observed that the relationship is curvilinear with higher $E_T(S)$ at 0.3 soil moisture tension. The relationship indicates that with the increase in soil moisture tension the $E_T(S)$ decreases. The following relationship between $E_T(S)$ and soil moisture tension is obtained considering the two seasons data :

N. tabacum

$$E_T(S) = 59.328 - 105.922 M + 60.126 M^2 \quad (4.33)$$

N. rustica

$$E_T(S) = 43.301 - 57.066 M + 26.624 M^2 \quad (4.34)$$

where,

$E_T(S)$ = Total evapotranspiration, cm

M = Soil moisture tension, atmosphere.

The decrease in total evapotranspiration with increase in soil moisture tension during both seasons is significant (Table 4.2).

TABLE 4.2 Variation in total evapotranspiration under different soil moisture tensions

Soil moisture tension, atm.	Total evapotranspiration, cm	
	1979-80	1980-81
0.3	31.353	30.187
0.6	20.159	15.906
0.9	14.844	11.363
S.Em \pm	0.063	0.426
C.D. at 5% level	0.184	1.243

The results (Table 4.2) reveal that the $E_T(S)$ value decreases by 41.4 per cent with the increase in soil moisture tension from 0.3 to 0.6 atmosphere (average data). It decreases further by 27.34 per cent when soil moisture tension increases from 0.6 to 0.9 atmosphere.

The reasons for decrease in evapotranspiration with the increase in soil moisture tension may be explained as follows : The resistance to the flow of water vapour through the soil increases with the increase in soil moisture tension (Ritchi,1971). Since, evapotranspiration is dictated by the evaporative demand of the atmosphere and the internal resistance to the flow of water, the decrease in evapotranspiration with the increase in internal resistance is logical (Maity, 1975). Moreover, the thermal contact coefficient of moist soil is relatively large and more of the net radiation enters into the soil. Since water is available, a large part of radiation is used up in evapotranspiration rather than the heating of the soil. As soil surface begins to dry up, moisture is not conducted fast enough in response to evaporative demand of the atmosphere, the evapotranspiration decreases (Hanks et al.,1968).

4.1.1.3 Nitrogen

The influence of levels of nitrogen on daily evapotranspiration was studied for both the varieties (N. tabacum and N. rustica) during two seasons (1979-80 and 1980-81). Daily evapotranspiration rates as function of days after transplanting have been plotted in Figures 4.18 to 4.20. The relationship indicates that the E_T

1979 - 80

- N₀
- -Δ- - N₁
- N₂
- ▲- N₃

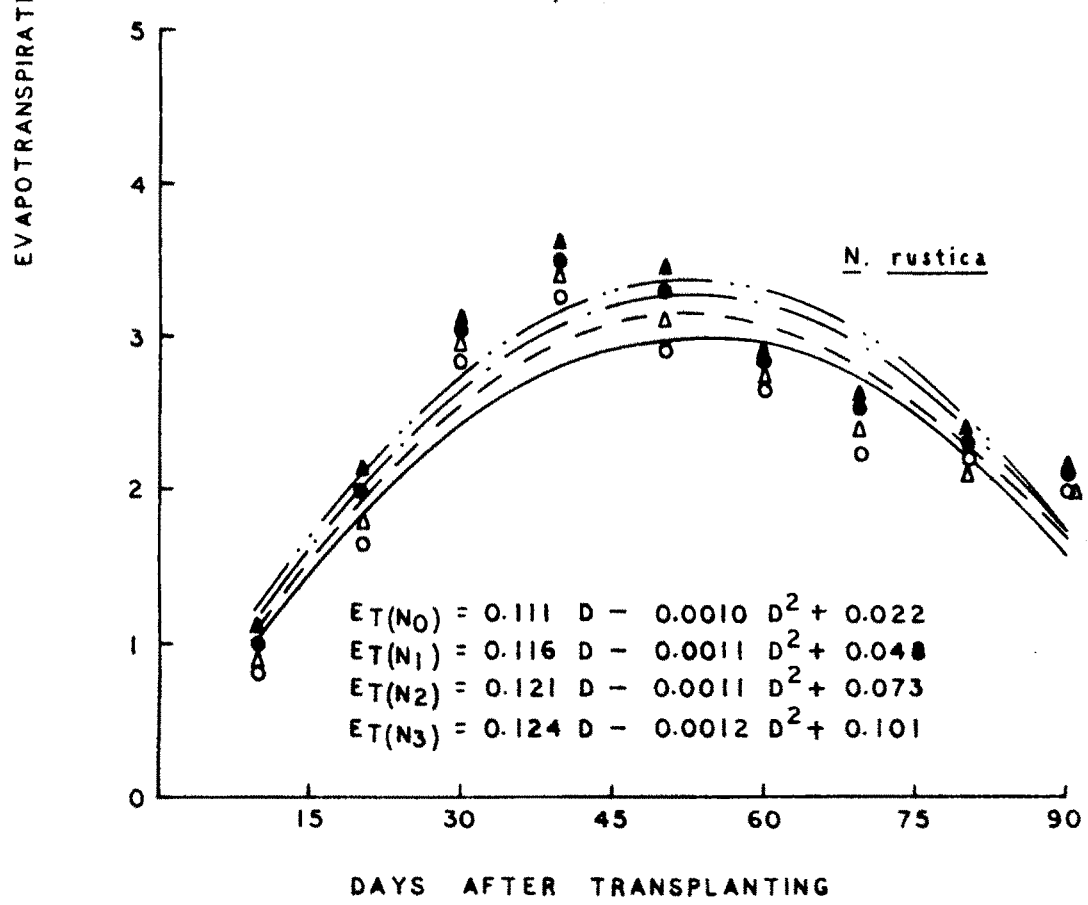
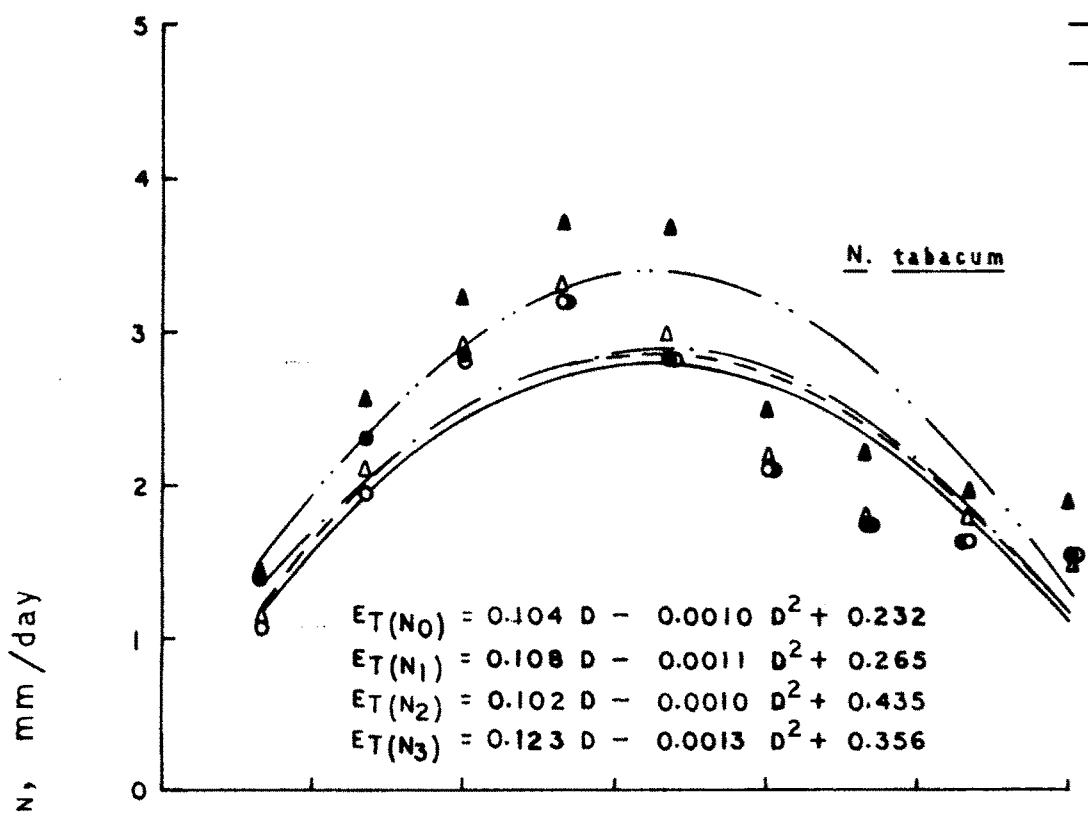


FIG. 4.18 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF DAYS AFTER TRANSPLANTING UNDER DIFFERENT NITROGEN LEVELS

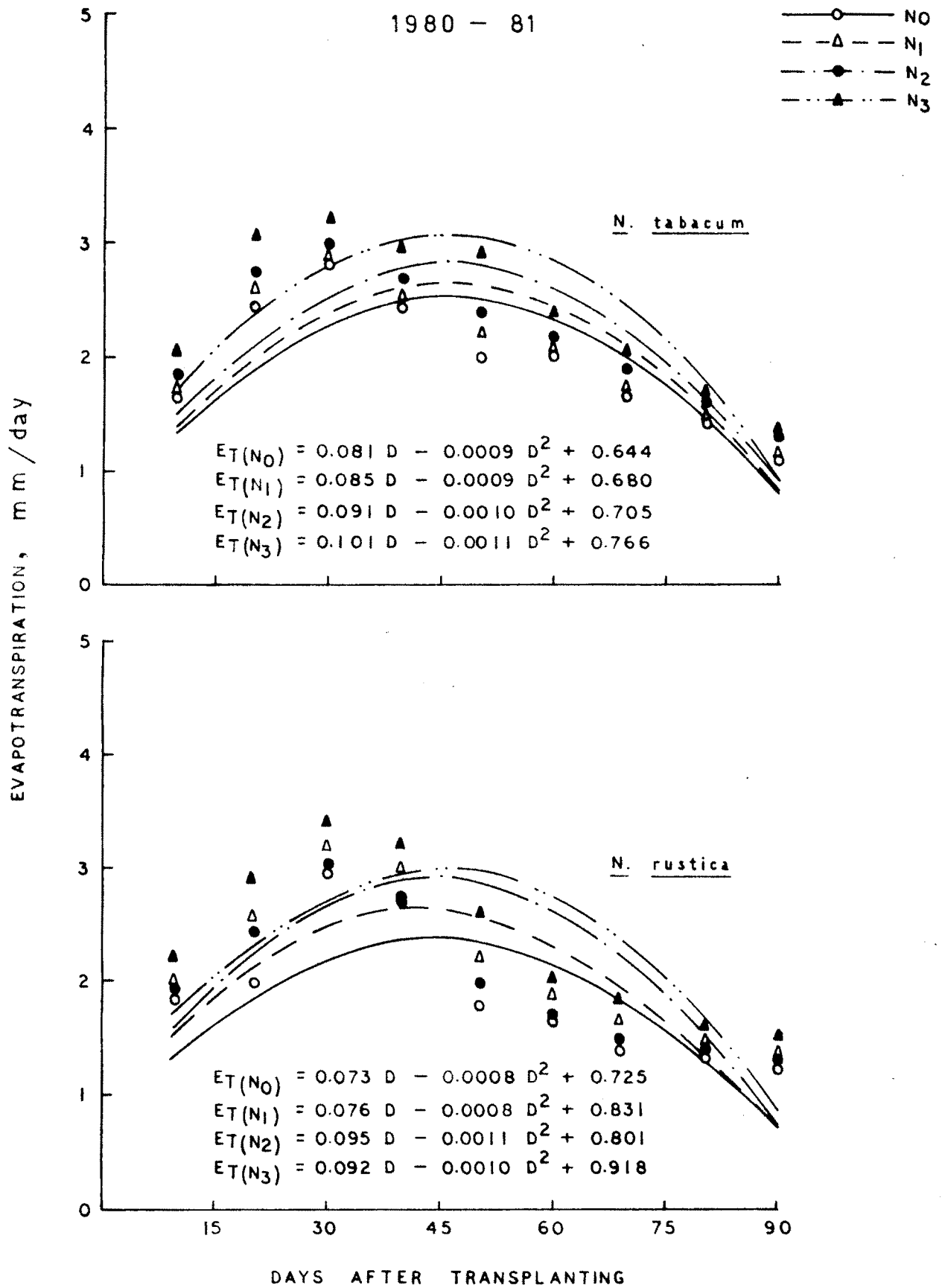


FIG. 4.19 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF DAYS AFTER TRANSPLANTING UNDER DIFFERENT NITROGEN LEVELS

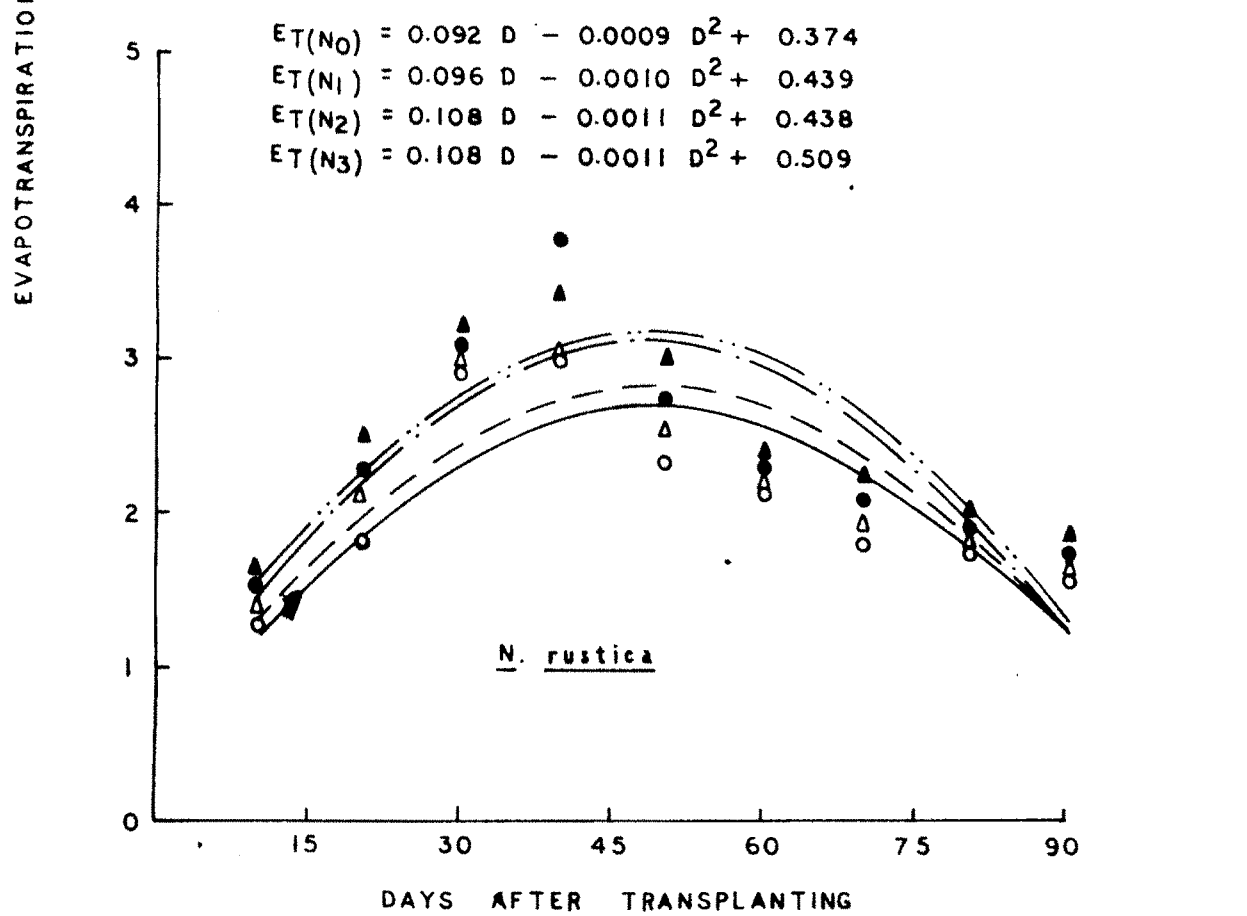
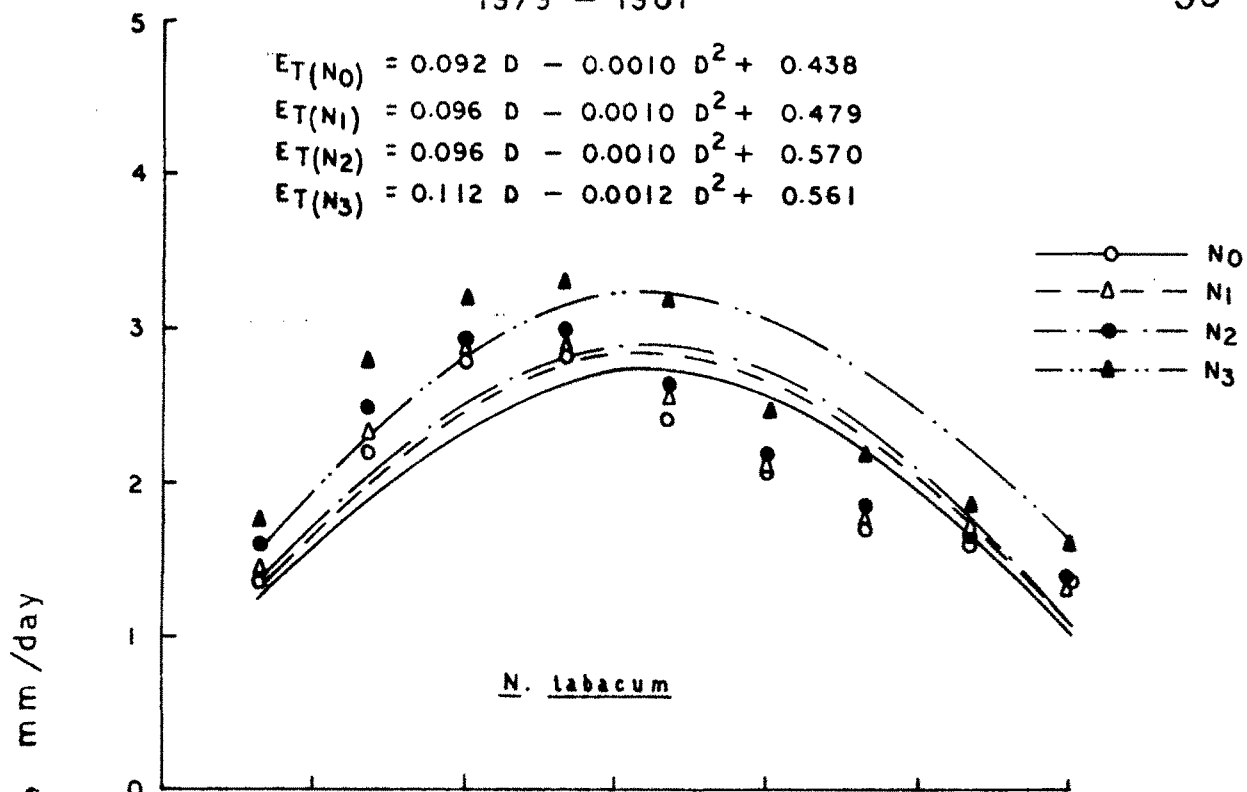


FIG. 4.20 MEAN EVAPOTRANSPIRATION RATE AS A FUNCTION OF DAYS AFTER TRANSPLANTING UNDER DIFFERENT NITROGEN LEVELS DURING TWO SEASONS

increases gradually with the days of growth till it reaches its peak during flowering or a week thereafter and the rate decreases again due to ageing of the crop. The daily rate of change varies with the application of nitrogen and with seasons. The general trend of the curves (Figures 4.18 and 4.19) are similar for both the varieties, but the rate of change of E_T varies with nitrogen application. In general, highest rate is observed throughout the growth period under 120 kg N/ha, the rate decreases with the decrease in applications of nitrogen.

