EFFECT OF SEASONAL CHANGES IN SOIL MOISTURE, ATMOSPHERIC HUMIDITY, AMBIENT TEMPERATURE AND RADIATION ON SHOOT WATER STATUS, GROWTH AND YIELD OF FOUR CLONES OF TEA, *Camellia sinensis* L.

By

HERMAN OKORO ODHIAMBO

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT
FOR THE DEGREE OF MASTER OF SCIENCE IN HORTICULTURE
OF THE UNIVERSITY OF NAIROBI

1991

DECLARATION BY THE CANDIDATE

The work reported in this thesis is based on my original work and ideas. It has not been presented for a degree in any other University. All assistance from colleagues and friends is acknowledged.

Signed .... Date 21/1/92

Herman Okoro Odhiambo

DECLARATION BY THE UNIVERSITY SUPERVISORS

This thesis has been submitted for examination with our approval as University Supervisors.

Signed .... Date 21/1/92

Dr Julius O Nyabundi

Signed .... Date 21/1/92

Dr James A. Chweya

DEDICATION

This work is dedicated to my mother Rosalina whose guidance formed the foundation on which we continue to build.

ACKNOWLEDGEMENTS

I would like to convey my sincere thanks to the Director and Board of the Tea Research Foundation of Kenya for providing the funds which facilitated this thesis.

My warm gratitude goes to my supervisors, Dr Julius Omondi Nyabundi and Dr James Chweya, for providing the ideas which shaped up the thesis.

I would like to thank Dr John Orchard of ODNRI and Mr Wilson Ng'etich of Crop Environment department (TRFK) whose assistance with instrumentation and whose constructive comments greatly helped in ensuring the shaping up and success of the project.

I am greatly indebted to the Technical staff of both Agronomy and Crop Environment departments of the Tea Research Foundation, who assisted in many ways throughout the course of the project.

I am grateful to Mr Joseph Mosonik for typing the thesis. The final typesetting by computer was done by Mary Ombasa, and to her I am very grateful.

Finally I am deeply indebted to my family, especially the children who had to endure many lonely hours when both parents were away.

CONTENTS

LIST OF TEXT

List of Tables

List of Figures

List of Plates

ABSTRACT

Studies on the effects of soil moisture, ambient temperature, atmospheric humidity and radiation on the yields of four commercial Kenyan tea clones were undertaken. The experiment was laid out in an established tea field of clones 6/8, 31/8, S15/10 and 57/15. This was a randomized complete block design replicated three times. The results of the study show that temperature was the main factor which limited the yields of tea at Timbilil Estate, Kericho, Kenya (altitude 2170m a.m.s.l.) during the 24 months of this experiment. Soil moisture and high vapour pressure deficits (VPD) reduced yields in the hot-dry period between January and February. The tea clones gave variable response to these climatic factors. Clone 6/8 was susceptible to low soil moisture and high vapour pressure deficits and consequently it had low shoot water potential, reduced rates of shoot extension, relatively low shoot density, low rates of shoot regeneration and lower yields than clones 31/8, S15/10 and 57/15 between January and February when high VPD and low soil moisture prevailed.

There was an increase in yields between October and December of both years when nearly 32% of the total annual yields were recorded. This was in response to the favourable environmental conditions. The high air temperatures, low soil moisture and low vapour pressure deficits were favourable between October and December.

Among the yield components the rates of shoot extension and the number of shoots per unit area and partly the rates of shoot regeneration varied with changes in climate while the mean shoot weights remained largely unchanged.

When subjected to the Multiple regression analysis, the combined effect of the yield components, namely, the rates of shoot extension, the number of shoots per unit area, the mean shoot weights and the rate of shoots regeneration had highly significant (P=0.01) relationship with clonal tea yields, but the effects of individual components was highly variable and did not relate with the yield potentials of clonal teas.

CHAPTER 1

1.1. GENERAL

1.1. 1 INTRODUCTION

Tea (*Camellia sinensis* (L) O. Kuntze) is a widely grown crop with cultivation ranging from as far north as 49°N (Outer Carpathians, USSR) and as far south as 33°S (Natal, South Africa) (Huang Shoubo, 1989). In Kenya, tea is grown in the highlands between 1500m and 2200m a.m.s.l. It is an important source of foreign exchange. The total value of tea export for 1989 was $ 2.6 billion (ITC 1990) making tea the leading crop in foreign exchange earnings. Apart from the foreign exchange earning the tea industry offers a sizeable employment opportunity in the agricultural sector offering a livelihood to more than 1 million people. Increased and sustainability of productivity of the tea industry is necessary for the continued provision of these services. But there is intense competition among cash crops themselves and with the food crops for the available land. Furthermore, the high potential land available for crop production in general is decreasing due to increasing population. It is therefore necessary to improve the productivity of the already cultivated land in order to raise the crop yields per unit land area. New planting where possible should also be done with improved plant cultivars which have high yield potentials and well adapted to the areas of production.

There are two main varieties of tea cultivated in East Africa. *Camellia sinensis* var *assamica*, the Assam tea and *Camellia sinensis* var *sinensis* or the china tea (Othieno 1978^a). The two varieties hybridize freely and several hybrids of the two are grown mainly in old seedling fields. Many improved cultivars have been developed from clonal selection within existing varieties. Visual selection of vigorous looking plants have been effected and the selected plants multiplied vegetatively (Green 1970).

One of the major factors which has hindered rapid cultivar improvement of tea is lack of proper criterion for clonal selection (Magambo 1983). In the areas of the world where tea is grown the seasonal growth of shoots differ. Large fluctuations in yields have been reported in Malawi, North East India , Japan and Soviet Union (Kulasegaram and Kathiravetpillai 1974). Flushes of very high yields that often lead to problems of leaf handling have been a recurrent problem for the tea Industry during peak seasons especially in the smallholders in Kenya. This often over stretches both the factories and the transportation of leaf to KTDA during such seasons. In Kericho at the Tea Research Foundation only 15% of the annual crop was produced in the first three month of the year 1989 while 36% of the crop was produced in the last quarter of the year (Odhiambo 1989[a]). The main problems arising from these seasonal yield fluctuations of the tea crop are: reduced annual yields, difficulties in planning the annual labour requirement due to fluctuating demand for labour and inability to utilize tea factories efficiently due to over supply of crop during peak periods and lack of crop during off-season (Tanton 1981). Lack of knowledge of the mechanisms by which basic environmental factors influence tea shoot growth fluctuations has severely limited the development of methods to control these variables (Tanton 1979). Some tea plant attributes have been shown to influence tea yields. They include the harvestable shoot size, the number of shoots per unit area and their rate of growth (Tanton 1979). Squire (1979) showed that the number of shoots per unit area and their weights may be important in determining yields between clones. The seasonal variation in yields was determined by the shoot growth rate and the occurrence of bud dormancy at different magnitudes during the year. Kulasegaram and Kathiravetpillai (1974) showed that seasonal yield variations mainly occurred due to differences of the number of shoots per unit area. Tanton (1982[a]) suggested that the study of clonal differences in shoot growth patterns could give an indication of varietal differences which could be exploited to alleviate seasonal yield differences. This could result in the utilization of the maximum potential yields of a particular tea cultivar in the most adaptable environment. Some of the environmental factors which have been implicated in shoot growth fluctuations are: temperature (Carr *et al* 1987), humidity (Tanton 1982), soil moisture (Stephen and Carr 1989), daylength (Barua 1969 & Laycock 1969) and radiation (Gogoi 1976). Smith *et al* (1990) and Stephens and Carr (1990) emphasized the need to establish the relationship between yield components and the elements of climate. The most important agro-meteorological factors thought to affect the yields and the distribution of yields in Kenya are: soil moisture, atmospheric humidity, radiation and temperature all of which tend to change mainly with changes in rainfall. There is need to understand how these factors cause fluctuations in clonal tea yields in order to institute more efficient management and the yield fluctuations.

1.2 OBJECTIVES OF THE STUDY

The objectives of this study are:

1. To undertake a comprehensive investigation of the response of yields and yield component of the four Kenyan tea clones to seasonal changes in humidity, soil moisture, temperature and radiation
2. To correlate the variation in components of yield of different clones with clonal yields and attempt to explain how the seasonal variations in yield components influence the yield distribution of the 4 tea clones.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The tea plant *Camellia sinensis* (L) O. Kuntze is a small shrub which when allowed to grow freely reaches a height of 5-10m (Magambo 1983). Under commercial cultivation the tea bush is manipulated into a flat topped shrub of 0.6 to 1.5m for ease of management. The tea crop is grown for it's young tender shoots that are used in making beverage tea. Tea harvesting is done at regular intervals of between 7 and 21 days throughout the year depending on the weather. The components determining the yield of tea are the number of actively growing shoots per unit area, the extension rate of these shoots and the dry weight at harvest (Squire 1979 and Smith *et al* 1990). The variation in tea yield distribution throughout the year has been reported in many areas (Stephens and Carr 1990) in Tanzania, (Squire 1979) and Tanton (1982[b] in Malawi and Odhiambo (1989[a]) in Kenya. Stephen and Carr 1990 stated that in many parts of the world the tea crop exhibits marked fluctuations both between and within seasons with obvious repercussions to management. The study of causes of tea yield variations arising from various factors have been undertaken in many parts of the world (Squire 1979, Stephens and Carr 1989, Laycock 1969). In some of the studies, it has been suggested that it would be possible to understand causes of yield variations if relations between yield and it's components could be evaluated (Smith *et al* 1990).

Yield was first partitioned into it's components by Engledow and Wadham (1923). Later Engledow and Ramiah (1930) compared and contrasted three British wheat cultivars and ranked the cultivars with various yield attributes whereby such components as average yield/plant, yield per ear and grain size played an important role in genotypic yield differences. The study of yield components has created an understanding of how they can be manipulated either through breeding or management to improve yield and crop adaptability to various agroclimatic factors. (Lynch and Tai 1989; Ellen and Van Oene, 1989).

In tea, attempts have been made to correlate certain environmental responses such as temperature response to growth rate. (Stephens and Carr 1990) and the number of shoots per unit area to fertilizer rates (Odhiambo 1989^{b}). Smith *et al* (1990) suggested that differences between genotypes and the effect of environmental factors and management should be evaluated by examining yield components. In potatoes, Lynch and Tai (1989) showed that responses of various potato genotypes to water stress occurred as a result of variations in sensitivity of different components of yield of the potato cultivars. Ellen and Van Oene (1989) also showed that the components of yield of different spring barley varieties gave responses to light intensity. In tea Smith *et al* (1990) showed that different tea clones selected from two different climates i.e. Malawi and Kenya, had variable dry matter content and varied in the rate of shoot growth. Stephens and Carr (1990) in Tanzania reported that different genotypes of tea gave differences in annual yield mainly due to the number of shoots per unit area while the rate of shoot growth caused variation in seasonal yields.

By evaluating the effects of soil moisture, radiation, temperature and atmospheric humidity on the yield components of tea in Kenya it could be established not only how different genotypes respond to these factors but also how the yield components affect the yield potential and the distribution of yields of different clones of tea.

2.2. The effects of soil moisture, and plant water status on the yields and yield components of tea

As soils get drier, the availability of water decreases resulting in the reduction in the soil water uptake by the plants (Fitter and Hay 1981). Water stress resulting from reduced soil water availability reduces crop growth and productivity (Hsiao, 1973). In coconut palms Kasturibai *et al* (1988) reported that a prolonged dry spell lasting for three to six months affected the palm growth and yields. The degree of damage to the palm growth and yields however depended on the rainfall pattern, the soil conditions and the other environmental variables. In Kenya, Othieno (1978a) stated that although most tea areas in East Africa received adequate rainfall the distribution of the rainfall throughout the year was not always satisfactory. The plantations are subjected to dry periods varying in severity and duration, as a result of which there is severe yield reduction and poor crop distribution throughout the year. Carr *et al* (1987) reported that in Tanzania the annual rainfall in Mufundi tea area was between 800 and 900 mm, the majority of which falls in the period between mid-November and May. This leaves about six months without rainfall during which large soil moisture deficits develop. During the six months a maximum soil moisture deficit of 60 mm was accumulated. The length of time during which the crop stays under moisture stress and the total magnitude of the stress are important factors which affect crop growth and yields. Stephens and Carr (1989) proposed a stress time index based on the daily summation of the differences between the potential soil water deficits and a specified critical moisture limiting value of the tea crop. Carr (1974) reported in Tanzania that soil water deficits in excess of 100 mm over a whole dry period significantly reduced yields. The changes which arise in the potential soil moisture deficits with time demonstrates how differences in water stress develop over time under different regimes of soil moisture (Stephens and Carr 1989).

Different crop species and different cultivars of the same species give variable response to soil water deficits. Ackerson (1983) reported varietal differences in corn response to drought conditions and in the response of different developmental stages of the same varieties to drought. Katsuribai *et al*, 1988) reported genotypic differences in response to water stress in coconut and . Othieno (1978b) reported that there was variation in clonal tea response to water stress during the dry seasons. The clones which were more susceptible to water stress showed a greater demand for water than those which showed less susceptibility. The physiological processes which are important in crop adaptation, acclimation, tolerance and resistance to drought however are not well understood. This has caused difficulties in the development of more drought tolerant crops through plant breeding.

Although the amount of water used directly in the biochemical reactions of photosynthesis is small compared with that transpired or stored by plants at any one time, the plant water status strongly influences plant growth and biomass production (Coombs *et al*, 1985). This influence occurs through the effect of plant water status on root and leaf expansion. Plant growth is controlled directly by plant water status and only indirectly by atmospheric and soil water deficits (Kramer, 1983). Plant water stress refers to situations where cells and tissues are less than fully turgid. Injurious plant water stress however results from low leaf water potential which develops over long periods of time because of decreasing soil water supply. Miller *et al* (1971) reported that plant water status could be reliably indexed from the leaf water potential. The leaf water potential varies inversely with diurnal trends of air vapour pressure deficits and soil moisture content. Genotypic differences in response to plant water stress have been observed in many crops including sesame (Hall *et al*, 1975), sorghum (Henzel *et al*, 1975), wheat (Quarrie 1980), and tea (Othieno 1978^c). According to Othieno (1978^c), drought susceptible clones of tea had low shoot water potential during dry periods and when high atmospheric vapour pressure deficits prevailed. Squire (1979) reported that the extension growth rate of tea shoots stopped when the shoot water potential of tea was lower than -16 bars under high atmospheric vapour pressure deficits of 35 mbars, However, in Tanzania, yields reductions of tea in the dry periods coincided with the periods when the shoot water potential dropped below -7 bars (Carr 1974). From the reviewed text it appears that the critical level of shoot water potential which may initiate stress of tea plants vary depending on the humidity, soil moisture and temperatures of a given area.

2.2.2. Effect of saturated atmospheric vapour pressure deficits on the growth of the tea plant.

Studies have shown that there is an inverse linear relationship between atmospheric vapour pressure deficit and the internal water status of the tea plants (Squire 1979, Tanton 1982^b, Miller, *et al* 1971, William 1971).

The tea plant benefits from high atmospheric humidity (Eden 1965). Lebedev (1961) showed that high humidity reduced air temperature around the tea bush, improved the plant water balance and favourably affected many physiological processes resulting in five-fold increase in yield of irrigated tea over the unirrigated control. In China Huang Shoubo (1989) reported that high atmospheric humidity was favourable for the tea plants during the growth period. Squire (1979) reported that the hot and dry seasons in the tea growing regions were characterized by low yields, however even when the tea was irrigated, the yields never rose to the levels obtained in the hot-wet season because yield was restricted by high vapour pressure deficits. Tanton (1982^b) showed that the growth of tea in the dry season was much lower than that predicted by the linear model of shoot extension based on mean air temperature. (Tanton 1982^b) showed that mean vapour pressure deficit deficit had no depressive effects on the rate of shoot growth of tea until the weekly mean deficit at 1400 hrs was between 22-23 mbars. When the vapour pressure deficits increased above 23 mbars rates of shoot extension progressively decreased. Thus vapour pressure deficit which is a measure of saturation of water vapour of the atmosphere was a major factor which reduced yields of tea in Malawi during the hot dry season. This explained why irrigation was not effective in increasing yields in Malawi where the vapour pressure deficits were higher but was effective in Tanzania where the vapour pressure deficits were lower than those in Malawi. On lychee trees Menzel and Simpson (1986) reported that despite the timing of irrigation to avert high soil moisture deficits there was always heavy and excessive rates of fruit abortion in irrigated orchards that could be attributed to the state of the aerial environment. Othieno (1978c) reported that growth rates and yields of tea are often reduced in the dry period in East Africa when sometimes the potential soil moisture deficit reached 400 mm and the vapour pressure deficits were up to 25 mbars. Kasturibai *et al* (1988) showed in coconut palms that there was a relationship between vapour pressure deficits, air temperature and radiation, where a rise in radiation caused a rise in air temperatures and a more negative xylem water potential of coconut shoots.

2.3. Effect of Ambient Temperature on the growth of the tea plant

Temperature is a major factor determining the natural distribution of plants and the success and timing of agricultural crops (Lange *et al*, 1981). Habitats occupied by plants show dramatic differences in temperature during the periods of active growth and in the same habitat individual plants are subjected to wide seasonal and diurnal fluctuations in temperature. Higher plants are normally unable to maintain their cells and tissues at a constant optimum temperature and therefore their leaves, stems and branches are normally within a few degrees of the surrounding air and soil (Fitter and Hay 1981). Because of this the growth and metabolism of plants are profoundly affected by the changes in environmental temperature.

In the tea crop temperature is an important factor determining the rate of growth and the limits to commercial production (Harler 1966). Various workers have undertaken studies on the growth response of the tea crop to different components of environmental temperature. Lebedev (1961) postulated an optimum temperature of 22°C and Eden (1965) stated the mean monthly temperatures for maximum growth of tea should be in the range 18-29°C. Green (1971) stated that poor yields were associated with the number of days with temperatures below 21°C or above 36°C in Malawi.

Different genotypes of tea have given variable yield and shoot growth responses to environmental temperature. Squire and Callander (1981) stated that whereas the number of shoots per unit area was the main discriminant for differences in yield between varieties the rate of growth caused by differences mainly in air temperature resulted in differences in seasonal growth of shoots. Stephens and Carr (1990) observed in Tanzania that there were clonal differences in base temperatures for shoot extension. The variations in base temperature between clones could be attributed to methods and techniques used in clonal selection. Tanton (1982^{a}) showed that shoot growth rate should be related to accumulated mean temperature and shoot extension rates be described by a linear relationship when the shoots are between 5 and 15cm. However the rate of shoot extension from the time of bud release to harvestable size was said to be best expressed by an exponential curve.

Although temperature is the most commonly measured environmental variable, the thermal regime of plants is often inadequately characterized. This is because the temperature most often used to characterize the plant growth response is the air temperature. The air temperature is usually measured in a standard environmental enclosure (Lange *et al*, 1981). Plant tissue temperature of the soil should determine the suitability of a particular soil environment for crop production.

Osmond *et al* (1980) observed in general terms that regions which may have the combination of low soil temperatures and low nutrient availability always had higher root/shoot ratios. In Taiwan, Wu and Kao (1954) studied nine meteorological parameters and five varieties of tea and reported that soil temperatures at the depth of 20cm below the grass surface had the largest single effect on tea shoot growth. However, Aono *et al* (1983) in Japan, recorded very fast rate of shoot growth with low soil temperatures of 5°C and high air temperatures of 15°C under glasshouse conditions. Tanton (1982^b) conducted a trial in winter in Malawi where the heated soil was kept constant at 25°C while the maximum and minimum temperatures for control was 18.7°C and 18.1°C at a depth of 15cm where he did not find any differences in shoot growth rate due to the soil temperature. In Kenya, Othieno (1978^a observed that mulch raised the soil temperature measured at 7.5cm below grass surface from 15°C to 18°C and consequently increased shoot growth rate and yields. Tanton (1982^b) attempted to explain the differences between his results and Othieno (1978^a) that the soil temperatures in Kenya are below those in Malawi and could be in the region where yield response is possible with rise in temperature.

2.4. Effect of radiation on the growth and yield of tea

In natural plant environments radiation originates either from the sun or from terrestrial sources. Light considered as energy, reaches maximum input on clear days with minimum particulate matter or water vapour in the atmosphere (Fitter and Hay 1981). The main effects of flux density occur on the processes that use light as an energy source-photosynthesis rather than on those which use light as an environmental indicator. Fitter and Hay (1981) indicated that for most plants photosynthesis becomes light saturated at flux densities well below the maximum they occasionally experience, largely due to the problems of CO_2 supply mainly in the tropics.

