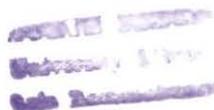


**STUDIES ON THE EFFECT OF CLIMATE AND NUTRIENTS
ON SELECTED PHYSIOLOGICAL AND BIOCHEMICAL
PARAMETERS OF SOME TEA
[*Camellia sinensis* (L.) O. Kuntze] CULTIVARS**

THESIS SUBMITTED FOR THE DEGREE OF
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This is to certify that Sayed Edward Kabir has carried out his work under our joint supervision. His thesis entitled **Studies on the effect of climate and nutrients on selected physiological and biochemical parameters of some tea [Camellia sinensis (L.) Kuntze]** cultivars is based on his original work and is being submitted for the award of Doctor of Philosophy (Science) degree in Botany in accordance with the rules and regulations of the University of North Bengal.



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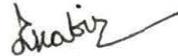
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INTRODUCTION

Each plant is the product of its genetics and the total environment in which it is grown (Kasperbauer, 1994). The yield potential of any crop is set by the climate and its day-to-day variation which is known as weather. Climate determines where a crop is grown and the potential yield; the actual yields obtained depend on the prevailing weather. When nutrients are not limiting the important weather variables are solar radiation (sunshine), temperature, saturation deficit of the air and soil water availability. An analysis of how the weather influences each of these processes can assist in (a) determining the potential yield in a given area (which is useful for planning purposes or when evaluating new sites available for commercial production) and (b) identifying other constraints to production which may be limiting yield and which could be correlated by appropriate management (Carr and Stephens, 1992). Dry matter is produced by the process of photosynthesis and lost by the process of respiration which provides the energy necessary for growth and maintenance.

Photosynthetic efficiency is the primary component of dry matter productivity. Banerjee (1993) reported that 95% of dry weight of plant is derived from photosynthesis and more efficient partitioning is the most logic step for increasing productivity. Gupta (1992) also reported that photosynthesis is the key to dry matter production and hence yield of economic organ. Thus increasing photosynthetic efficiency is the most important way of increasing productivity. It has, however, been found inconsistently related to economic yield because of several plant factors like - photorespiration, dark respiration, assimilate transport and partitioning efficiency, filling period duration and sink size - all interacting with aerial and soil environments. Proper understanding of the interactions between environmental and physiological factors is essential for any scientific planning of tea cultivation. When climate plays an important role on physiology of plant, it is essential to study the behaviour of tea plant physiology under varying climatic conditions.

Sage and Reid (1994) reported that the rate of photosynthesis is dependent on over 50 individual reactions, each of which potentially has a unique response to an environmental variable. The ability of plants to compensate for environmental effects on photosynthesis is critical to their performance and survival. Understanding mechanism controlling photosynthetic responses to environmental change is important for understanding controls on plant productivity, species distribution and the responses to climate change.

Under natural field conditions, plants are exposed to a large number of environmental, physiochemical and biotic stress factors that show irregular and regular diurnal and seasonal variations (Levitt, 1980). Hubert (1988) has reported that diseases and insect losses - decreased U.S. yields below the genetic potential by only 4.1 and 2.6% respectively. The remainder must be attributed to unfavourable physiochemical environments caused by weedy competitors, inappropriate soils, unfavourable climate and poor management practices. As far as climatic factors are concerned, according to the total indemnity made to U.S. farmers for crop losses - drought, excessive water and cold account for 71% (Boyer, 1982). 'Tea' is grown in 28 countries, ranging from 42° North in U.S.S.R. to 38° South in Brazil. Certain variations are caused in physiological behaviour of tea plants due to interaction with environment, requiring adjustment in its management (Jain and Tamang, 1988). According to Stephens et al. (1992), ecophysiology of tea has several applications : it can be used to assist planners in assessing the yield potential of new (or existing) areas of tea, the likely benefits from irrigation (Stephens and Carr, 1988). It can also allow the benefits of shade in different locations to be assessed (Hadfield, 1974) or the development of selection criteria for new clones, based on a knowledge of the base temperature for shoot growth (Stephens and Carr, 1990). Further, it can be used to help to specify objective harvesting policies.

The 'muscatel' flavour of Darjeeling tea holds the place of pride in the world and as such the image bearer of the tea exports in India. But the yield of tea in Darjeeling is only 650 Kg.ha⁻¹ which is

well below the all India average of 1730 Kg.ha⁻¹. Besides, the old age of the bushes and high rate of vacancy, the hill offers various types of stress conditions like low temperature, low soil moisture in winter, low atmospheric moisture during drought, less sunshine hours and most of the areas remain foggy during rainy season, high relative humidity in monsoon, winter dormancy etc. which are likely to affect growth and yield of tea significantly (Ghosh Hajra, 1992).

The role of micro- and macro-elements on the growth of the plants as well as physiological metabolism is well documented. The physiological function of elements on growth, development and metabolism of tea plants were also investigated periodically. The micro- and macro-elements help the plant overcome stress situation.

The present physiological studies on selected clones of Tea plants was primarily aimed on the study of effects of various environmental factors and nutrients on the physiological processes of tea clones in vivo conditions. In addition how under stressed situation, how the stress metabolites like ascorbic acid and proline content of the leaves are altered significantly will also be assessed.

REVIEW OF LITERATURE

Crop growth and production depend on the interaction of a biological system which is the plant or more often a population of plants and the physical environment in which the plant grows. The total growth and production are in fact derived from the environment through the special mechanism and properties possessed by the biological system (Williams and Joseph, 1976).

Huang Shoubo (1989) studied the meteorology of tea plant in China. He had observed that temperature influences the growth, development and yield of tea plant. In China, optimum temperature for most varieties is in the range 20°C-30°C. According to him, tea plants require 1000-1400 mm of annual rainfall : 100-150 mm of rain per month except for the high temperature months. Relative humidity of 80-90% is favourable for tea plants, below which shoot growth is affected.

Tanton (1982a) of Tea Research Foundation of central Africa, Malawi had studied the environmental factors affecting the yield of tea in respect of air temperature, soil temperature, day length, etc. He observed that shoot extension stopped below about 12.5°C air temperature. Soil temperatures between 18-25°C do not effect shoot extension. Othieno (1982) of Tea Research Foundation, Kericho, Kenya had worked on diurnal variations in soil temperature under tea plants. He observed that lower soil temperature affect growth and yield.

Hadfield (1976) found maximum CO₂ uptake at 30°-35°C. There was rapid fall beyond 37°C and there was no net photosynthesis at 42°C. Under natural conditions, temperature of fully exposed leaves was 2°C to 12°C higher than ambient temperature. Nakayama and Harada (1962) from Japan found that growth was most rapid at 30°C and growth ceased below 12-5°C. Barbora (1991) has reported that tea leaf retain its peak photosynthetic ability for about six months though it continues functioning till about 18 months before it is shed. According to him photosynthesis is impaired

at ambient temperature above 30°C and seasonal dormancy is related to short day length and low temperature. Carr and Stephens (1992) reported that the minimum air temperature required to support shoot growth appears to be 13-14°C with an optimum range 18-30°C. Day time maximum temperature in excess of 30°C and night temperature below about 14°C probably lead to a reduction in the growth rate. The minimum leaf temperature necessary to initiate shoot extension is apparently 12°C and at leaf temperature about 35°C, the rate of net photosynthesis falls off quickly. Long sunshine hours are probably essential for maximum yield. In most areas 150 mm of rain each month i.e. 1800 mm of annual rainfall will ensure continuous crop production.

Acclimation of plants to different light environments has profound influences on the structure and function of the photosynthetic apparatus (Anderson and Osmond, 1987; Anderson et al. 1988). After exposure to low temperature and high irradiance, sun leaves showed a sharp decline in photosynthetic activity (Brugnoli et al., 1994).

The main climatic variables influencing rates of shoot extension and yield of tea are temperature, the saturation deficit of the air and through their influence on plant and soil - water deficits, rainfall and evaporation (Carr, 1972; Squire and Callandar, 1981; Stephens and Carr, 1990). Manivel (1980) reported that the maintenance leaves below the plucking surface fix CO₂ photosynthetically and supply the photosynthetic to other parts of the plant. All the mature leaves in the plants were photosynthetically active even under the cold weather conditions prevailing in December. He found that even the fifth leaf from the top was contributing photosynthates towards the growth of pluckable shoots at the top. He observed highest rate of photosynthesis in the topmost leaf of the maintenance foliage.

Manivel and Hussain (1982) reported that topmost leaf in a canopy (maintenance canopy) contributed the highest proportion of photosynthates to the pluckable shoots. Manivel (1978) also referred that pluckable 'two

and a bud' also photosynthesizes, but to a much lesser extent than the mature leaves. Maintenance foliage in tea is the main source of carbohydrate.

Rustagi and Barman (1993a) has reported that optimum leaf temperature for maximum productivity has been estimated to be 25°-30°C. They also pointed out that experimentally it has been proved that maintenance foliage carry out photosynthesis throughout the year. Therefore, it is not the stoppage of photosynthesis which makes the bushes go dormant. Interflush dormancy is caused by low availability of moisture and various other factors whereas winter dormancy is caused by the interaction of some environmental factors like short day length and low temperature.

Moyer (1965) has reported that light intensity and CO₂ concentration are the primary external parameters which control photosynthesis. Temperature is a secondary factor. The effect of temperature on photosynthesis varies with light intensity, and the carbon dioxide supply. Both these factors control the photochemical reactions, which are generally independent of temperature. With low light intensity and adequate CO₂ or with low CO₂ and adequate light, the light reactions will be limiting. Reed (1946), however, inferred that photosynthesis is influenced by all the environmental factors viz., temperature, moisture supply, RH of the air, age of the leaf. Baker *et al.* (1990) observed that CO₂ concentration affects many plant processes, mainly through its direct effect on photosynthesis and stomatal physiology.

Sage and Reid (1994) reported that light has three major effects on photosynthesis. First, it provides the energy used in the production of ATP and NADPH. Second, light promotes the activation of key enzymes in the photosynthetic apparatus and stimulates stomatal opening. Third, light acts through photoreceptors such as phytochrome to modulate the development of leaves and the photosynthetic apparatus light promotes enzyme activation largely through its effect on electron system. Important light activated enzymes in photosynthesis include rubisco,

stromal fructose-1,6 biphosphatase, NADP-triose phosphate dehydrogenase, ribulose-5-phosphate kinase and sedoheptulose biphosphate.

The radiation reaching the surface of the earth from the sun has a maximum intensity of about 1.6 calorie per cm^2 per minute, corresponding to a visible irradiance of about 100,000 lux or metre-candles. The intensity, and to a lesser extent, the spectral composition, of solar radiation varies, of course, with time of day, weather, season and geographical position. Plants must make the best use they can of this mixed and variable radiation for the energy they need for photosynthesis. Variations in light intensity and duration of illumination affect photosynthesis directly (Fogg, 1972; Squire and Callandaer, 1981). The vast majority of this short wave radiation is interrupted ^{by} leaves in the top 0.3 m of the canopy, almost regardless of foliage geometry below 0.1 m (Hadfield, 1974) with only about 5% reaching the ground. Only a very small proportion of the net available energy is used in the process of photosynthesis, the vast majority is dissipated as latent heat (through the process of evaporation) and as sensible heat (heating the surrounding air).

Dhopte et al. (1992) reported that transpiration increases with increase in photosynthetically active radiation. Sunlight may fall on leaf either directly, after reflection by molecules in the air (sky-light) or after reflection from clouds (cloud light) or other surrounding object. The amount of solar radiation incident on the earth atmosphere, the so-called "solar constant" is about $8-4 \text{ J per cm}^2$ per minute and of this about 50% reaches the earth surface at sea level on a cloudless day when the sun is directly overhead light intensity reaches a maximum of about 10,000 lux under these conditions. The amount of radiation observed by a leaf depends on the wavelength and on its spectral characteristics. About 44% of the solar energy incident on the earth surface is useful for photosynthesis. The maximum light energy that a tea leaf can use for photosynthesis varies from clone to clone even under optimal conditions (Barua, 1993). The study of growth and yield of a plant requires the

knowledge of the photosynthetically active radiation (PAR) (Karalis, 1989). PAR is defined as the part of the solar spectrum between the wavelengths 400-700 n.m. (0.4-0.7 μm) (Stamper and Allen, 1979; Rao, 1984; Langholz and Hackel, 1985 and Monteith, 1993).