The following equations (Figure 4.20) are derived considering two seasons' data together :

N. tabacum

$$E_T(N_0) = 0.092 D - 0.0010 D^2 + 0.438 \quad (4.35)$$

$$E_T(N_1) = 0.096 D - 0.0010 D^2 + 0.479 \quad (4.36)$$

$$E_T(N_2) = 0.096 D - 0.0010 D^2 + 0.570 \quad (4.37)$$

$$E_T(N_3) = 0.112 D - 0.0012 D^2 + 0.561 \quad (4.38)$$

N. rustica

$$E_T(N_0) = 0.092 D - 0.0009 D^2 + 0.374 \quad (4.39)$$

$$E_T(N_1) = 0.096 D - 0.0010 D^2 + 0.439 \quad (4.40)$$

$$E_T(N_2) = 0.108 D - 0.0011 D^2 + 0.438 \quad (4.41)$$

$$E_T(N_3) = 0.108 D - 0.0011 D^2 + 0.509 \quad (4.42)$$

where,

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

D = Days after transplanting.

The equations (4.35 to 4.42) indicate that at any stage of growth higher evapotranspiration is associated with higher doses of nitrogen indicating the influence of nitrogen on evapotranspiration.

The variation in total E_T under different level of nitrogen (averaged over variety) is given in Table 4.3.

TABLE 4.3 Variation in total evapotranspiration under different level of nitrogen

Nitrogen, kg/ha	Total evapotranspiration, cm	
	1979 - 80	1980 - 81
0	20.783	17.208
40	21.617	17.558
80	22.495	20.117
120	23.579	21.725
S.Em \pm	0.073	0.492
C.D. at 5% level	0.213	1.435

While the total evapotranspiration in both seasons are significantly higher under 120 kg N/ha, it gradually decreases with decrease in nitrogen level. The difference in total evapotranspiration amongst four levels of nitrogen are significant except between 0 and 40 kg nitrogen during 1980-81. Thus total evapotranspiration are found to be increasing with the increasing supply of nitrogen.

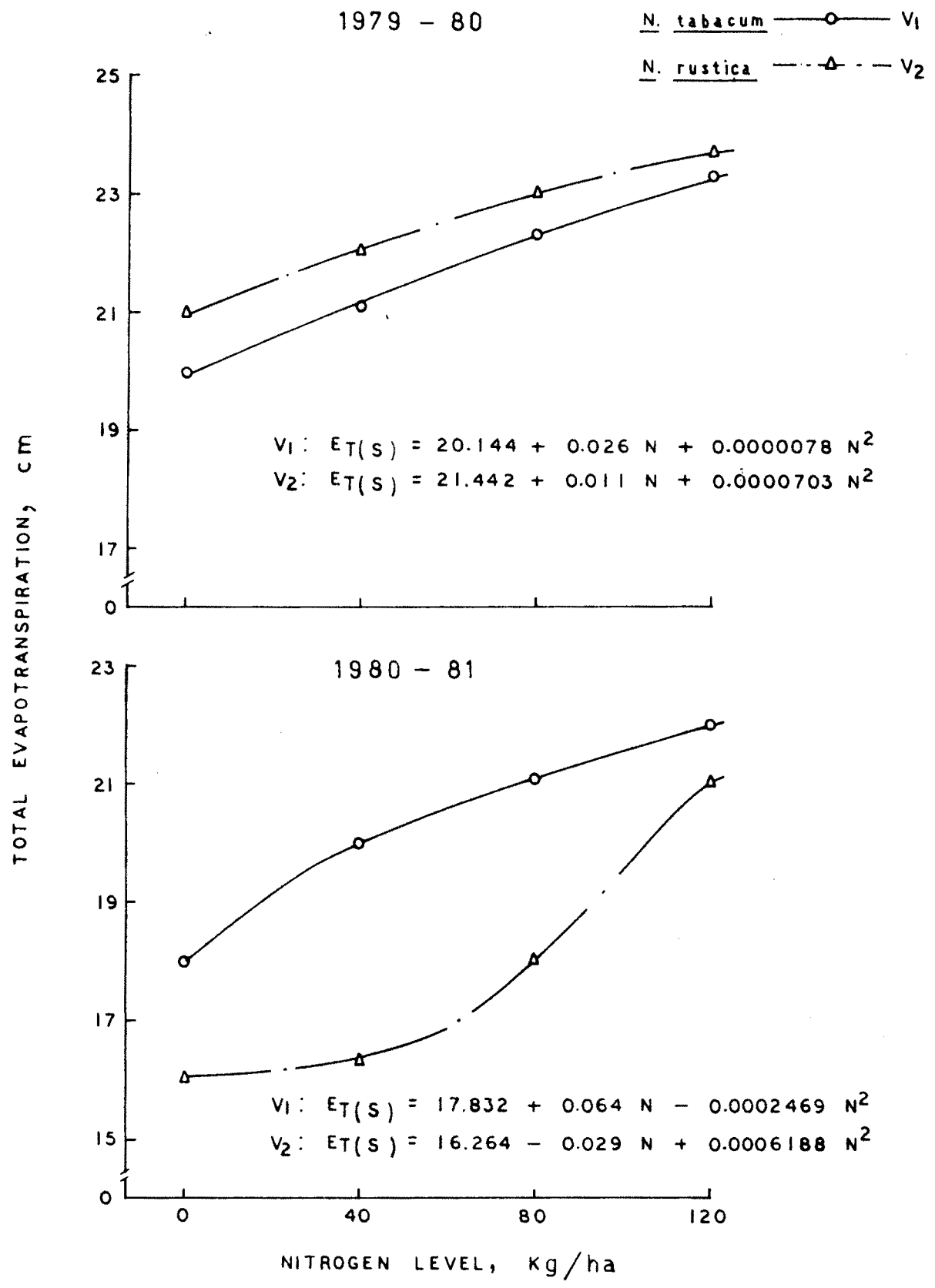


FIG. 4.21 RELATIONSHIP BETWEEN TOTAL EVAPOTRANSPIRATION AND NITROGEN LEVEL

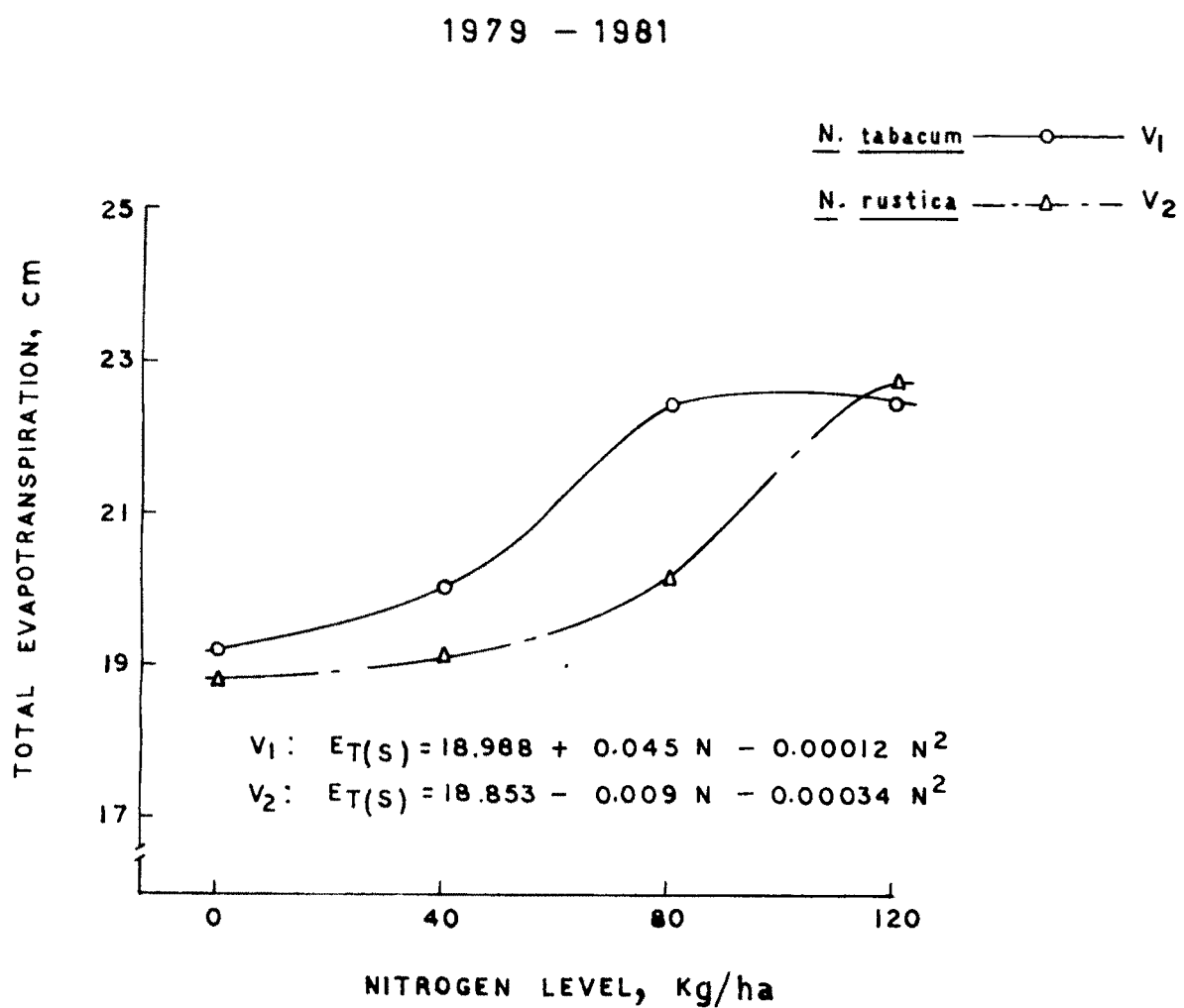


FIG. 4.22 RELATIONSHIP BETWEEN TOTAL EVAPOTRANSPIRATION AND NITROGEN LEVEL DURING TWO SEASONS

The relationship (Figures 4.21 and 4.22) between total evapotranspiration and nitrogen (averaged) may be expressed by the following equations :

N. tabacum

$$E_{T(S)} = 18.988 + 0.045 N - 0.00012 N^2 \quad (4.43)$$

N. rustica

$$E_{T(S)} = 18.853 - 0.009 N + 0.00034 N^2 \quad (4.44)$$

where,

$E_{T(S)}$ = Total evapotranspiration, cm

N = Nitrogen, kg/ha.

Increase in E_T with the increase in ^{nitrogen} application is due to (a) decrease in stomatal resistance (Nagarjah, 1981), (b) influence in vegetative growth (Hunter et al., 1961) and (c) extraction of more soil water from greater depth (Brown, 1971).

4.1.1.4 Interaction

Two seasons' results (Tables 4.4 and 4.5) indicate that at any soil moisture tension, the $E_{T(S)}$ increases with the increase in nitrogen irrespective of variety and season. Similarly at any nitrogen level, the highest $E_{T(S)}$ is at 0.3 atmosphere soil moisture tension irrespective of the variety and season. $E_{T(S)}$ gradually decreases with the increase of soil moisture tension. With the increase of soil moisture tension (a) from 0.3 to 0.6 atmosphere and (b) 0.6 to 0.9 atmosphere, the decrease in $E_{T(S)}$ with levels of nitrogen, varies between 46.64 and 47.56 per cent

TABLE 4.4 Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on total evapotranspiration (cm) during 1979-80

Levels of nitrogen, kg/ha	<u>N. tabacum</u>			<u>N. rustica</u>		
	Soil moisture tension, atm.			Soil moisture tension, atm.		
	0.3	0.6	0.9	0.3	0.6	0.9
0	32.15	16.45	11.75	27.80	21.35	15.20
40	33.40	17.30	13.10	28.10	22.40	15.25
80	34.10	18.15	14.35	29.45	22.57	16.35
120	33.45	19.50	15.25	30.23	23.55	17.50

Average	21.75			22.48		
			S.Em \pm	C.D. at 5%		
Difference between variety and nitrogen :			0.0730	0.2131		
Difference between variety and soil moisture tension :			0.0894	0.2610		
Difference between variety, nitrogen and soil moisture tension:			0.1789	0.5222		

in (a) and that between 19.53 and 33.23 per cent in (b) in respect of N. tabacum (Average data). For N. rustica, corresponding decrease varies between 31.39 and 38.22 per cent in (a) and 24.21 and 31.28 per cent in (b). The varying effects of soil moisture tension and nitrogen on $E_T(s)$ indicate the ability of N. tabacum in using water. The results further reveal that N. rustica had

more $E_T(S)$ at 0.6 and 0.9 atmosphere soil moisture tension at any level of nitrogen (Average data). However, the highest $E_T(S)$ is at 0.3 atmosphere soil moisture tension with 120 kg N/ha for both varieties, and the lowest is at 0.9 atmosphere soil moisture tension with 0 kg N/ha.

TABLE 4.5 Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on total evapotranspiration (cm) during 1980-81

Levels of nitrogen, kg/ha	<u>N. tabacum</u>			<u>N. rustica</u>		
	Soil moisture tension, atm			Soil moisture tension, atm		
	0.3	0.6	0.9	0.3	0.6	0.9
0	29.25	15.75	9.75	26.35	12.10	10.05
40	30.00	16.10	10.10	25.75	13.25	10.15
80	34.70	18.20	14.90	27.70	14.05	11.15
120	34.65	17.90	12.40	33.10	19.90	12.40

Average	20.31			18.00		
				S.Em \pm	C.D. at 5%	
Difference between variety and nitrogen :				0.4915	1.4347	

The higher $E_T(S)$ at 0.3 atmosphere soil moisture tension with 120 kg N/ha is due to lower resistance to the flow of water and better vegetative growth of the crop.

4.1.1.5 Crop

Of the different crop characters influencing the evapotranspiration rate, only leaf area index has been considered.

4.1.1.5.1 Leaf area index

For both varieties leaf area index (LAI) was measured at 30, 60 and 90 days after transplanting during both seasons under soil moisture tension and nitrogen.

Relationship between E_T and LAI averaged over seasons and soil moisture tension (Figure 4.23) indicate that E_T increases with the increase of LAI, the maximum limit of which varies with soil moisture tensions and levels of nitrogen under both the varieties.

The relationship (Figure 4.23) between E_T and LAI averaged over seasons and soil moisture tensions may be expressed by the equations :

N. tabacum

$$E_{T(M)} = 0.91 + 2.17 (LAI) - 0.58 (LAI)^2 \quad (4.45)$$

N. rustica

$$E_{T(M)} = 1.19 + 2.35 (LAI) - 0.72 (LAI)^2 \quad (4.46)$$

where,

E_T = Evapotranspiration, mm/day, subscripts M indicate the soil moisture tension, atmosphere.

LAI = Leaf area index.

Similarly, the relationship (Figure 4.24) between E_T and

1979 - 1981

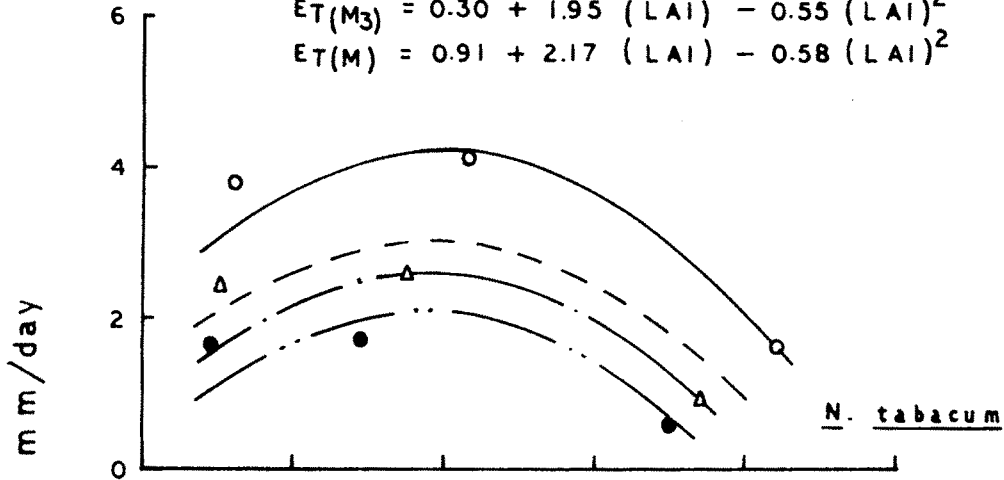
- M₁
- △-·- M₂
- M₃
- - - M

$$ET(M_1) = 1.20 + 3.05 (LAI) - 0.75 (LAI)^2$$

$$ET(M_2) = 1.20 + 1.55 (LAI) - 0.45 (LAI)^2$$

$$ET(M_3) = 0.30 + 1.95 (LAI) - 0.55 (LAI)^2$$

$$ET(M) = 0.91 + 2.17 (LAI) - 0.58 (LAI)^2$$



$$ET(M_1) = 2.40 + 2.00 (LAI) - 0.60 (LAI)^2$$

$$ET(M_2) = 0.90 + 2.75 (LAI) - 0.85 (LAI)^2$$

$$ET(M_3) = 0.30 + 2.30 (LAI) - 0.70 (LAI)^2$$

$$ET(M) = 1.19 + 2.35 (LAI) - 0.72 (LAI)^2$$

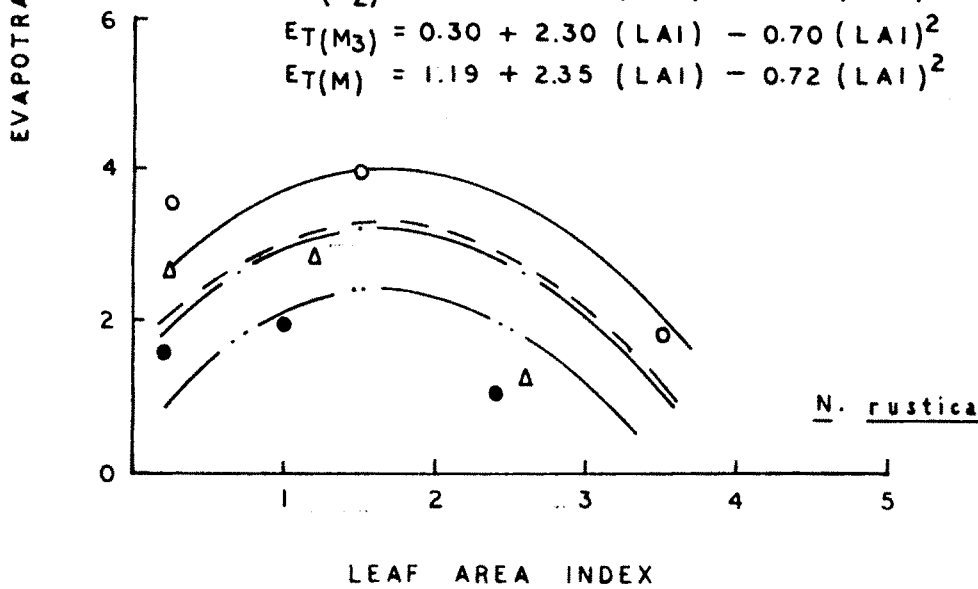


FIG. 4.23 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND LEAF AREA INDEX UNDER DIFFERENT SOIL MOISTURE TENSION DURING TWO SEASONS