If a radiant flux at the surface of a plant is known, photosynthetic or morphogenic responses of the plant can be predicted from physiological models (Lawlor 1987). Studies of light interception within plant canopies and its relationship with yield have provided a scientific basis for crop improvement and advances in crop management (Braun *et al*, 1989). many studies have been done on how light is converted into chemical energy, however little attention has been paid to the way in which leaves intercept light. even in the simplest of canopies, light absorption is affected by many variables such as: leaf angle, the sun's elevation in the sky, the finite width of the sun's disks, changes in the spectral distribution of photosynthetically active radiation through the canopy and the arrangement of leaves in the canopy (Coombs *et al*, 1985). Plants absorb photosynthetically active radiation in the wavelength range of 400-700 nm. The interception of PAR varies with plant cultivars specifically due to differences in canopy structure (Coombs *et al*, 1985). Calculation of canopy photosynthesis from the amount of incoming photosynthetically active radiation forms a central part of most crop growth simulation models. However a lot of assumptions are to be made when making light measurements on crop canopies because of the many factors which affect light interception (Spitters (1986). The light profile within the canopy is determined by the amount of light entering the top of the canopy and the extinction efficiency of the different radiation components.

The improvement of the incident light interception by plant canopies could tremendously improve yields. In the tea plant studies on the effect of light intensity on yields have been undertaken by several workers (Huang Shoubo 1989, Gogoi 1976, Hadfield 1975). In Malawi, Squire (1979) indicated that radiation in the month of May was 90% of the monthly average in the hot wet season of the tea growing areas, and leaf area index of well managed plantations was usually greater that six throughout both hot wet and cool seasons. But the cool season yields were much lower, suggesting that the small seasonal changes in the amount of radiation could not have accounted for the yield differences. Huang Shoubo (1989) reported that when CO_2 concentration, temperature and water were favourable, the photosynthetic rate of tea increased in proportion to the light intensity within a certain range. Growth analysis of young teas of different cultivars revealed that the net CO_2 assimilation rate was linearly related to the log of light intensity from 20 to 100% in all the cultivars (Gogoi, 1976). In India Hadfield (1974) reported that for a range of tea varieties, radiation was reduced by 99% within 30cm of the plucking table while in Malawi, Green (1971) reported that only 5% of the incoming radiation reached the ground. In Kenya, Callander and Woodhead (1981) reported that the net sum of the energy fluxes below the ground was 4% of net radiation while Obaga (1986) reported differences in total light penetration within different tea varieties.

2.5. Reasons for the study

From the reviewed texts, there emerges a need to establish the relationship between components of yield of various genotypes of tea and the stated agrometeorological factors. The study should also undertake to establish how each factor influences the components of yield with the view to ascertaining how these affect the clonal yield potential and the monthly yield distribution.

There is for example, conflicting evidence on the effect of soil moisture deficits and air temperatures on the rates of shoot extension and number of shoots per unit area as given in the texts reviewed. There is also clear difference in clonal tea response based on the geographical location of an area which suggests that the results realized in one area may not be reproducible in another. Similarly there were clonal differences as emerged from different responses reported in different crop cultivars.

Consequently it is important that such studies be taken for the range of clones grown under Kenyan conditions to establish if the components of yield of tea could be used as indicators of the yield potentials of clonal teas grown in Kenya and how the stated agrometeorological factors would influence changes in these yield components during different seasons of the year.

CHAPTER 3

MATERIALS AND METHODS

3.1. Experimental site

The experiment was conducted at the Tea Research Foundation of Kenya, Kericho, Kenya. The Foundation is situated about 40 km south of the equator at the altitude of 2178m a.m.s.l. with coordinates 0° 22'S and 35°21'E. The rainfall pattern was described by Othieno (1978^{a}) as weakly bimodal with totals of 2160mm per year, on average and a crop factor of 0.85 Eo (Laycock 1964). The soils were derived from a massive flow of phonolite lava and Kaolinite, is the predominant clay. According to the U.S.A. soil taxonomy, the soils are classified as humic nitisols. The experiment was done on an established field of clones 6/8, 31/8, S15/10 and 57/15. It was laid out in a randomized complete block design and replicated three times. The analysis of variance was done on Harvard Personal Computer.

3.2. Measurements of temperature, radiation and humidity

A battery-operated 21X Micro-logger (Campbell Scientific Limited, USA) (plates 1 and 2) was set at the experimental site to record humidity, temperature and radiation data. The Micro-logger has eight differential inputs or up to sixteen single-ended inputs using the differential channels. The programming on measurements was done according to the 21X Micro-logger Operator's Manual (Campbell Scientific Ltd, 1989). All the readings were stored into an ordinary cassette recorder from where decoding was done on Harvard micro-computer.

PLATE 1: (1) The 21X Micro-logger (Campbell Scientific Ltd. USA),
(2) An ordinary cassette recorder and
(3) the Millivolt integrators recording radiation, soil, air and plant tissue temperatures and saturated vapour pressure deficits of the atmosphere.

PLATE 2: Close-up of 21X Micro-logger showing thermistors connected to the channels. (Note the reading from one of the thermistors showing the air temperature).

Temperatures

Air, soil and leaf tissue temperatures were taken with type-T Copper-constantan thermocouples.

1. Tissue temperatures

For each clone, one shoot was selected on the leaf axil of the first leaf facing the west. The shoots were pierced with the thermocouples which were driven to a depth of 2mm. The tissue temperatures were continuously recorded at 2-second intervals and 30-min averages were recorded in the logger and later on stored onto an ordinary cassette recorder.

2. Soil temperature

Similar thermocouples as used for tissue temperature were dug into the soil at a depth of 10cm and the output connected to the logger.

3. Air temperature

Air temperature was also measured with a thermocouple which was shielded and placed just above the canopy.

3.2.2. Radiation

The interception of light was estimated using a series of tube solarimeters (Delta-T. Devices, U.K.) (plate 3). The photosynthetically active radiation was measured by a pair of 1m long total and filtered tube solarimeters. The pair of tubes were placed side by side parallel to each other at 10cm above the plucking table. The total tube solarimeter measured the total solar irradiance while the filtered tube responded to the infra-red light 700nm. The difference between the two being the visible light in the wavelength (400-700nm). At 30cm below the plucking table for each clone was placed a total solar tube. This region represents the area of maximum light extinction for the tea bush (Hadfield 1975).

The total radiation was recorded at this point and the difference between the total radiation above the canopy and at the point of maximum extinction represented intercepted net radiation. The photosynthetically active radiation available within the intercepted net radiation was derived from the ratio of total to filtered light above the canopy. The reflectance of the tea canopy was obtained by placing a total reflectance tube 1m above the plucking table and the canopy reflectance solarimeters were connected to Millivolt intergrators (Delta-T devices, U.K.). The total irradiance over the total experimental period was recorded in the integrators and computations done later to determine net irradiance.

PLATE 3: Tube solarimeters measuring (1) Reflected radiation and (2) Total intercepted incident radiation and filtered incident radiation (0.7 µn to 2.5 µn) to give PAR (0.4 - 0.7 µn). Note: Total tube solarimeters are placed 30cm below the plucking table of each clone to measure maximum canopy extinction.

3.2.3. Saturated atmospheric vapour pressure deficits

The relative humidity was recorded by two methods. The continuous recordings were taken by the micro-logger while the accuracy of the data was counter-checked at two-week intervals using as Asman's Psychrometer (plate 4 and 5).

Thermocouple sensors were connected to the logger and on the other end were connected to wet and dry bulb thermometers. The thermometers were protected from rainfall and direct radiation by a small screen. They were placed at about 20cm above the plucking table. The readings were recorded by the Micro-logger at 30 min intervals. The data was stored in ordinary cassette recorders where it was transferred whenever the memory was full.

3.3. Asmans phsychrometer

To confirm the reliability of the logged data, an Asmans Psychrometer (Cassella London) (plat 4 and 5) was used to record the diurnal temperature at hourly intervals once every two weeks. The psychrometer consists of one wet bulb and one dry bulb thermometers held side by side but screened from each other and protected from the environment. Air is drawn past the sensors by means of a miniature fan housed together with the thermometers. The wet sensor is cooled by evaporation and the resulting temperature difference between the two sensors can be converted into relative humidity or vapour pressure deficit. The psychrometer is set 5cm above the plucking table for relative humidity recording.

PLATE 4: A pressure chamber (plant water status console Model 3005, Soil Moisture Equip. Corp. USA) (left), and Asman's Psychrometer (Cassella London) (right). Measuring the xylem water potential of the tea shoots and vapour pressure deficits of the atmosphere, respectively.

PLATE 5: A close-up of the Asman's Psychrometer showing the chambers holding the wet and dry bulb thermometers and the housing for the miniature fan on extreme right.

PLATE 6: A close-up of the pressure chamber showing the chamber measuring gauge on the right and the cylinder in which the shoots are inserted for xylem water potential measurements, left.

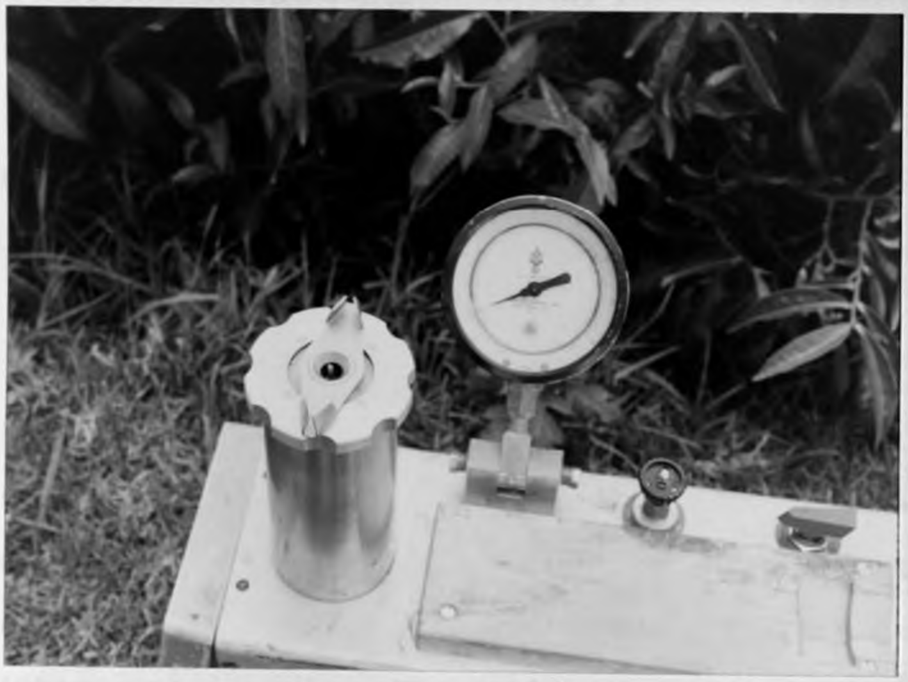


PLATE 7: Tightly closed chamber with the small piece of shoot being measured protruding above the lid.

3.4. Xylem water potential

From each clone, ten shoots were selected at random. At an interval of two minutes each shoot was excised at two leaves and a terminal bud stage. The shoot was fitted through a pressure chamber (plant Water Status Console Model 3005, Soil Moisture Equip. Corp. U.S.A.) (Plates 4,6 and 7), the shoot was sealed air tight with the cut end projecting through the lid. The instrument was then pressurized using nitrogen. As the pressure increased the sap moved to the cut end where it could be seen. The pressure at which the liquid just wet the surface was recorded. The pressure equals that which existed in the root before it was severed from the main plant. The records were taken at hourly intervals for a whole day on clear days. The recordings were done at weekly intervals.

3.5. Soil moisture

Soil samples for gravimetric moisture analysis were taken at 15 and 60cm soil depth. The soils were augered and placed into air-tight containers. They were transferred to the laboratory where the initial weights were recorded. The soils were then placed in the oven and dried at 105°C for 48 hours and thereafter weighed. The results were expressed as percentages of dry weight of the soil. The soil samples were taken every two weeks.

3.6. Plant measurements

3.6.1. Shoot density

The number of shoots per unit area from each clone was recorded using a $0.25m^2$ square grid. On each harvesting day the grid was randomly thrown onto the plucking table three times. All the shoots captured within the grid were counted and weighed.

3.6.2. Rate of shoot growth.

3.6.2.1. Rate of internode extension

The rate of internode extension was recorded from 5 uniform shoots per bush selected on three bushes per treatment. The shoots were selected when the first normal leaf was just unfolding. The rate of internode extension was then measured at an interval of three days until the shoots grew to a pluckable shoot size of two leaves and a terminal bud. After plucking the shoots were weighed, the leaf areas and the bud lengths also measured.

3.6.2.2. Rate of shoot regeneration

Five shoots were tagged when at one leaf and a terminal bud stage on each treatment. The growth of these shoots were followed until they matured into pluckable shoots of two leaves and a terminal bud. Once a shoot got ready for plucking it was replaced by another at the same stage of one leaf and a terminal bud as the previous shoots. The number of generations of these shoots in a year was recorded.

3.6.3. Mean shoot weight

The mean shoot weight (weight of individual shoots) was obtained as the weight of shoots in quadrat divided by the total number of shoots in the quadrat.

3.7. Yields

The total crop harvested from each plot was recorded and converted by the factor 0.225 into dry weights. The yield accumulated over the year was then converted into yields made tea per ha/year.

CHAPTER 4

RESULTS

4.1.1. VAPOUR PRESSURE DEFICITS (SVPD), XYLEM WATER POTENTIAL OF CLONAL TEA, RAINFALL AND CUMULATIVE POTENTIAL SOIL MOISTURE DEFICITS

Monthly rainfall was low in January averaging 35 mm/month for the two years (Figure 1). Vapour pressure deficits were high with an average midday maximum of 21.5 mbars in the months of January and February within the two years (Fig. 19). From the weather patterns in 1989 and 1990, the months of January and February were hot and dry because rainfall in February (200 mm) came in the last week of the month of February whereas vapour pressure deficits were high throughout the two months 21.5 mbars. Large soil moisture deficits averaging 86 mm prevailed in January for both years. The period between March and September 1989 and 1990 were cool and wet, with the average monthly rainfall of 183 mm the saturated vapour pressure deficits of 11.8 mbars and mean air temperature of 15.4°C (Fig. 3a). During this period, there was only very minor soil moisture deficits averaging 8.8 mm between June and July for both years. The months of October to December in 1989 and 1990 were warm and wet with an average rainfall of 151 mm/month, the average midday atmospheric vapour pressure deficit of 14.3 mbars and average air temperature of 16.5°C. There was a minor soil moisture deficit of about 21 mm on the average between November and December of the two years.

There were clonal differences in shoot water potential of clonal teas. The shoot water potential of clone 6/8 recorded during this period was below -10 bars while those of clones 31/8, S15/10 and 57/15 remained above -10 bars. Between March and December of the

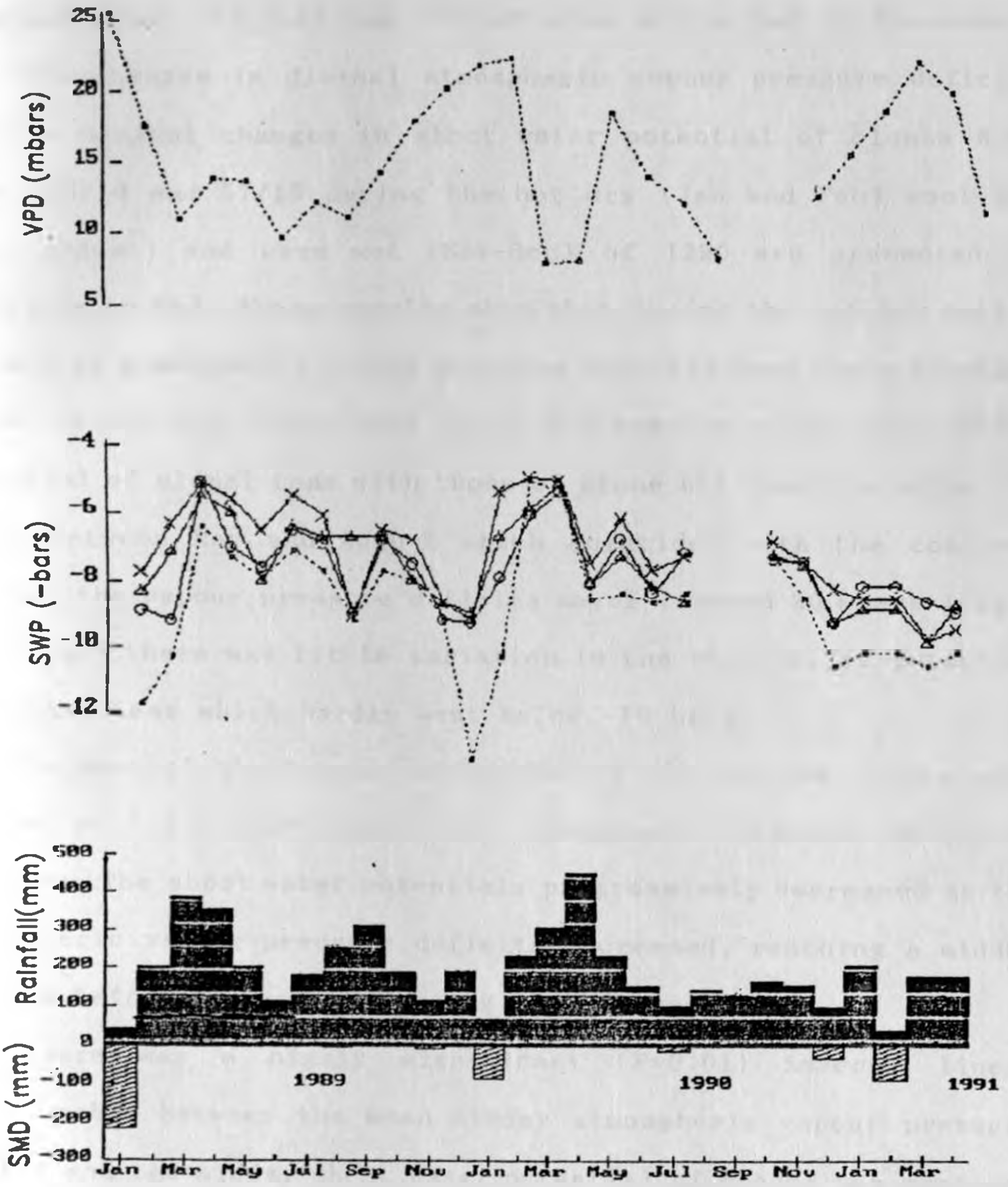


Fig 1: Monthly midday maximum vapour pressure deficit (VPD) and shoot water potential (SWP), monthly rainfall and cummulative soil moisture deficits (SMD), February 1989 to April 1991.

—•— 6/8 —×— 31/8 —△— 15/10 —○— 57/15

two years the shoot water potential of all the four tea clones remained above -10 bars and did not show any marked differences.

The changes in diurnal atmospheric vapour pressure deficits and the diurnal changes in shoot water potential of clones 6/8, 31/8 S15/10 and 57/15 during the hot dry (Jan and Feb) cool wet (July-August) and warm wet (Nov-Dec) of 1990 are presented in Tables 2a to 2h). These results show that during the hot dry period the midday atmospheric vapour pressure deficits were above 20 mbars (Figs. 2a and 2b). There were clonal differences in the shoot water potential of clonal teas with those of clone 6/8 reaching below -10 bars. Between May and August which coincided with the cool-wet period, the vapour pressure deficits never reached 20 mbars (Figs. 2c-2f) and there was little variation in the shoot water potential of clonal teas which hardly went below -10 bars.

In general shoot water potential of all the tea clones were highest at 7.0 o'clock when the atmospheric pressure deficits were low. The shoot water potentials progressively decreased as the atmospheric vapour pressure deficits increased, reaching a midday maximum before tailing off during the afternoon.

There was a highly significant (P=0.01) inverse linear relationship between the mean midday atmospheric vapour pressure deficit and the midday shoot water potential of clonal tea measured between February 1989 and December 1990 (Figs. 2i and j). The higher the midday atmospheric vapour pressure deficit the lower was the shoot water potential of clone 6/8. This general trend was similarly observed for all the other clones but only clone 6/8 was presented so as to avoid unnecessary crowding of similar data.