Water stress can reduce photosynthesis by reduction leaf area, closure of stomata. It affects practically every physiology and biochemistry (Kramer, 1969). There is abundant evidence that photosynthesis is inhibited due to high light intensity (Balasimha et al., 1991). Rosenberg (1974) observed high atmospheric stress is expected to reduce photosynthesis probably causing rapid evaporation from guard cells and causing stomata to close. Crafts (1968) inferred that decreasing water potential in leaves is known to reduce photosynthesis. Slavik (1965) points out, this is the result of three effects : (i) hydroactive closing of stomata, bringing about a reduced CO_2 supply, (ii) water stress in cytoplasmic ultrastructure affecting enzyme activity and (iii) dehydration of cuticle, epidermal walls and cell membranes reducing their avidity for and permeability to CO_2 . Kramer (1959) believed that reduction in water content usually reduce the rate of photosynthesis both because dehydrated protoplasm is less effective and because stomatal closure reduces the supply CO_2 . Fogg (1972) referred that photosynthesis and water economy of terrestrial plant are so intimately interrelated that water supply is normally one of the most important factors determining the amount of photosynthesis carried out. The decrease in photosynthesis at high values of stress may be due to stomatal closure, which has been shown to limit Pn in water stressed leave (Slatyer, 1973). Water stress reduced photosynthesis due to impaired stomatal conductivity (Barbora, 1994). Higher stomatal resistance could also affect gaseous exchange and consequently, the rate of photosynthesis (Rajasekar et al., 1991). Voleti et al. (1991) reported that under low light, reduction in photosynthesis occurred. Reduction of the photosynthetic rate as a result of moisture stress is well documented (Harris, 1973; Hsiao, 1973; Bielora and Hopmans, 1975; Ackerson et al., 1977; Sung and Krieg, 1979). The inhibition of photosynthesis by water stress may be attributed to both

stomatal and non-stomatal factors depending on the particular environmental conditions (Hutmacher and Krieg, 1983). Jones (1973) and Boyer (1976) suggested that stomatal resistance is the principal limitation to photosynthetic CO_2 . Since stomatal opening is more dependent on water balance than on light, photosynthesis may be limited severally during the period of water stress despite the fact that light and CO_2 supply are optimum (Gaastra, 1959). Fry and Walker (1964) found decrease in net photosynthesis with increased water stress. Steward (1960) observed that temperature limits photosynthesis by the heat denaturation of enzymes or structural proteins. According to him the external factors which influence the rate and efficiency of photosynthesis are light, humidity and CO_2 . Chapman et al. (1988) observed that exposure of plants to high light intensities can reduce photosynthetic rates and be a significant cause of reduced crop yield. Murty (1988) pointed out that reduction in photosynthesis under low light could be attributed to high stomatal resistance to CO_2 exchange. Minns and Pearson (1974) demonstrated that drought reduction in translocation was proportional to the decline in photosynthesis because the amount of water actually needed for the photosynthetic process would be very little in comparison with the amount needed to maintain the living plant. Therefore, since long a deficiency of the supply of water became inhibitory to photosynthesis in a direct manner, the indirect effect of a shortage of water could impair other vital processes of the biological mechanism retarding photosynthesis (Devlin, 1978). Oquist et al. (1982) observed that net photosynthesis were lower in developing than in mature and old leaves. Barua (1969) reported that low temperature and day length apparently interact including dormancy but their respective roles are not yet clear. Barbora (1994) inferred that photosynthetic response to temperature was mainly due to change in mesophyll activity rather than stomatal control. Gupta (1992) commented that high stomatal resistance in plants would be advantageous in water economy and resistance. Several scientists have attempted to select plant with high stomatal resistance (Miskin et al., 1972; Wilson, 1972). Rao et al. (1988) observed that stomatal resistance increased under water stress condition but the conductance reduced. Stomatal resistance increased under drought stress (Singh and Sahay, 1992). It is known that

moisture stress increases stomatal resistance (Handique and Manivel, 1990). Turner et al. (1978) reported decrease of photosynthesis with decrease in stomatal conductance. With slowly imposed water stress, it may be the effect of water deficit in reducing net photosynthesis that reduces stomatal conductance (Osmond et al., 1980). Stomatal conductance decreased significantly due to stress in all genotypes (Bansal and Nagarajan, 1986). Sastry and Dutta (1985) apprehend that the increased temperature of the stressed plant is due to stomatal closure. Viscoe and Gallagher (1975) concluded that leaf extension rate was a linear function of temperature. Heath (1959) found that high temperature exerts two opposing effects upon the stomata - (i) at a given light intensity, the minimum intercellular CO₂ concentration, increases with temperature, (ii) if excessive accumulation of CO₂ in the intercellular spaces does not occur, raising the temperature causes opening. Rao et al. (1988) inferred that leaf to air temperature difference was significantly higher under stressed condition.

Water loss by transpiration is the primary cause of plant water deficits. Transpiration is the dominant factor in plant water relations because evaporation of water produces the energy gradient which causes movement of water into and through plants. Therefore, it controls the rate of absorption and the ascent of sap (Kramer, 1969). Fry and Walker (1964) found decrease in transpiration with increase in stress. An increase in temperature almost always increases the rate of transpiration because it increases the steepness of the water vapour pressure gradient from plant tissue to air (Kramer, 1959). Visible light has important effect on transpiration through its control of stomatal opening (Kramer, 1959). Rao et al. (1988) found reduced rate of transpiration due to water stress. Soil moisture deficit reduced the transpiration rate (Barbora, 1994). In China type of clones the transpiration was lower at the higher soil moisture level, but its depression was minimum at low soil moisture status (Barbora, 1994). Soil moisture stress decreases transpiration rate (Handique and Manivel, 1990). Wind usually causes increased transpiration because it removes water vapour from the vicinity of transpiring surfaces and produces a steeper vapour pressure gradient from plant tissue to air,

but it also tends to cool leaves, thereby decreasing the steepness of the vapour pressure gradient (Kramer, 1959). Yang et al. (1990) reported that transpiration plays very important role in the hydraulic cycle of crops. While transpiration is an active plant response to climatic factors, leaf temperature is a passive outcome of the heat and mass exchange (Thom, 1975; Bott, 1983). Leaf temperature directly affects plant metabolic activities. Feldhake and Edwards (1992) observed that temperature regulates leaf biochemical process rates. Leaf temperature deviates from ambient air temperature in a manner dependent on solar radiation level and ambient vapour pressure deficit.

Stephens et al. (1992) observed that low soil temperature are always a major limiting factor to shoot extension. Othieno (1982) reported that soil temperature affects growth.

Handique and Manivel (1986) inferred that drought tolerant clones consistently exhibited higher water potential. Rao et al. (1988) observed that water potential decreases under water stress condition. Parameshwara et al. (1988) concluded that water stress lower the water potential values. Water potential of cold stressed plants was not altered at all. During the very winter months, value of water potential decreased than in the wet summer months (Manivel and Handique, 1983). There was no significant difference in water potential between the ages (Manivel and Handique, 1983). Leaf water potential was lower when photosynthesis was reduced (Bunce, 1990). Rustagi and Barman (1993b) have remarked that clones of China origin exhibited higher water potential compared to Assam clones.

Potassium has a very favourable effect on root development. The deficiency reduces growth in thickness through accelerated growth in length and the internodes are significantly long. The tea bushes acquire a loose appearance (Sharma, 1964). Plants with adequate potassium, lose less moisture because of the reduced transpiration rate. When exposed to desiccating winds, plants well supplied with potassium are able to close the stomata much more quickly than potassium deficient ones (Sekhon and

Ghosh, 1982). Leaf water potential increased significantly with increased levels of potassium application. Potassium reduces transpiration through regulation of factors like leaf water potential, stomatal resistance etc.

Khan (1991) reported that increase in stress increases leaf K content and potassium application further leaf K content. Manivel (1992) reported that application of Muriate of potash is found to impart drought tolerance in mature tea. Perrenond (1977) and Nelson (1978) pointed out the effect of potassium on increased tolerance to drought. But there are also reports that there was no beneficial effect due to foliar application of potassium during drought months (Anonymous, 1981). The fundamental roles of potassium in plant metabolism are largely regulatory. They also play a role in the opening and closing of stomata. It acts as an activator of many enzymes involved in carbohydrate metabolism (Jain, 1994). One of the enzymes activated by potassium is a respiratory enzyme called pyruvate kinase. It plays an important part in the formation of starch and in the production and translocation of sugars. Moyer (1965) reported that lack of potassium interferes seriously with assimilation and carbohydrate metabolism. Potassium affects plant growth mainly by its effect on cell extension (Berringer and Nothdurft, 1985; Hsiao and Lauchli, 1986).

Moyer (1965) reported that phosphorus and sulphur, essential elements in the photosynthetic enzymes, are directly involved in light reactions. Potassium, zinc, molybdenum etc. promote the dark reactions that dispose off the initial products of photosynthesis and maintain the supply of primary substrates for the light reactions. Phosphorus participates directly or indirectly in most of the reactions associated with photosynthesis. It supplies high energy bonds of ADP, DPN, PGA, RDA and many other phosphatic compounds involved in the photosynthetic and Krebs cycles.

Sulphur deficiency reduces photosynthetic rates. Sulphur participates in many of the enzymatic reactions in the leaf through the habits sulphhydryl, SH^{-1} group, also as a constituent of the essential amino acids - cysteine, cystine and methionine; the peptide glutathion; and the vitamins thiamine, biotin etc. Calvin (1956) suggested that the transfer of electrons from light excited chlorophyll (about 40K Cal

mole⁻¹) to produce the reduced form of triphosphopyridine nucleotide (TPNH), which in turn is instrumental in operating the photosynthetic cycle, is accomplished by an intermediate reduction of the disulfide form of 6,8-thioctic acid to the dethiol form. Further, the acetylating co-enzyme A, which mediates a pyruvic acid oxidase reaction between the photosynthetic cycle and Krebs cycle, contain sulfhydryl, disulfide and possibly thiazoline groups. Sulphur thus appears to be directly involved in the light reactions of photosynthesis. Potash is not only a major nutrient of tea but it also plays a major role in triggering the growth of young tissues and for maintenance of an optimum turgor needed for cell elongation and cell division (Ranganathan and Natesan, 1985).

Phosphorus occupies one of the most important positions in the carbohydrate metabolism of plants in general. In addition, phosphoric acid plays an important role on fat metabolism and is itself present in most of the enzymes known (Sharma, 1964). Enhancement of leaf photosynthesis by phosphate application was consistently related to non-stomatal factors (biochemical and/or anatomical) as indicated by changes in the intercellular CO₂ concentration. The intercellular CO₂ concentration tended to decrease with increase in photosynthesis. Phosphorus plays a major role in the growth of tea plants (Mann and Gokhale, 1960). Phosphorus plays a key role in DNA synthesis and indispensable for growth (Verma, 1993). Physiological efficiency of phosphorus absorption is the relative ability to maximize phosphorus concentration with minimal fixed carbon investment in root growth and metabolism (Brewster and Tinker, 1972). Phosphorus organic compounds are essential to metabolic processes and are especially active in energy transfers. In plants energy transfers are linked by ATP, which is high energy compound. When it undergoes hydrolytic reactions it exhibits a large decrease in free energy (Shuman, 1994).

Sulphur is essential for the growth of tea and other plants (Barua, 1989). It is an integral constituents of cystine, cysteine and methionine (amino acids) (Dev and Kumar, 1982). Sulphur is an essential element for growth and productivity of tea plants (Bhat and Ranganathan, 1981).

Crop response to micronutrient application is modified to a large extent by the environment. It is a common observation that micronutrient deficiencies in crop are acute in cold weather and mild or absent in warm weather (Randhawa and Nayyar, 1982).

Zinc is a constituent of several enzyme systems which regulate various metabolic reaction in the plant, for example, in oxidation-reduction reactions in the formation of chlorophyll. It also influences the synthesis of some growth hormones in the plant (Rahman and Sharma, 1974). Reed (1946) referred that zinc is a constituent of carbonic acid anhydrase present in the chloroplast, which catalyses the decomposition of carbonic acid to CO_2 and water. Zinc is also found in adolase which mediates the reversible, transfer of phosphoglyceraldehyde to fructose 1,6-diphosphate. Zinc is present in several dehydrogenase, proteinase and peptidase enzymes; promotes growth hormones and starch formation (Nyle, 1984). Studies conducted at Tocklai showed that foliar applied zinc to be at least 10 times more efficient than zinc applied to soil (Barua, 1989).

Molybdenum is involved in the reduction of nitrate to ammonia but its deficiency in tea has not so far been reported (Barua, 1989). It is present in nitrogenase (nitrogen fixation) and nitrate reductase enzymes : essential for nitrogen fixation and nitrogen assimilation (Nyle, 1984). Soil moisture content influences the behaviour of molybdenum. Soil wetness generally leads to increase in the availability of molybdenum.

Molybdenum is a constituent element of flavo-protein-nitrate enzyme reductase. Ascorbic acid formation is reduced by molybdenum deficiency (Moyer, 1965). Although molybdenum is a metal, it occurs as an Oxy-anion, MoO_4^{2-} and is absorbed by plants as the molybdate ion (Mengel and Kirby, 1982; Marschner, 1986).

Levitt (1980) observed that even in the highly drought resistant creosote bush, total amino acid content more than doubled under moisture stress. Kathju et al. (1988) concluded that water stress resulted in higher accumulation of free amino acids. Biswas and Chaudhuri (1986) observed that proline accumulates dramatically in water deficit stress plant due to higher proteolysis and/or higher synthesis of this amino. They are of the opinion that proline accumulation can be taken as a biochemical index for the characterization of water stress tolerance of the plant. Stewart (1977) inferred that wilting causes a decrease in proline utilization by decreasing protein synthesis. This leads to proline accumulation. Jagtap et al. (1992) observed that water stress treatments with short spells significantly increased proline content. The relationship between accumulation of total free amino acid and ascorbic acid (Draper, 1975; Levitt, 1980) and proline (Ghosh Hajra, 1992) with drought and hardiness are well established. Devay (1965) concludes that since ascorbic acid is a co-factor for the enzyme glutathion reductase, new enzymes are synthesized at the low temperature which lead to an increase in the tissue content of ascorbic acid. Under moisture stress conditions, proline oxidation was inhibited (Stewart, 1977) and this was thought to maintain high level of proline in the stressed tissue. No relationship between accumulation of proline and drought was observed in wheat and soyabean (Sinha and Rajagopal, 1977; Guo et al., 1988). Stress induced proline accumulation was related to the ability of the cultivar to recover after irrigation (Blum and Ebercon, 1976), an osmoticum, a protectant or a nitrogen reserve (Hanson et al., 1977).