1979 - 1981

- N₀
- △--- N₁
- ▲--- N₂
- N₃
- N

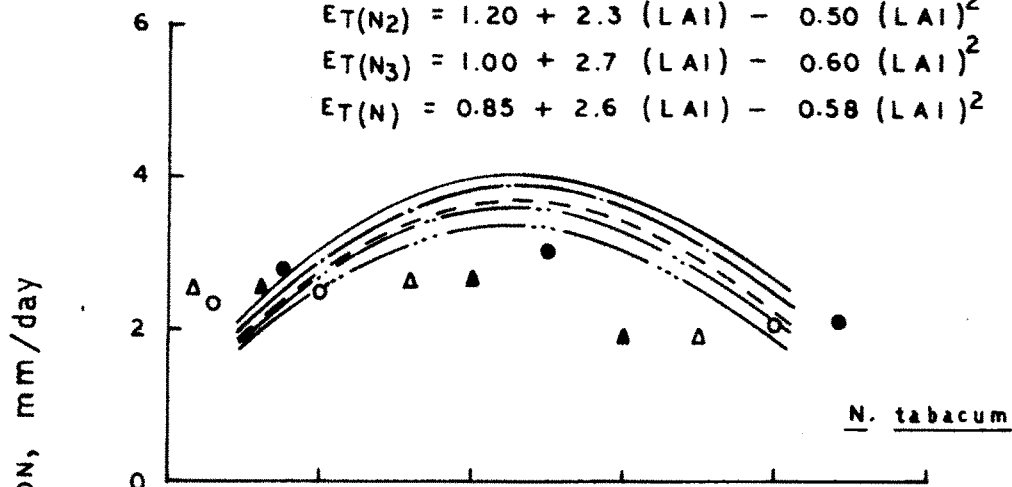
$$ET(N_0) = 0.60 + 2.6 (LAI) - 0.60 (LAI)^2$$

$$ET(N_1) = 0.60 + 2.7 (LAI) - 0.60 (LAI)^2$$

$$ET(N_2) = 1.20 + 2.3 (LAI) - 0.50 (LAI)^2$$

$$ET(N_3) = 1.00 + 2.7 (LAI) - 0.60 (LAI)^2$$

$$ET(N) = 0.85 + 2.6 (LAI) - 0.58 (LAI)^2$$



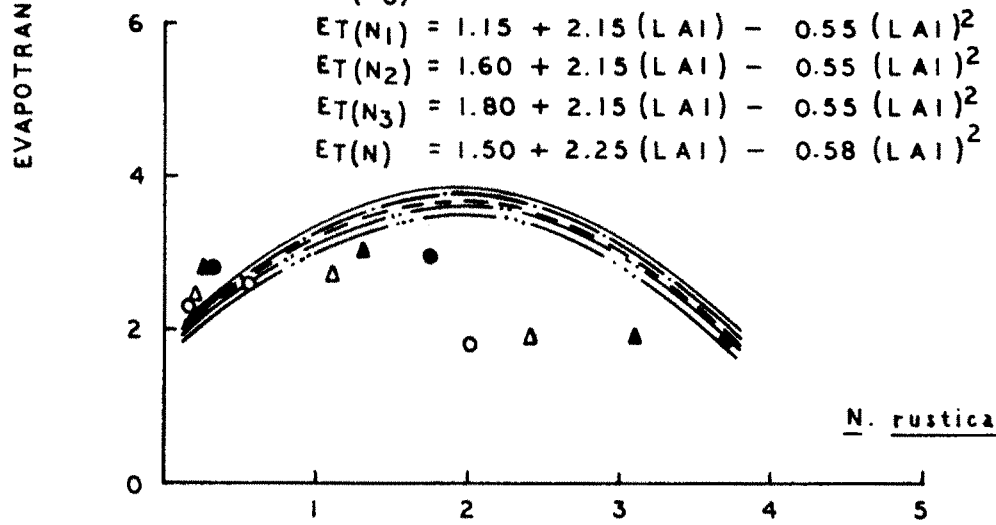
$$ET(N_0) = 1.10 + 2.55 (LAI) - 0.65 (LAI)^2$$

$$ET(N_1) = 1.15 + 2.15 (LAI) - 0.55 (LAI)^2$$

$$ET(N_2) = 1.60 + 2.15 (LAI) - 0.55 (LAI)^2$$

$$ET(N_3) = 1.80 + 2.15 (LAI) - 0.55 (LAI)^2$$

$$ET(N) = 1.50 + 2.25 (LAI) - 0.58 (LAI)^2$$



LEAF AREA INDEX

FIG. 4.24 RELATIONSHIP BETWEEN EVAPOTRANSPIRATION RATE AND LEAF AREA INDEX UNDER DIFFERENT NITROGEN LEVEL DURING TWO SEASONS

averaged over seasons and nitrogen may be expressed as follows :

N. tabacum

$$E_T(N) = 0.85 + 2.58 (LAI) - 0.58 (LAI)^2 \quad (4.47)$$

N. rustica

$$E_T(N) = 1.50 + 2.25 (LAI) - 0.58 (LAI)^2 \quad (4.48)$$

where,

E_T = Evapotranspiration rate, mm/day, subscripts N indicate levels of nitrogen

LAI = Leaf area index.

The equations indicate that for maximum E_T , the maximum LAI value is 1.870 for N. tabacum, while it is 1.63 for N. rustica.

The reason for increase in E_T with the LAI is due to greater interception of radiation (Penman et al., 1967). For maximum E_T , the LAI values vary with soil moisture tension mainly because water is freely available to plant roots (Nagawiecka and Boron, 1974). With further increase in LAI, the effective area for intercepting radiation does not increase because of natural shading and E_T actually decreases due to ageing of the crop.

4.2 Comparison Between Evapotranspiration and Pan Evaporation

4.2.1 Soil moisture tension

The relationship between evapotranspiration (E_T) and Pan evaporation (E_0) has been considered in terms of their ratio and presented in Table 4.6. It is observed that lowest ratio is

TABLE 4.6 Variation in T_m/T_0 under different soil moisture tension and nitrogen

Average of 1979-80 and 1980-81	<u>M. tabacum</u>				<u>M. rustica</u>			
	Soil moisture tension, atm.				Soil moisture tension, atm.			
	0.3	0.6	0.9	Mean	0.3	0.6	0.9	Mean
Ist fortnight	0.5275	0.2326	0.2303	0.3468	0.4649	0.2829	0.1817	0.3098
2nd fortnight	1.2669	0.7032	0.5468	0.8390	1.1340	0.7813	0.4664	0.7939
3rd fortnight	1.8033	1.0101	0.7371	1.1837	1.6421	1.1448	0.7160	1.1676
4th fortnight	1.5838	0.9029	0.6256	1.0374	1.4450	0.9993	0.6430	1.0291
5th fortnight	1.4794	0.7987	0.5301	0.9361	1.2962	0.8694	0.5559	0.9075
6th fortnight	0.8902	0.4720	0.4507	0.6010	0.8534	0.5924	0.4027	0.6162
Mean	1.2569	0.6949	0.5201	0.9240	1.1392	0.7734	0.4945	0.8040

	<u>M. tabacum</u>				<u>M. rustica</u>			
	Nitrogen, kg/ha				Nitrogen, kg/ha			
	0	40	80	120	0	40	80	120
Ist fortnight	0.4532	0.4792	0.5107	0.5769	0.4298	0.4665	0.5032	0.5280
2nd fortnight	0.8013	0.8432	0.8718	0.9798	0.7817	0.8344	0.9119	0.9591
3rd fortnight	1.0837	1.1372	1.0929	1.3184	1.0723	1.1370	1.2469	1.2772
4th fortnight	0.9203	0.9531	0.9755	1.1128	0.9879	0.9788	1.0677	1.0944
5th fortnight	0.7858	0.9199	0.8357	0.9454	0.9219	0.8333	0.9102	0.9392
6th fortnight	0.4653	0.4806	0.4721	0.5463	0.5036	0.5386	0.5659	0.5810
Mean	0.7516	0.7872	0.7931	0.9133	0.7670	0.7934	0.8676	0.8933

associated with 0.9 atmosphere irrespective of varieties. The ratio gradually increases with the decrease in soil moisture tension mainly due to higher E_T under lower soil moisture tension. It is also observed that the ratio gradually increases with age, irrespective of the varieties and the maximum is during January to February (3rd and 4th Fortnight). The ratio decreases then due to (1) ageing of the crop (2) increase of E_0 during later part of crop season.

4.2.2 Nitrogen

The relationship between E_T and E_0 has been considered in terms of their ratio under nitrogen (Table 4.6). While the lowest ratio is always associated with 0 kg N/ha application, the highest ratio is with 120 kg N/ha in both the varieties. The ratio gradually increases with the increase in doses of nitrogen in both the varieties. The highest ratio is also observed during the 3rd fortnight of the crop growth in both the varieties. The ratio then decreased due to (a) ageing of the crop (b) increase of E_0 during the latter part of the crop season.

The average seasonal co-efficient (Table 4.6) can be used in estimating E_T for both varieties of tobacco.

4.3 Growth Characters

Knowledge of growth and development of different parameters under different soil moisture tensions and levels of nitrogen are very important. As an attempt to evaluate the proper utilization

of water and fertilizer by the crop, the following growth characters at different stages of growth period are considered.

4.3.1 Height of plants

Since the height of tobacco plant influences to a great extent on the ultimate yield, the mean height of plants for both the varieties at different stages of growth were recorded under different soil moisture tensions and nitrogen levels.

4.3.1.1 Variety

The height of plants during two seasons increased with the number of days after transplanting in both the varieties. The relationship between height and days after transplanting indicate different rates of increase in two varieties in two seasons (Figures 4.25 and 4.26). It is observed (Table 4.7) that the plant height at 30 days after transplanting does not differ significantly during 1979-80. In 1980-81, significantly higher height is observed in N. rustica. At 60 days after transplanting, the plant height of N. rustica is greater over N. tabacum. But in the ultimate phase (90 days after transplanting) in both seasons, N. tabacum has developed maximum height and it is taller (9.64 and 44.75 per cent more in 1979-80 and 1980-81 respectively). The higher height in N. tabacum is probably due to its character.

The following equations have been developed considering two seasons average data to express the relationship between height and days after transplanting for two varieties (Figures 4.25 and 4.26).

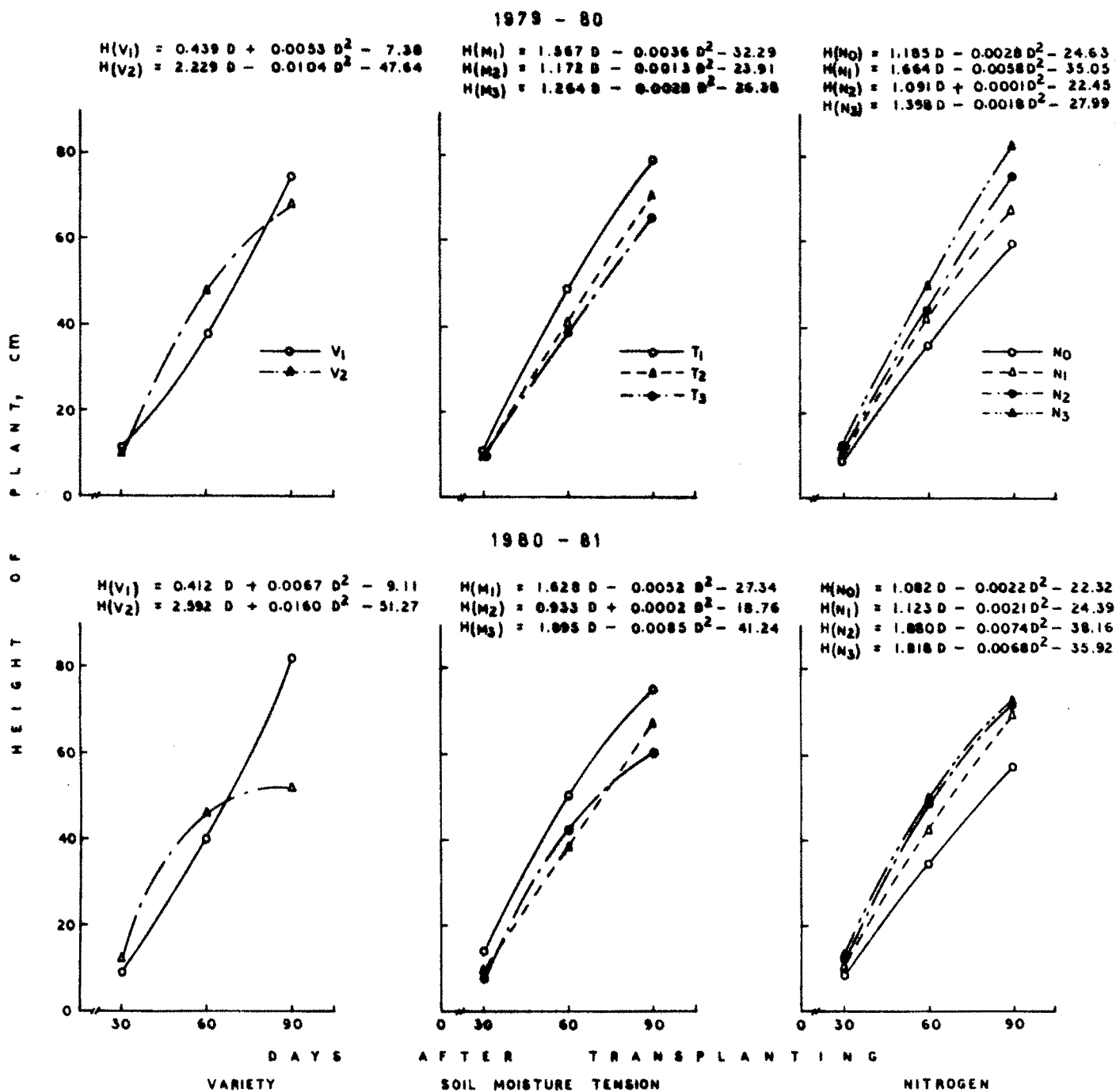


FIG. 4.25 RELATIONSHIP BETWEEN HEIGHT OF PLANT AND DAYS AFTER TRANSPLANTING UNDER DIFFERENT VARIETY, SOIL MOISTURE TENSION AND NITROGEN LEVELS

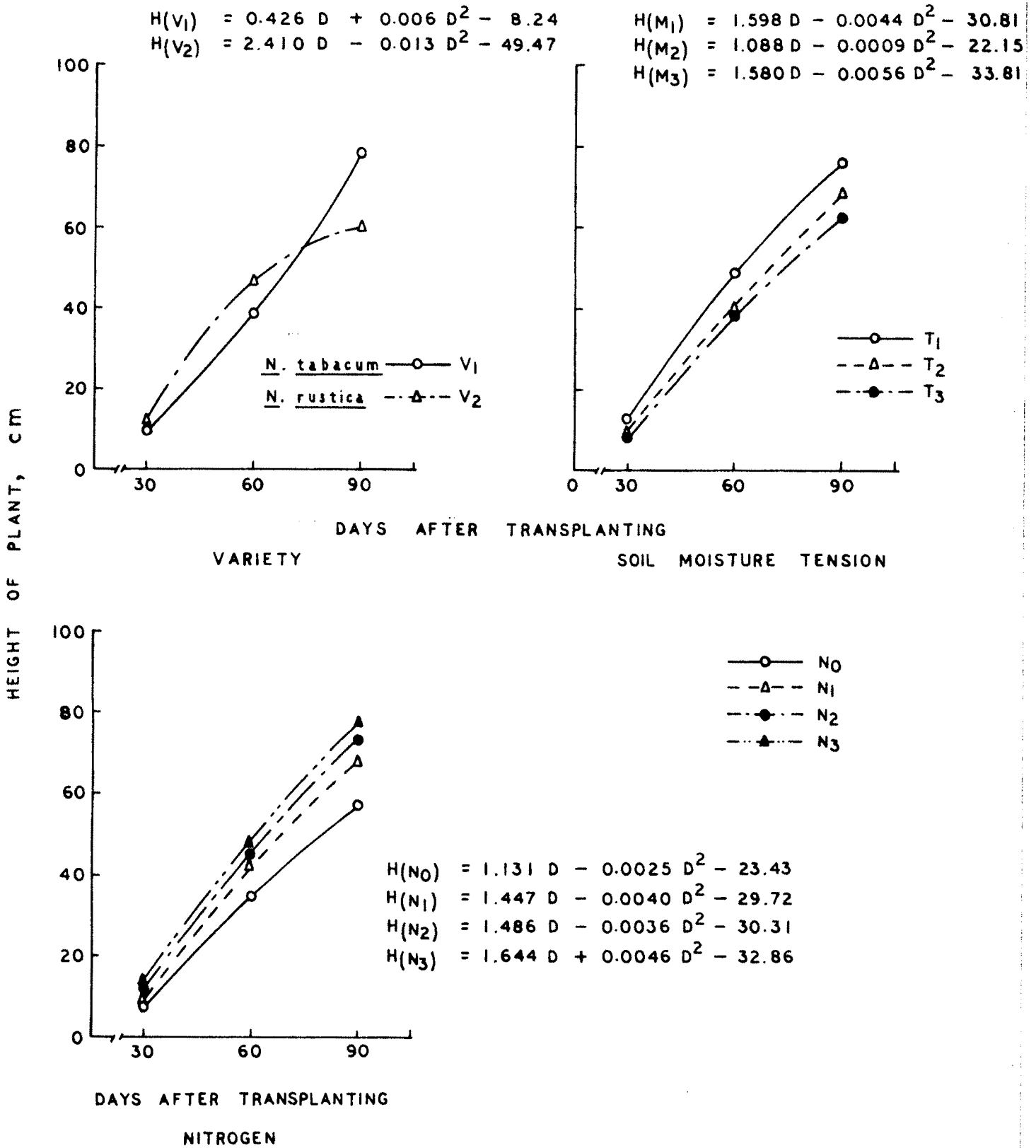


FIG. 4.26 RELATIONSHIP BETWEEN HEIGHT OF PLANT AND DAYS AFTER TRANSPLANTING UNDER DIFFERENT VARIETY, SOIL MOISTURE TENSION AND NITROGEN LEVELS DURING TWO SEASONS

TABLE 4.7 Variation in plant height under different soil moisture tension and nitrogen level

	Plant height cm					
	30 DAT		60 DAT		90 DAT	
	1979-80	1980-81	1979-80	1980-81	1979-80	1980-81
Variety						
V ₁	10.55	9.31	37.99	39.84	74.94	82.48
V ₂	9.81	12.07	48.48	46.57	68.35	52.23
S.E.m ±	0.39	0.66	1.95	1.24	2.17	2.20
C.D. at 5%	N.S.	1.93	5.70	3.62	6.32	6.42
Soil moisture tension, atmosphere						
0.3	11.44	14.82	48.61	49.60	79.22	75.00
0.6	10.04	9.29	41.57	38.20	70.69	66.72
0.9	9.06	7.95	39.53	41.81	65.03	60.34
S.E.m ±	0.49	0.81	2.39	1.52	2.65	2.69
C.D. at 5%	1.43	2.36	6.98	4.44	7.74	7.85
Nitrogen, kg/ha						
0	8.37	8.13	36.20	34.57	58.96	57.00
40	9.63	10.55	43.80	41.64	67.46	68.88
80	10.37	11.60	43.38	48.07	76.58	71.25
120	12.37	12.47	49.56	48.54	83.58	72.29
S.E.m ±	0.56	0.94	2.76	1.75	3.06	3.11
C.D. at 5%	1.63	2.74	8.06	5.11	8.94	9.08

V₁ = N. tabacum

V₂ = N. rustica

DAT = Days after transplanting.

$$H_{V_1} = 0.426 D + 0.006 D^2 - 8.24 \quad (4.49)$$

$$H_{V_2} = 2.410 D - 0.013 D^2 - 49.47 \quad (4.50)$$

where,

H = Plant height, cm and subscripts V_1 and V_2 represent varieties.

D = Days after transplanting.

These equations (4.49 and 4.50) can be used in predicting the height at any stage of growth.