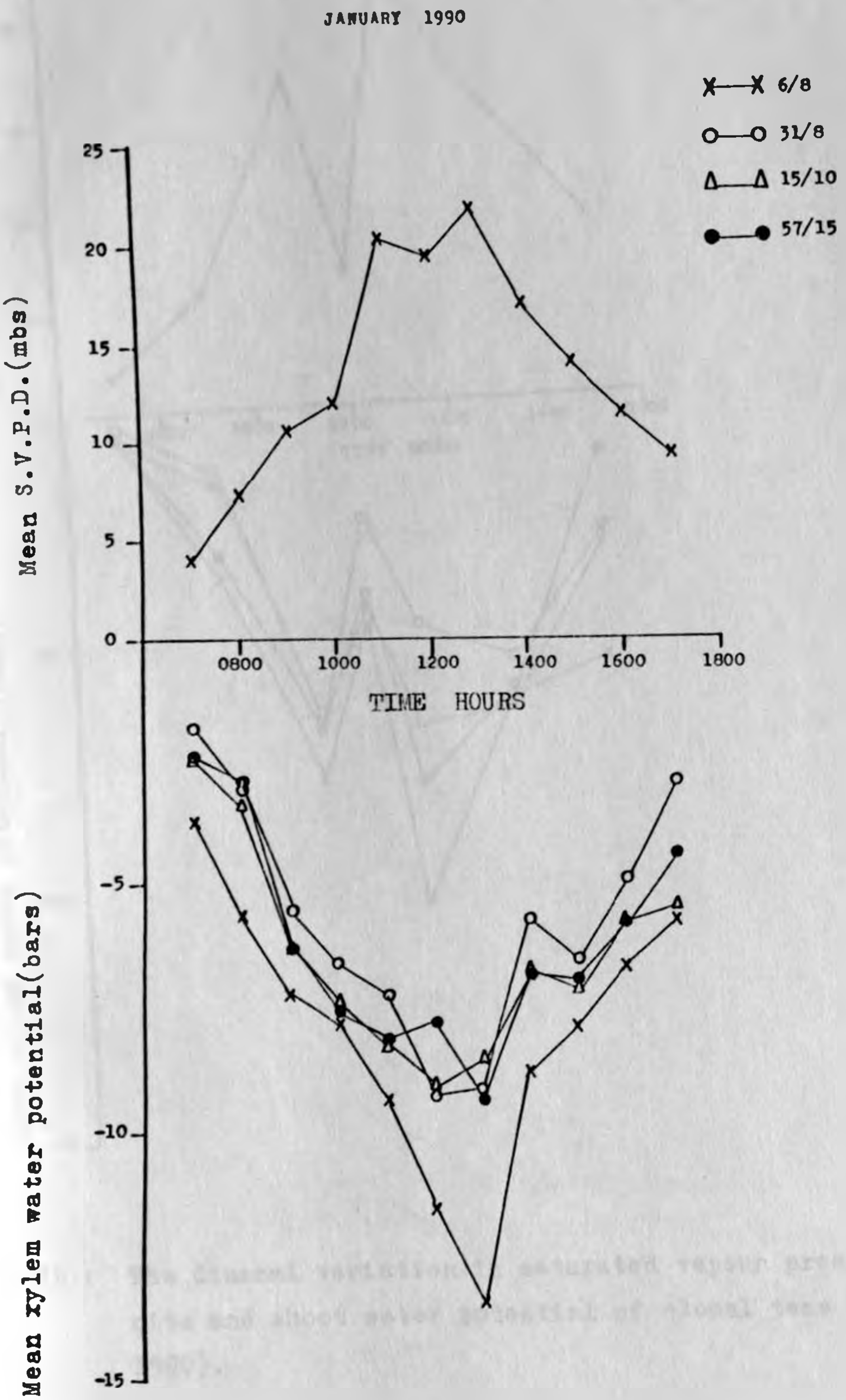


Fig. 2a : The diurnal variation in saturated vapour pressure deficits and shoot water potential of clonal teas (January 1990).

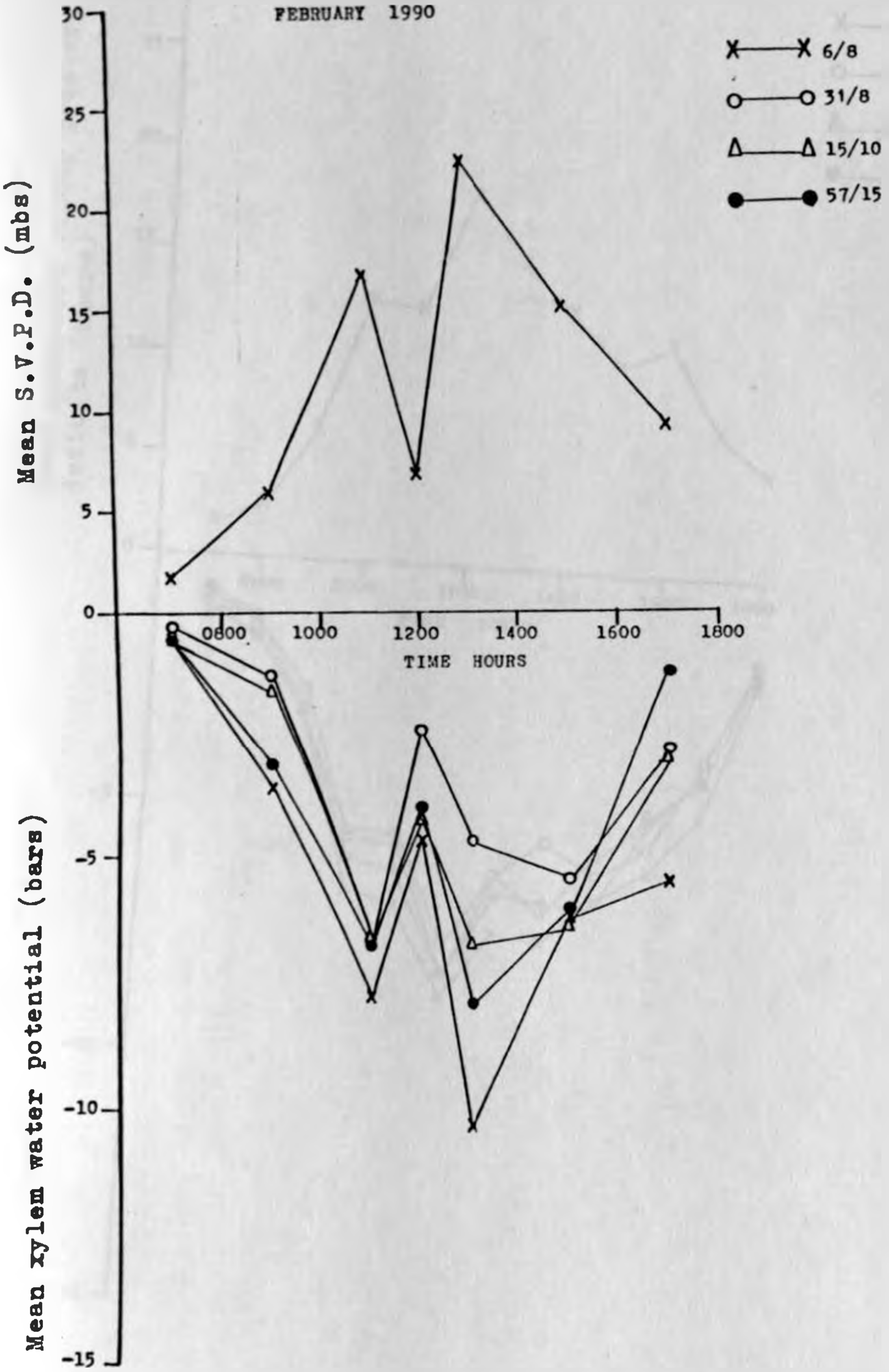


Fig. 2b : The diurnal variation in saturated vapour pressure deficits and shoot water potential of clonal teas (February 1990).

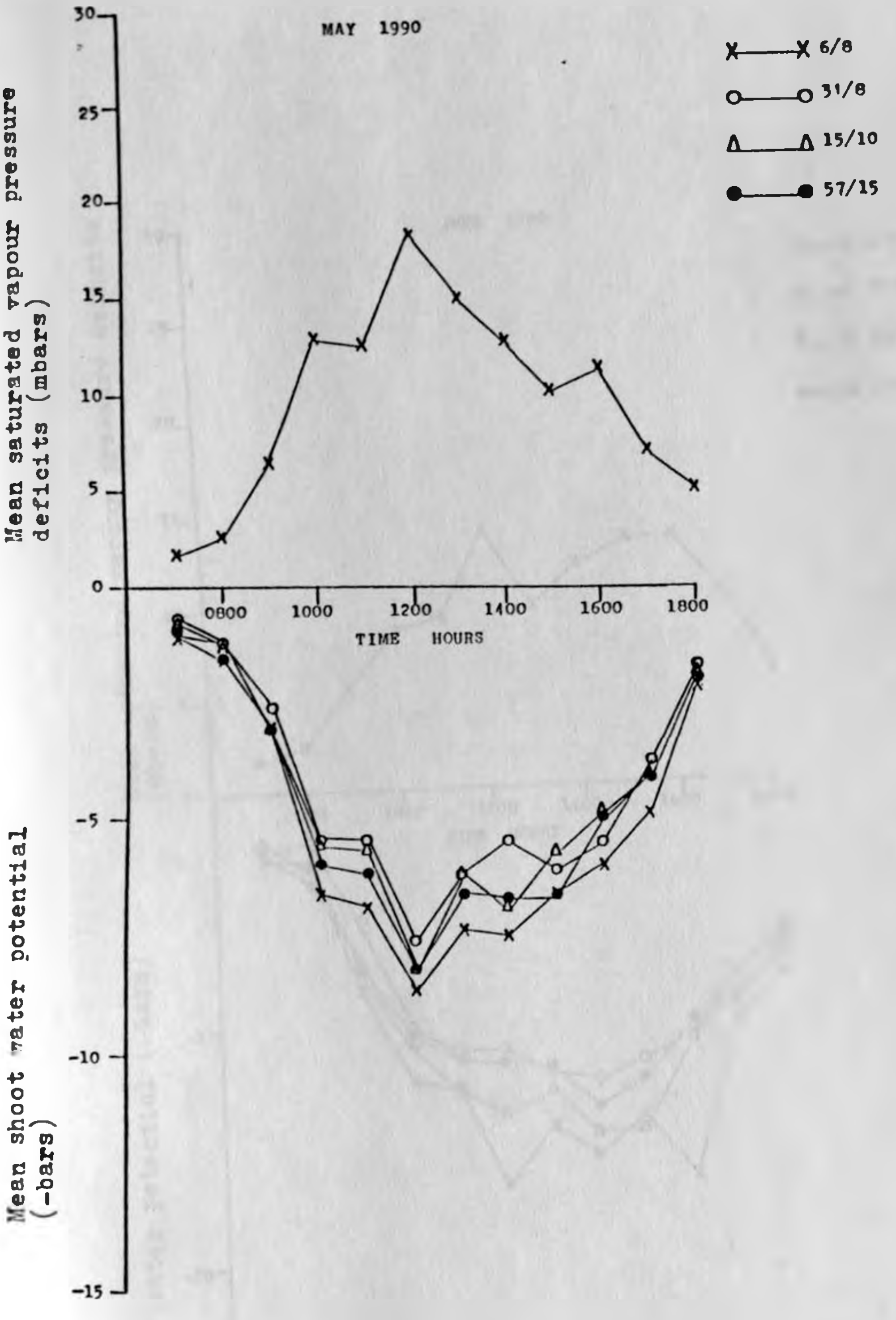


Fig. 2c : The mean diurnal variations in saturated vapour pressure deficits and shoot water potential of clonal teas (May 1990)

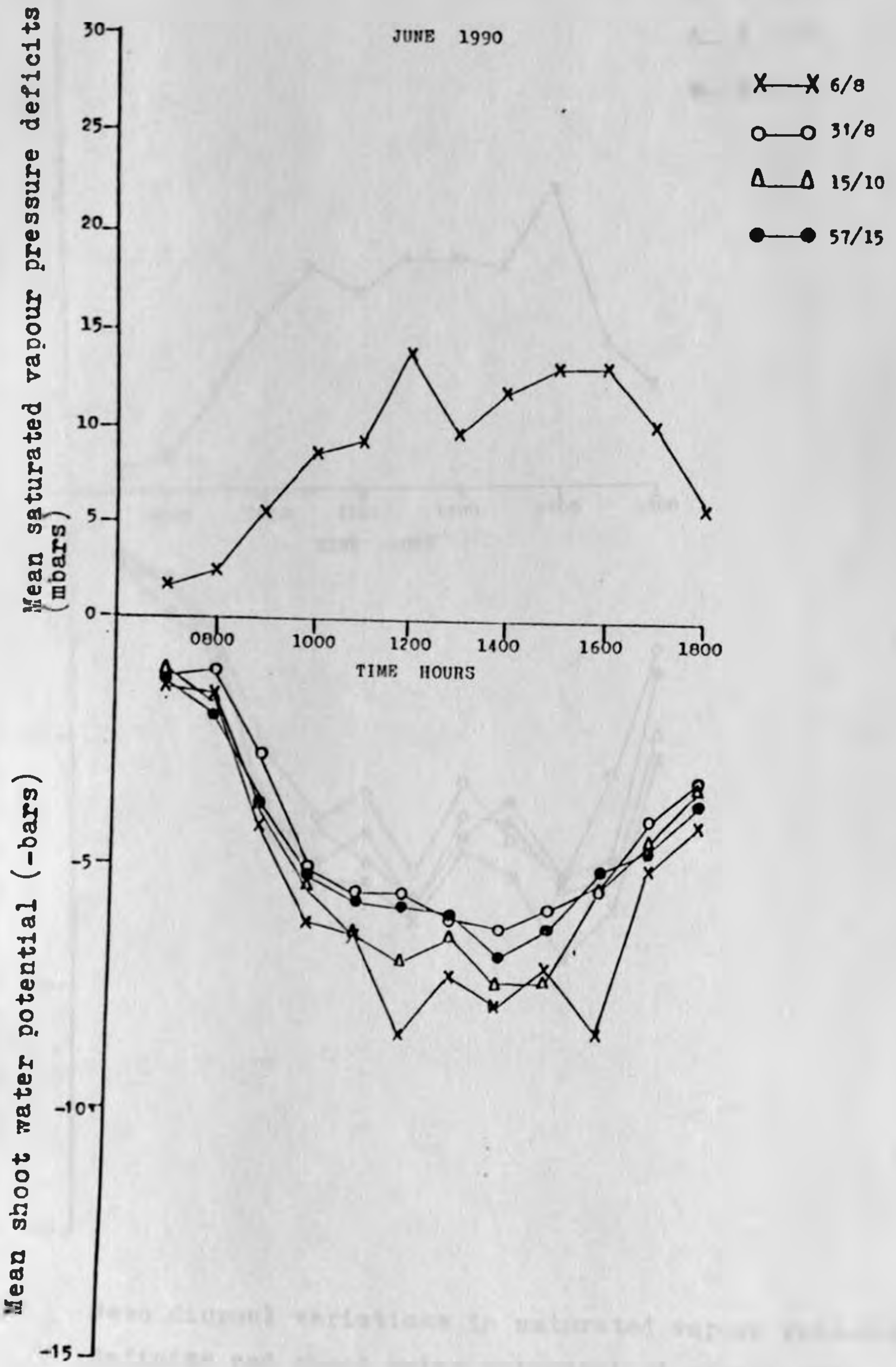


Fig. 2d : The mean diurnal variations in saturated vapour pressure deficits and shoot water potential of clonal teas (June 1990)

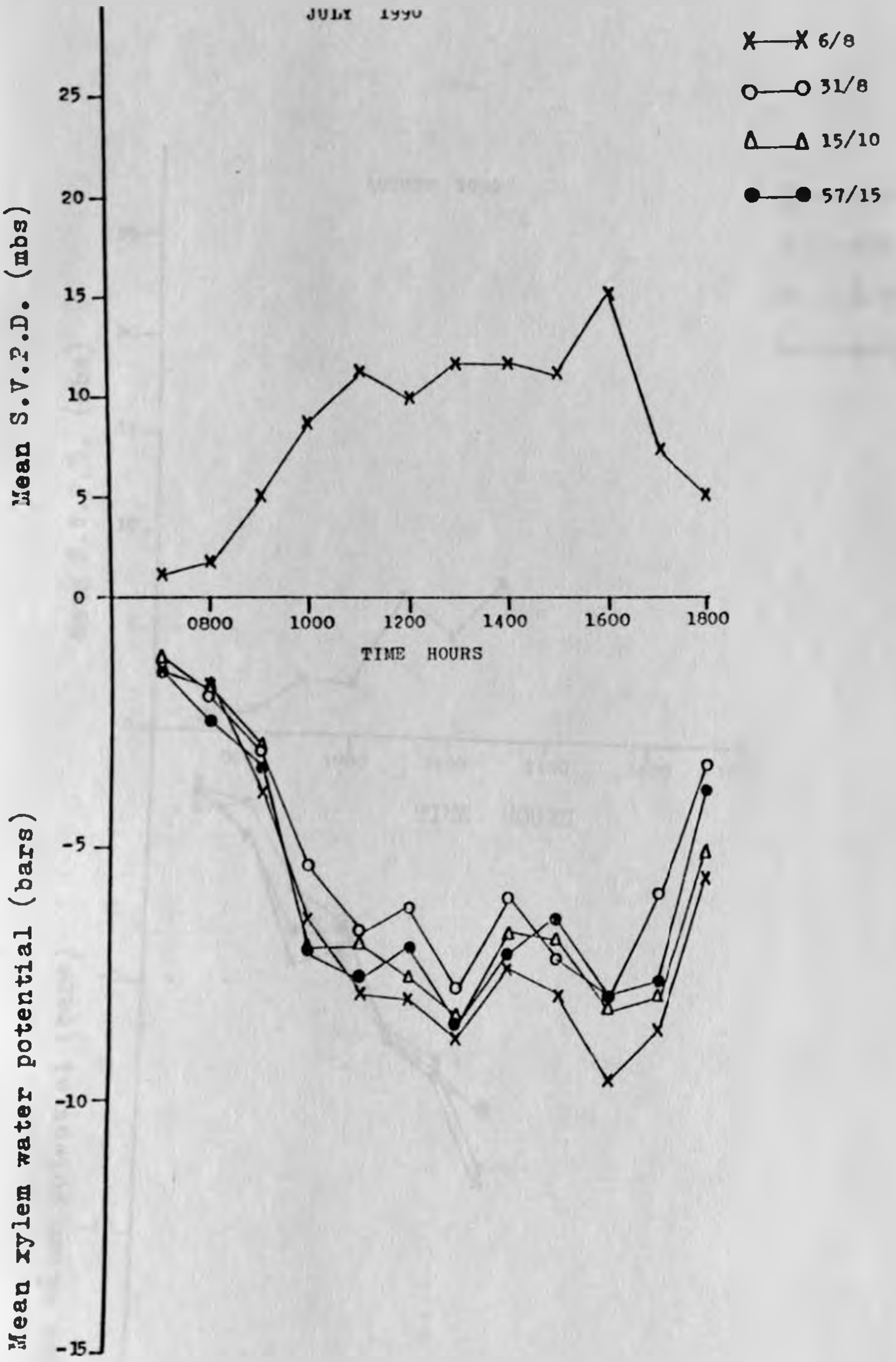


Fig. 2e : Mean diurnal variations in saturated vapour pressure deficits and shoot water potential of clonal teas (July 1990).

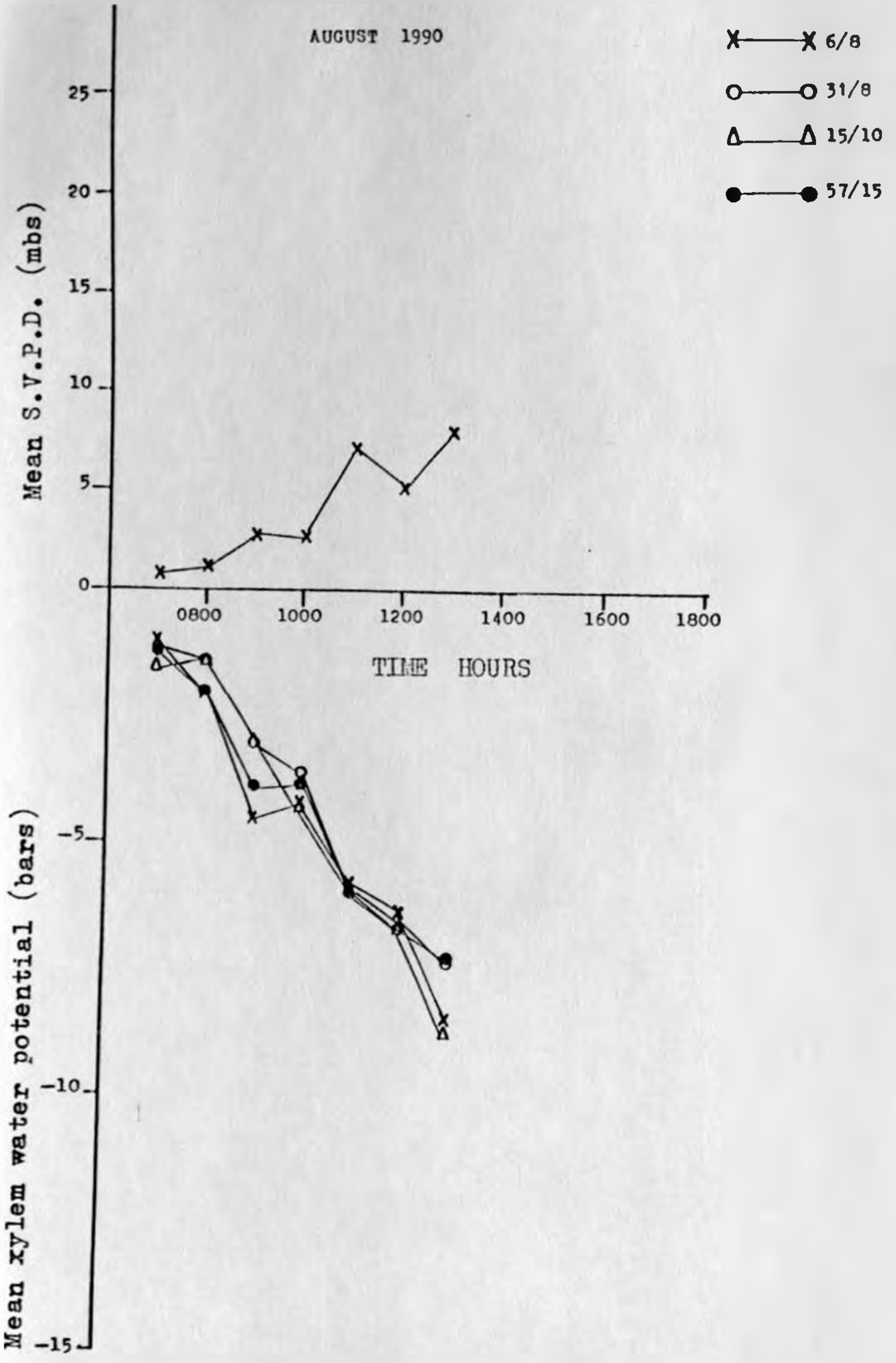


Fig. 2f : The mean diurnal variations saturated vapour pressure deficits and shoot water potential of clonal teas (August 1990).