Lewandowska and Jarvis (1977) inferred that chlorophyll is an important component of photosynthetic system. Therefore, the photosynthetic efficiency of a crop may be indicated by the amount of chlorophyll. Buttery and Buzzell (1977) observed high correlation of photosynthetic rate with chlorophyll content. Barman et al. (1993) reported that chlorophyll content has no direct correlation with yield. Water stress leads to a decline in total chlorophyll in all the clones (Rajasekar et al., 1991). Biswas and Choudhuri (1986) and Jagtap et al. (1992) also found the same result. Reduced ability to form protochloro-

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phyll was considered to be responsible for the inhibition of the development of the chlorophyll under moisture stress (Hsiao, 1973).

Baker (1974) and Bengston et al. (1978) inferred that epicuticular wax plays an important role in the plants ability to withstand water deficit and is known to increase due to stress. The increased wax deposition thereby reducing transpiration. Glauousness caused by the deposition of epicuticular wax which may be altered to suit the changing environment (Akunda, 1990). Photosynthesis rates may be influenced by the degree of reflectance caused by glauousness of leaf (Cameroon, 1970). Water stress led to a significant accumulation of epicuticular wax (Rajasekar, 1991; Voleti and Rajagopal, 1991; Rustagi and Barman, 1993b). Handique and Manivel (1990) reported high quantity of epicuticular wax in drought tolerant clones. They suggested that deposition of epicuticular wax may be correlated with reduction in transpiration rate and increase in stomatal resistance. Ziyad Mohammed et al. (1986) found that the wax contents of the drought resistant clones were higher than that of drought susceptible clones. The impervious epicuticular component effectively reduced water loss due to transpiration (Derma, 1970), contribute to the control of gaseous exchange (Jaffree et al., 1971) and influence the retention and redistribution of foliar applied chemicals (Holloway, 1970). This external layer influence the reception and subsequent redistribution of incident radiation either through reflection or convection away from the plant or by conduction into the internal tissues (Baker, 1972).

AIMS AND OBJECTIVES

Although India produces the highest quantity of tea in the world, little work has been carried out on effect of meteorological factors on growth and productivity of tea plants. Darjeeling Tea is famous for its world famous muscatel flavour but Darjeeling is also known as the area with lowest tea yield. As stated earlier the yield of tea Darjeeling is only 650 kg.ha^{-1} which is well below the all India's average of 1730 kg. The main reasons for low yield are adverse climatic conditions as well as variety of tea. The major area under tea is planted with China variety of tea, i.e. Camellia sinensis (L.) O. Kuntze, belonging to the family Ternstroemiaceae under the order Guttiferales. This variety is a low yielder with tiny leaves.

When the climatic condition is a barrier against increase in yield potential, it was essential to study the role of weather parameters on Darjeeling tea plants. But nothing of that sort had been taken up before this study. The yield potential also depends very much on physiology of the plant. The correlation between climatic factors and their effects on physiological and biochemical processes like synthesis of proline, ascorbic acid, amino acid etc. are very much noteworthy for further study. Many authors have identified proline and ascorbic acid as an indicator of stress physiology.

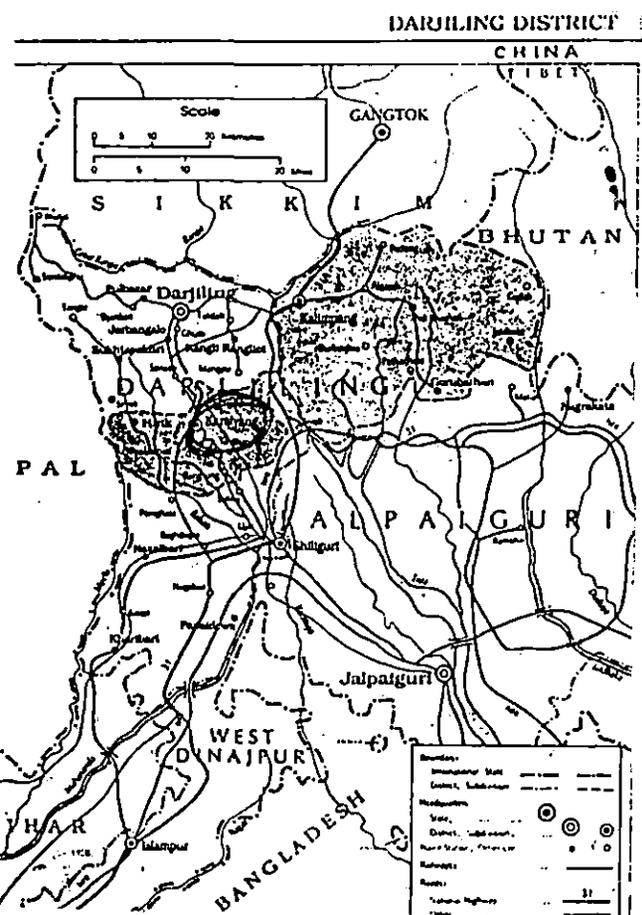
It is also well known that in hilly tracts of Darjeeling soil nutrient status with respect of some macronutrients and several micronutrients played a key role in growth and productivity of tea plants. In the past, quite a few fertilizer trial experiments were done in the aforesaid perspective using zinc, phosphorus, molybdenum, potassium and sulphur. But in the present investigation, the basic approach was to understand the effect of various doses of nutrients on tea plant's growth responses.

On the whole, the overall objectives of this investigation are listed at the next page :

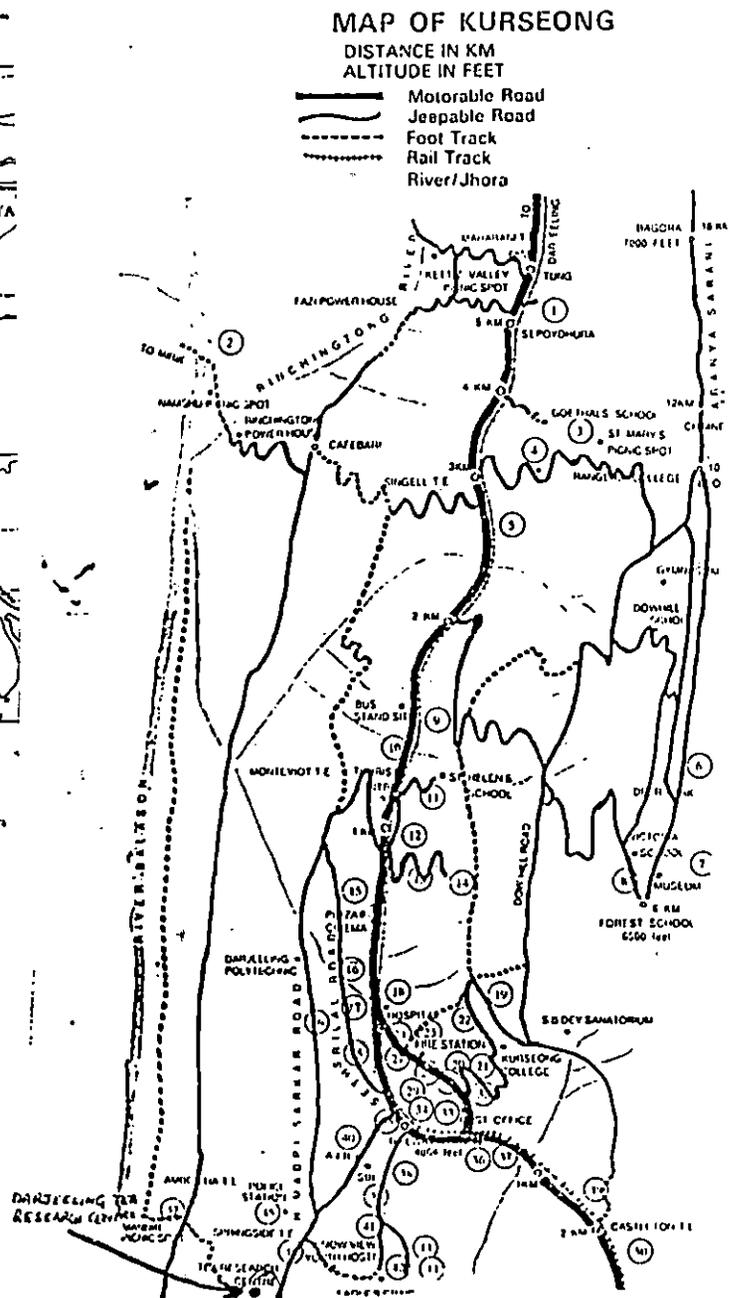
- (i) To study the effect of seasonal variation of environmental parameters (air & soil temperatures, photosynthetic photon flux density, sunshine hour, relative humidity, wind velocity, rainfall) on the physiological attributes (net photosynthesis, stomatal conductance, stomatal resistance, leaf water potential, transpiration and leaf temperature) on three major China hybrids. These are called as Darjeeling clones viz. Bannockburn-157, Phoobshering-312 and Tukdah-78. The bushes of different stages were considered for in vivo studies.
- (ii) To study the interactions between various physiological parameters under diverse weather conditions.
- (iii) To understand the water relations of tea plants and behaviour of three major Darjeeling clones in water stressed situation.
- (iv) To study the effect of foliar spray of micro(zinc and molybdenum) and macro (potassium, phosphorus and sulphur) on net photosynthesis, stomatal conductance and transpiration.
- (v) To study the seasonal variations of total free amino acid, total proline, ascorbic acid, total chlorophyll and epicuticular wax in the leaves of three varieties viz. Bannockburn-157, Phoobshering-312 and Tukdah-78 tea clones at different growth phases/ages.



A



B



C

Fig. 1 : Map of West Bengal (A), Darjeeling district (B) and Kurseong town (C) showing the location of Experimental sites

MATERIALS AND METHODS

Site of study : The field experiment was carried out in Springside area of Kurseong town in the tea plantation. Laboratory analysis works were done in Depts. of Botany and Tea Management, University of North Bengal and Dept. of Ecology, Kalyani University.

Geographical description : The field is located at 26°55'N and 88°12'E and at an altitude of around 1240 m above median sea level. The topography is of rolling and folded mountains.

Edaphic character : The soil is umbric Dystrochrept, has moderate permeability and is moderately well drained. Infiltration rate is 6-10 mm hr⁻¹ and run off is high. Soil texture is coarse and loamy. The top soil is 45 cm thick and subsoil is stony and bouldery. Physico-chemical properties of soil of the experimental area are presented in Tables 1 and 2.

The Crop : Study was carried out on tea plant (Camellia sinensis (L) O. Kuntze), Family Ternstroemiaceae under Order Guttiferales. There are altogether 30 clones of tea cultivated in Darjeeling area. Of these, three major clones are mostly grown in the gardens. These clones are selected for present investigation. A brief description of these clones are given as follows :

A. Bannockburn 157 (A clone developed in Bannockburn Tea Estate)

A medium sized, dark green glossy leafed China hybrid clone having similarity to domesticated Camellia. It has medium sized frame "shaving brush" type with dense plucking points and many trailing lower branches. This clone is rated to be strongly resistant against drought. A very early flusher and keeps flushing till late December. With adequate irrigation in dry weather, this clone starts flushing in mid-January.



A



B



C

Fig. 2 : Young (4-year old) plants of Bannockburn-157 (A), Phoobshering-312 (B) and Tukdah-78 (C) clone.

B. Phoobshering 312 (A clone developed in Phoobshering Tea Estate)

A China hybrid clone with leaf of medium size, semi-erect, dark green having pronounced serrations and matty foliage and wavy margin. Widespread and compact frame. It thrives well on all aspects but distinctly prefers the northern slopes and high altitudes.

C. Tukdah 78 (A clone developed in Tukdah Tea Estate)

This is very vigorous China hybrid cultivar with erect leaf of dark green colour, margin flat. This clone has good resistance to drought. A fairly good spreader with lax frame.

An overall characteristics of these three clones are given in Table 3 and Fig. 2.

The experimental designs and details in respect of mature and young plants and experiment on nutrients spray are presented in Tables 4 & 5.