4.3.1.2 Soil moisture tension

The height of plants, irrespective of varieties, increases with the days of growth after transplanting under all tensions (Figures 4.25 and 4.26). The relationship between height and days after transplanting (Figures 4.25 and 4.26) indicate the rate of change in height with days and soil moisture tension. While the maximum heights are under 0.3 atmosphere soil moisture tension in both the seasons, the lowest heights are under 0.9 atmosphere soil moisture tension. The height decreases with the increase in soil moisture tension. With the increase in soil moisture tension from (a) 0.3 to 0.6 atmosphere and (b) 0.6 to 0.9 atmosphere the average heights decrease by 26.35, 18.77, 10.90 per cent in (a) and 12.0, 1.96, 8.76 per cent in (b) under 30, 60 and 90 days after transplanting respectively (Table 4.7). The reduction in height is due to the soil moisture stress (Kozlowski, 1964). Similar observations in respect of wheat were made by Slatyer (1957) and Ghosh (1974). Reduction in plant height of

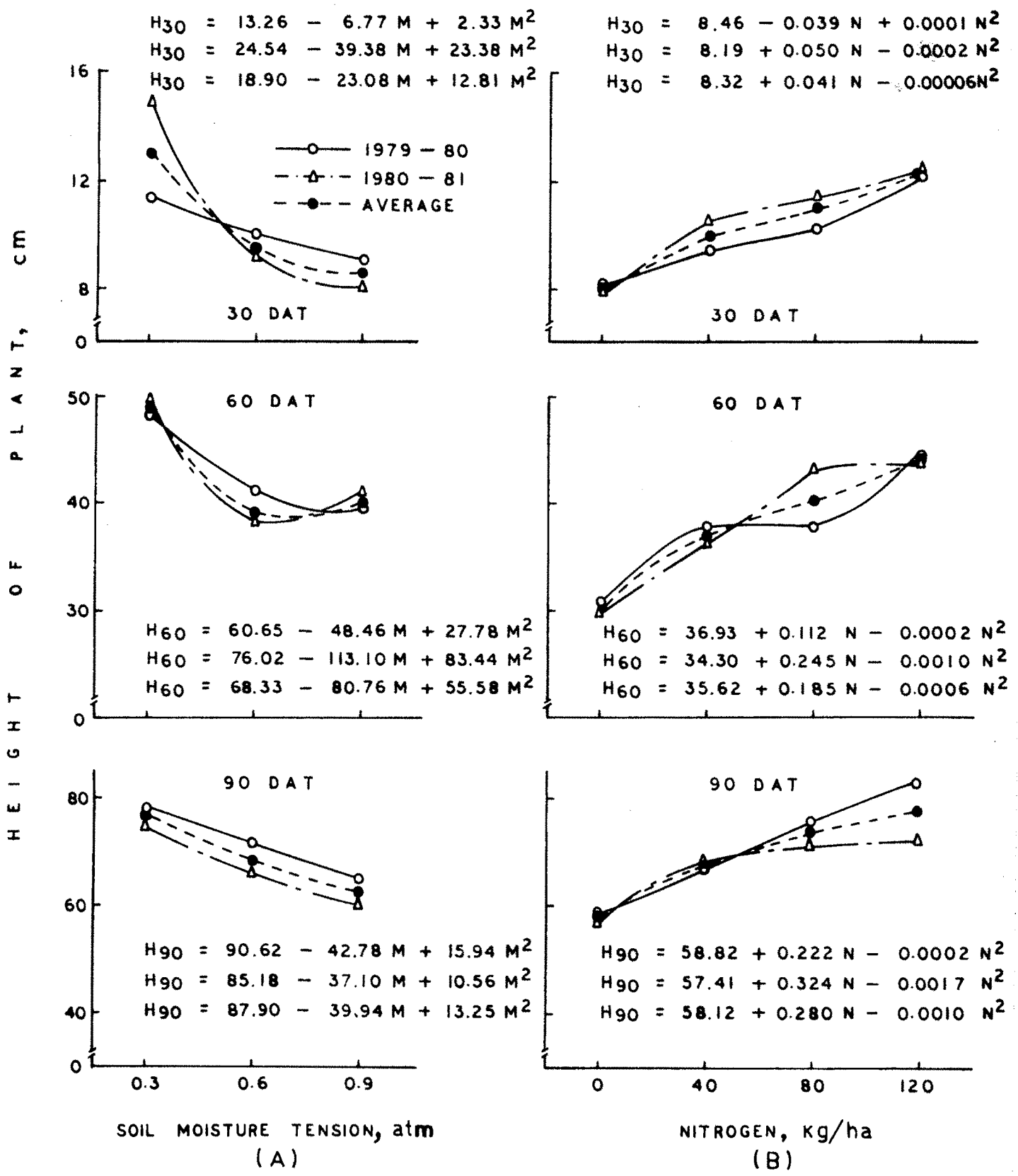


FIG. 4.27 RELATIONSHIP BETWEEN HEIGHT OF PLANT AND (A) SOIL MOISTURE TENSION, (B) NITROGEN

tobacco due to increase in soil moisture tension was observed by Takahashi et al. (1976) and Liu (1977).

The following equations have been developed considering two seasons' average data to express the relationship between height and soil moisture tension (Figure 4.27) at different stages of development.

$$H_{30} = 18.90 - 23.08 M + 12.81 M^2 \quad (4.51)$$

$$H_{60} = 68.33 - 80.76 M + 55.58 M^2 \quad (4.52)$$

$$H_{90} = 87.90 - 39.94 M + 13.25 M^2 \quad (4.53)$$

where,

H = Height of plant, cm and subscripts 30, 60 and 90 indicate the days after transplanting

M = Soil moisture tension, atmosphere.

4.3.1.3 Nitrogen

The effect of different nitrogen levels on the height attained by tobacco plants are shown in Table 4.7. While the maximum height was attained by the plants which received the highest dose of nitrogen (120 kg N/ha) throughout the growth period in both seasons, the height decreased progressively with the decrease in application of nitrogen with minimum height at 0 kg N/ha. The maximum height was recorded at 90 days after transplanting under 120 kg N/ha during 1979-80. With the increase in nitrogen level from 0 kg/ha to 120 kg/ha, the average height increases by 50.55, 38.62 and 34.42 per cent under 30, 60 and 90 days after transplanting respectively.

The following equations have been developed considering two

seasons average data to express the relationship between height and nitrogen level (Figure 4.27) at different stages of development.

$$H_{30} = 8.32 + 0.041 N - 0.00006 N^2 \quad (4.54)$$

$$H_{60} = 35.62 + 0.185 N - 0.0006 N^2 \quad (4.55)$$

$$H_{90} = 58.12 + 0.280 N - 0.0010 N^2 \quad (4.56)$$

where,

H = Plant height, cm and subscripts 30, 60 and 90 indicate the days after transplanting

N = Nitrogen level, kg/ha.

The relationship between height of plants with the days after transplanting are shown in Figures 4.25 and 4.26. With the increase of days after transplanting the plant height increases in a non-linear manner.

Similar observation in respect of increase in height due to increased application of nitrogen was made by Matar (1977) for tobacco, Pande et al. (1973) for paddy crop and Sandhu and Gill (1972) for wheat crop.

4.3.1.4 Interaction

The results (Table 4.8) indicate that at any nitrogen level, plant height, in general, is highest at 0.3 atmosphere soil moisture tension for both varieties, though the height varies with the variety. Results further reveal that the decrease in height with the increase in soil moisture tension (a) from 0.3 to 0.6 atmosphere and (b) from 0.6 to 0.9 atmosphere varies

between 7.06 and 25.53 per cent in (a) and that between 7.02 to 33.33 per cent in (b) in respect of N. tabacum . For the variety N. rustica the corresponding decrease varies between 10.44 to 14.07 per cent in (a) and between 7.07 and 13.07 per cent in (b).

TABLE 4.8 Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on plant height (cm) during the season 1979-80 (90 days after transplanting)

Levels of nitrogen, kg/ha	<u>N. tabacum</u>			<u>N. rustica</u>		
	Soil moisture tension, atm.			Soil moisture tension, atm.		
	0.3	0.6	0.9	0.3	0.6	0.9
0	70.50	52.50	47.00	67.50	58.00	58.25
40	75.25	80.00	53.00	64.00	64.75	67.75
80	92.00	85.50	72.25	74.25	66.50	69.00
120	105.75	87.75	77.75	84.50	70.50	75.25
Average	74.94			68.35		
				S.Em ±		C.D. at 5%
Difference between variety and soil moisture tension :				3.7498		10.9455

It is also observed that under 40 kg N/ha, the height increases slightly.

Results (Table 4.9) indicate that at any soil moisture tension the plant height increases with the increase in nitrogen levels irrespective of variety except that at 0.9 atmosphere with 120 kg N/ha for N. tabacum . It is also observed that upto 60 days

TABLE 4.9 Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on plant height (cm) during the season 1980-81

(60 days after transplanting)

Levels of nitrogen, kg/ha	<u>N. tabacum</u>			<u>N. rustica</u>		
	Soil moisture tension, atm.			Soil moisture tension, atm.		
	0.3	0.6	0.9	0.3	0.6	0.9
0	22.98	25.32	33.16	46.00	41.45	38.50
40	44.82	33.67	32.83	47.80	40.80	49.95
80	59.67	34.50	51.00	53.55	51.20	39.00
120	67.67	39.50	33.47	54.80	39.20	56.60

Average	39.88			46.57		
				S.Em ±	C.D. at 5%	
Difference between variety and nitrogen :				1.7531	5.1172	
Difference between variety, nitrogen and soil moisture tension :				4.2942	12.5344	

after transplanting the rate of increase in height for N. rustica is much faster but at the end stage the height of N. tabacum exceeds N. rustica. The reason for the variation in increase in height is probably due to the varietal character.

4.3.2 Diameter of plant

The diameter of the plant influences the yield to a great extent. The average diameter for both the varieties were recorded during the growth period under different soil moisture tension and nitrogen level.

4.3.2.1 Variety

The diameter of plants increased with the days after transplanting for both the varieties. The diameter of plant varied significantly at 30 days after transplanting in both the seasons as well as at 60 days after transplanting during 1979-80 only. But at the subsequent stage, the diameter of plants did not vary significantly. At 30 days after transplanting, the diameter of plant is higher in case of N. rustica. However, there is no remarkable difference in diameter between the varieties (Table 4.10) towards the final stage of maturity of the crop.

4.3.2.2 Soil moisture tension

The average diameter of plant increases at varying degrees throughout the growth period in both the seasons. The diameter of the plants increases significantly with the decrease in soil moisture tension with the maximum at 0.3 atmosphere, for both the seasons throughout the growth period (Table 4.10). The decrease in per cent of diameter with the increase in soil moisture tension from (a) 0.3 to 0.6 and (b) 0.6 to 0.9 atmosphere is 16.91, 7.96 and 9.02 at (a) and 2.06, 4.61 and 8.09 at (b) under 30, 60 and 90 days after transplanting respectively.

4.3.2.3 Nitrogen

Nitrogen has a significant bearing on the diameter of the plant. The increased rate of nitrogen application causes a significant increase in the diameter of the plant throughout the growth period in both the seasons (Table 4.10). Irrespective of seasons, the higher diameter of plant is always associated

TABLE 4.10 Variation in plant diameter under different soil moisture tension and nitrogen level

	Diameter of plant, cm					
	30 DAT		60 DAT		90 DAT	
	1979-80	1980-81	1979-80	1980-81	1979-80	1980-81
Variety						
V ₁	0.796	1.219	1.640	2.109	2.020	2.306
V ₂	1.371	1.334	1.788	2.103	1.948	2.227
S.E.m ±	0.026	0.026	0.050	0.031	0.046	0.042
C.D.at 5%	0.075	0.076	0.146	N.S.	N.S.	N.S.
Soil moisture tension, atm.						
0.3	1.191	1.477	1.878	2.229	2.178	2.466
0.6	1.053	1.177	1.716	2.074	1.966	2.259
0.9	1.006	1.178	1.547	2.068	1.808	2.075
S.E.m ±	0.032	0.032	0.061	0.038	0.056	0.058
C.D.at 5%	0.092	0.093	0.179	0.110	0.163	0.168
Nitrogen, kg/ha						
0	0.895	1.177	1.476	1.776	1.746	1.954
40	1.133	1.242	1.654	2.122	1.948	2.146
80	1.071	1.326	1.742	2.225	2.063	2.396
120	1.233	1.364	1.983	2.304	2.179	2.571
S.E.m ±	0.037	0.037	0.071	0.043	0.064	0.059
C.D.at 5%	0.107	0.107	0.207	0.127	0.188	0.175

with higher doses of nitrogen. The maximum diameter of the plant is under 120 kg N/ha at 90 days after transplanting during 1980-81 and is 2.571 cm. The increase in diameters at 120 kg N/ha over 0 kg N/ha at 30, 60 and 90 days after transplanting are 25.33, 31.86 and 28.38 per cent respectively.

4.3.2.4 Interaction

Two seasons results (Table 4.11) indicate that highest and lowest plant diameters for both varieties are at 0.3 atmosphere soil moisture tension with 120 kg N/ha and at 0.9 atmosphere soil moisture tension with 0 kg N/ha respectively.

It is also observed that, in general, diameter decreases with the increase in soil moisture tension at any level of nitrogen. The decrease in diameter due to increase in soil moisture tension from 0.3 to 0.6 atmosphere is 12.64, 16.39, 17.05 and 29.56 per cent at 0, 40, 80 and 120 kg N/ha respectively for variety N. tabacum (average data). The corresponding decrease in diameter for N. rustica is 5.90, 24.50, 1.13 and 20.06 per cent at 0, 40, 80 and 120 kg N/ha respectively. It is, therefore, evident that highest decrease in diameter for both varieties is at 120 kg N/ha with increase of soil moisture tension from 0.3 to 0.6 atmosphere.

4.3.3 Green weight of plant

The green weight (kg m^{-2}) of tobacco plants ultimately influenced the yield. The green weights (kg m^{-2}) for both the varieties were recorded at different stages of growth under different soil moisture tension and nitrogen level and are

TABLE 4.11 Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on the plant diameter (cm) at 30 days after transplanting

1979-80

Levels of nitrogen, kg/ha	<u>N. tabacum</u>			<u>N. rustica</u>		
	Soil moisture tension, atm.			Soil moisture tension, atm.		
	0.3	0.6	0.9	0.3	0.6	0.9
0	0.800	0.775	0.550	1.150	1.025	1.075
40	0.800	0.775	0.725	1.700	1.275	1.525
80	0.800	0.800	0.725	1.400	1.375	1.325
120	1.200	0.850	0.750	1.675	1.550	1.375
Average	0.7958			1.3708		
	S.E.M ±			C.D. at 5%		
Difference between variety and nitrogen :	0.0365			0.1066		

1980-81

Levels of nitrogen, kg/ha	<u>N. tabacum</u>			<u>N. rustica</u>		
	Soil moisture tension, atm.			Soil moisture tension, atm.		
	0.3	0.6	0.9	0.3	0.6	0.9
0	1.375	1.125	0.963	1.188	1.175	1.237
40	1.488	1.138	0.963	1.463	1.113	1.287
80	1.475	1.087	1.137	1.525	1.517	1.213
120	1.675	1.175	1.037	1.625	1.088	1.583
Average	1.2200			1.3340		
	S.E.M ±			C.D. at 5%		
Difference between variety and soil moisture tension :	0.0449			0.1310		
Difference between variety, nitrogen & soil moisture tension :	0.0897			0.2619		

presented in Table 4.12.

4.3.3.1 Variety

The green weight (Table 4.12) of plant increases with the number of days after transplanting for both the varieties. The green weight of the plant varies significantly at 30 and 60 days after transplanting during both the seasons. At the mid-stage of growth period (60 days after transplanting), there is no significant difference in green weight between the two varieties in both the seasons. It may be due to the rapid development of the plant at this stage. It is interesting to note that the green weight of N. tabacum is higher over N. rustica at the early and later stages of development with the exception at mid-stage of development in both the seasons (Table 4.12).

4.3.3.2 Soil moisture tension

Green weight of plant (kg m^{-2}) increases with the days after transplanting irrespective of soil moisture tension in both the seasons (Table 4.12).

The green weight varies significantly with different soil moisture tension at different stages of development. The highest green weight is always associated with lower soil moisture tension. The green weight decreases significantly with the increase in soil moisture tension in all stages of growth except at 90 days after transplanting of 1979-80 season. With the increase in soil moisture tension from 0.3 to 0.6 atmosphere while the green weights of plants decreases by 27.05, 22.43 and 16.03 per cent at 30, 60

TABLE 4.12 Variation in plant green weight under different soil moisture tension and nitrogen level

	Green weight of plant, kg m ⁻²					
	30 DAT		60 DAT		90 DAT	
	1979-80	1980-81	1979-80	1980-81	1979-80	1980-81
Variety						
V ₁	0.2513	0.2885	0.7127	1.9524	2.2311	3.3788
V ₂	0.1254	0.1116	0.8066	2.0820	1.2547	2.0847
S.E.m ±	0.0086	0.0153	0.0633	0.1653	0.1371	0.1147
C.D. at 5%	0.0252	0.0461	N.S.	N.S.	0.4002	0.3348
Soil moisture tension, atm.						
0.3	0.2418	0.2639	0.9484	2.6450	2.0275	3.1381
0.6	0.1867	0.1822	0.7268	2.0607	1.6993	2.6378
0.9	0.1375	0.1540	0.6036	1.3460	1.5020	2.4194
S.E.m ±	0.0106	0.0193	0.0775	0.2024	0.1675	0.1404
C.D. at 5%	0.0309	0.0564	0.2262	0.5908	N.S.	0.4098
Nitrogen, kg/ha						
0	0.1609	0.1610	0.5266	1.3912	1.1288	1.9880
40	0.1789	0.1763	0.6984	1.9939	1.7936	2.4868
80	0.1986	0.1953	0.8237	2.2219	1.8588	2.8547
120	0.2161	0.2675	0.9398	2.4619	2.1904	3.5975
S.E.m ±	0.0122	0.0223	0.0895	0.2337	0.1939	0.1622
C.D. at 5%	0.0356	0.0652	0.2612	0.6821	0.5660	0.4734

and 90 days after transplanting, the corresponding decrease are 20.98, 30.06 and 9.58 per cent due to further increase in soil moisture tension from 0.6 to 0.9 atmosphere.

4.3.3.3 Nitrogen

The green weight of plant varies significantly with different levels of nitrogen in both the seasons (Table 4.12). The green weight increases irrespective of nitrogen level with the days after transplanting. The green weight significantly increases with the increase of nitrogen level at different stages of development in both the seasons (Table 4.12). The highest green weight is under 120 kg/ha application of nitrogen irrespective of stages of growth during both seasons. The increase in green weights at 120 kg N/ha over 0 kg N/ha varies from 50.23 to 85.70 per cent.

4.3.4 Dry weight of plant

The results (Table 4.13) indicate the influence of soil moisture tension and levels of nitrogen on the dry weight of plant (kg m^{-2}) of two varieties of tobacco during the seasons 1979-80 and 1980-81.

4.3.4.1 Variety

The dry weight of plant increases for both the varieties with the days after transplanting (Table 4.13). The dry weight of the plant varies significantly at 30 and 90 days after transplanting during both the seasons. At 60 days after transplanting

TABLE 4.13 Variation in dry weight of plant under different soil moisture tension and nitrogen level

	Dry Weight of plant, kg m ⁻²					
	30 DAT		60 DAT		90 DAT	
	1979-80	1980-81	1979-80	1980-81	1979-80	1980-81
Variety						
V ₁	0.02137	0.02504	0.06348	0.16844	0.23254	0.45885
V ₂	0.01118	0.00980	0.07535	0.19513	0.17231	0.34196
S.E.m ±	0.00115	0.00172	0.00537	0.01572	0.01390	0.01990
C.D.at 5%	0.00335	0.00502	N.S.	N.S.	0.04060	0.0581
Soil moisture tension, atm.						
0.3	0.01961	0.02072	0.08591	0.24247	0.24078	0.47028
0.6	0.01624	0.01649	0.06809	0.18523	0.19619	0.36714
0.9	0.01298	0.01504	0.05426	0.11765	0.17031	0.36379
S.E.m ±	0.00141	0.00211	0.00658	0.01925	0.01703	0.02440
C.D.at 5%	0.00410	N.S.	0.01920	0.05620	0.04970	0.07120
Nitrogen, kg/ha						
0	0.01410	0.01342	0.05011	0.11725	0.14858	0.27837
40	0.01512	0.01479	0.06723	0.18291	0.18837	0.36707
80	0.01729	0.01817	0.07187	0.19723	0.22833	0.44787
120	0.01859	0.02329	0.08846	0.22974	0.24442	0.50829
S.E.m ±	0.00162	0.00243	0.00759	0.02223	0.01967	0.02820
C.D.at 5%	N.S.	0.00710	0.02216	0.06490	0.05740	0.08230

there is no significant difference in dry weight between the varieties. The maximum of 0.4589 kg m^{-2} dry weight of plant was observed under N. tabacum at 90 days after transplanting during 1980-81.