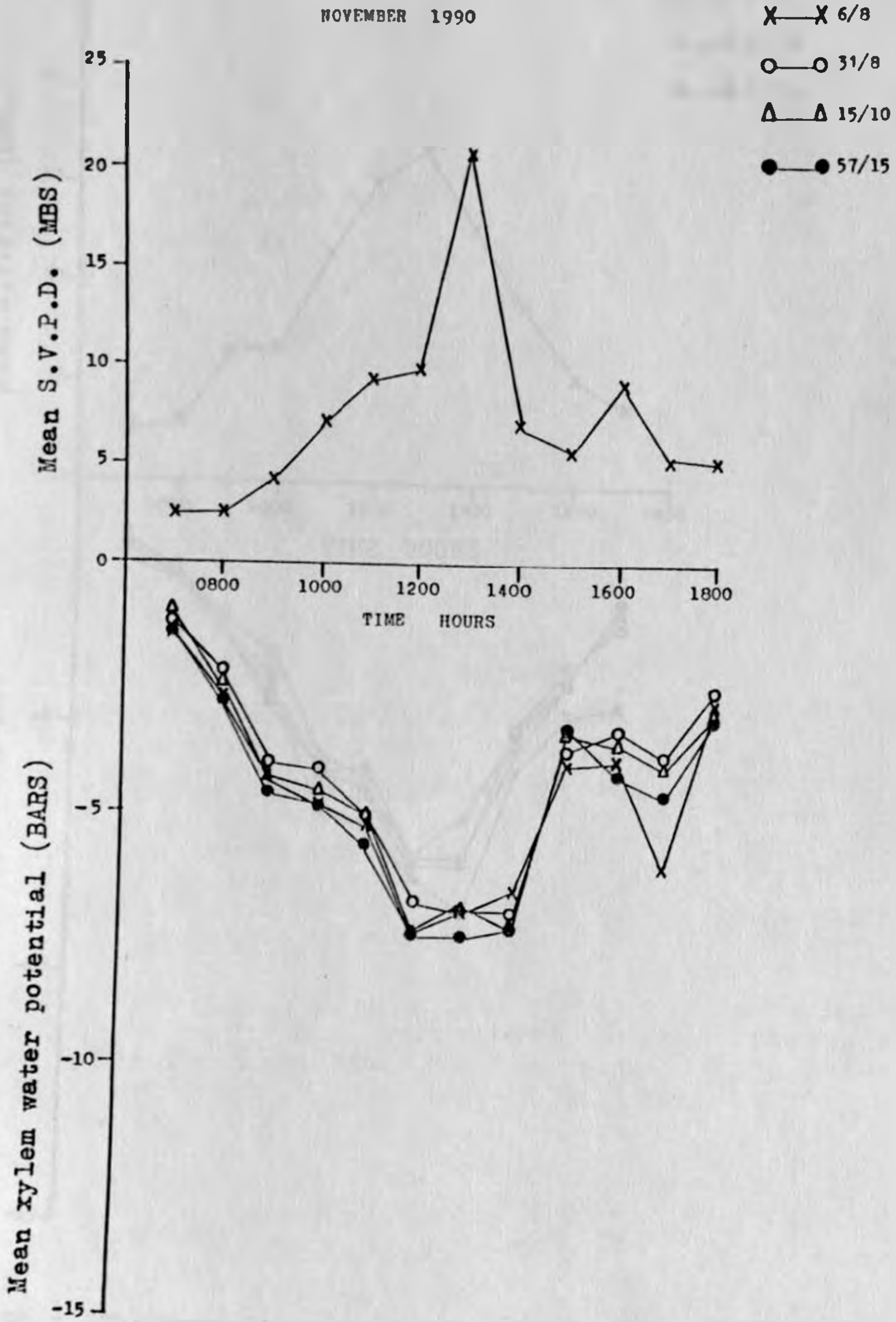


Fig. 2g : Mean diurnal variations in saturated vapour pressure deficits and shoot water potential of clonal teas (November 1990).

December 1990

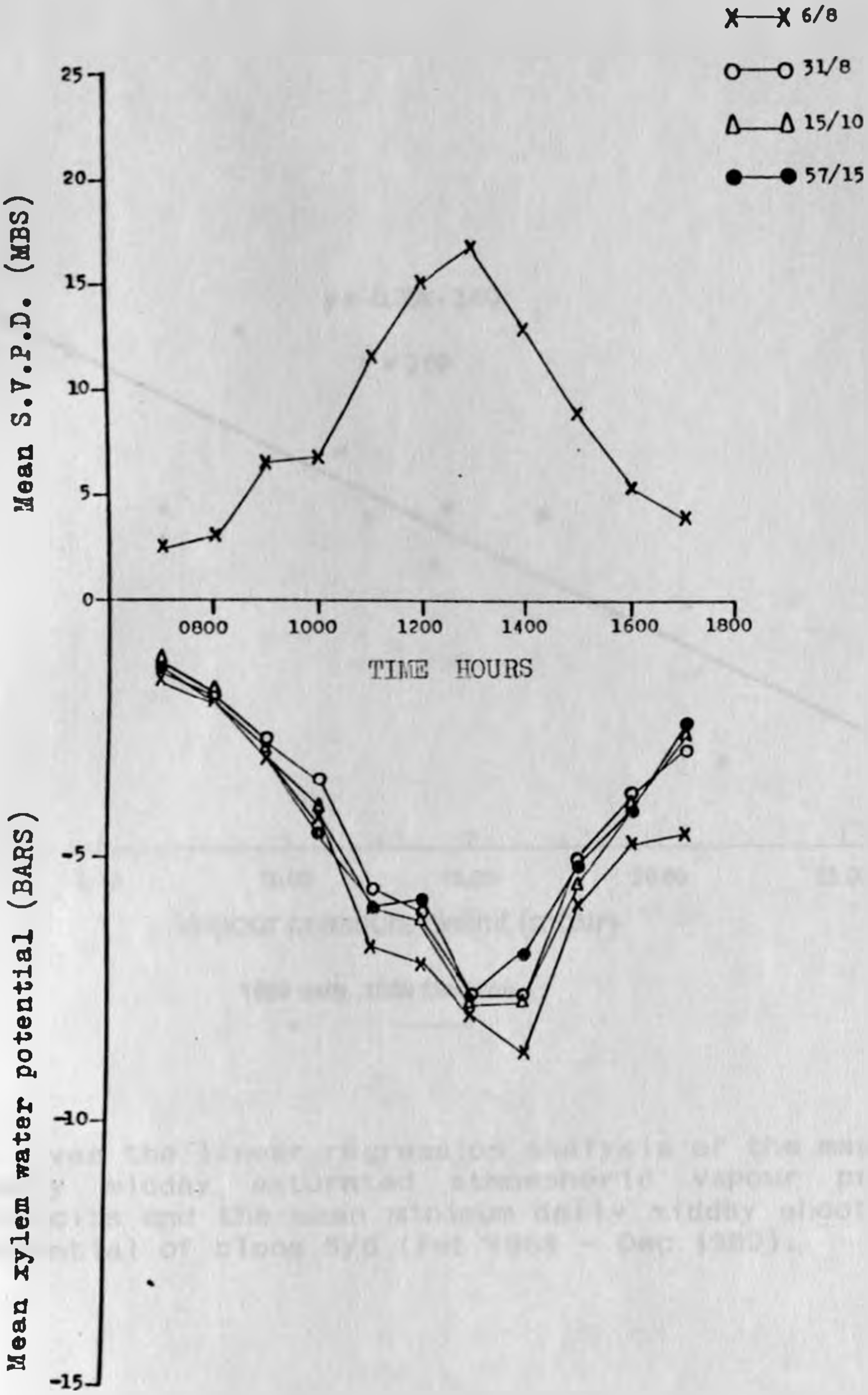


Fig. 2h : The mean diurnal variations in saturated vapour pressure deficits and shoot water potential of clonal teas (Dec. 1990).

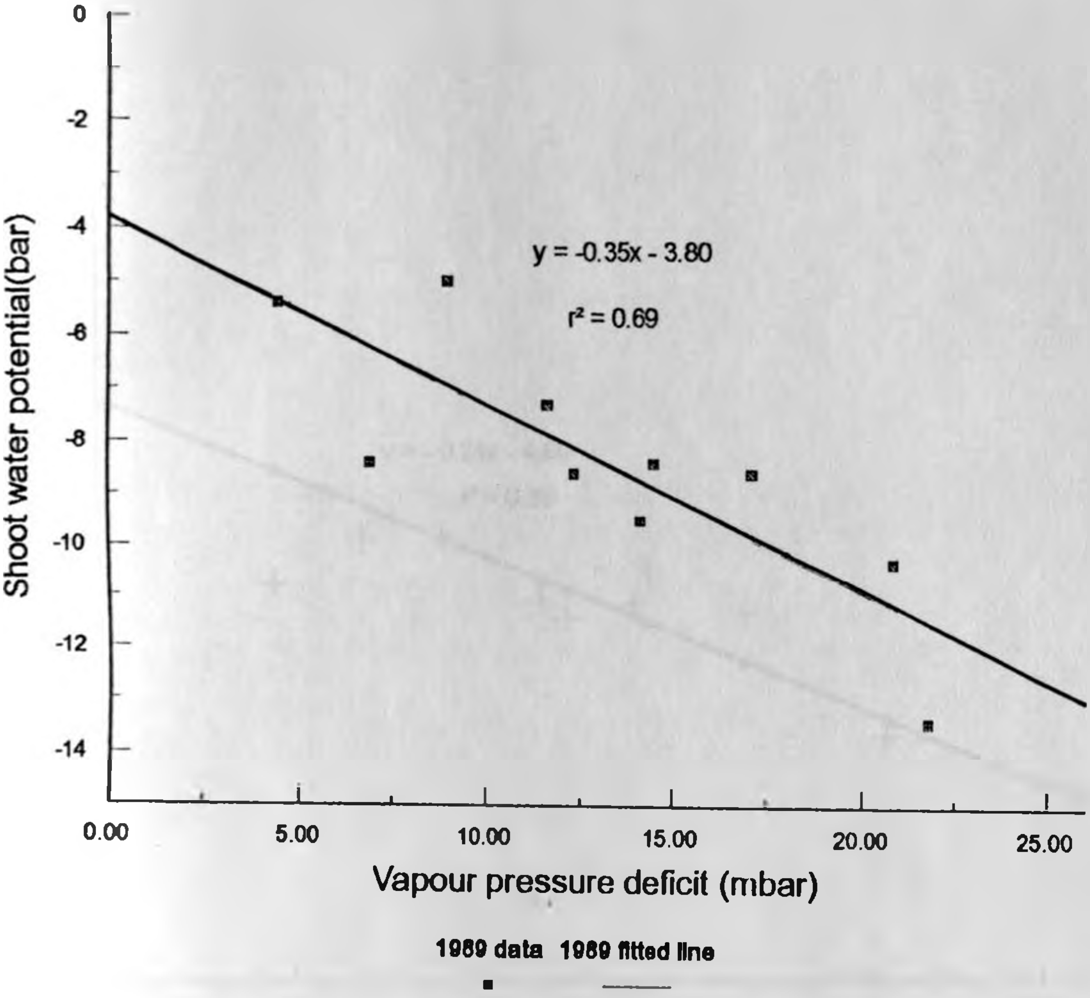


Fig.2i gives the linear regression analysis of the mean maximum daily midday saturated atmospheric vapour pressure deficits and the mean minimum daily midday shoot water potential of clone 6/8 (Feb 1989 - Dec 1989).

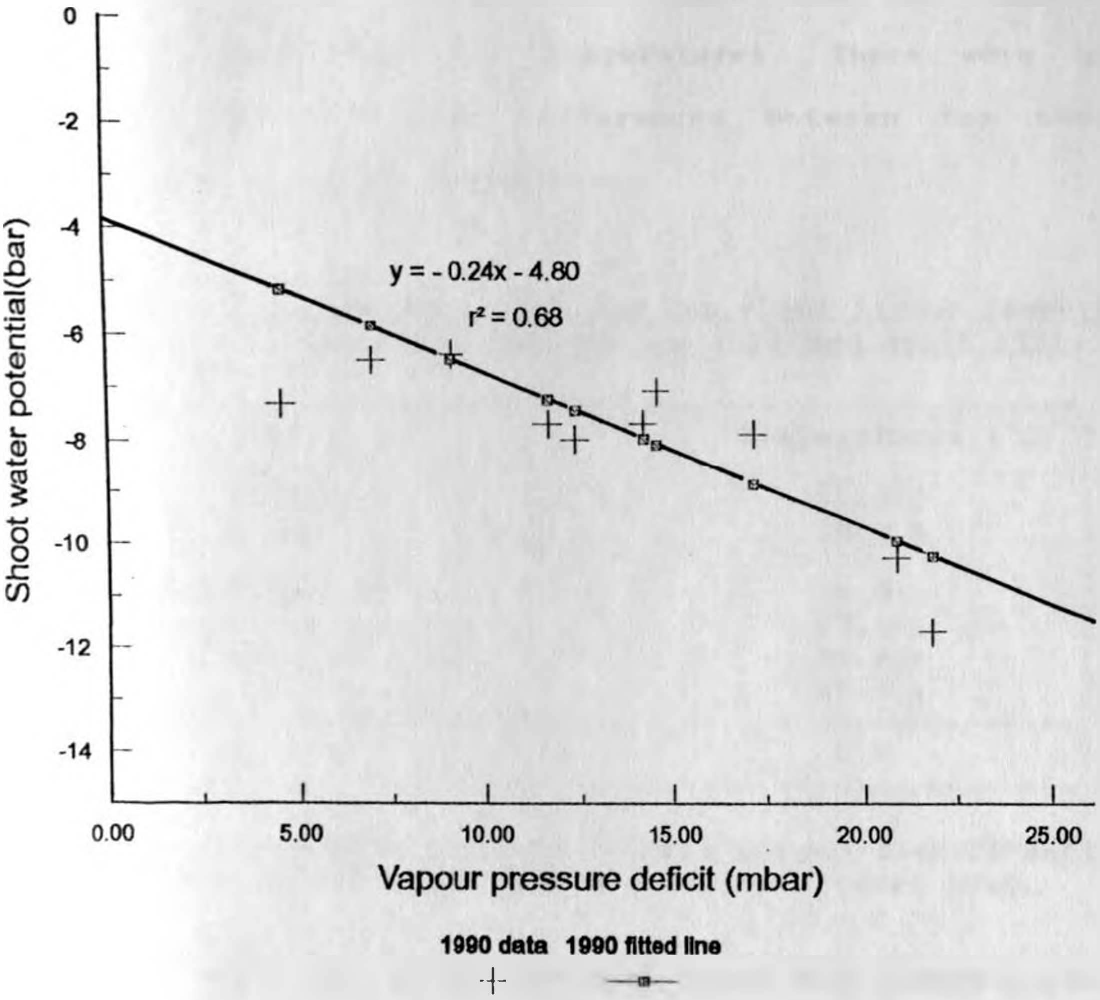


Fig.2j The linear regression analysis of the maximum daily mean midday saturated vapour pressure deficits and the minimum daily shoot water potential of clone 6/8 (Jan 1990 - Dec 1990).

4.2. TEMPERATURE

4.2.1. The Mean Air, Soil and Tea Shoot Tissue Temperatures °C

There were significant (P=0.05) differences between air, soil and tea shoot tissue temperatures (Table 1). The tea shoot temperatures were on the average 1.5°C higher than soil temperatures and 2.5°C higher than air temperatures. There were however no significant (P=0.005) differences between tea shoot tissue temperatures among themselves.

Table 1: The mean air, soil and tea shoot tissue temperatures (°C) measured between May 1989 and April 1991.

		Temperatures (°C)
	Air	15.3 C
	Soil	16.3 B
Tissues	6/8	18.0 A
	31/8	17.6 A
	S15/10	17.8 A
	57/15	17.8 A
	C.V. %	3.8

Numbers followed by the same letters are not significantly (P=0.05) different according to Duncan's Multiple range test.

Figure 3(a) gives the mean daily air temperatures for each month for the period January 1989 to December 1990. The results show that daily mean air temperatures above 16°C were recorded in January and February 1989 and 1990. Between April and September 1989 and May and August 1990, the mean daily air temperatures were below 16°C. For the remainder of the periods in both years mean daily air temperatures were above 16°C, but were not as high as those recorded in the first quarter of the year.

Figures 3(b)-3(f) give the diurnal changes in photosynthetically active radiation (PAR), the air, soils and plant tissue temperatures recorded in the months of January, February (1991), and July, September and December (1989). These months represent the hot-dry cool-wet and warm-wet seasons. The results show that there was a midday peak in photosynthetically active radiation. The peak of the PAR varied according to the season being lowest in the cool-wet season while there was minimal difference between the February and December peaks.

The diurnal changes in air, soil and plant tissue temperatures also varied depending on the seasons. The highest mean air temperatures were recorded between 11.00 and 15.00 hours in the hot-dry season, while the lowest were recorded during the cool-wet season. In general air temperatures increased to a midday maximum and then declined in the afternoons. On the other hand, the soil and tissue temperatures decreased to a minimum between 8.00 and 11.00 hrs after which there was a rapid increase reaching a maximum between 13.00 and 19.00 hrs. The maximum soil and tissue temperatures on the average were 9.0°C above the maximum air temperatures while the lowest tissue and soil temperatures were on the average 5.5°C below the minimum air temperatures.

In general the higher the PAR, the higher were the plant tissue, air and soil temperatures.

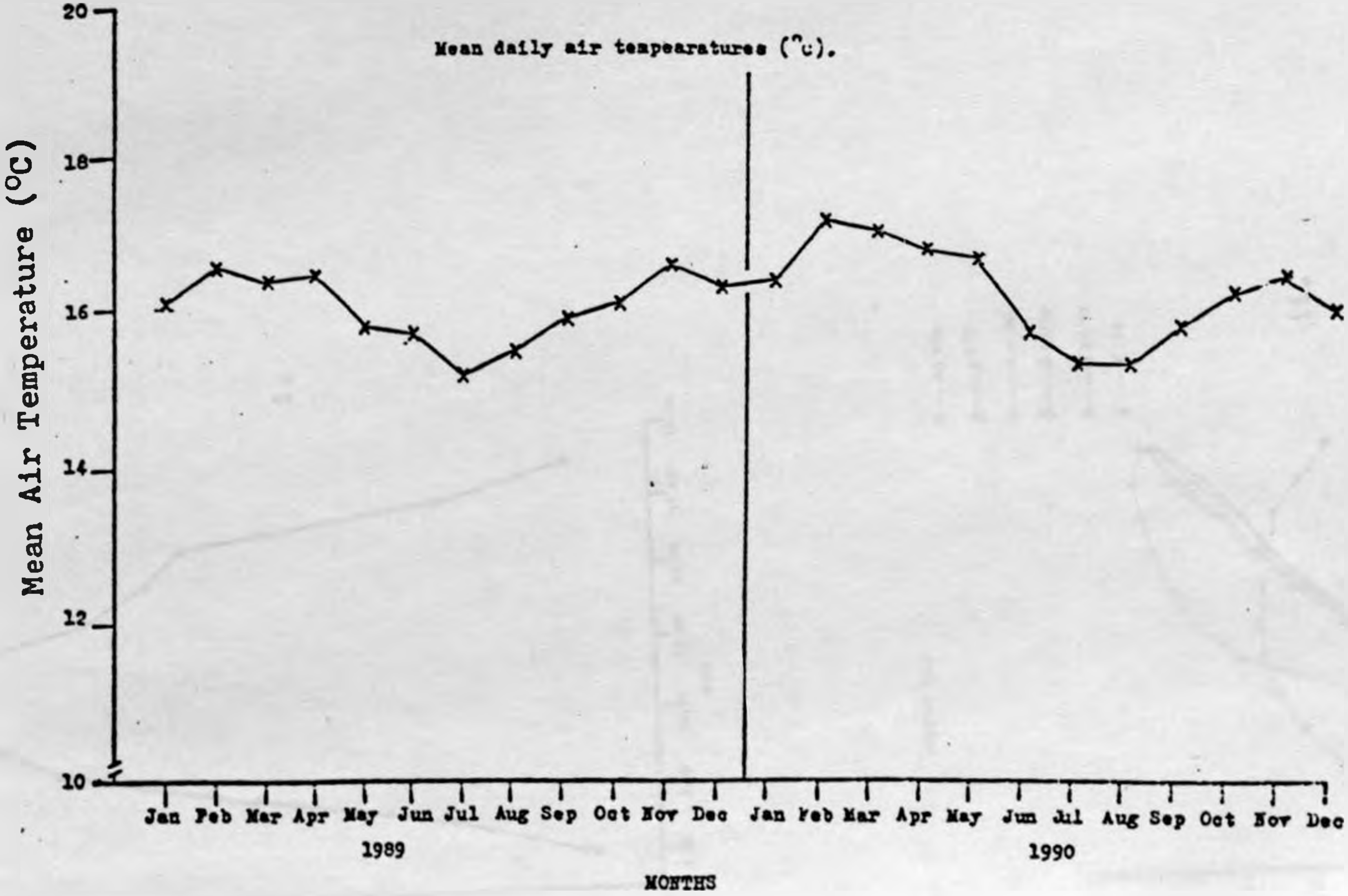


Fig. 3a : The mean daily air temperature recorded at the Tea Research Met. Station (January 1989 - December 1990).