Table 1 : Physical properties of soil of the experimental site

| Parameters | Name of horizon & depth (cm) | | | | |
|--|------------------------------|-------------------------|-------------------------|--------------------------|--------------|
| | A _P 0-13 | A _C 13-31 | B ₁ 31-97 | B ₂ 97-114 | C 114-130 |
| 1. Bulk density (g cm ⁻³) | 1.39 | 1.36 | 1.36 | 1.33 | 1.37 |
| 2. Water holding capacity (%) | 39.23 | 37.56 | 38.21 | 36.32 | 35.01 |
| 3. Porosity (%) | 40.02 | 38.26 | 39.59 | 37.29 | 36.31 |
| 4. Water retention characteristic | | | | | |
| i) 0.1 bar | 32.71 | 29.74 | 29.96 | 31.24 | 28.22 |
| ii) 0.3 bar | 25.62 | 21.32 | 20.01 | 22.23 | 20.62 |
| iii) 3.0 bar | 15.21 | 14.22 | 12.16 | 14.23 | 13.19 |
| iv) 15.0 bar | 4.65 | 5.01 | 3.21 | 3.11 | 3.04 |
| 5. Particle size distribution (%) (<2.0 mm fractions only) | | | | | |
| i) Coarse sand (0.25-2 mm) | 52.2 | 50.9 | 48.6 | 50.8 | 59.9 |
| ii) Fine sand (0.25-.05 mm) | 21.0 | 22.6 | 22.7 | 23.0 | 18.2 |
| iii) Coarse silt (.05-.02 mm) | 8.5 | 8.9 | 7.8 | 7.2 | 8.7 |
| iv) Fine silt (.02-.002 mm) | 5.6 | 7.2 | 6.3 | 5.3 | 6.3 |
| v) Clay (<0.002 mm) | 12.7 | 10.4 | 14.6 | 14.7 | 6.9 |
| 6. Ratio of : | | | | | |
| i) $\frac{\text{Fine sand}}{\text{Coarse sand}}$ | 0.402 | 0.444 | 0.467 | 0.430 | 0.303 |
| ii) $\frac{\text{Fine silt}}{\text{Coarse silt}}$ | 0.658 | 0.808 | 0.807 | 0.693 | 0.724 |
| 7. Textural class | Sandy loam | Sandy loam | Sandy loam | Sandy loam | Sandy loam |

Source : Saha *et al.* (1995)

Table 2 : Physico-chemical and chemical properties of soil of the experimental site

| Parameters | Name of horizon & depth (cm) | | | | |
|--|------------------------------|-------------------------|-------------------------|--------------------------|--------------|
| | A _P 0-13 | A _C 13-31 | B ₁ 31-97 | B ₂ 97-114 | C 114-130 |
| 1. pH (1:2.5) | | | | | |
| i) With distilled water | 4.91 | 5.01 | 5.23 | 5.20 | 5.12 |
| ii) With 1 N KCl | 4.52 | 4.61 | 4.66 | 4.72 | 4.65 |
| 2. Organic carbon (%) | 1.21 | 1.13 | 1.03 | 1.01 | 0.91 |
| 3. Organic matter (%) | 2.09 | 1.96 | 1.78 | 1.75 | 1.58 |
| 4. Total nitrogen (%) | 0.110 | 0.092 | 0.091 | 0.091 | 0.082 |
| 5. Available phosphate (%) | 0.021 | 0.024 | 0.027 | 0.023 | 0.020 |
| 6. C : N | 11.00 | 12.28 | 11.32 | 11.09 | 11.09 |
| 7. Cation Exchange Capacity (CEC) (Cmol kg ⁻¹) | 13.62 | 13.15 | 10.01 | 9.23 | 8.32 |
| 8. Exchangeable cations (mol kg ⁻¹) | | | | | |
| Ca ⁺⁺ | 1.65 | 1.16 | 1.05 | 1.09 | 1.32 |
| Mg ⁺⁺ | 0.30 | 0.41 | 0.48 | 0.21 | 0.11 |
| K ⁺⁺ | 0.156 | 0.184 | 0.181 | 0.207 | 0.204 |
| 9. Free Iron Oxide (%) | 7.26 | 7.64 | 7.38 | 7.92 | 6.01 |
| 10. Mobile Iron (%) | 0.72 | 0.75 | 0.75 | 0.73 | 0.76 |
| 11. Mobile Aluminium (%) | 0.60 | 0.58 | 0.68 | 0.37 | 0.22 |

Table 3 : Characteristic of Tea clones and for experimental varieties of Tea crops

| Characteristic | B157 | P312 | T78 |
|---|------|------|------|
| 1. Mean area of an individual leaf (cm ²) | 22.5 | 20.0 | 18.9 |
| 2. Length of the Lamina (cm) | 7.2 | 7.7 | 7.2 |
| 3. Breadth of the Lamina (cm) | 3.1 | 2.6 | 2.5 |
| 4. Length/Breadth Ratio | 2.3 | 3.0 | 2.9 |
| 5. Mean internode length below plucking surface (cm) | 2.2 | 2.8 | 2.0 |
| 6. Mean leaf angle from vertical (degrees) | 28.9 | 40.0 | 35.3 |
| 7. Fresh weight of individual leaf (g) | 0.73 | 0.65 | 0.57 |
| 8. Oven dry weight of individual leaf (g) | 0.28 | 0.25 | 0.23 |

Table 4 : Experimental designs and details of mature and young plants (Randomised Block Design)

| | <u>Mature Plants</u> | <u>Young Plants</u> |
|---------------------------|--|-----------------------|
| Year of planting | 1985 | 1990 |
| Spacing | 90 cm x 60 cm x 60 cm | Same as mature plants |
| Planting pattern | Regular double hedge | -do- |
| Replication | 5 (five) - Each plant one replication | -do- |
| Number of plants | Fifteen - 5 each of each variety (B157, P312, T78) | -do- |
| PARAMETERS STUDIED : | | |
| Physiological parameters | Net photosynthesis, Stomatal conductance, Stomatal resistance, Transpiration, Leaf water potential, Leaf temperature, Growth rate analysis | -do- |
| Biochemical parameters | Total free amino acid, Free proline, Ascorbic acid, Total chlorophyll and Epicuticular wax | -do- |
| Meteorological parameters | Relative humidity Air temperature, Photosynthetic photon flux density, maximum/ minimum & Soil temperature, wind velocity, sunshine hour and rainfall. | -do- |

**Table 5 : Design and details of the nutritional experiment
(Randomised Block Design)**

| | | |
|---|---|---|
| Year of planting | : | 1992 |
| Age of the plants at the time of planting | : | 1½ years |
| Replication | : | 3 (three) |
| Treatment | : | Spray of molybdenum, potassium, phosphorus, sulphur and zinc spray @ 2% in April/May and September/October at fortnightly interval (total 4 sprays) with 1 litre capacity ASPEE hand sprayer. |
| Varieties | : | Bannockburn 157, Phoobshering 312 and Tukdah 78 |
| No. of pots | : | Total 54 pots |
| Size of pot | : | Circumference of upper rim - 2 m Diameter (inner) upper open face- 32 cm Height from ground level - 30 cm Weight of empty pot - 3 Kg Weight of soil per pot - 10 Kg |
| Parameters studied | : | Net photosynthesis, Stomatal conductance, transpiration, girth & height. |
| Period of recording | : | Pre-monsoon, monsoon, Post-monsoon and winter. Girth and height once a year. |



Fig. 3 : A portable photosynthesis system (LI6200, LICOR Inc., USA) used for recording net photosynthesis, stomatal conductance and resistance, transpiration, leaf temperature, etc.

Measurement of Physiological Parameters

A portable photosynthesis system (LI 6200 - LICOR Inc., U.S.A.) was used to measure the rate of net photosynthesis, stomatal conductance, stomatal resistance and leaf temperature (Fig. 3).

When a plant photosynthesizes, it takes up CO_2 . As it respire, it gives off CO_2 . The net exchange of CO_2 between a leaf and the atmosphere is measured with the LI-6200 by enclosing a leaf in a closed chamber and monitoring the rate at which the CO_2 concentration in the air changes over a fairly short time interval (typically 10-20 seconds). The net photosynthesis is then calculated using this rate of change the amount of leaf area enclosed, the volume of the enclosure, temperature and pressure. When a leaf is enclosed in the chamber, the humidity within the chamber from the change in humidity with time and rate of flow of dry air. Transpiration rate is then used with the leaf and air temperatures to calculate stomatal conductance. Photosynthetic photon flux density leaf temperature, air temperature, relative humidity are measured with the help of quantum sensor, leaf temperature thermocouple, air temperature sensor and humidity sensor.

At the time of recording the instrument was calibrated and programmed. In situ reading of the physiological parameters were taken in the field without destruction of leaves. First, second and third leaves (recently matured leaves) were taken for observation. Recording were done during morning hours of every alternate month. Photosynthetically active period was ascertained by taking repeated readings. The leaf chamber was connected to the console. A leaf still connected to the plant, inserted in the leaf chamber and closed the chamber. The relative humidity was made constant adjusting the flow meter. The leaf was taken out and again inserted after allowing enough air to enter the leaf chamber. The log button was then pressed to record the data. The data from the measurement were automatically logged into the scratch pad in the LI-6200's memory. After the observation was complete, the instrument computed mean and range for each data. The data



Fig. 4 : A dew point microvoltmeter (HR 33T, WESCOR Inc., USA) used for measurement of leaf water potential.

were stored and printed in the Laboratory using a printer (L800 EPSON, JAPAN). the first, second and third leaves from each plant were used separately for physiological study.

Measurement of Leaf Water Potential

A dew point microvolt meter (HR33T, WESCOR Inc.) (Fig. 4) was used for the measurement of leaf water potential. Water moves from regions of high water potential to regions of low water potential. The greater the differences in the potential of two, the greater will be the energy exchange in the transfer of water. Thermocouple hygrometer provide a means of measurement of the total water potential. The measurement is based on the energy and is an actual measurement of the water potential. The technique of measuring water potential by determining the dew point depression temperature. A thermocouple is cooled below the dew point by means of the Petlier effect (Spanner, 1951), thereby collecting microdroplets of condensed water upon the junction surface. The thermocouple temperatures converges to the dew point, where it remains with a static amount of water. The e.m.f. produced by the temperature difference between the junction at the dew point temperature and the ambient temperature is a linear function of the water potential. The proportionately constant is approximately $-0.75 \text{ Volts bar}^{-1}$.

At the time of recording the sample chamber is connected to the console and calibrated. Leaf disc punched from very young flush and at once inserted in the sample chamber. The leaf disc come into contact with the thermocouple. Sufficient time is allowed thereafter for thermal and vapour equilibration. The samples were kept for 20-30 minutes. After that the sample was cooled for 15-30 seconds and put to dew point. The reading was taken in microvolt unit which was converted in bar unit dividing by -0.75 .

Methods of Biochemical Estimations

Each biochemical parameter was studied during pre-monsoon, monsoon and post-monsoon - three times in each season replicated five times, each genotype. Total 135 samples in a year were analysed for each biochemical parameter.

Estimation of Total Free Amino Acid (Moore and Stein, 1948)

Third leaves of the maintenance foliage were plucked and carried to the laboratory. 1g of the plant sample was weighed with the help of a top loading electronic balance and grinded in a pestle and mortar with 10 ml of 80% ethanol. The extract was filtered with the help of Whatman No. 1 filter paper. The filtrate or supernatant was saved. The extraction was repeated twice with the residue and all the supernatant were pooled. The volume was made up to 25 ml adding 80% ethanol.

1 ml of Ninhydrin solution was added to 1 ml of the extract in test tube. The mixture was boiled in a boiling waterbath for 20 minutes. 5 ml of the dilute solvent was added and the contents were mixed and kept for 15 minutes. Then the intensity of the purple colour was read against a reagent blank in spectrophotometer at 570 nm. The reagent blank was prepared by taking 1 ml of 80% ethanol.

50 mg of glycine was dissolved in 50 ml of distilled water in a volumetric flask. 10 ml of this stock standard was taken and diluted to 10 ml in another volumetric flask for working standard solution. A series of volume 0.1 to 1 ml of this standard solution (concentration range 10 mg to 100 mg) was prepared and proceeded as that of the sample and spectrophotometric readings were taken.

A standard curve was drawn using absorbance versus concentration. The concentration of the total free amino acids in the sample was determined with the help of the standard curve.

Estimation of Proline (Bates et al., 1973)

Third leaves of the maintenance foliage were plucked and carried to the laboratory. 1g of the plant sample was weighed with the help of a top loading electronic balance and grinded in a pestle and mortar with 10 ml of 3% Aqueous sulphosalicylic acid. The extract was filtered with the help of Whatman No. 2 filter paper. The filtrate or supernatant was saved. The extraction was repeatedly pooled. The volume was made up to 25 ml adding 3% sulphosalicylic acid.

2 ml of filtrate was taken in a test tube. 2 ml of glacial acetic acid and 2 ml of acid ninhydrin was added. This set was boiled in boiling waterbath for 1 hour. The reaction was terminated by placing the tube in icebath. 4 ml of toluene was added and stained well for 20-30 seconds. The toluene layer was separated with the help of Pasteur pipette and warmed to room temperature. The red colour intensity was measured at 520 nm in an U/V spectrophotometer against a reagent blank.

50 mg of proline was dissolved in 50 ml of 3% sulphosalicylic acid in a volumetric flask. 10 ml of this stock standard was taken and diluted to 10 ml in another volumetric flask for working standard solution. A series of volume 0.1 to 1 ml of this standard solution (concentration range 10 mg to 100 mg) was prepared and proceeded at that of the sample and spectrophotometric readings were taken.

A standard curve was drawn using absorbance versus concentration. The concentration of free proline in the sample was determined with the help of the standard curve.