4.3.4.2 Soil moisture tension

Dry weight of plant (kg m^{-2}) increases with the days of growth after transplanting in all levels of soil moisture tensions (Table 4.13). While the maximum dry weight of plant was recorded under 0.3 atmosphere soil moisture tension in both the seasons, the lowest dry weight of plant was under 0.9 atmosphere soil moisture tension. The dry weight of plant increased significantly with the decrease of soil moisture tension in all stages of crop growth except 30 days after transplanting during 1980-81. The decrease of dry weight (per cent) with the increase in soil moisture tension from (a) 0.3 to 0.6 atmosphere and (b) 0.6 to 0.9 atmosphere are 18.84, 22.85 and 20.77 at (a) and 14.39, 32.13 and 5.19 at (b) under 30, 60 and 90 days after transplanting respectively.

4.3.4.3 Nitrogen

The dry weight of plant increases significantly with the increase of level of nitrogen in all stages of development in both the seasons (Table 4.13). The maximum dry weight of plant is under the highest dose of nitrogen (120 kg/ha) in both seasons. While the maximum quantity of dry weight of plant (0.5083 kg m^{-2}) was with 120 kg N/ha at 90 days after transplanting during 1980-81, the lowest was associated with 0 kg N/ha in both the seasons.

The increase in dry weight of plant under 120 kg N/ha over 0 kg N/ha at 30, 60 and 90 days after transplanting are 52.18, 90.13 and 75.70 per cent respectively (Table 4.13).

4.3.5 Leaf area index

The leaf area index (LAI) has been considered as the best measure of the capacity of a crop for producing dry matter. The amount of chlorophyll content depends largely on the area of leaves and at the same time it performs the vital functions like transpiration, respiration and carbon assimilation. The leaf area index for tobacco during growth period under different soil moisture tension and nitrogen levels were studied.

4.3.5.1 Variety

The leaf area index (LAI) increased with the days after transplanting for both the seasons irrespective of variety (Figures 4.28 and 4.29). The LAI varies significantly with variety in all the three stages of development in both seasons. The higher leaf area index is always associated with N. tabacum in both seasons (Table 4.14). The maximum of 4.5053 was observed at 90 days after transplanting with N. tabacum during 1980-81. The relationship between leaf area index and days after transplanting indicates different rates of increase in LAI for two varieties in both the seasons (Figures 4.28 and 4.29). The following equations have been developed considering two seasons average data to express their relationship (Figure 4.29).

$$\text{LAI } V_1 = 0.002 D + 0.0004 D^2 + 0.078 \quad (4.57)$$

$$\text{LAI } V_2 = 0.0003 D + 0.0004 D^2 - 0.126 \quad (4.58)$$

1979 - 80

1980 - 81

124

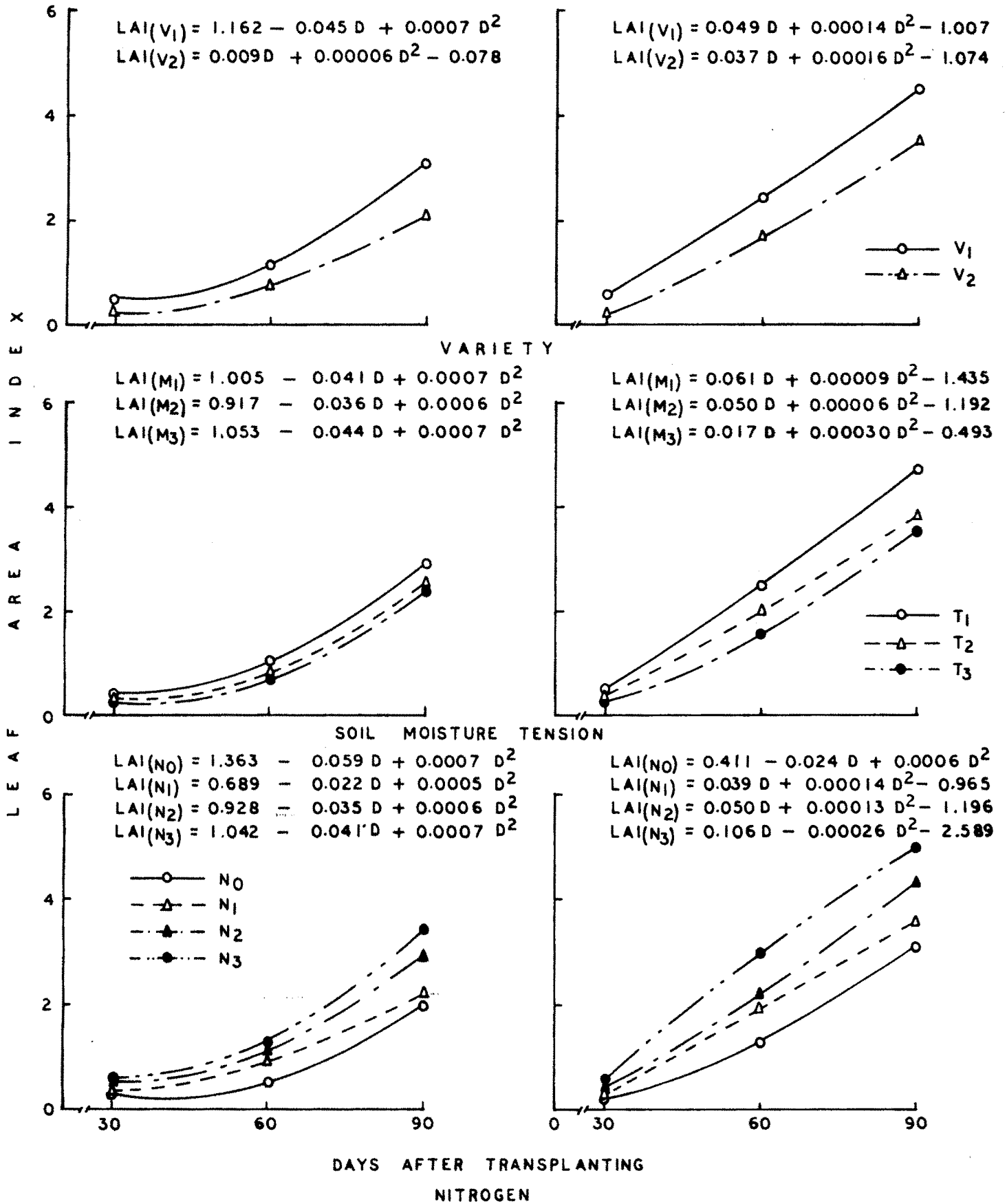


FIG. 4.28 RELATIONSHIP BETWEEN LEAF AREA INDEX AND DAYS AFTER TRANSPLANTING UNDER DIFFERENT VARIETY, SOIL MOISTURE TENSION AND NITROGEN LEVELS

$$LAI(V_1) = 0.002 D + 0.0004 D^2 + 0.078$$

$$LAI(V_2) = 0.0003 D + 0.0004 D^2 - 0.126$$

$$LAI(M_1) = 0.0099 D + 0.0004 D^2 - 0.214$$

$$LAI(M_2) = 0.0069 D + 0.0003 D^2 - 0.137$$

$$LAI(M_3) = -0.0013 D + 0.0005 D^2 + 0.280$$

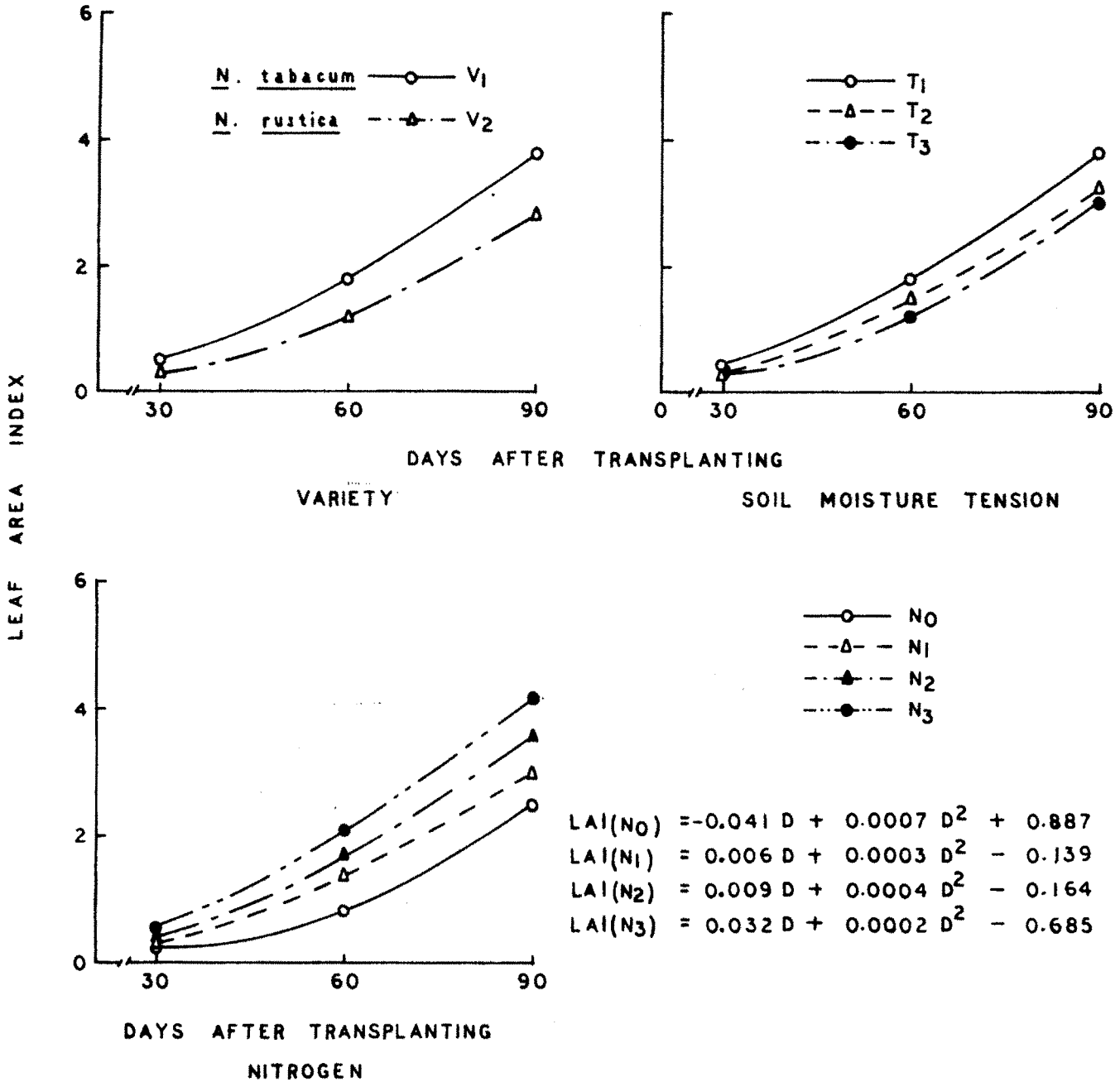


FIG. 4.29 RELATIONSHIP BETWEEN LEAF AREA INDEX AND DAYS AFTER TRANSPLANTING UNDER DIFFERENT VARIETY, SOIL MOISTURE TENSION AND NITROGEN LEVELS DURING TWO SEASONS

where,

LAI = Leaf area index and subscripts V_1 and V_2
represents varieties

D = Days after transplanting.

4.3.5.2 Soil moisture tension

The LAI under different soil moisture tension increases significantly with the decrease of soil moisture tensions (Figures 4.28 and 4.29) and with the days after transplanting. The highest LAI is always associated with 0.3 atmosphere soil moisture tension (Table 4.14). The maximum LAI of 0.4623, 2.5193 and 4.7349 were observed at 30, 60 and 90 days after transplanting respectively under 0.3 atmosphere soil moisture tension during 1980-81. With the increase in soil moisture tension from (a) 0.3 to 0.6 atmosphere and (b) 0.6 to 0.9 atmosphere the average LAI decreases by 15.35, 17.67 and 17.44 per cent in (a) and 15.37, 17.82 and 6.23 per cent in (b) under 30, 60 and 90 days after transplanting respectively.

The following equations have been developed considering two seasons average data to express the relationship (Figure 4.30) between LAI and soil moisture tension.

$$\text{LAI}_{30} = 0.511 - 0.273 M + 0.056 M^2 \quad (4.59)$$

$$\text{LAI}_{60} = 2.154 - 1.319 M + 0.297 M^2 \quad (4.60)$$

$$\text{LAI}_{90} = 4.978 - 4.589 M + 2.621 M^2 \quad (4.61)$$

where,

LAI = Leaf area index and subscripts 30, 60 and 90
indicate the days after transplanting

M = Soil moisture tension, atmosphere.

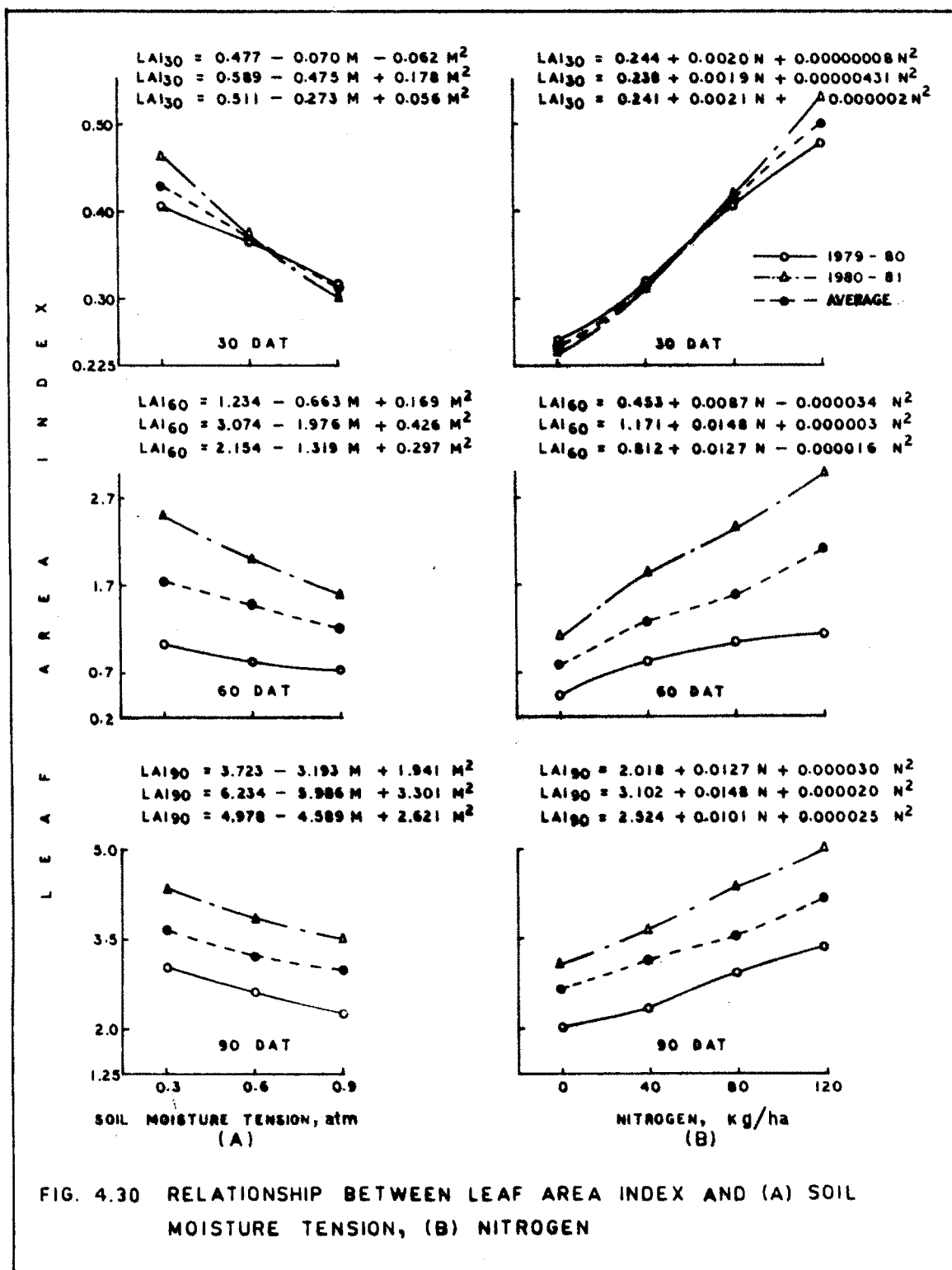


FIG. 4.30 RELATIONSHIP BETWEEN LEAF AREA INDEX AND (A) SOIL MOISTURE TENSION, (B) NITROGEN

TABLE 4.14 Variation in leaf area index under different soil moisture tension and nitrogen level

	Leaf area index					
	30 DAT		60 DAT		90 DAT	
	1979-80	1980-81	1979-80	1980-81	1979-80	1980-81
Variety						
V ₁	0.4845	0.5810	1.1423	2.4184	3.1354	4.5053
V ₂	0.2441	0.1739	0.6732	1.7159	2.1092	3.5517
S.E.m ±	0.0073	0.0164	0.0463	0.0697	0.1168	0.1876
C.D. at 5%	0.0213	0.0479	0.1351	0.2034	0.3409	0.5476
Soil moisture tension, atm.						
0.3	0.4059	0.4623	1.0509	2.5193	2.9397	4.7349
0.6	0.3680	0.3669	0.8977	2.0416	2.5059	3.8305
0.9	0.3189	0.3030	0.7749	1.6406	2.4214	3.5202
S.E.m ±	0.0089	0.0200	0.0568	0.0853	0.1430	0.2298
C.D. at 5%	0.0261	0.0584	0.1658	0.2490	0.4175	0.6708
Nitrogen, kg/ha						
0	0.2451	0.2374	0.4457	1.1359	1.9653	3.1063
40	0.3212	0.3233	0.8507	1.8666	2.2778	3.6647
80	0.4076	0.4172	1.0739	2.2588	2.8710	4.3270
120	0.4832	0.5313	1.2608	3.0074	3.3752	5.0161
S.E.m ±	0.0103	0.0231	0.0655	0.0986	0.1651	0.2653
C.D. at 5%	0.0301	0.0674	0.1912	0.2872	0.4820	0.7745

The increase in LAI with the decrease in soil moisture tension is probably due to less water stress resulting in higher turgidity. The results is in conformity with those of Liu (1977) and Bae and Kang (1976) on tobacco.

4.3.5.3 Nitrogen

The relationship between nitrogen and leaf area index has been presented in Figure 4.30. The rate of increase of LAI varies with days after transplanting and amount of nitrogen (Figures 4.28 to 4.30). In both the seasons, with the increase in the nitrogen levels, the LAI increases significantly (Table 4.14). The maximum LAI was observed under 120 kg N/ha and the minimum LAI was under 0 kg N/ha in both the seasons. The increase in LAI due to application of 120 kg N/ha is 110.26, 169.86 and 65.46 per cent at 30, 60 and 90 days after transplanting respectively.

Considering the average data, the following equations have been developed to express the relationship (Figure 4.30) between LAI and nitrogen.

$$\text{LAI}_{30} = 0.241 + 0.0021 N + 0.000002 N^2 \quad (4.62)$$

$$\text{LAI}_{60} = 0.812 + 0.0127 N - 0.000016 N^2 \quad (4.63)$$

$$\text{LAI}_{90} = 2.524 + 0.0101 N + 0.000025 N^2 \quad (4.64)$$

where,

LAI = Leaf area index and subscripts 30, 60 and 90 indicate the days after transplanting

N = Nitrogen, kg/ha

Since increased N application increases vegetative growth (Hunter et al., 1961), higher LAI at higher N application is

logical. Similar observations were made by Raper (1966), Ghosh (1974) and Sarkar (1975).

4.3.6 Coefficient for estimating leaf area

The measurement of leaf area is important in many investigations of growth and productivity of many crops including tobacco. It is particularly important as an index of growth for the intermediate stages.