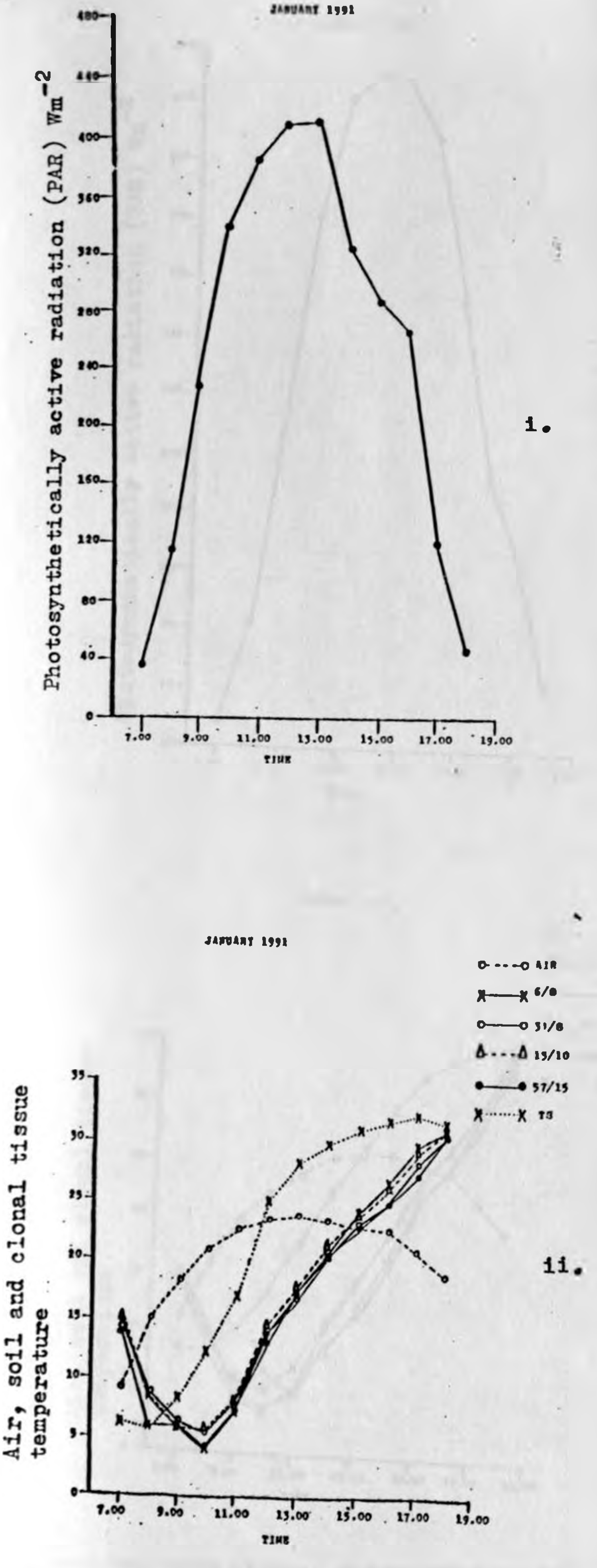


Fig. 3b : The mean diurnal photosynthetically active radiation (PAR) Wm^{-2} and mean diurnal air soil and tea plant meristem tissue temperatures °C (Jan. 1991).

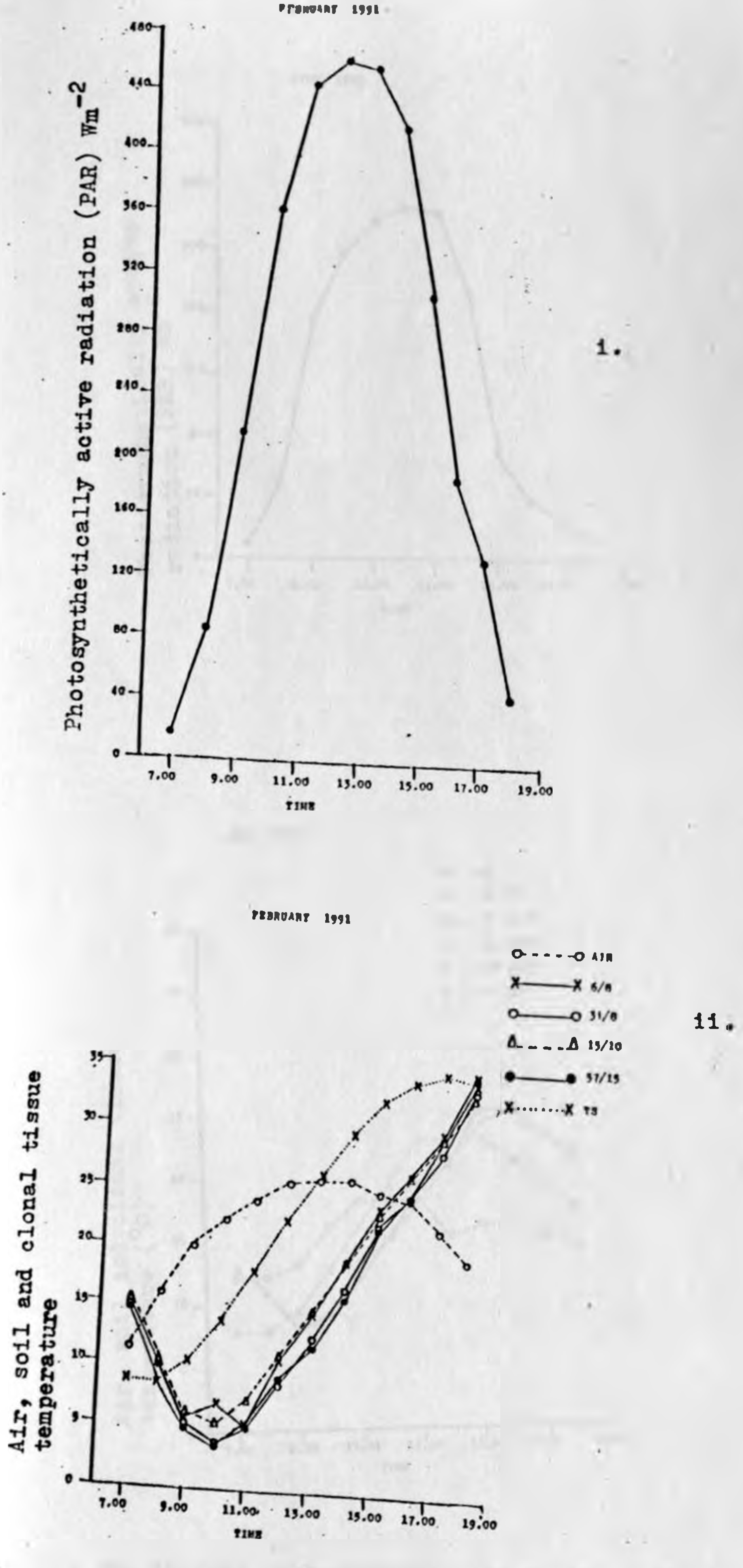


Fig. 3c : The mean diurnal photosynthetically active radiation (PAR) Wm^{-2} and diurnal air, soil and tea plant tissue temperatures (^{o}C) (February 1991).

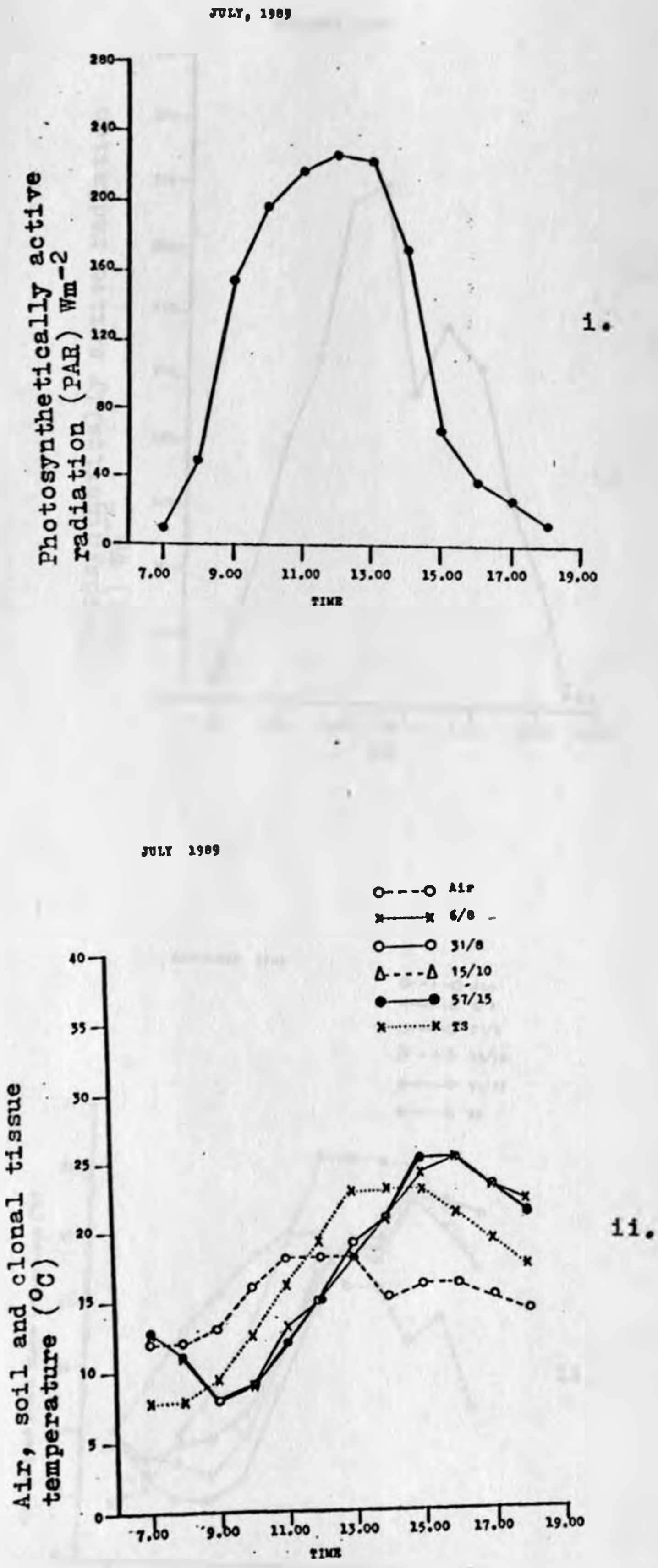


Fig. 3d : The diurnal photosynthetically active radiation (PAR) Wm^{-2} and the diurnal air, soil and tea shoot meristem temperatures °C (July 1989).

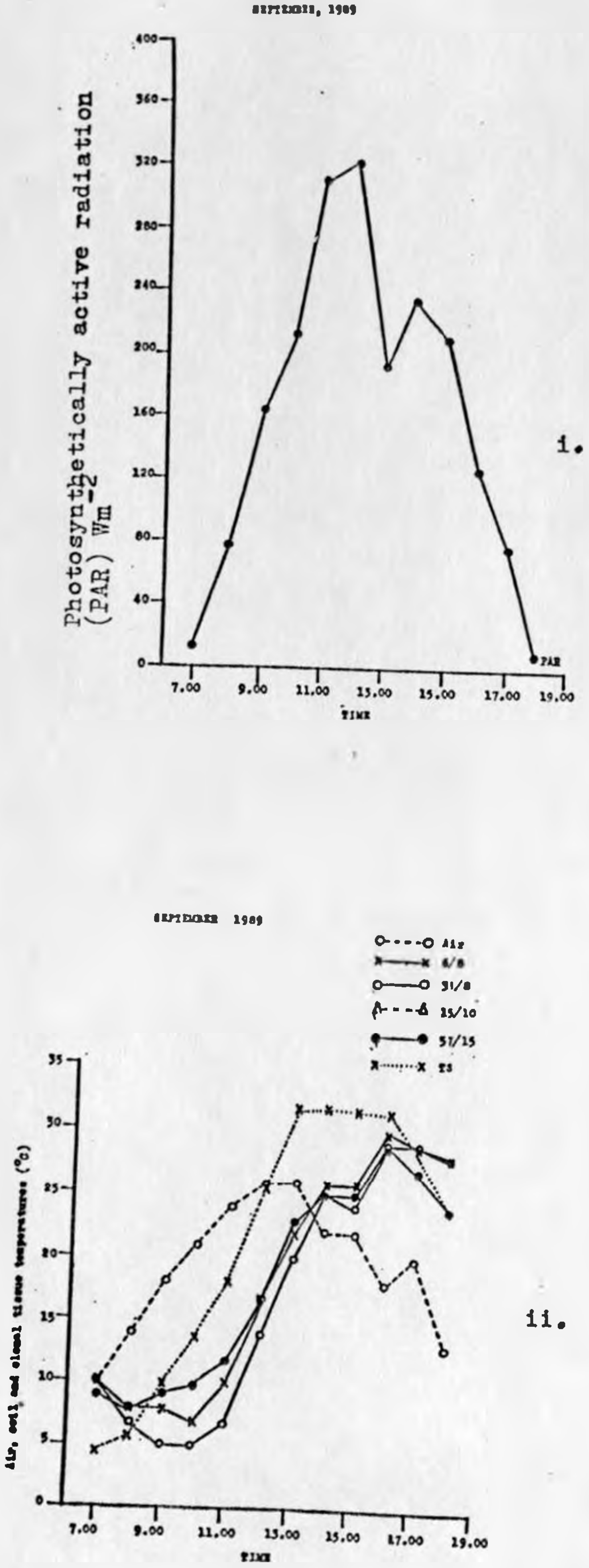


Fig. 3e : The diurnal photosynthetically active radiation (PAR) Wm^{-2} the diurnal air, soil and tea shoot meristem temperatures ^{o}C (Sept. 1989).

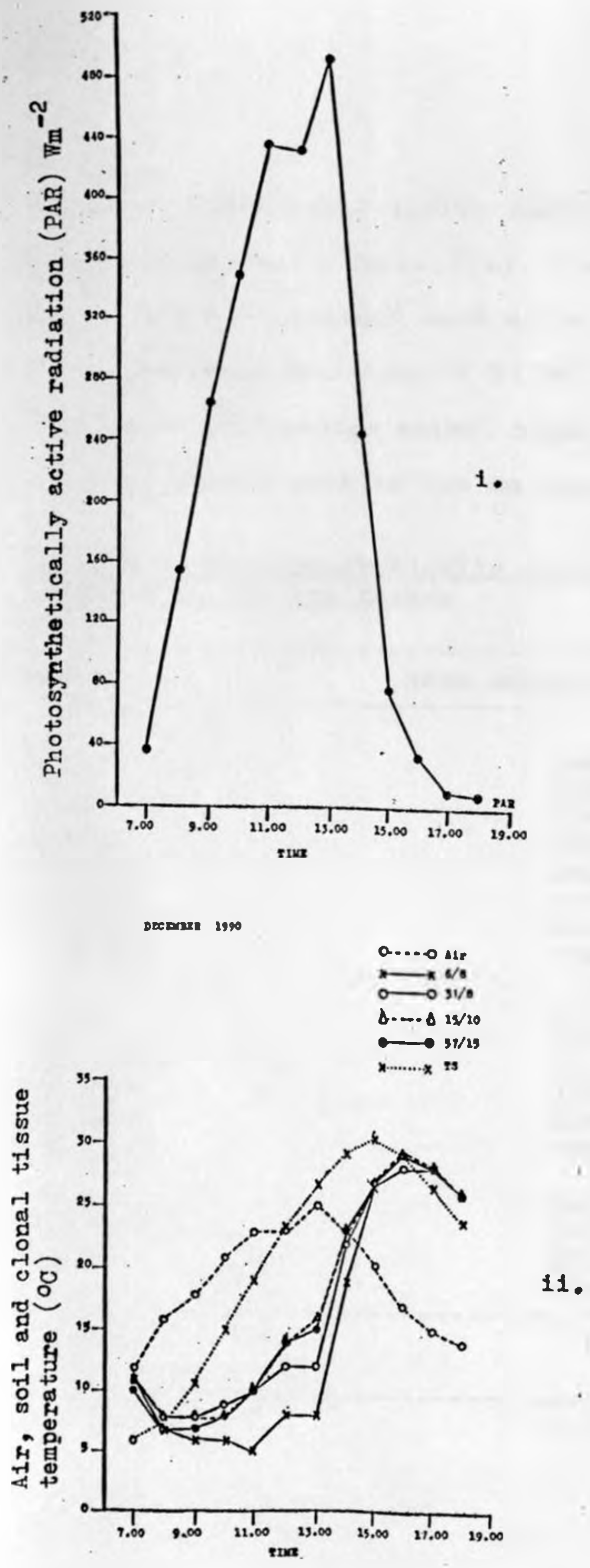


Fig. 3f. The diurnal photosynthetically active radiation (PAR) Wm^{-2} and the diurnal air, soil and tea shoot meristem temperatures ^{o}C (Dec. 1990).

4.3. RADIATION

The mean daily photosynthetically active radiation (PAR) incident on the tea bushes are given in Table 2(a). The results show that the daily means of the PAR recorded each month did not show large differences with a standard deviation of 27 WM^{-2} and the mean of 195 WM^{-2}. Despite the small differences noted, higher PAR were recorded on relatively hotter months such as Jan to March 1991.

TABLE 2(a): <u>Mean daily photosynthetically active radiation absorbed by the tea bushes</u>

	Month	Mean monthly PAR WM^{-2}
1989	May	162
	June	202
	July	176
	August	166
	September	168
	October	171
	November	182
	December	176
1990	January	221
	February	194
	September	213
	October	176
	November	170
	December	200
1991	January	243
	February	248
	March	237
	April	208
	Mean	195
	SD	27

Table 2(b) Total radiation incident on the tea bush canopy, the photosynthetically active radiation (PAR) fraction of the total light reflected by the tea canopy and the extinction fraction of different clones of tea recorded between 27/9/90 and 23/2/91 (WM^{-2}).