Estimation of Ascorbic Acid (Harris and Røy, 1935)

Third leaves of the maintenance foliage were plucked during morning hours, labelled and carried to the laboratory. 2g leaves were weighed with the help of a top loading electronic balance and crushed in a clean mortar pestle 20 ml of 5% metaphosphoric acid

solution. The extract was filtrated using Whatman Filter paper No. 1. The extract was repeated twice with the residue. The volume of the supernatant was made up to 100 ml adding 5% metaphosphoric acid solution. The ascorbic acid content was titrated using 10 ml of dye solution (dichlorophenol indophenol).

Estimation of Chlorophyll (Arnon, 1949)

Leaves of the maintenance canopy were plucked during morning hours and carried to the laboratory 0.5g leaf samples were weighed with the help of a top loading electronic balance.

The samples were ground to a fine pulp in a mortar pestle with 10 ml of 80% Acetone solution. The extracts were filtered through Whatman No. 1 filter paper. The supernatant was saved. The residue was again ground and filtered. The procedure was repeated till the residue was colourless. The volume was made up to 10 ml with 80% acetone. The absorbance of the solution was read at 645 nm and 663 nm against the solvent (80% acetone) blank.

$$\text{Mg chlorophyll/g tissue} = \frac{(20.2 \times \text{Absorbance at } 645 \text{ nm} + 8.02 \times \text{Absorbance at } 663 \text{ nm}) \times \text{Final volume of chlorophyll extract in } 80\% \text{ acetone}}{1000 \times \text{Fresh weight of tissue extracted}}$$

Estimation of Epicuticular Wax Content (Silva Fernandes et al., 1961)

Second leaves of the maintenance canopy were plucked in the morning hours and carried to the laboratory. Ten leaf blades were immersed, one at a time, each for 15 seconds in 100 ml redistilled chloroform. The extract was filtered and evaporated. The residue was weighed. The amount of wax was calculated against leaf area and against the fresh weight.

Ten leaves of each plant were measured with the help of a

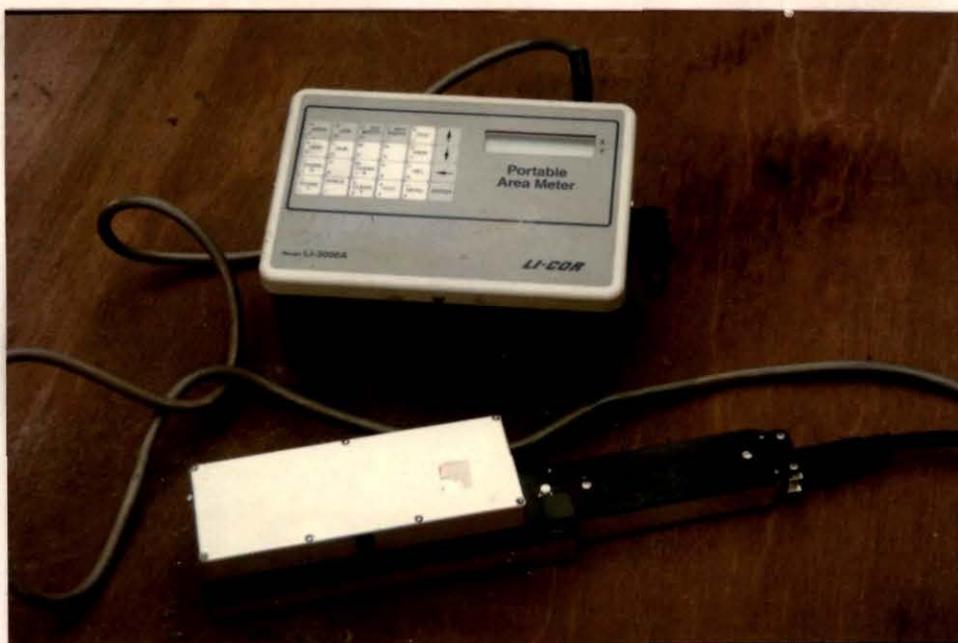


Fig. 5 : A portable area meter (LI 3000A, LICOR Inc., USA) used for measurement of leaf area, length and width.

Measurement of Environmental Parameters

Minimum, maximum, wet bulb and dry bulb thermometers (National Instruments, Calcutta) housed in a Stevenson screen, sunshine recorder (National Instruments, Calcutta), cup counter anemometer (Electromech Equipments, Pune), soil thermometer (A. Paul Instrument Co. Ltd., Haryana), and rain gauge (Ramkala, Pune) were used. All the instruments were tested and approved by Indian Meteorological Department, Pune. Following weather parameters were recorded - maximum temperature, minimum temperature, relative humidity, rainfall, sunshine, hour, soil temperature, wind velocity etc.

Soil moisture was estimated by oven dry method every alternate months. Soil was derived at a depth of 0-15 (top) and 15-30 cm (subsoil) dried in the oven at 110°C for 48 hours. Maximum, minimum, dry bulb, wet bulb and soil temperatures, wind run were recorded every day at 6.39 and 13.39 hours while rainfall was recorded at 8.30 and 17.00 hours everyday. Fresh sunshine cards inserted everyday after sunset replacing the used card. Using a portable photosynthesis system (LI 6200, inside leaf chamber of LI 6200, LICOR Inc., U.S.A.) the carbon dioxide concentration and photosynthetic photon flux density were measured when physiological readings were taken.

Statistical Computations

Critical Difference (C.D.) or Least Significant Difference (L.S.D.), Co-efficient of Variance (C.V.) and Correlation Coefficient were calculated using the method referred by Panse and Sukhatme (1989) while in case of regression, the method referred by Gupta and Kapoor (1986) was used.

R E S U L T S

As the growth and development of a plant is very much dependent on a number of climatic variables the present study attempted to understand their interactions. Among the weather factors, temperature, rainfall, relative humidity, sunshine hours and edaphic factors like soil nutrient status are very important. In addition, the plants' genetic behaviour in relation to the climatic status also play a key role in the growth and developmental process.

In the present study, an intensive search was made about the genetic behaviour of three different tea clones with respect to their climatic variables, particularly through long term seasonal investigation followed by fertilizer trials were attempted. In addition, the reflection of the growth and developmental processes on the physiological behaviour of the plants in different climate status (seasonwise) was thoroughly investigated to find the desired agro-climatic requirement of each variety. To elucidate the stress factors, particularly, the biochemical basis that develop during different season, were also thoroughly examined.

Climatic Variables

The climate was subtropical with mild winter. Although situated in tropical climate zone, it has developed subtropical to temperate character owing to higher altitude. As a result the ambient temperature never reaches lethally higher which could affect the general metabolic activities of plants. On the other hand, being situated on a medium height hill, the temperature never reaches freezing level. The snowfall is experienced on the higher altitudes of Kurseong Subdivision but at the site of study, no snowfall occurred till date. In most parts of the year this area remains foggy and humid (Fig. 6). Only during pre-monsoon dry spell



Fig. 6 : Fog infested tea plantation on a misty day.

prevails in this territory when the plants suffer water stress situation. Heavy precipitation occurs during rainy season which extends generally from June to September. Low temperature prevails in this region during January and February, while higher temperatures prevail from April to September. Rainfall is very less from November to April. Sunshine hour is very low from July to September, while it is high during November, December, March and April. Wind velocity is high from April to July, while it is low during September to November and January to February. Relative humidity is highest during July to September, while it is lowest in April. Weather data and soil moisture status (mean of three years) presented in Tables 6 and 7 show following features :

Table 6 : Bimonthly records of weather parameters *

| Month | Feb | Apr | Jun | Aug | Oct | Dec |
|--|-------|--------|--------|-------|--------|--------|
| Weather parameters | | | | | | |
| Mean Maximum Temperature (°C) | 14.8 | 22.8 | 23.5 | 23.3 | 20.7 | 16.6 |
| Mean Minimum Temperature (°C) | 8.4 | 15.1 | 18.3 | 18.9 | 14.9 | 10.2 |
| Mean Soil Temperature (°C) (10 cm depth) | 12.4 | 20.9 | 22.5 | 22.4 | 19.0 | 12.3 |
| Sunshine Hours (hr. day ⁻¹) | 3.9 | 5.7 | 1.7 | 1.5 | 4.1 | 5.1 |
| Wind Velocity (Km. hr. ⁻¹) | 4.0 | 5.3 | 5.4 | 4.4 | 4.2 | 4.3 |
| Mean Relative Humidity (%) | 74.4 | 67.9 | 92.0 | 94.0 | 85.6 | 76.8 |
| Mean Rainfall (mm day ⁻¹) | 0.5 | 1.4 | 24.6 | 24.1 | 3.3 | 0.3 |
| Ambient CO ₂ (ppm) | 356.4 | 360.7 | 360.5 | 346.7 | 351.0 | 352.6 |
| PPFD (μ mol m ⁻² s ⁻¹) | 706.7 | 1361.0 | 1287.0 | 561.8 | 1364.0 | 1193.0 |

* Mean of three years (1992-94);

Table 7 : Soil moisture percentage of the field at the time of experimentation

| Month | Top Soil (0-15 cm) | Sub Soil (15-30 cm) | Mean |
|----------|-----------------------|------------------------|------|
| February | 22.1 | 23.5 | 22.8 |
| April | 22.2 | 24.2 | 23.2 |
| June | 31.4 | 32.4 | 31.9 |
| August | 30.9 | 32.4 | 31.6 |
| October | 28.7 | 30.0 | 29.3 |
| December | 25.9 | 27.7 | 26.8 |

Figures in the parenthesis indicate the soil depth.

(a) Air temperature

During April, June and August, higher air temperatures were observed in this area. Highest mean maximum temperature being around 23°C. Lowest temperature was recorded during February. The month of October showed moderate temperature. Annual range of temperature on an average was found to be 8.4°C - 23.5°C. Due to very high temperature during April, when relative humidity was found to be very low, a droughty situation prevailed. It may be noted that high rainfall was not able to bring down the temperature. It can be seen from the table that the months of June and August which had the highest rainfall also showed highest air temperatures. The temperature in the month of December was in between the temperatures of October and February. The difference in Mean Maximum and Mean Minimum temperature was highest during April and lowest during June and August. The difference was same in February and December. This denotes that the month of April had hot days but colder nights. Highest temperature on a single day within these three years was 30°C (inside the Stevenson screen) recorded on 16.4.92 and lowest 3.1

recorded on 2nd, 3rd and 4th February, 1993. Although mean temperature of June and August was little more than April but April contained extremely high temperature on many days.

(b) Soil temperature

Soil temperature recorded at 10 cm depth showed that high soil temperature prevailed during April, June and August, while during February and December it was very low. The soil temperature mean show that during February and December it was at par. This result does not coincide with the air temperature. Because the air temperature of December was much higher than that of February. The range of soil temperature was 12.3°C-22.5°C. The soil temperature mean was always found to be more than minimum temperature but less than maximum temperature.

(c) Sunshine duration

Very high sunshine hours recorded during April followed by December. It may be mentioned that these sunshine hours represent bright sunny atmosphere when a burning in the sunshine card was noticed. It is not similar with total day length. During June and August, sunshine hours were found to be very low. In October and February, it was moderate. The mean sunshine hours ranged between 1.5 to 5.7 hours per day. During rainy seasons, for days together this area remains deprived from any sunshine. For example, in June 1994, for thirteen days there was no sunshine at all. In winter, although foggy weather prevails in majority days of the months, it supplements with sunshine too i.e., there is a combination of sunshine and fog. However, in most parts of the year visibility range can be termed as poor. During these three years highest sunshine hour on a single day was found to be 11 hours per day.

(d) Wind run

April and June showed high wind velocity while the wind run during August, October, December and February ranged between 4.0 to 4.4 km per hour. Wind velocity of this area within these three years reached highest 15.7 km per hour.

(e) Relative humidity

In most parts of the year high percentage of relative humidity was noticed. The months of June and August recorded highest relative humidity (>90%). During August 1992, 100% relative humidity was observed on sixteen days in a month. Lowest relative humidity was observed during April 1994, which is the most dry month as far as atmospheric moisture content is concerned. At times, the relative humidity comes down to 12-20%. However, the monthly mean of relative humidity ranged between 67.9-94%. Since irrigation is a difficult proposition in this hilly terrain, the low relative humidity is indeed an alarming feature for the physiological activities of the plants. Very high humidity during rainy season and very dry spell in pre-monsoon is the character of the area.

(f) Soil moisture

Corresponding with atmospheric moisture, the soil moisture was found to be highest during the months of June and August. October and December also showed considerable amount of soil moisture. In case of atmospheric moisture, April showed lowest range compared to February, but in case of soil moisture the percentage was at par in February and April. The reason why the month of February showed higher atmospheric moisture was dew fall and foggy weather. In all the cases the moisture content was more in subsoil compared to top soil.

(g) Rainfall

Among the six months, when the data were recorded, highest amount of rainfall was observed in June, closely followed by August. Kurseong is known as a heavy rainfall area. High rainfall leads to top soil erosion. While October showed moderate rainfall, it was almost nil in April, December and February. Mean rainfall ranged between 0.3-24.6 mm per day. Within these three years highest rainfall on a single day was recorded on 23.8.92 was 198.2 mm. August 1993 saw 23 rainy days in a month.

(h) Photosynthetic photon flux density (PPFD)

PPFD was recorded on the days when physiological readings were taken. It was recorded at the beginning, end and middle of a month and mean data derived from three readings. Very high photosynthetic photon flux density was found in October and April. During these months the sky remains clear and visibility range increases. Lowest PPFD was observed in August. PPFD ranged between 561.8 - 1384 $\mu\text{mol m}^{-2}\text{s}^{-1}$.