4.3.6.1 Leaf area and product of length and maximum width

The co-efficient of the leaf area is largely dependent on the leaf ^{position} on the stalk. The relationship between the area of a leaf and the product of its length and maximum width is found linear with the regression line passing through the origin of the co-ordinates. The following equations represents the relationship between leaf area measured and the product of the length and width of the leaf (Average data).

N. tabacum

$$A_{(T)} = 0.686 LW, \quad r = 0.95 \quad (4.65)$$

$$A_{(M)} = 0.583 LW, \quad r = 0.90 \quad (4.66)$$

$$A_{(B)} = 0.491 LW, \quad r = 0.86 \quad (4.67)$$

N. rustica

$$A_{(T)} = 0.853 LW, \quad r = 0.99 \quad (4.68)$$

$$A_{(M)} = 0.851 LW, \quad r = 0.99 \quad (4.69)$$

$$A_{(B)} = 0.786 LW, \quad r = 0.94 \quad (4.70)$$

where,

A = Leaf area, cm^2 and subscripts T, M and B are the top, middle and bottom position of leaves on the stalk

L = Length of leaf, cm

W = Maximum width of leaf, cm.

The co-efficient of leaf varies with the position of the leaf on the stalk (equations 4.65 to 4.70) and with variety (Figure 4.31). The regression co-efficients vary with the position of leaves on the stalk (according to size group). It was observed that the large leaves generally had more irregular edges than small leaves. The variation of co-efficient with the position of leaves is due to geometric shape of leaves. This is in agreement with the results of Suggs et al. (1960). The variation in co-efficients for variety may be due to the geometric shape of the leaves.

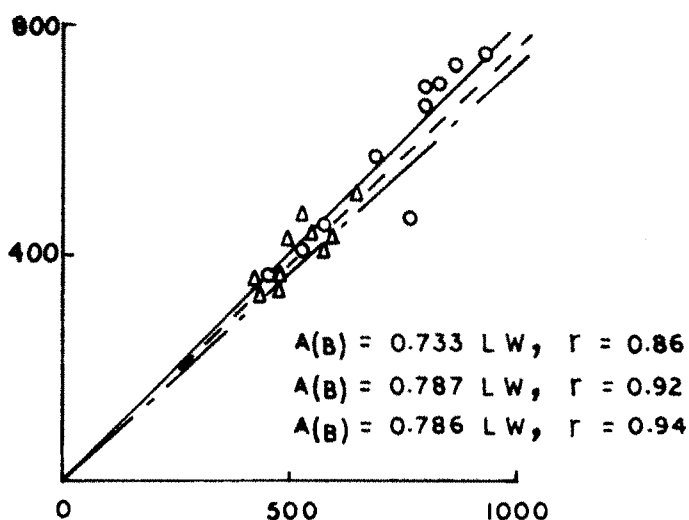
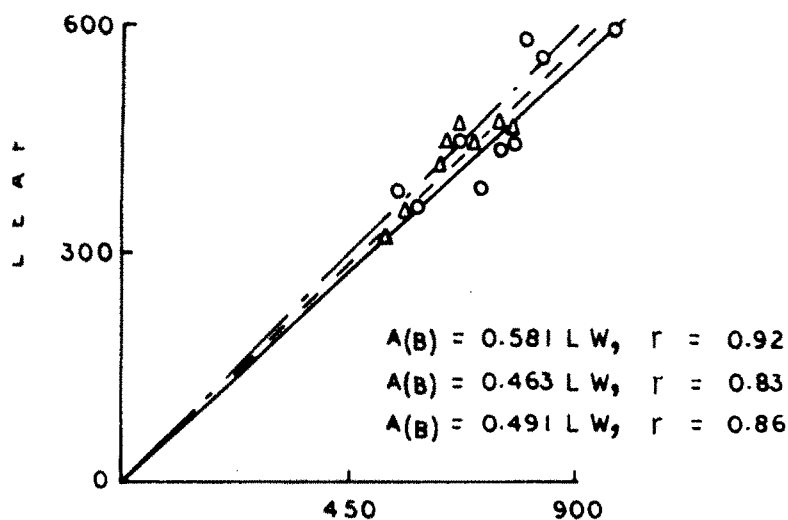
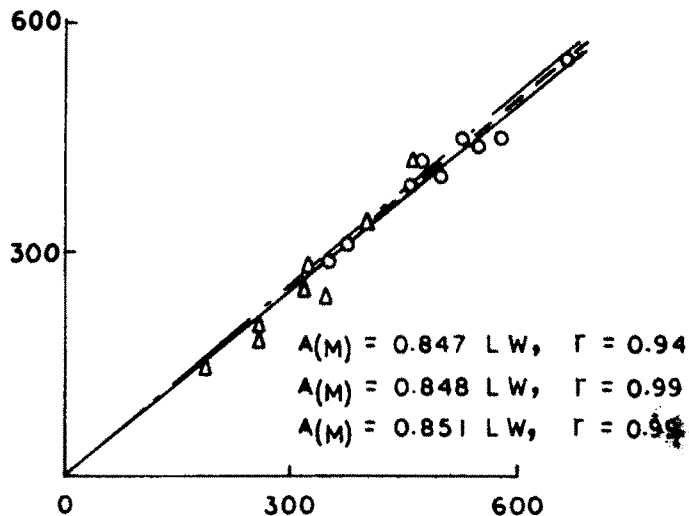
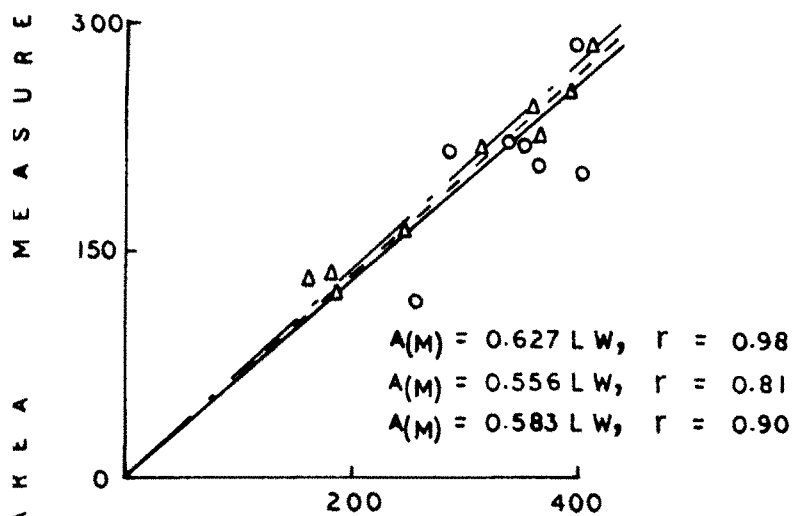
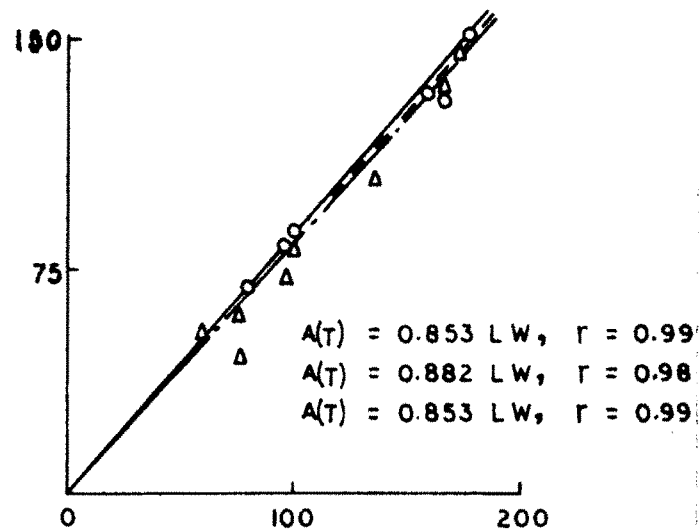
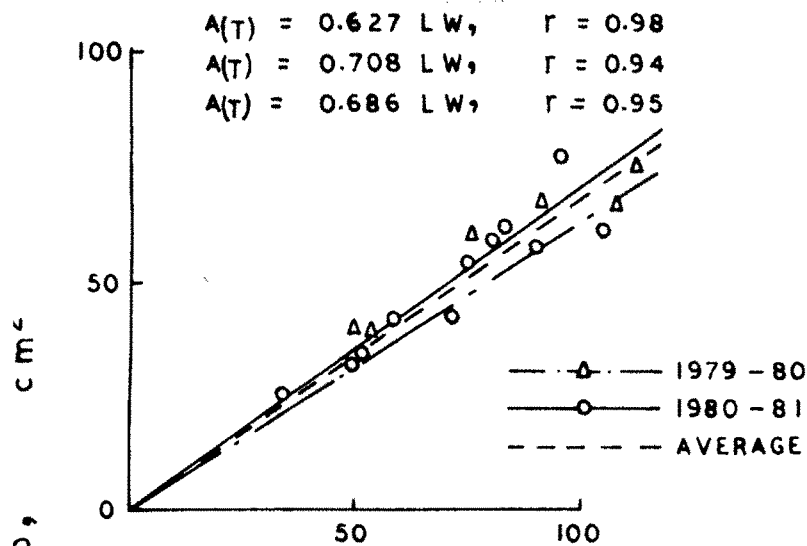
4.3.6.2 Variety

The ratio (co-efficient) of leaf area and its product of length and maximum width varies considerably with variety. The co-efficient also varies with the days of growth after transplanting (Table 4.15).

The average co-efficient for leaf area, decreases with the increase in days after transplanting for N. tabacum (Table 4.15). In case of N. rustica, the co-efficient is highest at 60 days after transplanting. The variation in co-efficient under varieties may be due to the variation in geometric shape of the leaf (Polster and Reichenback, 1958).

N. tabacum

N. rustica



PRODUCT OF LENGTH AND MAXIMUM WIDTH, cm^2

FIG. 4.31 RELATIONSHIP BETWEEN LEAF AREA MEASURED AND THE PRODUCT OF LENGTH AND MAXIMUM WIDTH

TABLE 4.15 Variation in co-efficient under varieties at different stages of development

Variety	Co-efficients			
	30 DAT	60 DAT	90 DAT	Mean
<u>N. tabacum</u>	0.7214	0.6882	0.6797	0.6964
<u>N. rustica</u>	0.7745	0.8310	0.7699	0.7918

4.3.6.3 Soil moisture tension

The data (Table 4.16) relate to the average of two seasons' observations. For N. tabacum the co-efficient decreases with the increase in soil moisture tension at 30 and 90 days after transplanting but the trend is $M_1 < M_2 > M_3$ for 60 days after transplanting. For N. rustica, the trend in the co-efficient is $M_1 > M_2 < M_3$ for 30 days after transplanting and is $M_1 < M_2 > M_3$ for 60 days after transplanting (Table 4.16).

For N. tabacum, the co-efficient for leaf area shows a decreasing trend with increasing days after transplanting, while for N. rustica, it increases with days upto 60 and then decreases.

4.3.6.4 Nitrogen

The data (Table 4.17) relate to the average of two seasons' observations. The average influence of nitrogen on co-efficient for leaf area varies with the days and variety. While for N. tabacum, the coefficient decreases with the days, for N. rustica it increases upto 60 days after transplanting.

TABLE 4.16 Variation in co-efficients for leaf area
under different soil moisture tensions

Soil moisture tension, atmosphere	Co-efficients			
	30 DAP	60 DAP	90 DAP	Mean
<u><i>N. tabacum</i></u>				
0.3	0.7342	0.6831	0.6962	0.7045
0.6	0.7167	0.6991	0.6733	0.6964
0.9	0.7133	0.6825	0.6697	0.6885

Average	0.7214	0.6882	0.6797	0.6964
<u><i>N. rustica</i></u>				
0.3	0.7812	0.8226	0.7625	0.7888
0.6	0.7697	0.8405	0.7753	0.7952
0.9	0.7726	0.8300	0.7719	0.7914

Average	0.7745	0.8310	0.7699	0.7918

TABLE 4.17 Variation in co-efficients for leaf area under different nitrogen level

Nitrogen, kg/ha	Co-efficients			
	30 DAT	60 DAT	90 DAT	Mean
<u>N. tabacum</u>				
0	0.7341	0.6511	0.6187	0.6679
40	0.6990	0.6963	0.7217	0.7057
80	0.7265	0.6885	0.6927	0.7026
120	0.7258	0.7167	0.6858	0.7094

Average	0.7214	0.6882	0.6797	0.6964
<u>N. rustica</u>				
0	0.7599	0.8055	0.7752	0.7802
40	0.7760	0.8560	0.7950	0.8090
80	0.7699	0.8283	0.7825	0.7936
120	0.7920	0.8341	0.7270	0.7843

Average	0.7745	0.8910	0.7799	0.7918

4.4 Yield

The influence of soil moisture tension as well as levels of nitrogen, on the yield of tobacco has been studied.

4.4.1 Leaf yield

4.4.1.1 Variety

The yield of leaves for two varieties varies significantly with the seasons (Table 4.18). The higher yield is always associated with N. tabacum during both the seasons. The average yield of N. rustica is 28.33 per cent lower than that of N. tabacum. The higher rate of yield in N. tabacum may be due to the genetic character of the crop.

4.4.1.2 Soil moisture tension

The influence of soil moisture tension on the yield of cured leaves of tobacco varies with season and variety (Figures 4.32 and 4.33). The highest leaf yield is under 0.3 atmosphere soil moisture tension (Table 4.18). The yield decreases significantly with the increase in soil moisture tension in both the varieties (Figures 4.32 and 4.33) and the lowest yield is under 0.9 atmosphere soil moisture tension. With the increase in soil moisture tension from 0.3 to 0.6 atmosphere and from 0.6 to 0.9 atmosphere, the average yield of leaves decreases by 14.90 per cent and 8.77 per cent respectively.

The relationship (Figure 4.33) between the leaf yield and soil moisture tension (average data) is given below :

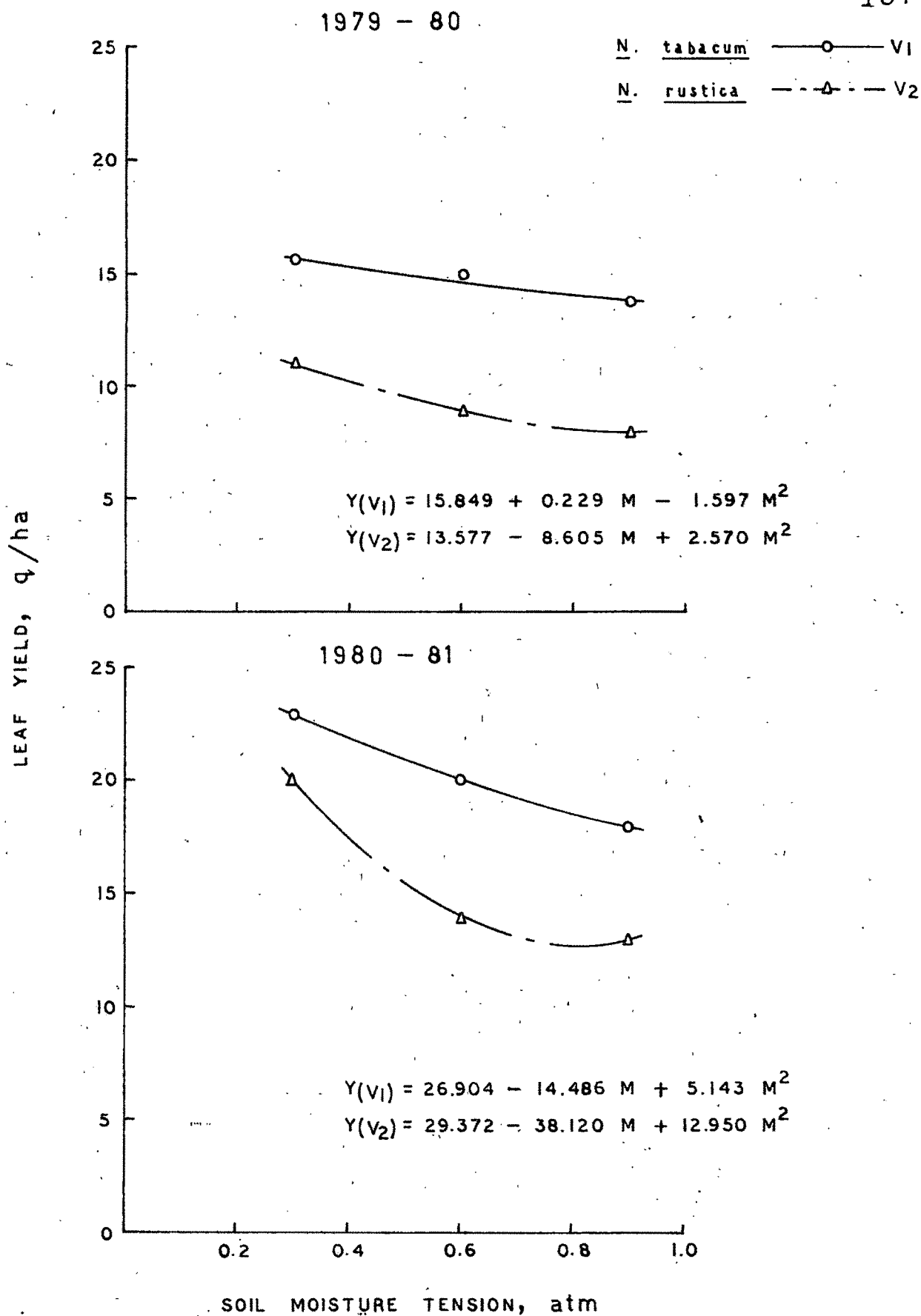


FIG. 4.32 RELATIONSHIP BETWEEN LEAF YIELD AND SOIL MOISTURE TENSION

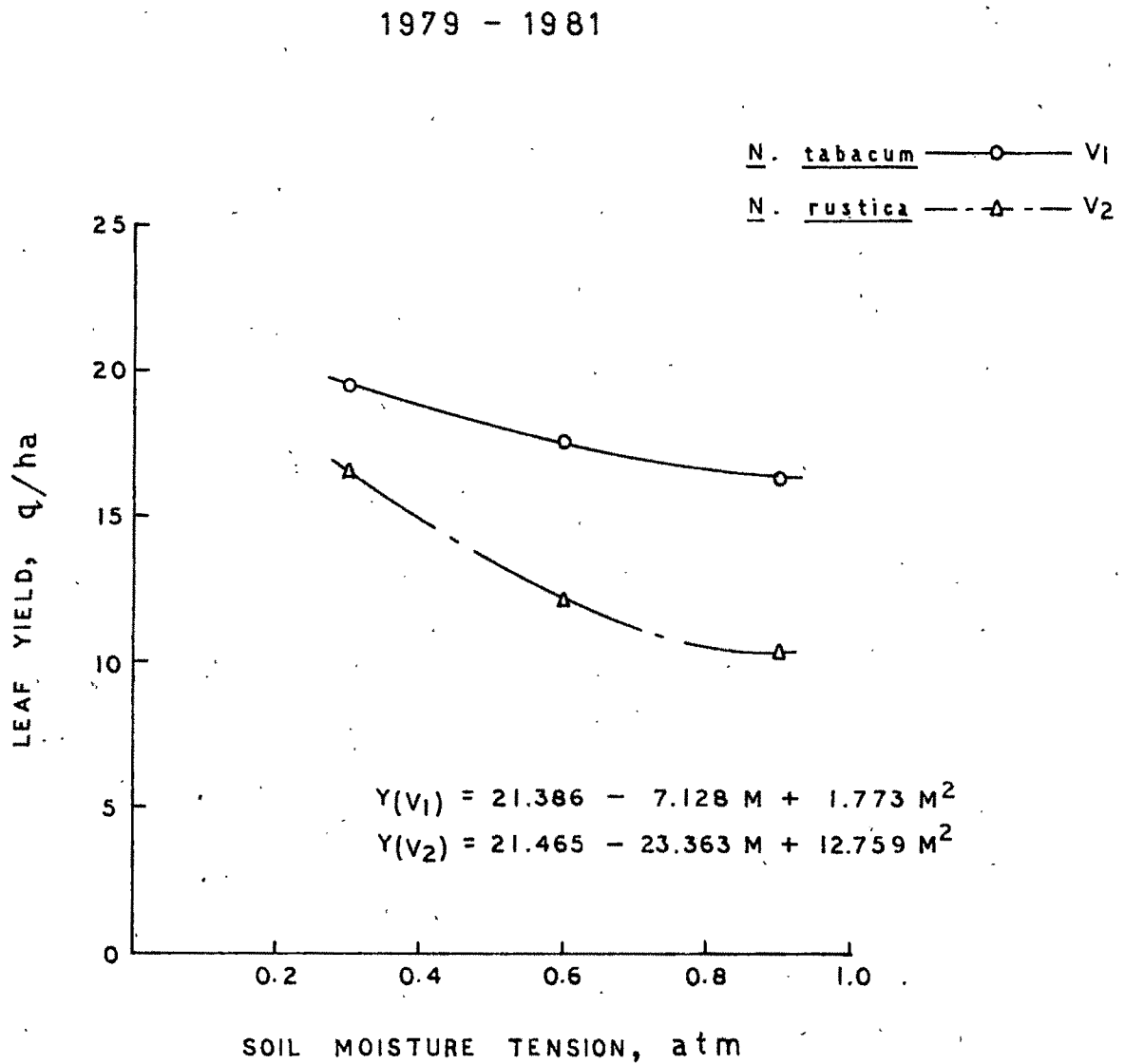


FIG. 4.33 RELATIONSHIP BETWEEN LEAF YIELD AND SOIL MOISTURE TENSION DURING TWO SEASONS

TABLE 4.18 Variation in leaf and stalk yield (q/ha) under different soil moisture tension and nitrogen level

	Leaf yield, q/ha		Stalk yield, q/ha	
	1979-80	1980-81	1979-80	1980-81
Variety				
<u>N. tabacum</u>	15.32	20.39	8.50	22.91
<u>N. rustica</u>	9.49	16.12	8.63	18.34
S.E.m \pm	0.21	0.83	0.36	1.12
C.D. at 5% level	0.62	2.42	N.S.	3.27
Soil moisture tension, atmosphere				
0.3	13.50	21.51	10.04	25.43
0.6	12.38	17.41	7.96	19.20
0.9	11.34	15.84	7.70	17.25
S.E.m \pm	0.07	1.01	0.44	1.37
C.D. at 5% level	0.20	2.96	1.28	4.00
Nitrogen, kg/ha				
0	8.29	14.10	5.69	13.67
40	11.60	16.48	7.54	17.80
80	13.49	19.67	9.86	22.83
120	16.23	22.77	11.17	28.20
S.E.m \pm	0.09	1.17	0.51	1.58
C.D. at 5% level	0.26	3.42	1.48	4.63

N. tabacum

$$Y = 21.386 - 7.128 M + 1.773 M^2 \quad (4.71)$$

N. rustica

$$Y = 21.465 - 23.363 M + 12.759 M^2 \quad (4.72)$$

where,

Y = Yield of leaves, q/ha

M = Soil moisture tension, atmosphere.