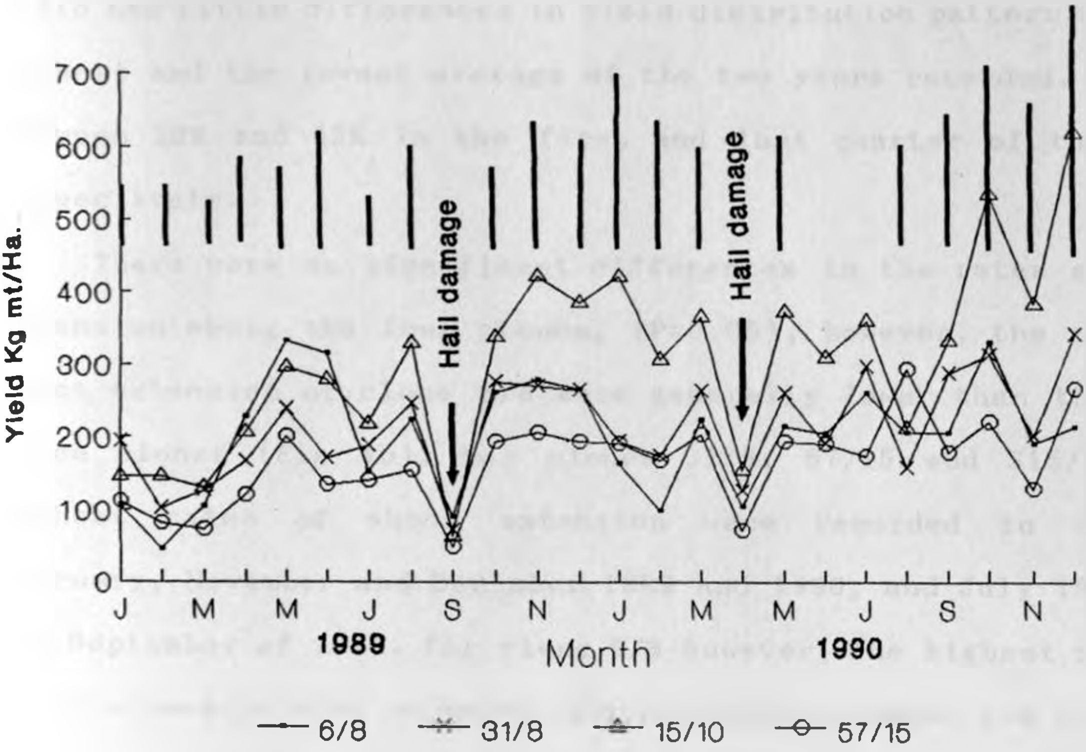
	Clones					
	6/8	57/15	31/8	S15/10	Mean	SD
Total	5970	5995	6404	6567	6234	298
PAR	2985	2997	3667	3350	3249	325
Reflected	1785	1792	1908	1956	1860	85
Extinction	179	180	128	166	163	24
Net PAR	1199	2104	1294	1326	1255	64

The results in Table 2(b) show that PAR was 50% of the total light incident on all the tea bushes. Nearly 30% of the total incident light was reflected. The light extinction coefficient of the tea bushes was 3%, while net PAR was 20% of the total light. There were no clonal differences in either photosynthetically active radiation, reflectance or canopy extinction coefficients.

4.4. Monthly distribution of yields and yield components

The monthly yields of clonal teas Figure 4(a) show that there were significant differences between clonal yields during the 24 months of recording. S15/10 was the highest yielding clone during most of the year except for January 1989 when it was outyielded by 31/8 and April and May 1989 when it was outyielded by 6/8. Clone 31/8 was the second highest yielder and 57/15 was the lowest yielding clone.

The nature of monthly yield distribution also varied with clones and within the different years. S15/10, although the highest yielding clone had one of the poorest yield distributions giving only 19% of its two year average yields in the first quarter of the



* Error bars represent LSDs at p=0.05

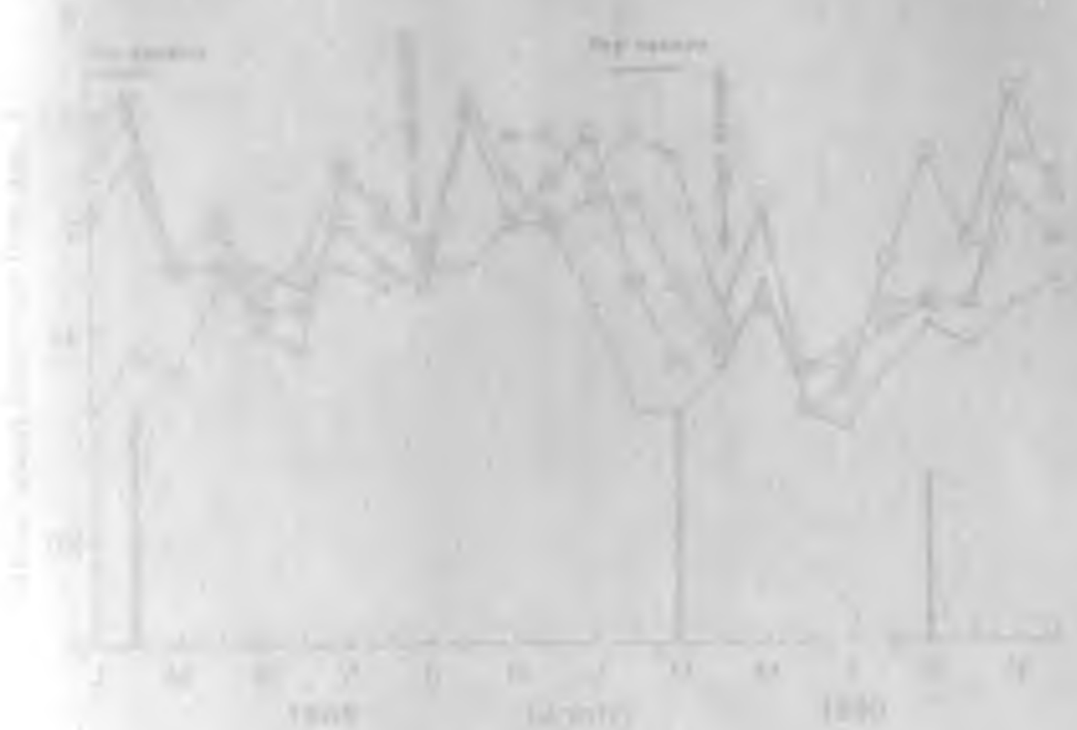
Fig. 4a : Mean monthly yields of clonal tea bushes (kg mt/ha/month) between January 1989 and December 1990.

year and 37% of the total yields in the last quarter. 31/8 and 57/15 had little differences in yield distribution pattern with the highest and the lowest average of the two years recorded, varying between 20% and 32% in the first and last quarter of the year, respectively.

There were no significant differences in the rates of shoot extension among the four clones, (P=0.05), however, the rates of shoot extension of clone 6/8 were generally lower than the other three clones (Fig 4b). For clones 31/8, 57/15 and S15/10, the highest rates of shoot extension were recorded in January, February, November and December 1989 and 1990, and July 1989, May and September of 1990. For clone 6/8 however, the highest rates of shoot extension were recorded in May, April, November and December, 1990.

There were significant differences (P=0.05) in monthly density of pluckable shoots (Fig 4d). Clone 6/8 had the highest overall number of pluckable shoots per unit area in 1989, however in 1990 clone S15/10 had the highest number of pluckable shoots per unit area. There was a general decline in shoot density in all the four clones, in January and February although the relative shoot density of clone 6/8 was much lower than those of the clones 31/8, 57/15 and S15/10. The shoot densities were highest in all the clones mainly in the last three months of the year. In September 1989, there was severe hail damage which reduced the shoot densities drastically in all the clones. The data for August and September 1990 were accidentally erased from the diskette.

There were significant (P=0.05) differences in mean weight of shoots (Fig. 4). Clone S15/10, exhibited the highest weight followed by clone 31/8. Clones 6/8 and 57/15 had the lowest mean shoot weights throughout the period. There were no significant differences in the monthly changes in mean shoot weights.



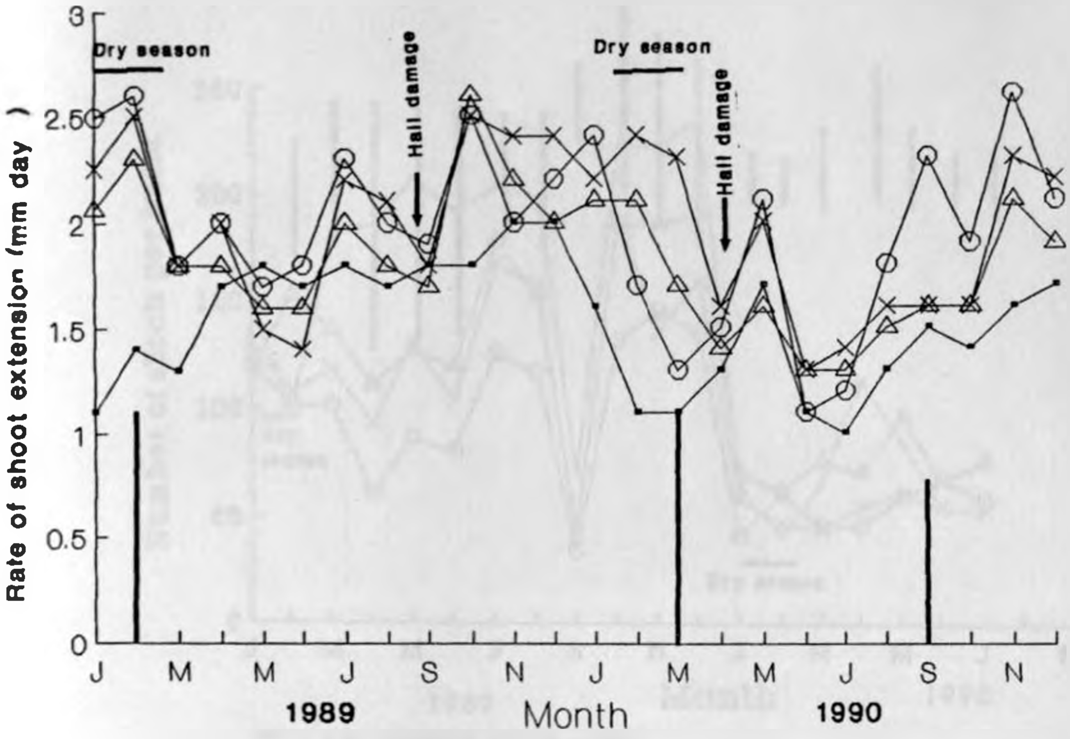
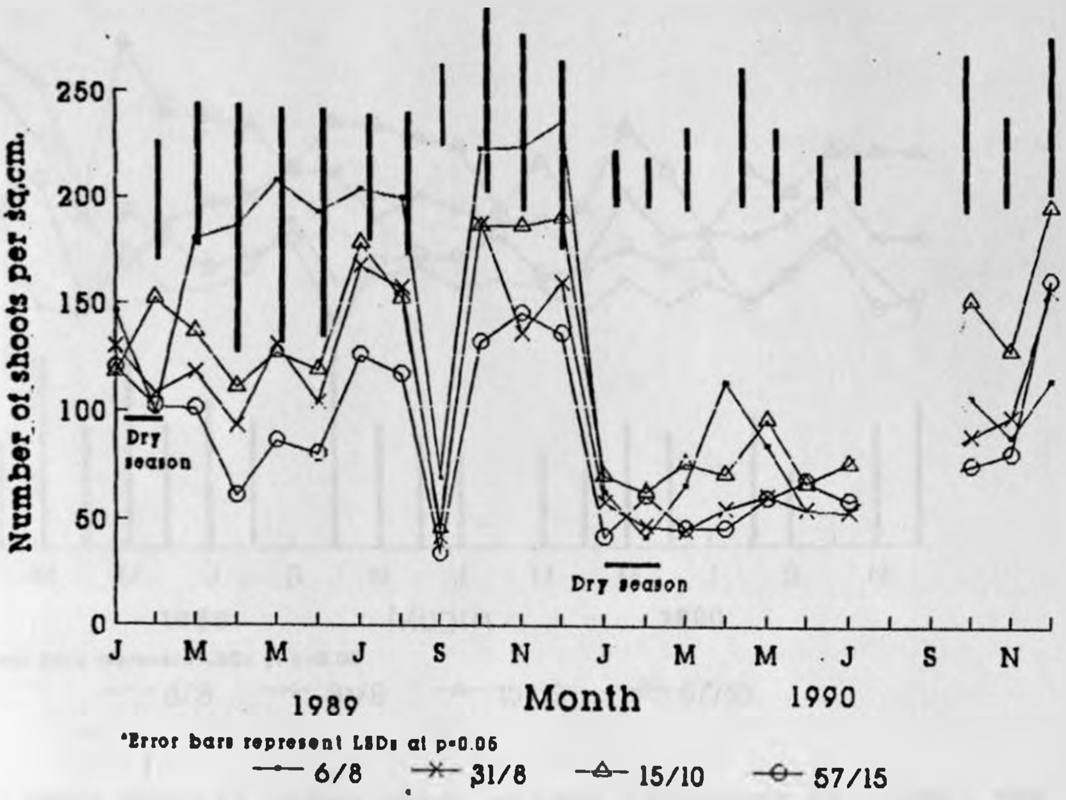


Fig. 4b : Monthly rates of shoot extension of clonal tea bushes (cm/da) between January 1989 and December 1990.



*Error bars represent LSDs at p=0.05

Fig. 4c ; Mean monthly shoot density of clonal tea bushes S/m^2/month between January 1989 and December 1990.

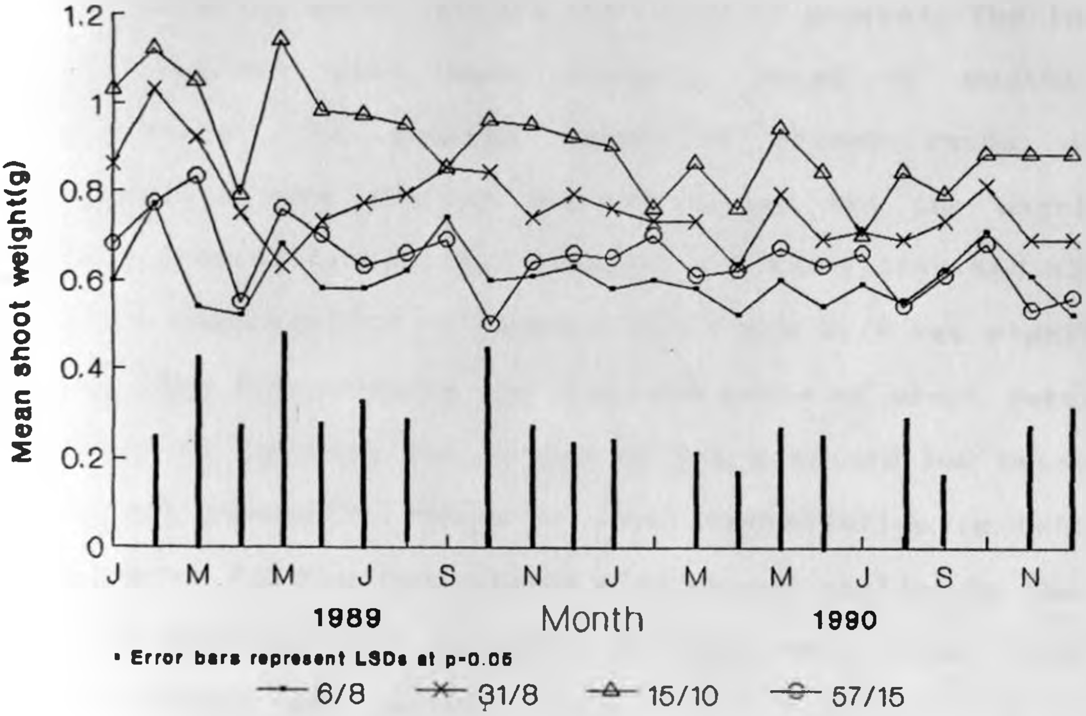


Fig. 4d : Mean monthly fresh shoot weight (g/shoot) of clonal tea bushes between January 1989 and December 1990.

The rate of monthly replacement of the shoots during the 24-month period are graphed in Figure 4(e). There were significant differences among the varieties in the monthly rates of shoot regeneration mainly due to the high rates in S15/10 and rather low and fluctuating rates of 6/8 and 57/15 in general. The individual clones however gave very variable rates of monthly shoot regeneration. The general trend of clonal rates of shoot regeneration were similar for all clones but the magnitude of changes were different. For example, all the clones had high rates of shoot regeneration in January, but clone 31/8 was significantly higher than 6/8. Despite the observed rates of shoot regeneration observed in January, the yields of tea remained low because low. Clone 6/8 showed low rates of shoot regeneration in February of both years. All the four clones also showed decline in the rate of shoot regeneration in December of both years with 57/15 giving significantly lower rates.

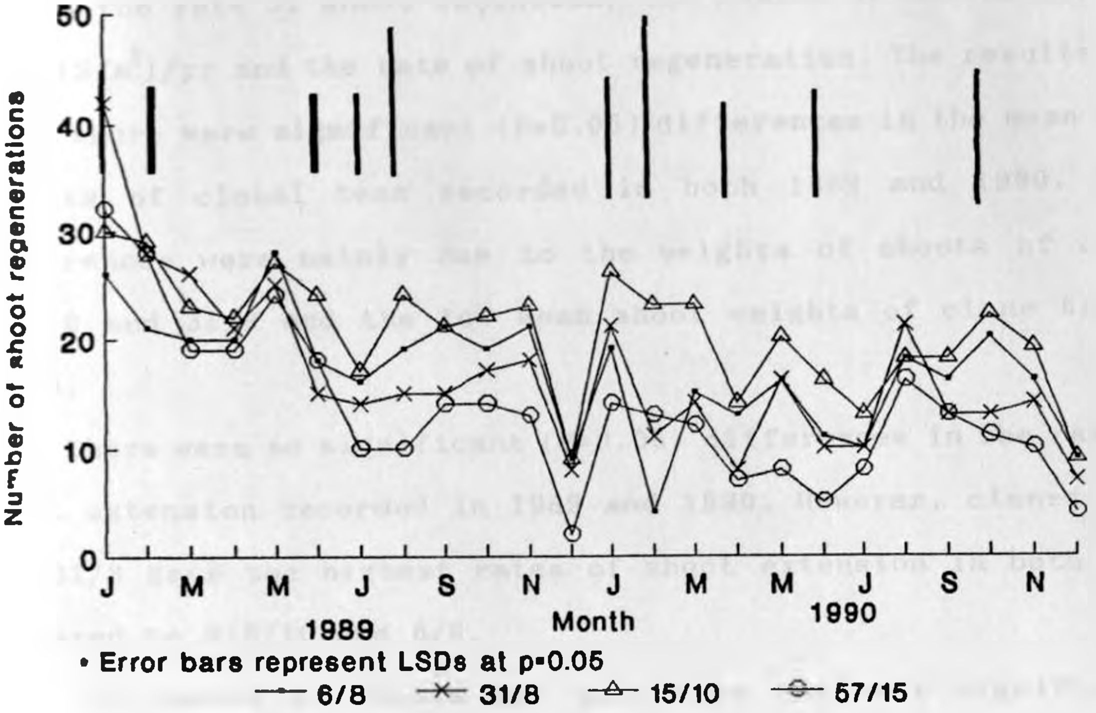


Fig. 4e : The mean monthly rate of shoot regeneration of clonal tea bushes (shoots/month) between January 1989 and December 1990.

4.5. Analysis of yield and yield components of clonal tea

Table 3(a) gives the mean fresh weight of the individual shoots the rate of shoot extension, the number of shoots per unit area (S/m^2)/yr and the rate of shoot regeneration. The results show that there were significant (P=0.05) differences in the mean shoot weights of clonal teas recorded in both 1989 and 1990. These differences were mainly due to the weights of shoots of clones S15/10 and 31/8 and the low mean shoot weights of clone 6/8 and 57/15.

There were no significant (P=0.05) differences in the rates of shoot extension recorded in 1989 and 1990. However, clones 57/15 and 31/8 gave the highest rates of shoot extension in both years compared to S15/10 and 6/8.

The number of shoots per unit area was very significantly (P=0.05) different for clonal tea during both years. Clone 6/8 gave the highest shoot density of 2160 shoots/m2/yr in 1989. This was followed by clone S15/10 with 1707, 31/8 which had 1534 and lastly clone 57/15 which had 1228 shoots/m^2. Rate of shoot regeneration recorded dbetween 1989 and 1990 among different clones were significantly P=0.05 different. Clone S15/10 gave the highest rate of shoot regeneration folowed by clone 31/8, 6/8 and lastly 57/15.

TABLE 3(a): Mean fresh shoot weight (g/shoot), rate of shoot extension (cm/day), number of shoots per unit area (S/m^2), the number of shoots regenerated (Shoots/yr) and the yields of tea in kg mt/ha/yr of the four commercial clones - 1989/90.

1989

Clones	Wt	Ext.(cm/day)	$N/m^2/yr$	RR	kg mt/ha/yr
31/8	0.80B	0.208 A	1534 B	245 AB	2287 B
6/8	0.62C	0.166 A	2160 A	238 AB	2356 B
57/15	.67 C	.21 A	1228 C	202 B	1681 C
15/10	.97 A	.195 A	1707 B	269 A	2953 A
Mean	0.76	0.195	1657	238	2319
C.V. %	4.3	5.3	12.7	6.7	8.6

1990

Clones	Wt	Ext.(cm/day)	$N/m^2/yr$	RR	kg mt/ha/yr
31/8	0.70 B	0.186 A	1189 B	168 B	2852 B
6/8	0.58 C	0.137 A	1299 A	160 BC	2366 B
57/15	0.62 C	0.180 A	1070 B	120 C	2129 B
15/10	0.83 A	0.168 A	1582	220 A	4439 A
Mean	0.68	0.167	1285	167	2946
C.V. %	4.6	8.4	6.5	12.8	12.8

Key:

Wt = Weight of fresh shoots (g/shoot)
Ext = Rate of shoot extension (cm/day)
N/m^2 = Number of shoots/m^2/yr
RR = Rate of shoot regeneration. (Out of 15 original shoots, the number of shoots which reach pluckable size in a year).
kg mt/ha = Yield in kg made tea/ha/yr

Numbers followed by the same letters are not significantly different (P=0.05) according to Duncan's Multiple range test. Tables 3(b) and 3(c) give the results of the Multiple regression analysis of the monthly yields of clonal teas on the yield components. The results in Table 3(b) show that among individual components in 1989 there were very highly significant and positive (P=0.01) relationship between yields and the number of shoots per unit area while all the other components individually did not show any relationship with yields. Among the yield components themselves there was no significant (P=0.05) relationship in 1989. The combined (R^2) had very highly (P=0.001) significant relationships with yields. The results in Table 3(c) show that in 1990 the mean shoot weights, the rate of shoot regeneration and the number of shoots per unit area had significant (P=0.05) relationship with yields while the rate of shoot regeneration had no correlation with yields. Among the yield components there was a negative but significant (P=0.05) relationship between the rate of shoot regeneration and the number of shoots per unit area.