An overall summary of monthwise variability of weather parameters are described below :

- February : Lowest temperature, low rainfall, low humidity, low soil moisture.
- April : Highest sunshine hours, high temperature, high PPFD, low rainfall, lowest relative humidity, high ambient CO_2 , high wind velocity, low soil moisture.
- June : High temperature, high ambient CO_2 , high relative humidity, high wind velocity, low sunshine hour, highest soil temperature, soil moisture.
- August : High temperature, lowest sunshine hour, highest relative humidity, lowest PPFD, high rainfall, lowest ambient CO_2 , high soil moisture.

- October : Highest PPF_D, moderate temperature, moderate rainfall, moderate ambient CO₂, moderate sunshine hours, and moderate wind velocity, moderate soil moisture.
- December : High sunshine hour, moderate wind velocity, low temperature, moderate PPF_D and moderate soil moisture.

Based on the weather parameters the month of April considered as pre-monsoon, June and August as monsoon, October and December as post-monsoon and February as winter.

PHYSIOLOGICAL CHARACTERISTICS OF THE PLANTS

Net Photosynthesis (P_n)

In April - the summer month when the atmosphere was very dry with lowest percentage of humidity, the rate of net photosynthesis was found to be lowest (Table 8 and Figs. 7 & 8). In June and August, the monsoon months, the rate of net photosynthesis was almost at par. In February, the winter month, the rate was lower than all other months except April. Highest rate of net photosynthesis was noted during post-monsoon (October and December).

Among the clones, Bannockburn-157 showed highest photosynthetic efficiency except during water stress period. Overall rate of net photosynthesis was lowest in Tukdah-78, while Phoobshering-312 occupying the middle berth. In mature plants, the annual range of net photosynthesis in case of Bannockburn-157, Phoobshering-312 and Tukdah-78 was found to be 2.8-11.6, 3.7-10.1 and 3.1-11.1 $\mu \text{ mol m}^{-2} \text{ S}^{-1}$ respectively, while in young plants, the annual range was 3.1-11.3, 4.1-10.4 and 3.5-10.2 $\mu \text{ mol m}^{-2} \text{ S}^{-1}$ respectively.

Both in mature (1985 planted) and young (1990 planted) the rate of photosynthesis was almost at par. Since, the difference in age of the plants was only five years, there was no marked difference in the photosynthetic potential.

Net Photosynthesis Under Varied Weather Conditions

In February (winter) air temperature was lowest, so was the soil moisture, relative humidity was low, rainfall too was low. Sunshine hour, photosynthetic photonflux density and wind velocity were moderate. The rate of net photosynthesis was low but higher than that of April. During summer (April) the rate of net photosynthesis was lowest when the air and soil temperatures were high, light intensity was high, wind

Table 8 : Seasonal changes in net photosynthesis (P_n) ($\mu \text{ mol m}^{-2} \text{ S}^{-1}$) for mature and young plants of three genotypes of tea

| Month | Age | Clones | | | Mean | LSD P=0.05 | CV % |
|----------|-----|--------|--------|--------|------|---------------|---------|
| | | B157 | P312 | T78 | | | |
| February | MP | 7.502 | 6.122 | 6.291 | 6.6 | 0.95 | 8.86 |
| | YP | 7.518 | 6.756 | 7.163 | 7.1 | 2.25 | 8.25 |
| April | MP | 2.817 | 3.672 | 3.081 | 3.2 | 0.68 | 4.99 |
| | YP | 3.138 | 4.145 | 3.491 | 3.6 | 0.62 | 3.78 |
| June | MP | 8.443 | 8.390 | 7.210 | 8.0 | 0.59 | 3.88 |
| | YP | 8.268 | 8.414 | 7.583 | 8.1 | 1.29 | 2.78 |
| August | MP | 9.185 | 9.801 | 8.552 | 9.2 | 1.59 | 1.75 |
| | YP | 8.954 | 8.901 | 8.019 | 8.6 | 1.22 | 8.99 |
| October | MP | 11.58 | 10.024 | 11.072 | 10.9 | 1.32 | 3.47 |
| | YP | 11.304 | 9.731 | 0.188 | 10.4 | 1.29 | 2.04 |
| December | MP | 10.557 | 10.144 | 9.247 | 10.0 | 0.53 | 3.47 |
| | YP | 10.774 | 10.401 | 9.194 | 10.1 | 1.29 | 2.04 |

MP = Mature plant
YP = Young plant

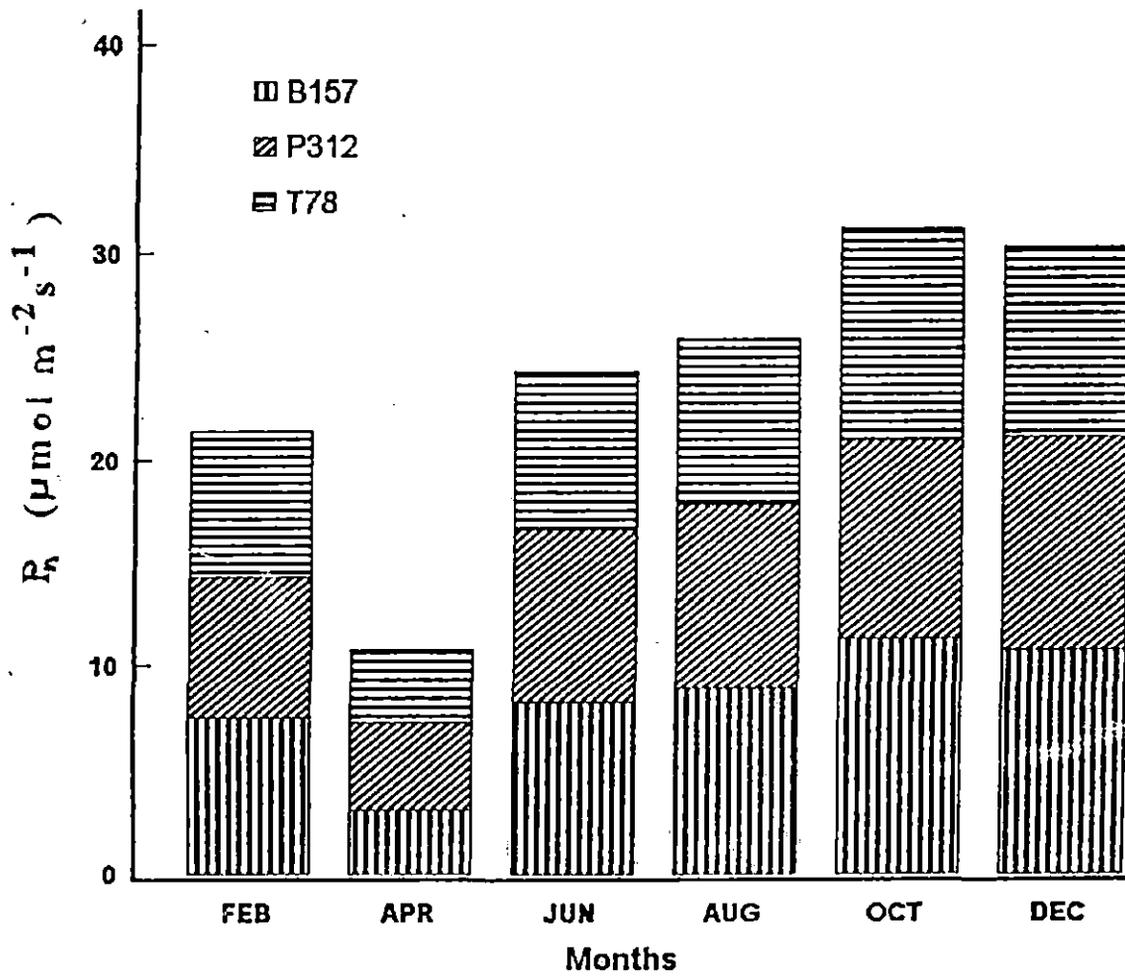


Fig 7. Status of net photosynthesis in young plants.

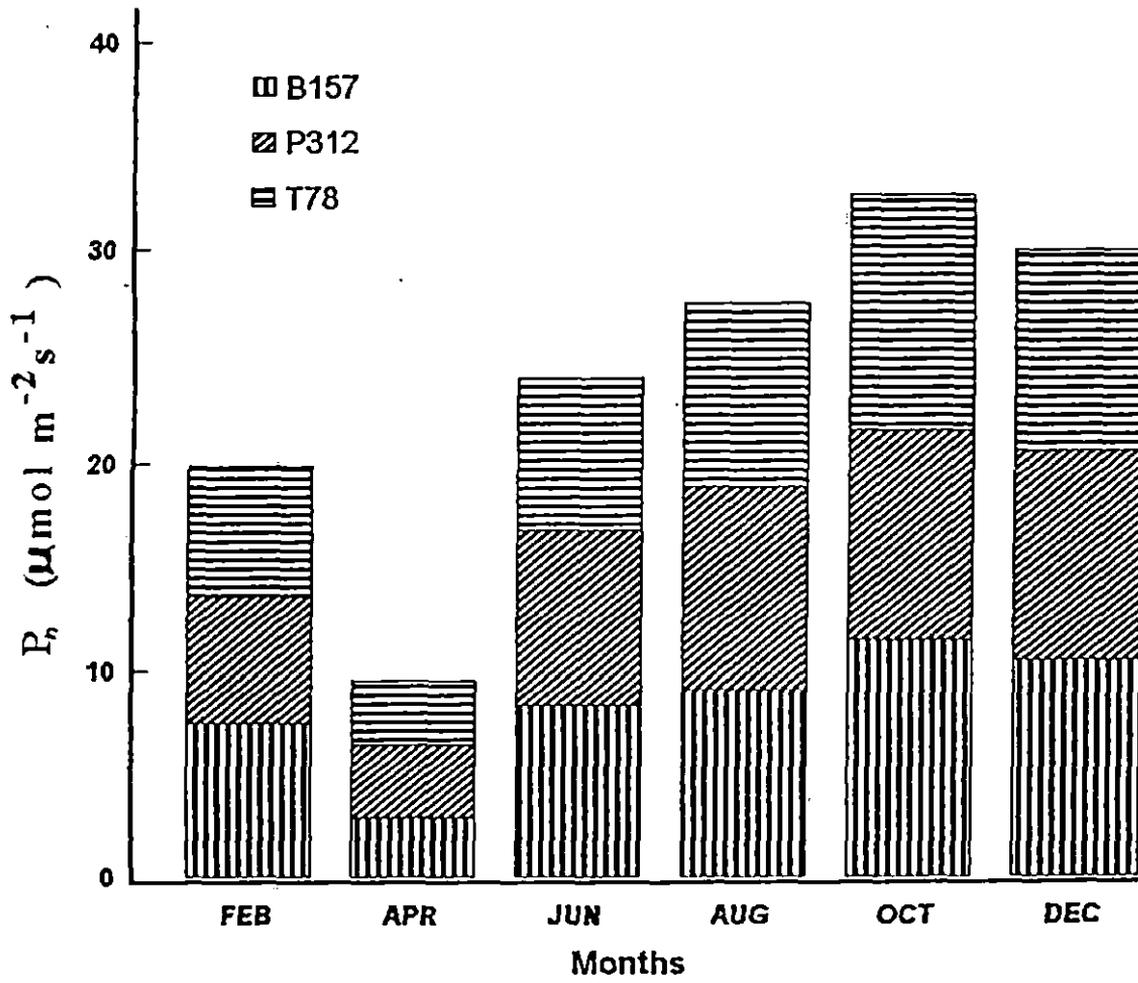


Fig.8. Status of net photosynthesis in mature plants.

velocity was high, sunshine hour was highest but relative humidity was lowest. During monsoon, rainfall, soil and atmospheric moisture, air and soil temperatures were high but sunshine duration was low. Under these circumstances mediocre range of net photosynthesis was observed. During post-monsoon, when air temperature wind velocity, soil and atmospheric moisture contents were moderate, light intensity and sunshine duration were very high, highest rate of net photosynthesis was achieved.

Stomatal Conductance

In case of mature plants, high rate of stomatal conductance was observed in October, December and February and lowest in April (Table 9 and Figs. 9 & 10). But in young plants, the rate of stomatal conductance, in February was little lower than that of mature plants. In young plants too, post-monsoon months showed highest rate of stomatal conductance. Conductance was lowest in April followed by June.