4.4.1.3 Nitrogen

The influence of different levels of nitrogen on the yield of tobacco leaves varies with season and varieties (Figures 4.34 and 4.35). The highest yield is under 120 kg N/ha (Table 4.18).

The yield increases significantly with the increase in levels of nitrogen under both season and the lowest yield is under 0 kg N/ha. With the increase in nitrogen level from 0 kg/ha to 120 kg/ha, the average increase in leaf yield is 74.18 per cent.

The relationship (Figure 4.35) between the yield and levels of nitrogen (average data) is given below :

N. tabacum

$$Y = 13.79 + 0.068 N - 0.000015 N^2 \quad (4.73)$$

N. rustica

$$Y = 8.49 + 0.065 N - 0.000056 N^2 \quad (4.74)$$

where,

Y = Yield of leaves, q/ha

N = Nitrogen, kg/ha.

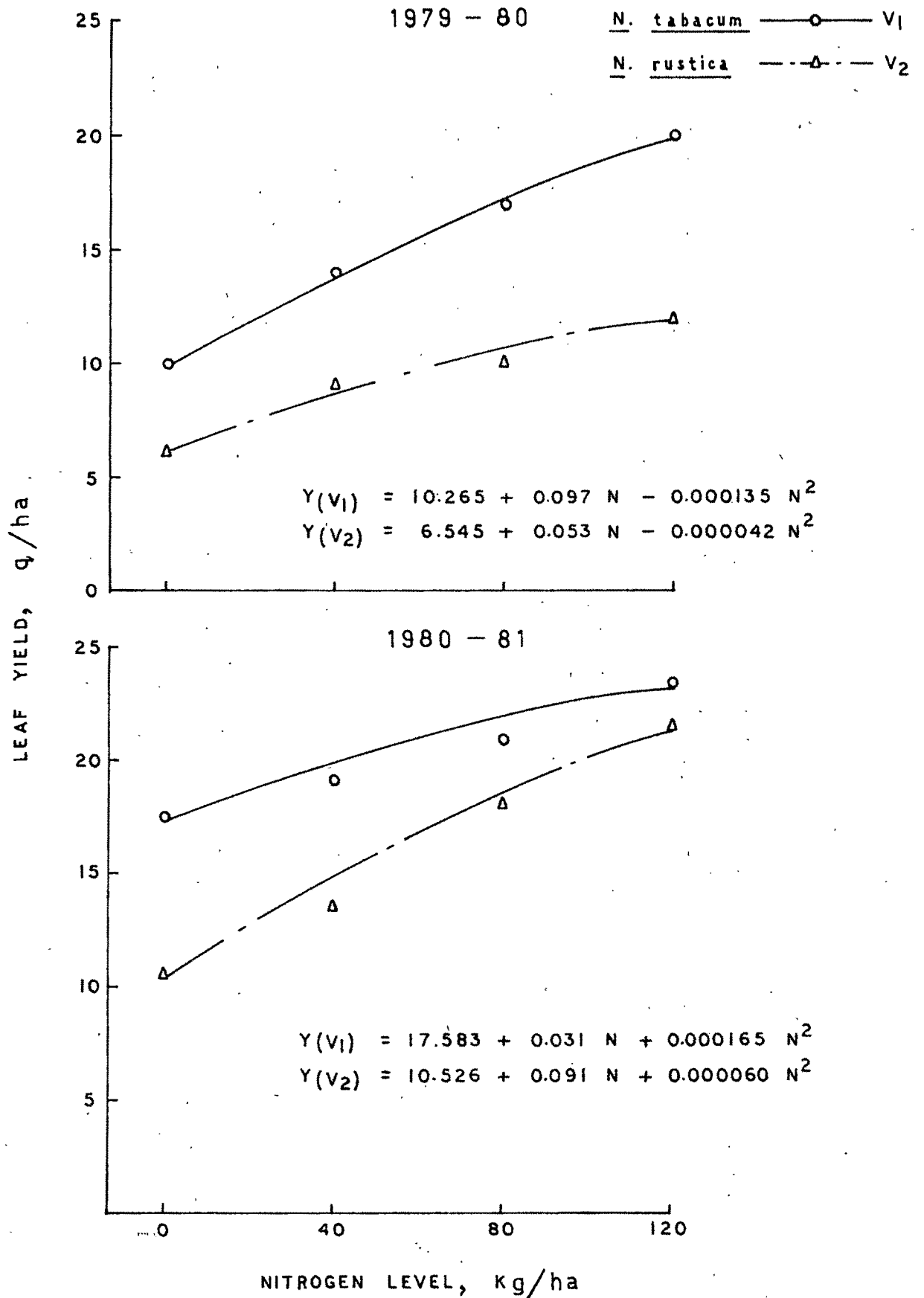


FIG. 4.34 RELATIONSHIP BETWEEN LEAF YIELD AND NITROGEN LEVEL

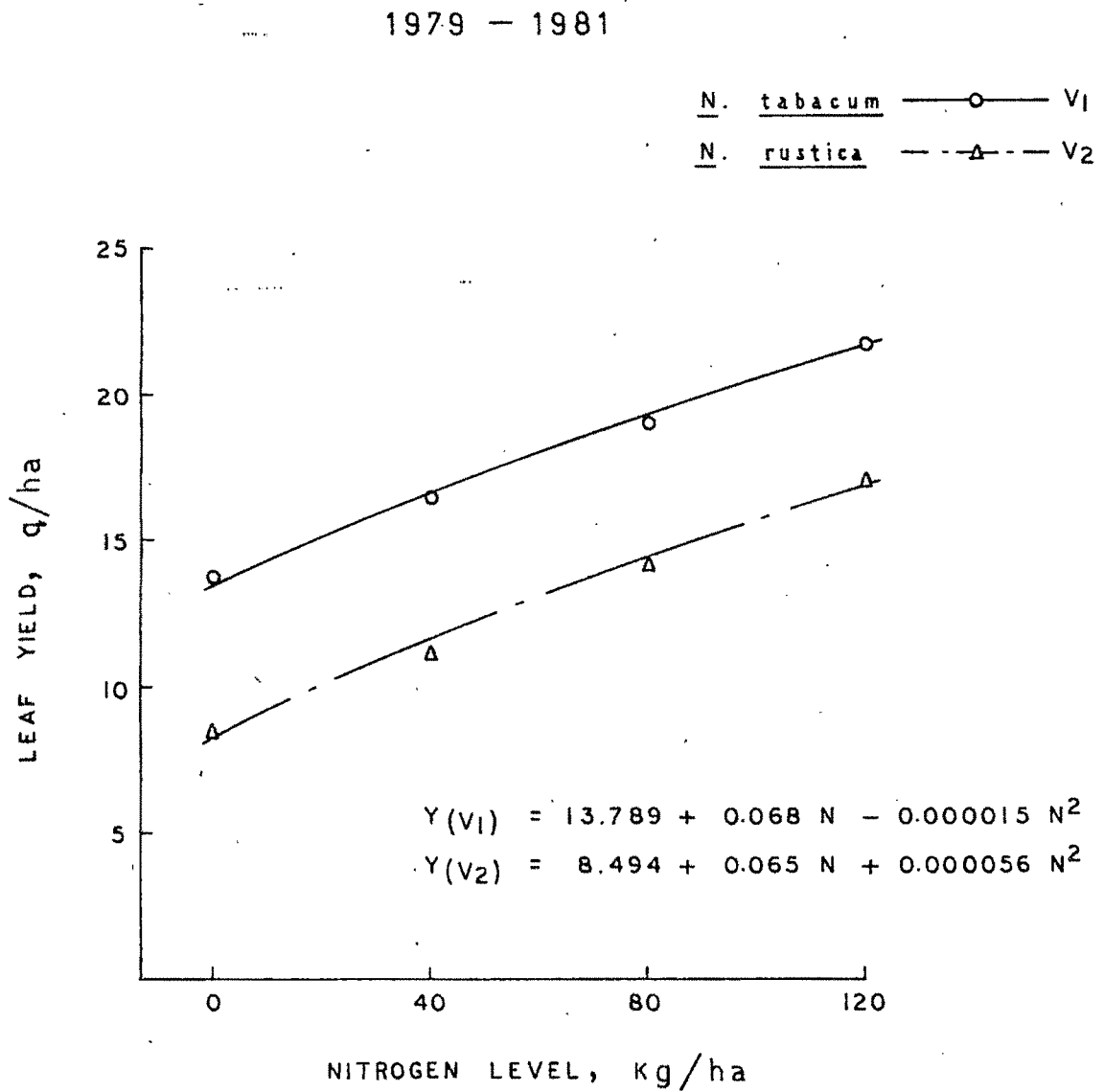


FIG. 4.35 RELATIONSHIP BETWEEN LEAF YIELD AND NITROGEN LEVEL DURING TWO SEASONS

4.4.1.4 Interaction

Results (Table 4.19) indicate that ~~any~~ at any level of nitrogen, the significantly higher leaf yield is with N. tabacum. Similarly, at any soil moisture tension, significantly higher leaf yield is with N. tabacum. While the highest leaf yield is at 0.3 atmosphere with 120 kg N/ha, the lowest leaf yield is at 0 kg N/ha with 0.9 atmosphere soil moisture tension for both varieties.

The per cent increase in leaf yield at 0.3 atmosphere with 120 kg N/ha over the lowest yield is 123.56 for N. tabacum and that for N. rustica is 212.50 per cent. The results further indicate that the influence of nitrogen on leaf yield is more pronounced for the variety N. tabacum (96.08 per cent increase in leaf yield at 120 kg over 0 kg N). It is also observed that the decrease in leaf yield due to increase in soil moisture tension from 0.3 to 0.9 atmosphere is 29.51 per cent for N. rustica and that for N. tabacum is only 6.43 per cent (Table 4.19).

4.4.2 Stalk yield

4.4.2.1 Variety

The stalk yield of tobacco for both varieties varied significantly during two seasons.

4.4.2.2 Soil moisture tension

The influence of different soil moisture tension on the stalk yield varies with seasons (Table 4.18) and varieties. The highest stalk yield is under 0.3 atmosphere soil moisture tension

TABLE 4.19 Influence of variety, soil moisture tension (atmosphere) and nitrogen (kg/ha) on leaf yield (q/ha) during the season 1979-80

Levels of nitrogen, kg/ha	<u>N. tabacum</u>			<u>N. rustica</u>		
	Soil moisture tension, atm.			Soil moisture tension, atm.		
	0.3	0.6	0.9	0.3	0.6	0.9
0	10.95	10.10	9.55	7.30	6.65	5.20
40	13.75	14.00	14.60	10.55	9.20	7.50
80	17.05	17.55	16.25	10.80	10.10	9.20
120	21.35	20.00	18.65	16.25	11.40	9.75

Average	15.32			9.49		

				S.E.m ±	C.D. at 5%	
Difference between variety and nitrogen :				0.3012	0.8792	
Difference between variety and soil moisture tension :				0.3688	1.0765	
Difference between nitrogen and soil moisture tension :				0.5216	1.5225	

irrespective of seasons (Table 4.18) and it decreases significantly with the increase in soil moisture tension. With the increase in soil moisture tension from 0.3 to 0.6 atmosphere and 0.6 to 0.9 atmosphere, the average stalk yield decreases by 23.43 per cent and 8.14 per cent respectively.

4.4.2.3 Nitrogen

The influence of different levels of nitrogen on the stalk yield of tobacco varies with seasons (Table 4.18). The highest yield is under 120 kg N/ha (Table 4.18). The stalk yield increases significantly with the increase in nitrogen level in both the varieties under both seasons. With the increase in nitrogen level from 0 kg/ha to 120 kg/ha, the average stalk yield is increased by 115.26 per cent.

The yield of tobacco is usually considered in terms of its dry leaf and stalk weight. While dry leaf weight depends on the leaf area and dry matter accumulation, the stalk yield largely depends on its height, diameters and dry matter. Since in N. tabacum leaf area, dry matter accumulation, height and diameter of the stalks are higher compared to N. rustica, higher leaf and stalk yield in N. tabacum is logical.

Since lower soil moisture tension maintains a favourable atmosphere in the rootzone for greater leaf area, dry matter, height of the plant and diameter of the stalk, higher leaf and stalk yield at 0.3 atmosphere is justified. The results are in general agreement with those of Patel (1964), Yang (1967),

Mehrotra et al. (1970), Gurbev (1972), Vardabasso and Cutolo (1975) and Liu (1978).

Higher leaf and stalk yield of tobacco at 120 kg N/ha is mainly due to higher plant height, greater stalk yield, higher dry matter and larger leaf area. Similar observations were made by Atkinson (1966), Atkinson et al. (1969), Sims et al. (1972), Ling (1975), and Jones and Tramel (1979).

4.5 Nicotine Content of Tobacco Leaf

Quality of cured tobacco leaves is the most important character for market value. The assessment of leaf quality under different conditions is one of the most important criterion to be considered. Quality is currently an object of subjective evaluation and best defined as "that for which the buyer pays money". Perhaps, the best known tobacco compound is the volatile base, nicotine. The "strength" of a smoke is a measure of the nicotine content and must be carefully controlled. The production of tobacco involves the picking of a rather brittle yellowish green leaf containing around 85 per cent water. If the field crop is grown well and handled correctly this leaf is transformed by the curing process into a flexible, stretch, yellow to orange or mahogany piece of tissue with the characteristics of aroma and smoking quality. The variation in nicotine content at harvest under different varieties, soil moisture tensions and nitrogen levels is presented in Table 4.20.

4.5.1 Variety

The influence of variety on nicotine content is significant in both the seasons (Table 4.20). A significantly high per cent of nicotine is found with N. rustica in comparison to N. tabacum. The maximum of 5.6725 per cent of nicotine in case of N. rustica compared to only 1.6206 per cent nicotine in N. tabacum is found during 1979-80. This variation in nicotine content is probably due to the genetic variation of the crop.

4.5.2 Soil moisture tension

The nicotine content of tobacco is significantly influenced by soil moisture tension (Table 4.20) in both the seasons. With the increase in soil moisture tension, nicotine content increases. The lowest 3.2348 per cent nicotine was associated with 0.3 atmosphere soil moisture tension during 1980-81. Similar observations were also made by Mehrotra et al. (1970), Honda and Arakawa (1971), Mandy and Kiss (1975), and Bae and Kang (1976). The maximum of 3.9513 per cent of nicotine is under 0.9 atmosphere soil moisture tension (Table 4.20).

This may be explained as follows :

Increase of nicotine content under conditions of soil moisture stress may be due to the increased cuticle thickness causing decreased volatilization of free nicotinic acid and the formation of more stable nicotine salts due to the low pH associated with dry conditions.

TABLE 4.20 Variation in nicotine content of tobacco leaves at harvest under different varieties, soil moisture tension and nitrogen level

	Nicotine content, per cent	
	1979-80	1980-81
Variety		
<u>N. tabacum</u>	1.62058	1.42879
<u>N. rustica</u>	5.67250	5.66500
S.Em ±	0.10484	0.13689
C.D. at 5% level	0.30602	0.39958
Soil moisture tension, atmosphere		
0.3	3.45728	3.23475
0.6	3.53106	3.51431
0.9	3.95130	3.89163
S.Em ±	0.12840	0.16766
C.D. at 5% level	0.37479	0.48938
Nitrogen, kg/ha		
0	3.39710	3.19755
40	3.60185	3.32208
80	3.69810	3.68933
120	3.88916	3.97858
S.Em ±	0.14827	0.19359
C.D. at 5% level	N.S.	0.56508

4.5.3 Nitrogen

Nitrogen is considered to be a dominant factor which influences the level of strength in tobacco smoke. Nitrogen is an integral constituent of the nicotinic molecule, and thus nitrogen is an important factor in nicotine synthesis. The accumulation of nicotine in the plant is largely regulated by the nitrogen supply than by any other plant nutrient.

The nicotine content varies significantly with the nitrogen levels in both the seasons (Table 4.20). With the increase in nitrogen levels, the nicotine content increases significantly in both the seasons. While the maximum nicotine content (3.9786 per cent) is under 120 kg N/ha during 1980-81, the lowest (3.1976 per cent) nicotine content is under 0 kg N/ha during 1980-81 (Table 4.20). Similar conclusions were also made by Ling (1975), and Jones and Tramel (1979).

4.6 Influence of evapotranspiration

The relationship between yield and total evapotranspiration averaged over two seasons (Figure 4.36) for both the varieties indicate that with the increase in total evapotranspiration, yield increases in a linear manner. The slope of the line indicates that for each cm of water used, the yield increases by 0.562 q/ha for N. tabacum and by 0.548 q/ha for N. rustica. Similar result was observed by Ghosh (1974) on wheat under furrow irrigation.