The combined effect (r^2) value had a very highly significant (P=0.001) relationship with yields in 1990.

Table 3(b): Multiple Regression analysis of monthly yields and yield components of clonal teas, 1989.

Correlation Matrix

	Wt	RR	Ext	N/m^2	Yield
Wt	1.0				
RR	0.380	1.0			
Ext	0.202	-0.027	1.0		
N.M^2	-0.203	-0.143	0.068	1.0	
Yield	0.139	-0.053	0.091	0.687	1.00

Determinant of Matrix = 0.763

Correlation coefficient Matrix

	Wt	RR	Ext	N/m^2
Wt	1.0			
RR	0.375	1.0		
Ext	-0.244	0.107	1.0	
N.M^2	-0.183	0.060	-0.106	1.0

Coefficient of Determination (R-square) = 0.556
Adjusted R square = 0.515
Multiple R = 0.746
Standard Error = 62.86

Analysis of Variance Table

	Sum of Squares	df.	Mean square	F	Sign.
Regression	212998	4	53249	13	999**
Residual	169948	43	3952		
Total	382947	47			

Table 3(c) Multiple regression analysis of monthly yields and yield components of clonal tea, 1990

Correlation Matrix

	Wt	RR	Ext	N/m^2	Yield
Wt	1.0				
RR	0.316	1.0			
Ext	0.228	0.141	1.0		
N.M^2	0.239	0.634	0.165	1.0	
Yield	0.696	0.620	0.115	0.642	1.00

Determinant of Matrix = 0.501

Coefficient Correlation Matrix

	Wt	RR	Ext	N/m^2
Wt	1.0			
RR	-214	1.0		
Ext	-0.191	-0.005	1.0	
N.M^2	-0.034	-0.604	-0.090	1.0

Coefficient of Determination (R-square) = 0.760
Adjusted R square = 0.737
Multiple R = 0.872
Standard Error = 54.701

Analysis of Variance Table

	Sum of Squares	df.	Mean square	F	Sign.
Regression	406859	4	101714	34	0.999^{***}
Residual	128665	43	2992		
Total	535524	47			

The mean value of each yield component and the yield of tea in kg made tea per hectare per year Table 4, (1). The ratios of the value of each component in the total value of all components (2), the products of the ratios of individual components for each clone (3) and the overall ratios of the products of the values of each component (4). These results show that the products of the components of yield could be used to estimate the individual yield potentials of each clone with r^2 value being 0.999.

TABLE 4: Estimation of the potential yields of clonal tea given the components of yield, 1990

(1)	Components of yield			Actual yield	
	Wt(g/s)	Ex(cm/day)	D.(s/m²)	RR	kg mt/ha
Clones					
31/8	0.70	0.186	1189	160	2852
6/8	0.58	0.137	1299	168	2366
57/15	0.62	0.180	1070	120	2129
S15/10	0.83	0.168	1582	220	4439
Totals	2.73	0.671	5140	668	11786
(2) Ratio of clones in each total for each component					
31/8	0.256	0.277	0.231	0.240	0.242
6/8	0.212	0.204	0.253	0.251	0.200
57/15	0.228	0.269	0.208	0.180	0.181
15/10	0.304	0.250	0.308	0.329	0.377

(3) Contribution of each component into individual clonal yields

31/8 0.256 x 0.277 x 0.231 x 0.240 = 0.00393

6/8 0.212 x 0.204 x 0.253 x 0.251 = 0.00275

57/15 0.228 x 0.269 x 0.208 x 0.180 = 0.00230

15/10 0.304 x 0.250 x 0.308 x 0.329 = 0.00770

Totals = 0.0167

(4) Ratio of each clonal component in the totals

31/8	0.235
6/8	0.166
57/15	0.140
15/10	0.460

(5) Estimated yield of tea (kg mt/ha)

31/8 = 0.235 x 1176 = 2769

6/8 = .165 x 11786 = 1955

57/15 = 0.140 x 11786 = 1650

15/10 = 0.460 x 11786 = 5421

(6) Linear regression : Estimated to Actual yields

	Estimate	Actual
31/8	2769	2852
6/8	1956	2366
57/15	1650	2129
15/10	5421	4421

R^2 = 0.999
Correlation coefficient = 0.999^{**}

C.V.(%) = 20.46

Wt(g/s) = Weight (grams/shoot)

Ex = Extension rates (cm/day)

D = Shoot density (shoot/m^2)
R/R = Rate of shoot regeneration (shoots generated/year)

CHAPTER 5

5.1. DISCUSSION

The results of this study have shown that in Timbilil Estate, Kericho, Kenya at 2170m a.m.s.l., the mean air temperatures (16°C) were below the optimum for tea shoot growth, (20-24°C). This may have been the main factor which limited the yields of tea in the years 1989 and 1990. The mean rates of shoot extension of clonal teas was 0.16 cm/day. Compared to Malawi where the extension rates in the warm wet season were 1 cm/day (Smith *et al*, (1990) and Tanzania where the average rate was 0.43 cm/day (Stephens and Carr (1990), the rate of shoot extension at high altitude in Kenya was low and may have contributed to the low yields. The low extension rates resulted in staggered rates of shoot regeneration with each generation of shoots at the linear phase taking 23 days whereas in Malawi it took 10-11 days for shoots in the linear phase to reach pluckable size (Smith *et al*, 1990). The optimum air temperature for tea shoot growth have been reported to be 20-24°C (Squire, 1981), 20-29°C (Eden, 1965) and 22°C (Lebedev, 1961). These are all above the mean air temperatures of 16°C recorded in this study and bears credibility to the conclusion reached about the yields of tea. In Kenya, the average annual yields is 2500 kg mt/ha/year (Othieno, 1991), but tea in Kenya is harvested throughout the year although relatively lower yields are recorded during some seasons. In Malawi, 85% of the tea is harvested within the 5 months of the hot-wet season, Herds and Squire (1976), and yet the average yields in Kenya are similar to the average yields in Malawi. Given that similar conditions as the warm-wet season in Malawi could prevail in Kenya where tea is harvested throughout the year, the yields of tea in Kenya could be more than 5000 kg mt/ha per year. This potentiality is however limited by the low temperatures prevailing most of the year.

Soil moisture deficits and vapour pressure deficits (VPD) were limiting mainly in January and February during the two years. The mean midday maximum VPD during January and February were above 20 mbars while the average soil moisture deficits in January assuming a crop factor of 0.85 Eo (Laycock 1964) was 85 mm. These conditions were severe enough to cause changes in the internal plant water deficits, however the clonal teas gave variable response to the stress arising from the high VPDs and high soil moisture deficits. Clones 31/8, S15/10 and 57/15 had relatively high shoot water potential which remained above -10 bars despite the prevailing high soil moisture and high VPD. Clone 6/8 which is susceptible to drought (Othieno 1978c) had the lowest midday shoot water potential during this period which was below -10 bars. This confirms the observations made by Othieno (1978c) who suggested that shoot water potential could be used to index for susceptibility of clonal teas to soil moisture deficits.

Among the yield components different clones showed variability in response to high VPD and high soil moisture deficits. The rates of shoot extension of clone 6/8 was reduced between January and February in both 1989 and 1990 (Fig. 3b). In clones 31/8, S15/10 and 57/15 the rates of shoot extension were at the maximum during the two months. Despite the high rates of shoot extension recorded during this period, the yields of tea were low mainly as a result of low shoot densities which prevailed during this period. Whereas the high vapour pressure deficits and the high soil moisture deficits were sufficient to reduce shoot extension rates of clone 6/8, it did not affect the rates of shoot extension of clones 31/8, S15/10 and 57/15. Within this season the mean air temperatures in Kericho were at a maximum (17°C) (Fig. 2a). This may have promoted the fast growth rate in the three tolerant clones as shoot growth was still increasing with air temperatures (Eden 1965). Hence the rate of shoot extension could be an important marker in the selection of tea clones that could tolerate dry conditions.

There was a general decrease in the number of pluckable shoots per unit area of the four clones of tea during January and February. Although there was a more than proportionate decrease in the shoot density of clone 6/8 compared to the other three clones. The decrease in shoot density could be a conservation mechanism by which the tea plants reduced the leaf surface area available for transpiration in order to reduce the rate of water loss (Wilson *et al* 1976). This is achieved through increased apical bud dormancy (Squire 1979) which increases the proportion of dormant to active shoots on the plucking table. Whereas for the plant this could be a positive attribute which helps it to conserve itself and survive the drought, it is a negative tea plant attribute for the economic production of the crop. Tea is grown for its young shoots which are harvested throughout the year. Any mechanism which reduces the number of pluckable shoots reduces the economic yield of tea. Selection programmes should therefore identify clonal teas with alternative water conserving mechanisms such as boundary layer resistance which may not interfere with the number of pluckable shoots per unit area.

The rates of shoot regeneration decreased in December of both 1989 and 1990 in all the clones. There was a minor decrease in the rate of shoot regeneration of clone 6/8 in February of both years. The general decrease in regeneration rates in December could be attributed to the synchronized growth of shoots arising from the improved conditions, starting from October (Fordham effect). This may have resulted in all the initiated shoots coming into plucking at the same time in December, thus leaving a long period when all the new generation of shoots had to start from the new axils. This resulted into a long period before the new generation of crops could come into plucking (Fordham and Palmer-Jones, 1977). As a result of this only a few generations of shoots could be obtained in December as opposed to the other months when there was staggered regeneration. The decline in the rates of regeneration of shoots of clone 6/8 in February could be attributed to the reduced rate of shoot extension as a result of which the tagged shoots took longer to reach pluckable size.

There were clonal differences in mean shoot weights although they did not vary with seasons. This confirms Squire's (1979) and Tanton's (1982b) observations that mean shoot weights were not affected by changes in environment.

There was a steep decline in overall yields of tea during the months of January and February during the years 1989 and 1990. This could mainly be attributed to the reduction in the number of pluckable shoots as a result of increased bud dormancy. Hence the main cause of decrease in yields during the stress periods arising from high soil moisture deficits and high vapour pressure deficits was the decline in the number of pluckable shoots per unit area. As the drought progressed the rates of shoot extension also decreased resulting in fewer generations of pluckable shoots within a given time. This caused further decline in yields.

The period between March and September of the years 1989 and 1990 could generally be described as cool and wet with mean air temperatures averaging 15.6°C, mean rainfall of 183 mm and the midday maximum VPD of 11.8 mbars. There were no differences in shoot water potentials of clonal teas during this season.

The rates of shoot extension of all the four clones were relatively low, particularly in clones 31/8, S15/10 and 57/15. Since neither soil moisture nor atmospheric vapour pressure deficits were limiting, it could be suggested that mean air temperatures were the major cause of reduced rates of shoot extension, during the cool wet season. Whereas the differences in air temperature were minor, 17°C (maximum 24.9°C and minimum 9.5°C) in February and 15.4°C (maximum 22.8°C and minimum 8°C) in July, Obaga *et al* (1988) had shown that minor differences in temperature had a large effect on rates of tea shoot extension which was reflected in yield variations at different sites. One of the main factors which could have been expected to have reduced the rate of growth during the cool wet season was the amount of light available for photosynthesis. The cool-wet season is characterized by many days with overcast conditions, which reduces the total incident light intercepted by the tea bush canopy. In Kericho, however, there were at least 10 hours with the minimum PAR which was higher than 50wm^{-2} and the maximum of 300 wm^{-2} of PAR (Figures 3b-f). This is considered optimal for plant growth (Gallagher and Biscoe 1977). Coulson (1985) reported on beans, that PAR was not limiting at high altitudes in the tropics. Hence radiant light may only have been inadequate as source of heat to raise the mean air temperatures but could not have affected the rates of photosynthesis.

The number of shoots per unit area and the mean shoot weights were not affected by changes in air temperature. The effects of air temperature on yields were therefore through reduced rates of shoot extension which reduced the frequency of plucking and thus the overall yields during the cool-wet season. Yields obtained between October and December which comprise three months of production, were more than 30% of the total annual crop, leaving only 70% of crop in the cool-wet and hot-dry season. This was mainly due to the favourable conditions which prevailed during this period, which was characterized by moderately high mean air temperatures (16.5°C) (maximum 23.9°C and minimum 8.8°C), and averagely high rainfall of 154 mm. These conditions were favourable for growth and yields of clonal tea. Both shoot density and rates of shoot extension recorded within the two years were high, hence the high yields. Whereas some of these yield components were affected by the measured environmental factors, it has also been shown that these components could be used to predict the potential yields of individual clones. The relationship between individual component i.e. mean shoot weight and yields of individual clones was poor but the combine (r^2) value had a highly significant relationship with yields.

Secondly, the product of the ratios of each yield component when subjected to linear regressions with the actual yields of each clone gave a highly significant linear relationship. This shows that a marker clone whose yield potential is known and with well defined yield components could actually be used as a reference clone against which other materials being selected could be compared. All the genotypes whose components are inferior to the reference clone could be eliminated. This could substantially reduce the selection period in the clonal selection programme.

5.2. CONCLUSIONS AND RECOMMENDATIONS

In the tea growing areas where the mean air temperatures are below 16°C, air temperature is the cause of reduced productivity of the tea crop when other factors are not limiting.

In Kericho, Kenya, soil moisture deficits and saturated atmospheric vapour pressure deficits reduced the yields of tea during the hot-dry season at the beginning of the year (January to February) in the years 1989 and 1990.

Clonal teas had differences in yield and yield component response to the seasonal environmental changes. This gave rise to differences in yields and yield distribution during different seasons.

Clonal teas which were susceptible to drought had low shoot water potential, reduced shoot extension rates, reduced rate of shoot regeneration, low shoot density and low yields during the hot-dry season. Mean air temperatures resulted in low rates of shoot extension and low yields, in the cool-wet season.

The products of the ratios of yield components could be used to predict the yield potentials of clonal teas.

This study has therefore shown that the shoot water potential of clonal teas, the rates of shoot extension and shoot density and to some extent the rates of shoot regeneration could be used as indicators of clonal tea susceptibility to water stress whereas shoot extension rate was the major component affected by air temperatures. The combined effect of the four yield components in a multiple regression analysis could be used as a predictor of the yield potential of clonal teas in a clonal selection programme.

Despite these findings, further work under controlled conditions need to be done, in order to isolate the specific effect of each element of climate studied, on individual yield components and the overall tea yields.

CHAPTER 6

REFERENCES

1. Ackerson, R.C. (1983). Comparative physiology and water relations of two Corn Hybrid during water stress. Crop Science, 23: 278-283.

2. Aono, H.; Sakai, S.; Tanaka, S.; Nagata, T. and Yanase, Y. (1983). The effects of air and subterranean temperatures in winter season on the growth and changes of components of tea plant. Study of tea, 64: 1-14 (In Japanese with English Summary).

3. Barua, D.N. (1969). Seasonal dormancy in tea. Nature, London, 224: 514.

4. Braun, J.W., Jeannie, K.L.; Gart, T.H. and Brun, C.A. (1989). Distribution of foliage and fruit in association with light microclimate. Journ. Hort. Sc. 64(5): 565-572.

5. Callander, B.A. and Woodhead, T. (1981). Canopy conductance of Estate tea in Kenya. Agric. Meteorol. 23: 151-167.

6. Carr, M.K.V. (1974). Irrigating seedling tea in Southern Tanzania. Effects on total yields, distribution of yield and water use. Journal of Agricultural Science (Cambridge) 83: 363-378.

7. Carr, M.K.V.; Dale, M.O. and Stephens, William (1987). Yield distribution in irrigated tea (*Camellia sinensis*) at two sites in Eastern Africa. Experimental Agriculture. 23: 75-85.

8. Coombs, J.; Hall, D.O.; long, S.P.; Scurlock, J.M.O. (1985). Techniques in Bioproductivity and photosynthesis. 2nd Ed. Pergamon Press. 41-19.

9. Coulson, C.L. (1985). Radiant energy conversion in three cultivars of *phaseolus vulgaris*. Agricultural For. Meteorol. 35: 21-19.

10. Eden, T. (1965). Tea 2nd Ed. Longmans.

11. Ehrler, W.L. (1973). Cotton leaf temperatures as related to soil water depletion. Agron. Journ. 65: 404-409.

12. Ellen, J. and Van Oene, H. (1989). Effects of light intensity on yield components, carbohydrate economy and cell-wall constituents in Spring Barley (*Hordeum distichum L.*) Netherlands journal of Agricultural SCience. 37: 83-95.

13. Engledow, F.L. and Ramiah, K. (1930). Investigation on yield in cereals (vii). A study of development and yield of wheat based upon varietal comparison. Journal of Agricultural Research. 20: 265-344.

14. Engledow, F.L.; Wodham, S.M. (1923). Investigation of yields in cereals. Journal of Agricultural Science, U.K. 13: 390-439.

15. Fitter, A.H. and Hay, R.K. (1981). Environmental physiology of plants. Academic Press Inc. New York, 31-42.

16. Fordham, R. and Palmer-Jones, R.N. (1977). Simulation of Intra-seasonal yield functions of tea in Malawi. Expl. Agric. 13: 33-42.

17. Gallagher, J.N. and Biscoe, P.V. (1978). Radiation absorption, growth and yield of cereals. J. Agric. Sci. 91: 47-60.

18. Gogoi, B.N. (1976). A review of research in shade trees. Two and a Bud. 23: 67-73.

19. Green, M.J. (1970). Clonal selection on Timbilil. TRIEA ANN. REP. 1970 : 38.

20. Green, R.M. (1971). Weather and the seasonal growth of tea in Malawi. M. Phil. Thesis, Nottingham University.

21. Hadfield, W. (1968). Leaf temperature, leaf pose and productivity of the tea bush. nature, London. 219: 282-284.

22. Hadfield, W. (1974). Shade in North East India tea plantations. I. The shade pattern. J. App. Ecol. 11: 151-178.

23. Hall, H.E. and Yermanos, D.M. (1975). leaf conductase and leaf water status of sesame strains in hot dry climates. Crop science. 15: 789-793.

24. Harler, C.R. (1966). Tea growing. London Oxford Univ. Press.

25. Henzel, R.H.; McCree, K.J.; Van Banel, C.H.M. and Shortz, K.F. (1975). Method for screening sorghum genotypes for stomatal sensitivity to water deficits. Crop Sci. 15: 516-518.

26. Herd, E.M. and Squire, U.R. (1976). Observations on the winter dormancy of tea (Camellia sinensis L.) in Malawi. Journal of Horticultural Science 51: 267-279.

27. Hsiao, T.C.(1973). Plant response to water stress. Annual Review of Plant Physiology. 24: 519-570.

28. Huang, Shoubo (1989). Meteorology of the tea plant on China. A review. Agricultural and Forest Meteorology. 47: 19-30.

29. International Tea Committee. Ann Bulletin of Statistics, 1989. P.41.

30. Kasturibai, K.V.; Voleti, S.R. and Rajagopal, V.(1988). Water relations of coconut palms as influenced by environmental variables. Agric. and Forest Meteorol. 48: 193-199.

31. Squire, G.R. and Callander B.A. (1981) Tea Plantations. In water deficits and plant growth Vol. VI. Ed. Kozlowski T.T. Woody plant communities. 471-510. Academic press, New York.

32. Kramer, P.J. (1983). Plant and soil water relationships. A modern synthesis . McGraw-Hill Book Company.

33. Kulasegaram, S. and Kathiravetpillai, A. (1974). The influence of climate and GA_3 on yield of tea clones. Tea Q. 44(2/3): 100-112.

34. Lange, O.L., Nobel, P.S.; Osmond, C.B. and Ziegler, H. (1981). Physiological Plant Physiology. I. Response to the physical environment. Springer-Verlag, Berlin. 10-105.

35. Lawlor, D.W. (1987). Photosynthesis: Metabolisms control and physiology. John Wiley and Sons Inc. New York, pages 1-53.

36. Laycock, D.H, (1964). Tropical Agriculture Trinidad 41: 229.

37. Laycock, D.H.(1969). Latitude, daylength and crop distribution. Proceedings of the 24th Tocklai Conference, Tocklai Experimental Station, Jorhat, India.

38. Lebedev, G.V. (1961). The tea bush under irrigation. Izd Akad Nauk (Mosk) in Russian.

39. Lynch, D.R. and Tai, G.C.C. (1989). Yield component response of eight potato genotypes to water stress. Crop Science. 29: 1207-1211.