Table 9 : Status of stomatal conductance (cm S^{-1}) in experimental plants

| Season | Plant age | Varieties | | | Mean | LSD P=0.05 | CV % |
|--------------|-----------|-----------|------|------|------|---------------|---------|
| | | B157 | P312 | T78 | | | |
| Pre-monsoon | MP | 0.21 | 0.26 | 0.23 | 0.23 | 0.04 | 4.57 |
| | YP | 0.26 | 0.33 | 0.26 | 0.28 | 0.06 | 1.00 |
| Monsoon | MP | 0.96 | 0.87 | 0.80 | 0.88 | 0.39 | 19.43 |
| | YP | 0.77 | 0.69 | 0.62 | 0.69 | 0.15 | 10.46 |
| Post-monsoon | MP | 0.97 | 0.89 | 0.86 | 0.91 | 0.12 | 6.85 |
| | YP | 1.25 | 1.16 | 1.14 | 1.18 | 0.11 | 6.58 |

MP = Mature plants, YP = Young plants

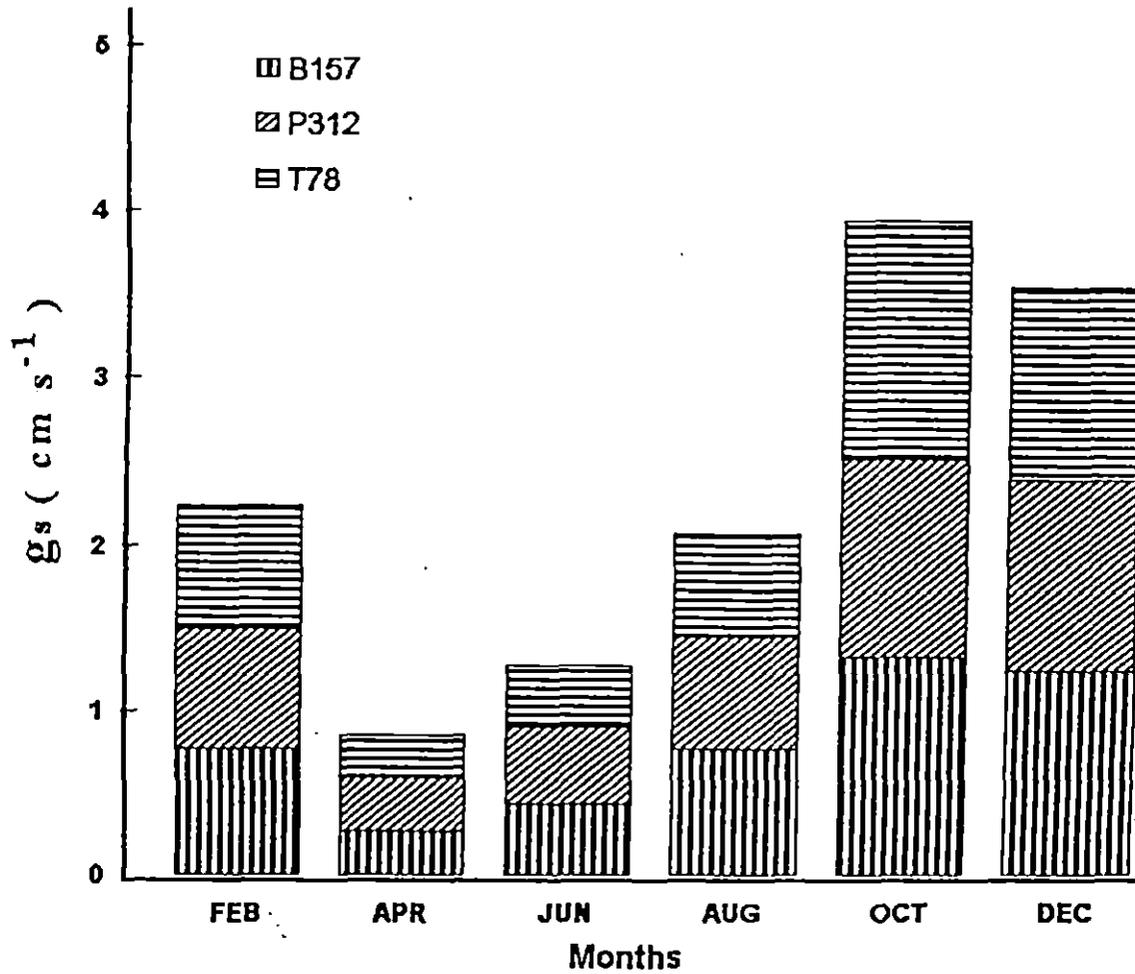


Fig. 9. Status of Stomatal Conductance in young plants.

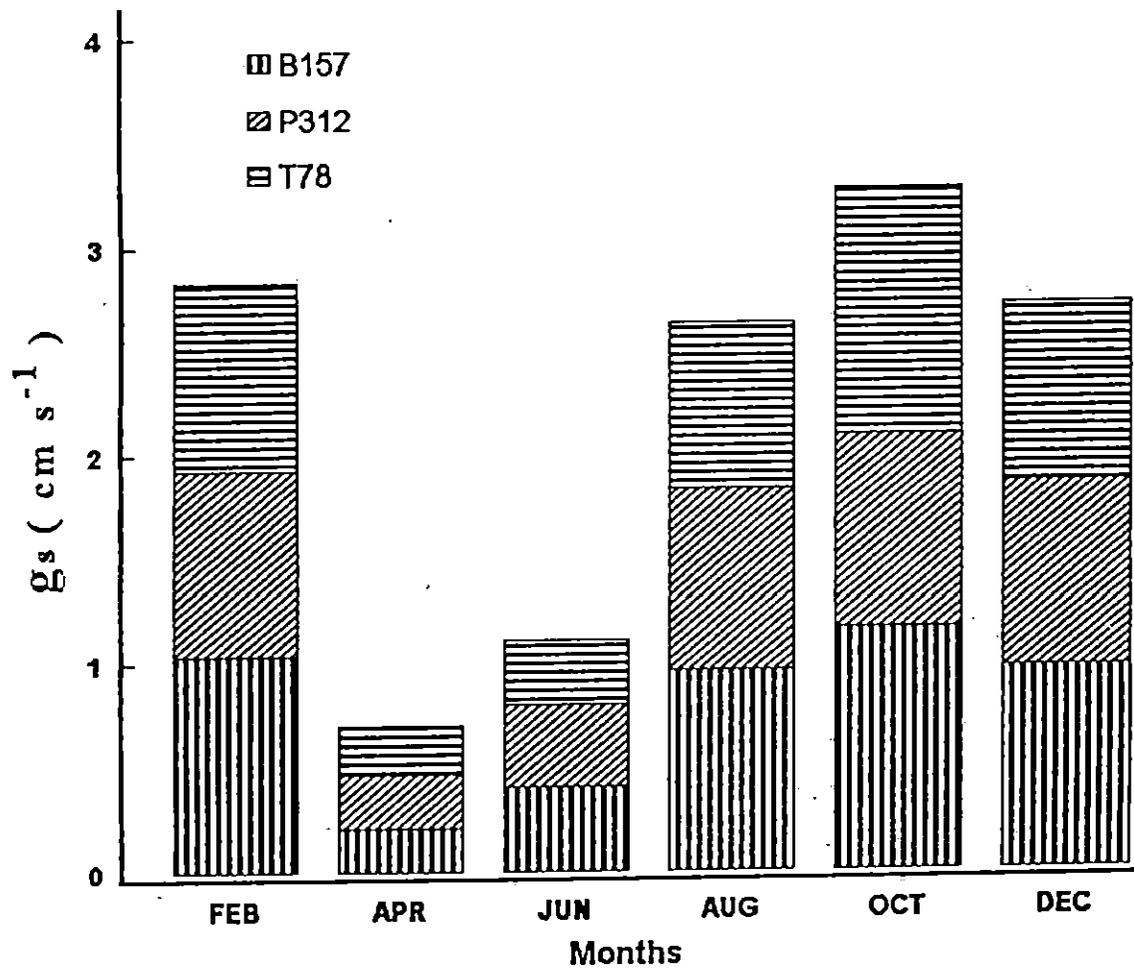


Fig.10. Status of Stomatal Conductance in mature plants.

There was no pronounced genotypic variation of stomatal conductance. However, in water stress period, Bannockburn-157 showed lowest conductance which can be considered as a desirable character. In droughty condition, Phoobshering-312 showed highest rate of stomatal conductance compared to other genotypes. In case of mature plants, Bannockburn-157 showed highest conductance in February, June, August, October and December while Tukdah-78 showed lowest conductance in June, August, October and December compared to other varieties. In case of young plants, Bannockburn-157 showed higher conductance in February, August, October and December while Tukdah-78 showed lowest rate in June, August and December. In mature plants, the annual range of stomatal conductance in case of Bannockburn-157, Phoobshering-312 and Tukdah-78 was 0.21-1.16, 0.26-0.93 and 0.23-1.18 cm s^{-1} respectively. In young plants the annual range was 0.26-1.34, 0.33-1.16 and 0.26-1.41 respectively.

The age factor of the plant did not have any definite effect on the rate of conductance; in some cases mature plants showed higher conductance while in other young plants showed higher rates.

Stomatal Resistance (rs)

Both in mature and young plants, highest rate of stomatal resistance was observed in the month of April followed by June (Table 10 and Figs. 11 & 12). But in other months there was not much variation in the rate of resistance.

Compared to other varieties, Bannockburn-157 showed low resistance in February, June, August, October and December but in April it showed highest stomatal resistance. In mature plants the annual range of stomatal resistance in Bannockburn-157, Phoobshering-312 and Tukdah-78 was 0.9-6.3, 1.0-4.5 and 1.1-5.1 s cm^{-1} respectively. In young plants, the range was 1.0-5.2, 1.2-4.1 and 1.1-5.0 s cm^{-1} respectively.

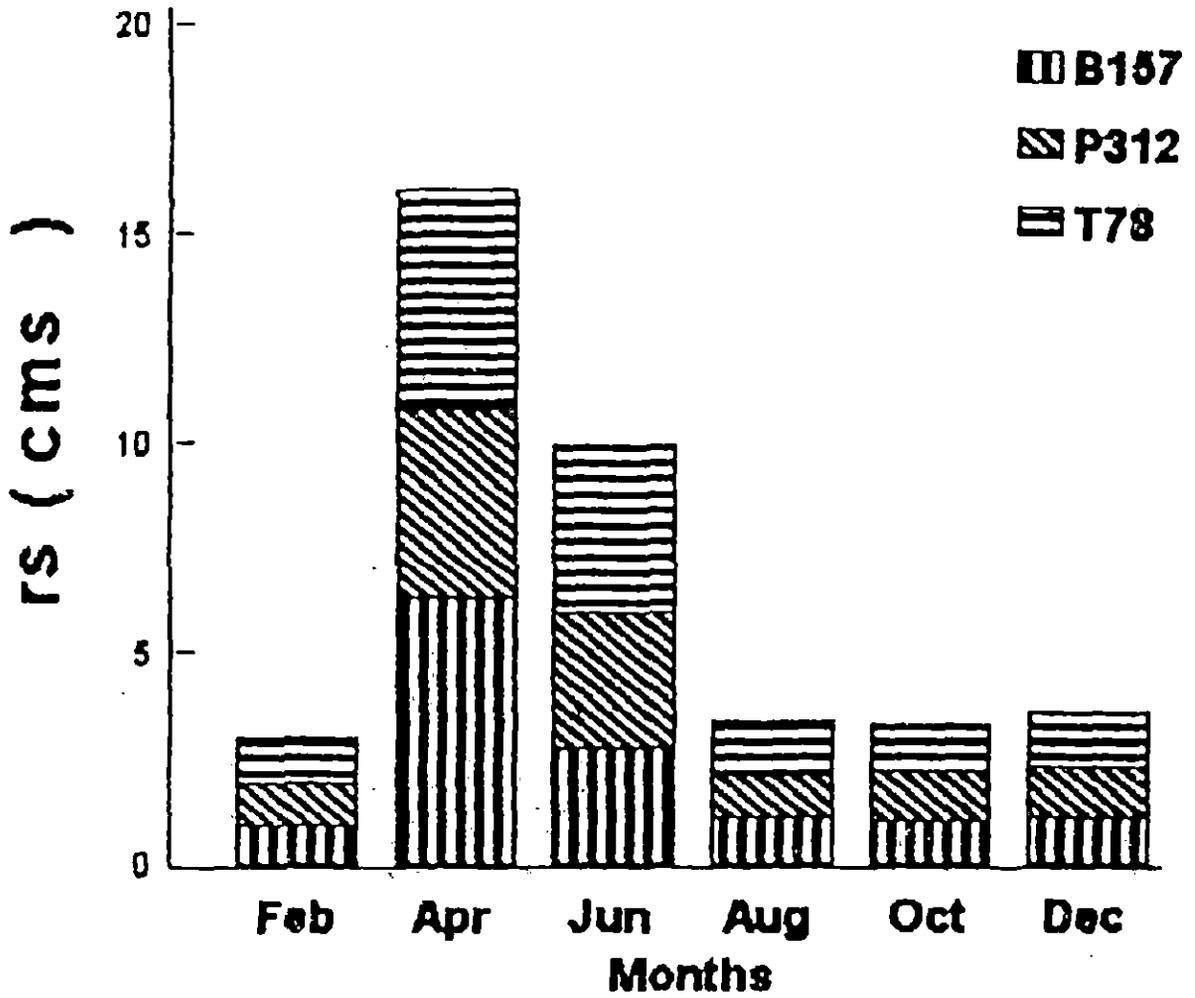


Fig. 11. Status of stomatal resistance in young plants.