The relationship (Figure 4.36) is expressed by the

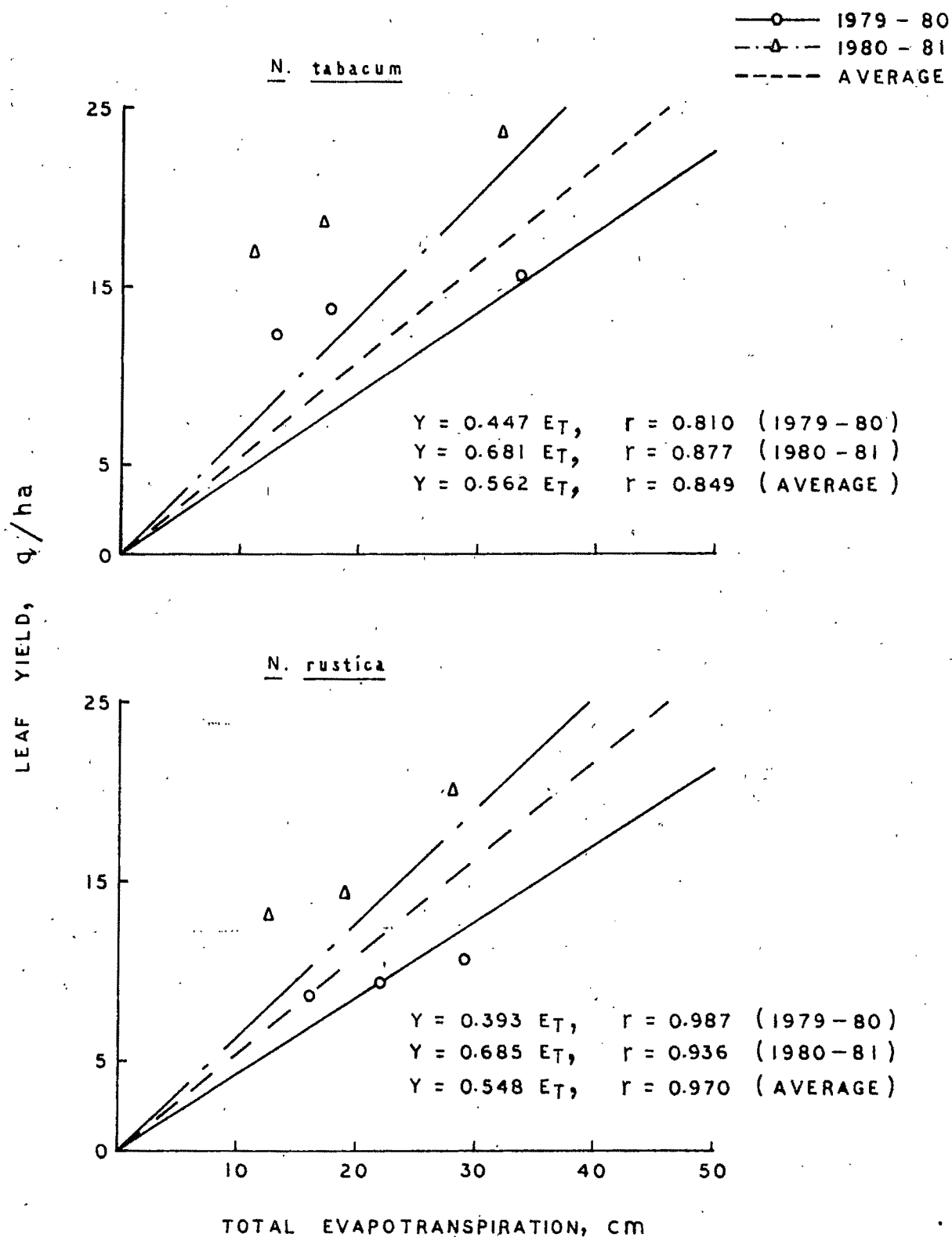


FIG. 4.36 RELATIONSHIP BETWEEN LEAF YIELD AND TOTAL EVAPOTRANSPIRATION

following equations :

N. tabacum

$$Y = 0.562 E_T, \quad r = 0.849 \quad (4.75)$$

N. rustica

$$Y = 0.548 E_T, \quad r = 0.970 \quad (4.76)$$

where,

Y = Yield, of leaf, q/ha

E_T = Total evapotranspiration, cm.

4.7 Development of Equation for Evapotranspiration

Since, the evapotranspiration is not only influenced by the climatic factors, but also with the system of irrigation, soil moisture tension, levels of nitrogen and plant characters, for estimating evapotranspiration, an equation may be developed considering as many factors as possible. In this present study, an attempt has been made to develop an equation with climatic variables, soil moisture tension and levels of nitrogen.

Using weekly average data of measured evapotranspiration, mean air temperature, wind velocity, hours of bright sunshine, vapour pressure deficit, soil moisture tension and nitrogen, the following equations (one for N. tabacum and the other for N. rustica) have been developed through multiple regression analysis in the form of

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

where,

E_T = Evapotranspiration rate, mm/day

T = Mean air temperature, °C

W = Average wind velocity, km/hr

S = Hours of bright sunshine

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

M = Soil moisture tension, atmosphere

N = Nitrogen, kg/ha

$b_0, b_1, b_2, b_3, b_4, b_5$ and b_6 are Regression co-efficients.

Considering the data averaged over two seasons the following values of regression co-efficients $b_0, b_1, b_2, b_3, b_4, b_5$ and b_6 have been determined by the least square method (Table 4.21) and the significance of regression has been verified by the analysis of variance (Table 4.22).

TABLE 4.21 Values of regression co-efficients

Regression co-efficients	<u>N. tabacum</u>	<u>N. rustica</u>
b_0	7.1678	5.7214
b_1	-0.3377	-0.3371
b_2	0.4540	0.5632
b_3	0.2643	0.3607
b_4	-0.0139	-0.0356
b_5	-3.3330	-2.9300
b_6	0.0018	0.0032

The resulting equations thus reduces to :

N. tabacum

$$E_T = 7.1678 - 0.3377 (T) + 0.4540 (W) + 0.2643 (S) \\ - 0.0139 (e_s - e_a) - 3.3330 (M) + 0.0018 (N) \\ (R = 0.7717) \quad (4.77)$$

N. rustica

$$E_T = 5.7214 - 0.3371 (T) + 0.5632 (W) + 0.3607 (S) - 0.0356 \\ (e_s - e_a) - 2.9300 (M) + 0.0032 (N) \\ (R = 0.7690) \quad (4.78)$$

TABLE 4.22 Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Level of significance
<u>N. tabacum</u>					
Regression equation	6	46.33	7.72	20.86	$P < 0.001$
Error	84	31.46	0.37		
Total	90	77.79			
<u>N. rustica</u>					
Regression equation	6	40.78	6.79	19.97	$P < 0.001$
Error	84	28.18	0.34		
Total	90	68.96			

The high values of F in the analysis of variance (Table 4.22) indicate that the regression equations account for the major portion

of variations of the dependent variable and hence the relationship fits the data reasonably well.

To estimate evapotranspiration (E_T), the temperature, wind velocity, sunshine hours, vapour pressure deficit, soil moisture tension and levels of nitrogen need be known. Similar equation was developed by Maity and Pandya (1975) on potato crop grown in lysimeters.

4.8 Combined influence of soil moisture tension and nitrogen on leaf yield

The foregoing discussions reveal the importance of the different levels of nitrogen and soil moisture tensions on the leaf and stalk yield. It is, therefore, considered necessary to develop an equation with these two parameters in predicting the leaf yield of both varieties.

In order to develop an equation the observations of leaf yield (averaged over two years) was taken into consideration. Through multiple regression analysis equation of the following form was developed.

$$Y = b_0 + b_1 M + b_2 N$$

where,

Y = Yield of leaf, q/ha

M = Soil moisture tension, atmosphere

N = Nitrogen, kg/ha,

and b_0 , b_1 and b_2 are the empirical constants.

By using least square method, the following values of constants were determined separately for both the varieties.

The equations thus reduced to the following :

N. tabacum

$$Y = 16.8999 - 5.0008 (M) + 0.0659 (N) \quad (4.79)$$

N. rustica

$$Y = 14.4709 - 9.9679 (M) + 0.0716 (N) \quad (4.80)$$

TABLE 4.23 Analysis of variance

Source of variation	Degrees of freedom	Sum of square	Mean square	Variance ratio	Level of significance
<u>N. tabacum</u>					
Regression equation	2	244.44	122.21	5.5125	P < 0.001
Error	9	199.53	22.17		
Total	11	443.97			
<u>N. rustica</u>					
Regression equation	2	389.01	194.51	6.08	P < 0.001
Error	9	286.11	31.99		
Total	11	675.12			

The high values of F in the analysis of variance (Table 4.23) indicate that the equations account for a major portion of variations in the variable and hence the equations fit the data reasonably well.

CHAPTER V

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

5.1 Summary

Studies on evapotranspiration and growth analysis on tobacco (Nicotiana sp.) under different soil moisture tension (0.3, 0.6 and 0.9 atmosphere) and nitrogen levels (0, 40, 80 and 120 kg/ha) were undertaken during two winter seasons of 1979-80 and 1980-81 at Kalyani, Nadia, West Bengal to examine :

1. (a) the relationship between measured evapotranspiration rate and each of ^{four} climatic variables, soil moisture tension, nitrogen levels and leaf area index,
- (b) the relationship between evapotranspiration and pan evaporation data,
- (c) the influence of different soil moisture tension and nitrogen levels on growth characters of tobacco,
- (d) the influence of different soil moisture tension and nitrogen levels on leaf and stalk yield of tobacco,
- (e) to estimate the nicotine content of tobacco under different soil moisture tension and nitrogen levels, and

2. (a) to develop equations for estimating evapotranspiration from tobacco varieties, using four climatic variables, soil moisture tension and nitrogen levels,
- (b) to develop equations for predicting leaf yield of tobacco varieties with different combinations of soil moisture tensions and nitrogen levels.

The experiment was laid out in completely randomised design with two varieties, three soil moisture tensions and four levels of nitrogen with twentyfour treatments allotted to fortyeight plots.

The influence of four climatic variables like temperature (T), wind velocity (W), sunshine hours (S) and vapour pressure deficit ($e_s - e_a$) on evapotranspiration rate (E_T) was studied on tobacco. The relationship between these climatic variables on E_T was found linear, irrespective of soil moisture tensions and seasons, though the rate of change varied with the climatic variables and soil moisture tensions. While the evapotranspiration rate was maximum under 0.3 atmosphere soil moisture tension, it gradually decreased with the increase of soil moisture tension.

The maximum E_T was observed under 120 kg N/ha and the E_T gradually decreased with the decrease in nitrogen levels.

For estimating E_T , two equations have been developed with four climatic variables for both the varieties.

The following equations expressed the curvilinear

relationship between soil moisture tension and total evapotranspiration of two varieties of tobacco :

N. tabacum cv. S-5

$$E_{T(s)} = 59.328 - 105.922 M + 60.126 M^2$$

N. rustica cv. DD 437

$$E_{T(s)} = 43.301 - 57.066 M + 26.624 M^2$$

where,

$E_{T(s)}$ = Total evapotranspiration, cm

M = Soil moisture tension, atmosphere.

While the peak E_T reached at about 50th day after transplanting, the higher E_T was always associated with lower soil moisture tension.

The relationship between nitrogen levels and total evapotranspiration for both the varieties was found curvilinear. Higher $E_{T(s)}$ was always associated with higher levels of nitrogen irrespective of varieties and seasons. Their relationship was expressed by the following equations :

N. tabacum

$$E_{T(s)} = 18.988 + 0.045 N - 0.00012 N^2$$

N. rustica

$$E_{T(s)} = 18.853 - 0.009 N + 0.00034 N^2$$

where,

$E_T(s)$ = Total evapotranspiration, cm

N = Nitrogen levels, kg/ha.

At any soil moisture tension, $E_T(s)$ increased with the increase in nitrogen irrespective of variety and seasons and at any nitrogen level highest $E_T(s)$ was at 0.3 atmosphere soil moisture tension irrespective of ~~variety and season~~.

The evapotranspiration rate increased with the increase of LAI, the maximum limit of which varied with soil moisture tension and levels of nitrogen under both the varieties.

The measured E_T values were compared with the USWB Class A pan evaporation in terms of their ratio under different soil moisture tension and nitrogen levels. The ratio gradually increased with the decrease in soil moisture tension and maximum was during January to February. The lowest and highest ratios of E_T/E_0 were always associated with 0 kg/ha and with 120 kg/ha application of nitrogen respectively.

The influence of soil moisture tension and nitrogen levels on plant height varied significantly at different stages of growth, although the rate of change in height varied. The height of plant also varied significantly in respect of variety. With the decrease of soil moisture tension and increase of nitrogen levels the plant height increased.

At any soil moisture tension, the height increased with the increased level of nitrogen and at any level of nitrogen, the height increased with the decrease of soil moisture tension irrespective of varieties and seasons.

The influence of soil moisture tension and nitrogen levels on diameter of plant varied significantly at different stages of development, although the rate of change in diameter varied. The diameter of plant increased with the decrease in soil moisture tension and increase in nitrogen levels. The highest diameter of plant was always associated with 0.3 atmosphere soil moisture tension and 120 kg N/ha at different stages of development.

The highest and lowest diameters of plant for both varieties were at 0.3 atmosphere soil moisture tension with 120 kg N/ha and 0.9 atmosphere soil moisture tension with 0 kg N/ha respectively.

The green weight of plant increased with the decrease in soil moisture tension and increase in nitrogen levels. The highest green weight was at 0.3 atmosphere soil moisture tension with 120 kg/ha application of nitrogen in all stages of development in both the seasons.

The dry weight of plant increased with the decrease of soil moisture tension in both the seasons. The highest and lowest dry weights of plant were associated with 0.3 atmosphere and 120 kg N/ha and 0.9 atmosphere soil moisture tension with 0 kg N/ha respectively.

While the highest leaf area index (LAI) was observed under 0.3 atmosphere soil moisture tension in all stages of growth, it gradually decreased with the increase in soil moisture tension in both the seasons. The LAI was largely influenced by the application of nitrogen in both the seasons. The LAI also varied

significantly with the varieties. N. tabacum had higher LAI in all the stages of growth.

The relationship between the leaf area measured and the product of length and maximum width was observed linear with the regression line passing through the origin of co-ordinates. The average co-efficients for N. tabacum and N. rustica were found 0.6964 and 0.7918 respectively. The influence of soil moisture tension and nitrogen levels on leaf co-efficient was pronounced.

Although the influence of soil moisture tension on the yield of tobacco varied with seasons, the maximum yield was recorded under 0.3 atmosphere soil moisture tension in both the seasons. The yield of tobacco increased significantly with the decrease in soil moisture tension. The relationships between leaf yield averaged over two seasons and soil moisture tension for both the varieties were given by the following equations :

N. tabacum

$$Y = 21.386 - 7.128 M + 1.773 M^2$$

N. rustica

$$Y = 21.465 - 23.363 M + 12.759 M^2$$

where,

Y = Yield of leaves, q/ha

M = Soil moisture tension, atmosphere.

The leaf yield increased significantly with the increase in

nitrogen levels in both the seasons and the lowest leaf yield was under 0 kg N/ha. With the increase in nitrogen level from 0 kg/ha to 120 kg/ha, the average increase in leaf yield was 74.18 per cent. The relationships between the leaf yield and levels of nitrogen were given by the equations :

N. tabacum

$$Y = 13.79 + 0.068 N - 0.000015 N^2$$

N. rustica

$$Y = 8.49 + 0.065 N - 0.000056 N^2$$

where,

Y = Yield of Leaves, q/ha

N = Nitrogen levels, kg/ha.

While the yield of stalk in lower soil moisture tension was significantly higher than that of higher soil moisture tension, the yield of stalk was significantly higher under 0.3 atmosphere soil moisture tension. The yield of stalk was increased significantly with the increase in nitrogen levels.

While the highest leaf yield was at 0.3 atmosphere with 120 kg N/ha, the lowest leaf yield was at 0 kg N/ha with 0.9 atmosphere soil moisture tension for both varieties.

The influence of variety, soil moisture tension and nitrogen on nicotine content was significant in both the seasons. A significantly higher per cent of nicotine content was with N. rustica. With the increase in soil moisture tension, nicotine content

increased. The nicotine content increased significantly with the increase in nitrogen levels.

The relationship between total evapotranspiration and yield was linear.

Two equations (one for N. tabacum and the other for N. rustica) were developed for estimating evapotranspiration of tobacco using weekly average data of measured evapotranspiration, temperature, wind velocity, sunshine hours, vapour pressure deficit, soil moisture tension and nitrogen.

N. tabacum

$$E_T = 7.1678 - 0.3377 (T) + 0.4540 (W) + 0.2643 (S) \\ - 0.0139 (e_s - e_a) - 3.3330 (M) + 0.0018 (N)$$

N. rustica

$$E_T = 5.7214 - 0.3371 (T) + 0.5632 (W) + 0.3607 (S) \\ - 0.0356 (e_s - e_a) - 2.9300 (M) + 0.0032 (N)$$

where,

E_T = Evapotranspiration rate, mm/day.

T = Mean air temperature, °C.

W = Average wind velocity, km/hr.

S = Hours of bright sunshine.

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

M = Soil moisture tension, atmosphere.

N = Nitrogen, kg/ha.

The significance of these equations were verified by the analysis of variance.

The following equations were developed for prediction of leaf yield using soil moisture tension and nitrogen :

N. tabacum

$$Y = 16.8999 - 5.0008 (M) + 0.0659 (N)$$

N. rustica

$$Y = 14.4709 - 9.9679 (M) + 0.0716 (N)$$

where,

Y = Yield of leaves, q/ha

M = Soil moisture tension, atmosphere

N = Nitrogen, kg/ha.

The high value of F for both the equations in the analysis of variance indicated that the equations fitted the respective data reasonably well and to predict the probable yield of leaves of tobacco, from the soil moisture tensions and the nitrogen levels, these equations could be used during the relevant season under ecological conditions similar to this locality.

5.2 Conclusions

Evapotranspiration is not only influenced by temperature, wind velocity, sunshine hours, vapour pressure deficit and leaf area index but also is influenced by levels of nitrogen together with soil moisture tension. The influence of soil moisture tension was very pronounced. Therefore, in any evapotranspiration study, inclusion of climatic variables, soil moisture tension and levels of nitrogen is essential. While the relationship between

evapotranspiration and climatic variables is linear, that between evapotranspiration and stages of growth is curvilinear.

In the absence of evapotranspiration study, pan evaporation data can be used in predicting evapotranspiration using the ratio of E_T/E_0 .

Growth characters like height of plant, diameter of plant, green weight of plant, dry weight of plant, ^{and} leaf area index are largely influenced by the soil moisture tensions and nitrogen levels. All these growth characters increase with the decrease in soil moisture tension and increase in nitrogen levels and the maximum growth is at 0.3 atmosphere soil moisture tension with 120 kg N/ha.

The co-efficient for leaf area largely depends on the geometric shape of leaf and variety.

The yield of leaf as well as stalk increases significantly with the decrease in soil moisture tension and increase in nitrogen levels. The maximum yield is obtained by maintaining soil moisture tension at 0.3 atmosphere with 120 kg N/ha. The response due to the application of nitrogen on the yield of tobacco is found quadratic.

The quality character, that is, nicotine content is influenced by soil moisture tension and nitrogen levels. So, these two inputs should be applied carefully because the market value of

tobacco is largely controlled by its quality.

The equations developed for prediction of evapotranspiration rate from tobacco (N. tabacum and N. rustica), may be used considering climatic variables, soil moisture tension and nitrogen levels.

The equations developed for prediction of leaf yield of N. tabacum and N. rustica may be used with different soil moisture tension and nitrogen levels.

CHAPTER VI

FUTURE SCOPE OF RESEARCH

FUTURE SCOPE OF RESEARCH

Further research investigation may be undertaken for tobacco cultivation in the following lines :

1. Evapotranspiration study should include measurement of actual stomatal aperture under soil moisture tension and nitrogen levels.
2. Because of limitations to experimental facilities, the soil moisture tensions and nitrogen levels could not be increased further. This requires further extension to evaluate optimum levels for these two vital inputs for tobacco cultivation.
3. Crop study is not complete unless its economic aspects are studied properly. Hence economic optimisation of different inputs needs proper study for this crop along with agronomic optimisation.
4. Crop study in relation to inputs of incident solar energy and total heat sum needs evaluation. Hence tobacco cultivation in relation to these inputs requires proper investigation.
5. Evaluation of suitable crop growth models for tobacco cultivation incorporating all the inputs directly and indirectly influencing its growth and development.

CHAPTER VII

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