40. Magambo, M.J.S. (1983). Dry matter production and partitioning in clonal tea (*Camellia sinensis* L.) in Kenya. PhD. Thesis, University of NAirobi.

41. Menzel, C.M. and Simpson, D.R. (1986). Plant water relations in lychae. Diurnal variations in leaf conductase and leaf potential. Agricultural and Forest Meteorology, 37: 267-277.

42. Miller, A.; Jensen, R.E.; Baner, A. and Norum, E,B. (1971). Influence of atmospheric and soil environmental parameters on the diurnal fluctuations of leaf and water status of barley. Agricultural and Forest Meteorology. 8:93-105.

43. Obaga, S.M.O. (1986). Diurnal solar energy water and CO_2 exchanges in mature clonal tea (*Camellia sinensis)* bushes. Proc. TRFK. Techn. Conf. 20-21st March 1986. PP. 88-94.

44. Obaga, S.M.O.; Squire, G.R. and LAngat, J.K. (1988). Altitude, temperature and the growth rate of tea shoots. Tea 9(1): 28-33.

45. Odhiambo, H.O. (1989a). Effects of seasons on clonal shoot growth TRFK ANNUAL REPORT 1989 PP. 8-11.

46. Odhiambo, H.O. (1989^b). Nitrogen rates plucking frequency on tea. The effect of plucking frequency and nitrogenous fertilizer rates on yield and yield components of tea (*Camellia sinensis)* in Kenya. Tea, 10(2): 90-96.

47. Osmond, C.B.; Bjorkman, O.; Anderson, D.J. (1980). Physiological processes on plant ecology toward a synthesis with Atriplex. Springer Berlin Heidelberg, New York.

48. Othieno, C.O. (1978^a). Effect of mulching on soils and the growth of the tea plant. PhD. Thesis, University of Nairobi.

49. Othieno, C.O. (1978^b. Supplementary irrigation of young clonal tea in Kenya. I. Survival, growth and yields. Expl. Agric. 14: 229-238.

50. Othieno, C.O. (1978^c) Supplementary irrigation of young clonal tea in Kenya. II. Internal waster status. Expl. Agric. 14: 309-316.

51. Othieno, C.O. (1991). Dissemination of Research Information to Tea Farmers: Kenya's Experience. Tea 12(1): 46-51.

52. Quarrie, S.A. (1980). Genotypic differences in leaf water potential. abscisic acid and proline concentration in spring wheat during drought stress. Annals of Botany. (London. 44: 323-332.

53. Smith, R.I.; Harvery, F.J. and Cannell, M.G.R. (1990). Pattern of tea shoot growth. Experimental Agriculture. Vol.26, 197-208.

54. Spitters, C.J.T. (1986). Separating the diffuse and direct components of global radiation and its implications for

modelling canopy photosynthesis Part II. Calculation of canopy photosynthesis. Agricultural and Forest Meteorology. 38(3): 231-242.

55. Squire, G.R. (1979). Weather physiology and seasonally of tea (*Camellia sinensis*). Yields in Malawi. Experimental Agriculture. 15: 321-330.

56. Squire, G.R. (1981). Thermal time in tea. In "Plants and Their Environment". Blackwell Scientific Publications. Oxford London p. 363-368.

57. Stephens, W. and Carr, M.K.V. (1989). A water stress index for tea. Experimental Agriculture. 25: 545-558.

58. Stephens, W. and Carr, M.K.V. (1990). Seasonal and clonal differences in shoot extension rates and numbers in tea (*Camellia sinensis*). Experimental Agriculture. 26: 83-98.

59. Tanton, T.W. (1979). Some factors affecting the yield of tea. Experimental Agriculture. 15: 187-191.

60. Tanton, T.W. (1981). Crop growth and yield of the tea plant. Experimental Agriculture. 17: 323-331.

61. Tanton, T.W. (1982[a]) Environmental factors affecting the yield of tea. I. Effects of air temperature. Experimental Agriculture. 18: 47-52.

62. Tanton, T.W. (1982[b]). Environmental factors affecting the yield of tea. Daylength, soil temperature and air temperature. Experimental Agriculture. 18: 53-63.

63. Williams, E.N.D. (1971). In "Water and the tea plant". Tea Research institute of East Africa, Kericho, Kenya.

64. Wilson, A.M.; Hyder, D.N. and Briske, D.D. (1976). Drought resistance characteristics of blue grama seedlings. Agronomy Journal 68: 479-484.

65. Wu, C.T. and Kao, M.J. (1954). Memories of the Pin Chin tea. Experimental Station, Taiwan. 1: 177. (In Chinese with English Summary).

Appendix

1. Analysis of variance table for number of shoots per unit area, s/m^2 (January 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	154.38	77.19	0.06	0.94
Treatments	3.00	106322.86	35440.95	26.74	0.00
Error	6.00	7952.75	1325.46		
Non-additivity	1.00	56.07	56.07	0.04	
Residual	5.00	7896.68	1579.34		
Total	11.00	11443.00			

2. Analysis of variance table for number of shoots per unit area, s/m^2 (February 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	371.64	185.82	0.05	0.95
Treatments	3.00	287479.74	95826.58	27.79	0.00
Error	6.00	20687.90	3447.98		
Non-additivity	1.00	9131.43	9131.43	3.95	
Residual	5.00	11556.47	2311.29		
Total	11.00	308539.29			

3. Analysis of variance table for number of shoots per unit area, s/m^2 (March 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	3383.93	1691.97	2.33	0.18
Treatments	3.00	44943.84	14981.28	20.67	0.00
Error	6.00	4349.65	724.94		
Non-additivity	1.00	7.51	7.51	0.01	
Residual	5.00	4342.14	868.43		
Total	11.00	52677.42			

4. Analysis of variance table for number of shoots per unit area, s/m² (April 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	21473.21	10736.61	9.60	0.01
Treatments	3.00	155414.79	51804.93	46.31	0.00
Error	6.00	6711.28	1118.55		
Non-additivity	1.00	181.85	181.85	0.14	
Residual	5.00	6529.43	1305.89		
Total	11.00	183599.27			

5. Analysis of variance table for number of shoots per unit area, s/m² (July 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	1480.15	740.08	0.24	0.80
Treatments	3.00	57388.96	19129.65	6.10	0.03
Error	6.00	18817.26	3136.21		
Non-additivity	1.00	4037.55	4037.55	1.37	
Residual	5.00	14770.71	2954.14		
Total	11.00	77686.37			

6. Analysis of variance table for number of shoots per unit area, s/m² (September 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	8531.06	4265.53	4.23	0.07
Treatments	3.00	46549.32	15516.44	15.39	0.00
Error	6.00	6050.80	1008.47		
Non-additivity	1.00	579.74	579.74	0.53	
Residual	5.00	5471.05	1094.21		
Total	11.00	61131.17			

7. Analysis of variance table for number of shoots per unit area, s/m² (November 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	16678.14	8339.07	5.56	0.04
Treatments	3.00	129487.94	43162.65	28.76	0.00
Error	6.00	9006.09	1501.02		
Non-additivity	1.00	5572.37	5572.37	8.11	
Residual	5.00	3433.72	686.74		
Total	11.00	155172.17			

8. Analysis of variance table for number of shoots per unit area, s/m² (December 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	7369.53	3684.77	1.60	0.28
Treatments	3.00	66901.41	22300.47	9.67	0.01
Error	6.00	13833.29	2305.55		
Non-additivity	1.00	10030.90	10030.90	13.19	
Residual	5.00	3802.39	760.48		
Total	11.00	88104.23			

9. Analysis of variance table for number of shoots per unit area, s/m² (January 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	3111.04	1555.52	0.71	0.53
Treatments	3.00	74604.47	24868.16	11.30	0.01
Error	6.00	13199.25	2199.88		
Non-additivity	1.00	0.29	0.29	0.00	
Residual	5.00	13198.96	2639.79		
Total	11.00	90914.76			

7. Analysis of variance table for number of shoots per unit area, s/m^2 (November 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	16678.14	8339.07	5.56	0.04
Treatments	3.00	129487.94	43162.65	28.76	0.00
Error	6.00	9006.09	1501.02		
Non-additivity	1.00	5572.37	5572.37	8.11	
Residual	5.00	3433.72	686.74		
Total	11.00	155172.17			

8. Analysis of variance table for number of shoots per unit area, s/m^2 (December 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	7369.53	3684.77	1.60	0.28
Treatments	3.00	66901.41	22300.47	9.67	0.01
Error	6.00	13833.29	2305.55		
Non-additivity	1.00	10030.90	10030.90	13.19	
Residual·	5.00	3802.39	760.48		
Total	11.00	88104.23			

9. Analysis of variance table for number of shoots per unit area, s/m^2 (January 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	3111.04	1555.52	0.71	0.53
Treatments	3.00	74604.47	24868.16	11.30	0.01
Error	6.00	13199.25	2199.88		
Non-additivity	1.00	0.29	0.29	0.00	
Residual	5.00	13198.96	2639.79		
Total	11.00	90914.76			

10. Analysis of variance table for number of shoots per unit area, s/m^2 (February 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	2222.15	1111.08	2.77	0.14
Treatments	3.00	56932.95	18977.65	47.27	0.00
Error	6.00	2408.82	401.47		
Non-additivity	1.00	55.85	55.85	0.12	
Residual	5.00	2352.87	470.57		
Total	11.00	61563.91			

11. Analysis of variance table for number of shoots per unit area, s/m^2 (April 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	3234.27	1617.14	1.24	0.35
Treatments	3.00	30882.68	10294.23	7.92	0.02
Error	6.00	7803.55	1300.59		
Non-additivity	1.00	4314.03	4314.03	6.18	
Residual	5.00	3489.51	697.90		
Total	11.00	41920.50			

12. Analysis of variance table for number of shoots per unit area, s/m^2 (May 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	3224.00	1612.00	3.22	0.11
Treatments	3.00	11133.17	3711.06	7.40	0.02
Error	6.00	3007.08	501.18		
Non-additivity	1.00	1319.32	1319.32	3.91	
Residual	5.00	1687.75	337.55		
Total	11.00	17364.25			

13. Analysis of variance table for number of shoots per unit area, s/m² (June 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	1411.12	705.56	0.62	0.57
Treatments	3.00	46443.89	15481.30	13.55	0.00
Error	6.00	6852.81	1142.14		
Non-additivity	1.00	1296.79	1296.79	1.17	
Residual	5.00	5556.02	1111.20		
Total	11.00	54707.83			

14. Analysis of variance table for number of shoots per unit area, s/m² (July 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	2342.64	1171.32	4.43	0.07
Treatments	3.00	30196.98	10065.66	38.07	0.00
Error	6.00	1586.35	264.39		
Non-additivity	1.00	164.52	164.52	0.58	
Residual	5.00	1421.83	284.37		
Total	11.00	34125.97			

15. Analysis of variance table for number of shoots per unit area, s/m² (August 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	9627.90	4813.95	1.38	0.32
Treatments	3.00	65724.25	21908.08	6.30	0.03
Error	6.00	20861.47	3476.91		
Non-additivity	1.00	14885.61	14885.61	12.45	
Residual	5.00	5975.86	1195.17		
Total	11.00	96213.62			

16. Analysis of variance table for number of shoots per unit area, s/m² (September 1991)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	515.89	257.95	0.83	0.48
Treatments	3.00	6093.97	2031.32	6.55	0.03
Error	6.00	1861.79	310.30		
Non-additivity	1.00	21.49	21.49	0.06	
Residual	5.00	1840.30	368.06		
Total	11.00	8471.65			

17. Analysis of variance table for number of shoots per unit area, s/m² (October 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	392.66	196.33	0.49	0.63
Treatments	3.00	20221.74	6740.58	16.95	0.00
Error	6.00	2386.13	397.69		
Non-additivity	1.00	25.40	25.40	0.05	
Residual	5.00	2360.73	472.15		
Total	11.00	23000.53			

18. Analysis of variance table for number of shoots per unit area, s/m² (November 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	685.04	342.52	0.64	0.56
Treatments	3.00	14739.66	4913.22	9.11	0.01
Error	6.00	3234.29	539.05		
Non-additivity	1.00	691.03	691.03	1.36	
Residual	5.00	2543.27	508.65		
Total	11.00	18658.99			

19. Analysis of variance table for number of shoots per unit area, s/m^2 (December 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	77.31	38.66	0.06	0.94
Treatments	3.00	15015.09	5005.03	7.96	0.02
Error	6.00	3774.33	629.06		
Non-additivity	1.00	2913.42	2913.42	16.92	
Residual	5.00	860.91	172.18		
Total	11.00	18866.73			

20. Analysis of variance table for daily shoot extension rates cm/day (January 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	0.00	0.00	0.51	0.62
Treatments	3.00	0.04	0.01	18.06	0.00
Error	6.00	0.00	0.00		
Non-additivity	1.00	0.00	0.00	1.75	
Residual	5.00	0.00	0.00		
Total	11.00	0.04			

21. Analysis of variance table for daily shoot extension rates, cm/day (February 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	0.00	0.00	1.55	0.28
Treatments	3.00	0.03	0.01	8.66	0.01
Error	6.00	0.01	0.00		
Non-additivity	1.00	0.00	0.00	0.47	
Residual	5.00	0.01	0.00		
Total	11.00	0.03			

22. Analysis of variance table for daily shoot extension rates, cm/day (February 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	0.00	0.00	0.75	0.51
Treatments	3.00	0.02	0.01	20.38	0.00
Error	6.00	0.00	0.00		
Non-additivity	1.00	0.00	0.00	0.57	
Residual	5.00	0.00	0.00		
Total	11.00	0.03			

23. Analysis of variance table for daily shoot extension rates, cm/day (August 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	0.00	0.00	0.30	0.75
Treatments	3.00	0.01	0.00	8.62	0.01
Error	6.00	0.00	0.00		
Non-additivity	1.00	0.00	0.00	0.47	
Residual	5.00	0.00	0.00		
Total	11.00	0.04			

24. Analysis of variance table for rates of shoot regeneration, shoot/year (January 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	33.50	16.75	0.81	0.49
Treatments	3.00	437.67	145.89	7.07	0.02
Error	6.00	123.83	20.64		
Non-additivity	1.00	14.71	14.71	0.67	
Residual	5.00	109.12	21.82		
Total	11.00	595.00			

27. Analysis of variance table for rates of shoot regeneration, shoot/year (August 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	26.00	13.00	6.88	0.03
Treatments	3.00	308.67	102.89	54.44	0.00
Error	6.00	11.33	1.89		
Non-additivity	1.00	0.10	0.10	0.04	
Residual	5.00	11.23	2.25		
Total	11.00	346.00			

28. Analysis of variance table for rates of shoot regeneration, shoot/year (April 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	1.17	0.59	0.14	0.35
Treatments	3.00	106.25	35.42	8.68	0.01
Error	6.00	24.50	4.08		
Non-additivity	1.00	2.51	2.51	0.57	
Residual	5.00	21.99	4.40		
Total	11.00	140.92			

29. Analysis of variance table for rates of shoot regeneration, shoot/year (June 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	255.50	127.75	18.62	0.00
Treatments	3.00	164.33	54.78	7.99	0.02
Error	6.00	41.17	6.86		
Non-additivity	1.00	5.66	5.66	0.80	
Residual	5.00	35.50	7.10		
Total	11.00	461.00			

30. Analysis of variance table for rates of shoot regeneration, shoot/year (October 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	136.17	68.09	4.45	0.07
Treatments	3.00	262.92	87.64	5.72	0.03
Error	6.00	91.83	15.31		
Non-additivity	1.00	1.92	1.92	0.11	
Residual	5.00	89.91	17.98		
Total	11.00	490.92			

31. Analysis of variance table for number of shoots per unit area, s/m^2 (January 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	1275.50	637.75	6.85	0.28
Treatments	3.00	1473.00	491.00	5.28	0.04
Error	6.00	558.50	93.08		
Non-additivity	1.00	58.50	58.50	0.58	
Residual	5.00	500.03	100.01		
Total	11.00	3307.00			

32. Analysis of variance table for number of shoots per unit area, s/m^2 (March 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	802.17	401.09	0.59	0.58
Treatments	3.00	10306.92	3435.64	5.08	0.04
Error	6.00	4061.83	676.97		
Non-additivity	1.00	0.00	0.00	0.00	
Residual	5.00	3193.00	638.60		
Total	11.00	15170.92			

33. Analysis of variance table for number of shoots per unit area, s/m² (April 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	825.50	412.75	0.65	0.55
Treatments	3.00	25314.00	8438.00	13.38	0.00
Error	6.00	3784.00	630.67		
Non-additivity	1.00	1565.35	1565.35	3.53	
Residual	5.00	2219.15	443.83		
Total	11.00	29924.00			

34. Analysis of variance table for number of shoots per unit area, s/m² (May 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	429.17	214.59	0.24	0.79
Treatments	3.00	23286.33	7762.11	8.78	0.10
Error	6.00	5302.17	883.70		
Non-additivity	1.00	1384.25	1384.25	1.77	
Residual	5.00	3914.91	782.98		
Total	11.00	29017.67			

35. Analysis of variance table for number of shoots per unit area, s/m² (June 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	18.67	9.34	0.01	0.99
Treatments	3.00	21366.00	7122.00	9.67	0.01
Error	6.00	4420.00	736.67		
Non-additivity	1.00	1830.55	1830.55	3.53	
Residual	5.00	2589.45	517.89		
Total	11.00	25804.67			

36. Analysis of variance table for number of shoots per unit area, s/m² (July 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	5937.17	2968.59	6.09	0.04
Treatments	3.00	9407.58	3135.86	6.43	0.03
Error	6.00	2926.17	487.70		
Non-additivity	1.00	1207.66	1207.66	3.51	
Residual	5.00	1718.50	343.70		
Total	11.00	18272.92			

37. Analysis of variance table for number of shoots per unit area, s/m² (August 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	876.17	438.09	1.12	0.39
Treatments	3.00	10594.92	3531.64	9.00	0.01
Error	6.00	2353.83	392.31		
Non-additivity	1.00	135.05	135.05	0.30	
Residual	5.00	2218.78	443.76		
Total	11.00	13824.92			

38. Analysis of variance table for number of shoots per unit area, s/m² (November 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	474.50	237.25	2.02	0.21
Treatments	3.00	14518.25	4839.42	41.27	0.00
Error	6.00	703.50	117.25		
Non-additivity	1.00	21.56	21.56	0.16	
Residual	5.00	681.94	136.39		
Total	11.00	15696.25			

39. Analysis of variance table for number of shoots per unit area, s/m^2 (December 1989)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	8216.00	4108.00	7.82	0.02
Treatments	3.00	16614.67	5538.22	10.54	0.01
Error	6.00	3153.33	525.56		
Non-additivity	1.00	1617.19	1617.19	5.26	
Residual	5.00	1536.14	307.23		
Total	11.00	27984.00			

40. Analysis of variance table for number of shoots per unit area, s/m^2 (January 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	26.00	13.00	0.51	0.62
Treatments	3.00	127425.00	424.00	16.77	0.00
Error	6.00	152.00	25.33		
Non-additivity	1.00	49.32	49.51	2.40	
Residual	5.00	102.68	20.54		
Total	11.00	1452.25			

41. Analysis of variance table for number of shoots per unit area, s/m^2 (April 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	428.67	214.33	1.93	0.22
Treatments	3.00	7851.00	2617.00	23.00	0.00
Error	6.00	666.00	111.00		
Non-additivity	1.00	432.00	432.00	9.30	
Residual	5.00	233.00	46.00		
Total	11.00	8946.00			

42. Analysis of variance table for number of shoots per unit area, s/m^2 (May 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	2878.00	1439.00	29.00	0.00
Treatments	3.00	2798.00	932.00	19.00	0.01
Error	6.00	288.00	48.00		
Non-additivity	1.00	115.00	115.00	3.30	
Residual	5.00	173.00	34.00		
Total	11.00	5964.00			

43. Analysis of variance table for number of shoots per unit area, s/m^2 (July 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	55.00	27.00	0.79	0.49
Treatments	3.00	967.00	322.00	9.20	0.01
Error	6.00	209.00	34.00		
Non-additivity	1.00	29.00	29.00	0.82	
Residual	5.00	180.00	36.00		
Total	11.00	1231.00			

44. Analysis of variance table for number of shoots per unit area, s/m^2 (October 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	1836.00	918.00	5.60	0.05
Treatments	3.00	10008.00	3336.00	18.70	0.00
Error	6.00	1066.00	177.00		
Non-additivity	1.00	202.00	202.00	1.17	
Residual	5.00	864.00	172.00		
Total	11.00	12912.00			

45. Analysis of variance table for number of shoots per unit area, s/m²
(November 1990)

Source	Degree of freedom	Sums of Squares	Mean squares	F-Value	Probability
Replications	2.00	192.00	96.00	0.48	0.64
Treatments	3.00	3995.00	1331.00	6.60	0.03
Error	6.00	1210.00	201.00		
Non-additivity	1.00	903.00	903.00	14.67	
Residual	5.00	306.00	61.00		
Total	11.00	5397.00			