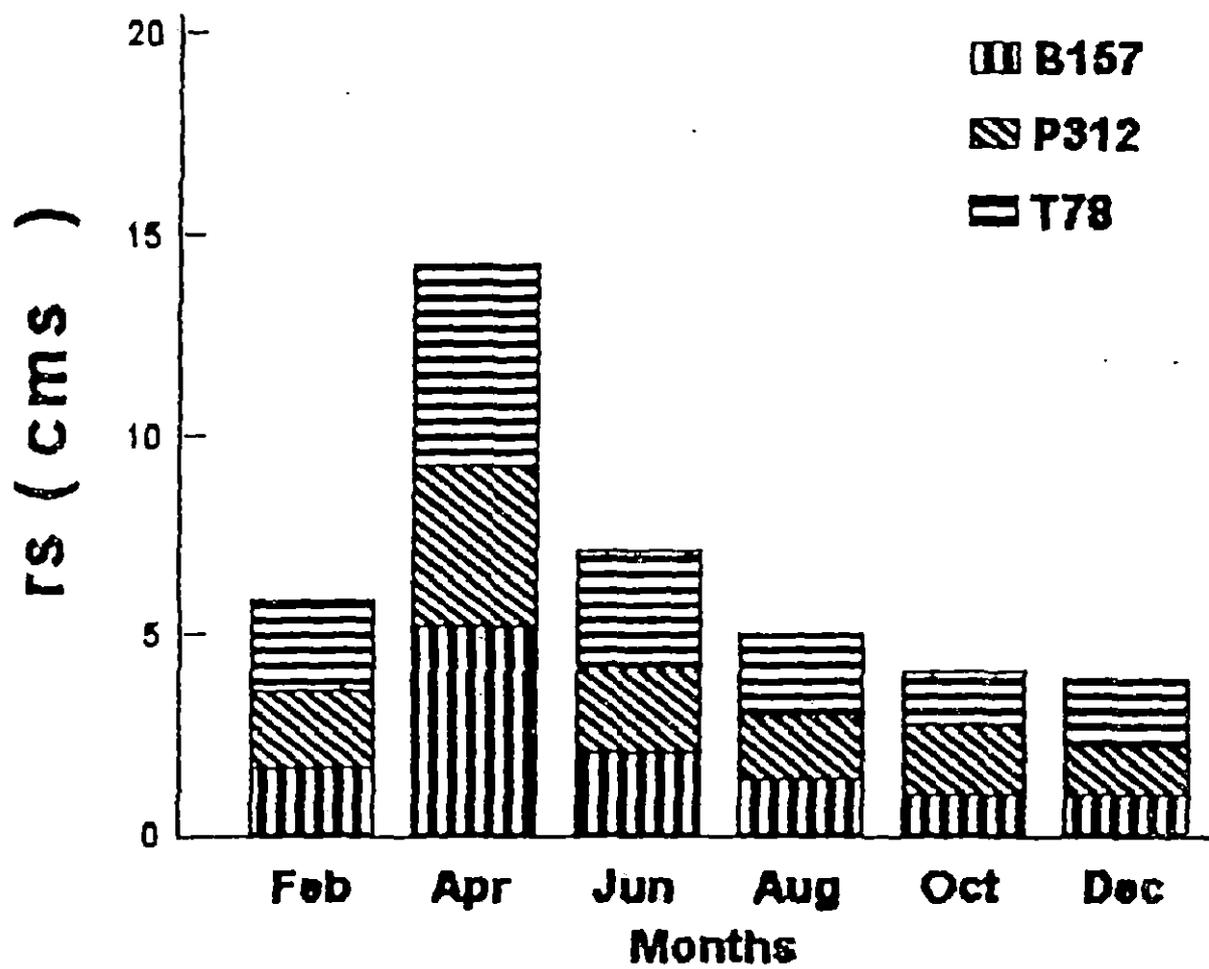


Fig. 12. Status of stomatal resistance in mature plants

There was no marked difference in the stomatal resistance of mature and young plants.

Table 10 : Status of stomatal resistance ($s\text{ cm}^{-1}$) in experimental plants

| Season | Plant age | Varieties | | | Mean | LSD P=0.05 | CV % |
|--------------|-----------|-----------|------|------|------|---------------|---------|
| | | B157 | P312 | T78 | | | |
| Pre-monsoon | MP | 6.33 | 4.46 | 5.15 | 5.31 | 1.29 | 8.49 |
| | YP | 5.21 | 4.08 | 5.03 | 4.77 | 1.08 | 22.12 |
| Monsoon | MP | 1.12 | 1.05 | 1.28 | 1.15 | 0.26 | 15.03 |
| | YP | 1.36 | 1.61 | 2.04 | 1.67 | 0.54 | 10.24 |
| Post-monsoon | MP | 1.08 | 1.24 | 1.34 | 1.22 | 0.22 | 5.44 |
| | YP | 1.01 | 1.22 | 1.70 | 1.31 | 0.41 | 10.98 |

MP = Mature plants, YP = Young plants

Transpiration (E)

High rate of transpiration was observed in October and December followed by August. Lowest rate was found in April (Table 11 and Figs. 13 & 14).

There was no definite trend of transpiration observed as regards to varietal difference. In mature plants, the annual range of transpiration in Bannockburn-157, Phoobshering-312 and Tukdah-78 was found to be 2.3-5.9, 2.7-5.5 and 2.6-5.8 $\text{m mol m}^{-2}\text{s}^{-1}$ respectively, while in young plants the annual range was 2.8-4.8, 2.9-5.0 and 2.5-4.7 $\text{m mol m}^{-2}\text{s}^{-1}$ respectively. Any particular variety could not be singled out as possessing highest transpiration potential.

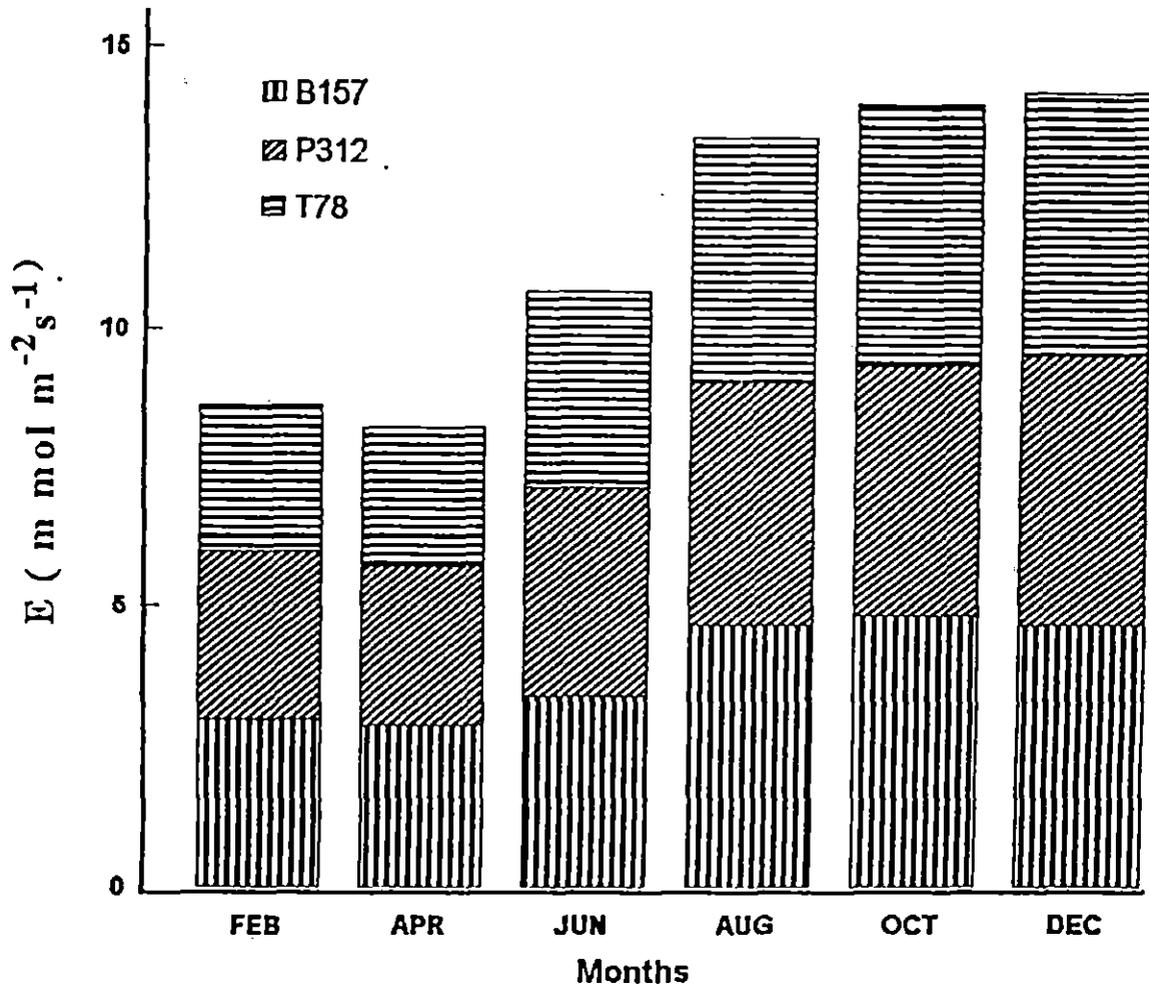


Fig.13. Status of transpiration in young plants.

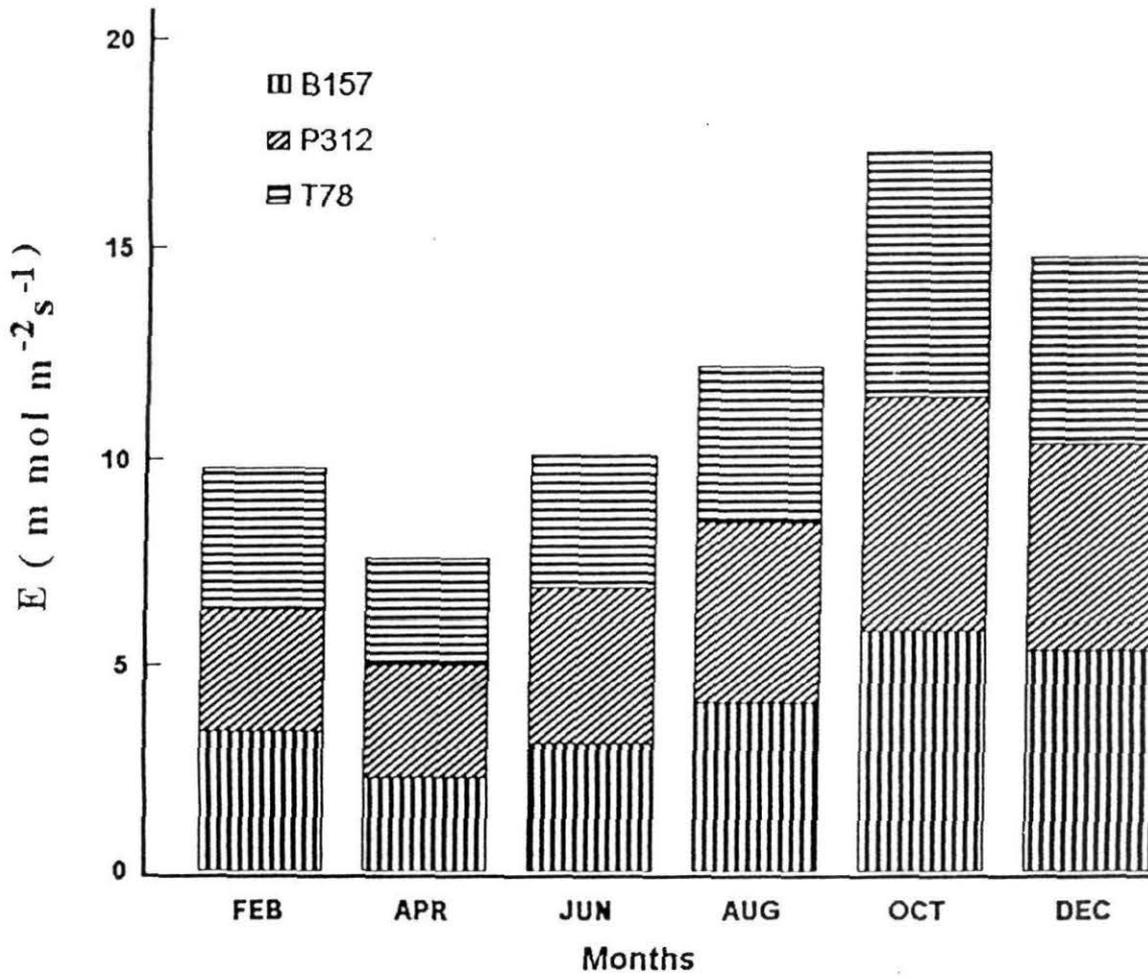


Fig.14. Status of transpiration in mature plants.

There was no marked difference of transpiration rate due to age difference; same kind^{of} trend followed in mature and young plants.

Table 11 : Status of transpiration ($\text{m mol m}^{-2} \text{s}^{-1}$) in experimental plants

| Season | Plant age | Varieties | | | Mean | LSD P=0.05 | CV % |
|--------------|-----------|-----------|------|-----|------|---------------|---------|
| | | B157 | P312 | T78 | | | |
| Pre-monsoon | MP | 2.3 | 2.7 | 2.6 | 2.5 | 0.49 | 8.77 |
| | YP | 2.8 | 2.9 | 2.5 | 2.7 | 0.74 | 10.85 |
| Monsoon | MP | 4.1 | 4.4 | 3.7 | 4.1 | 0.72 | 4.43 |
| | YP | 4.6 | 4.4 | 4.4 | 4.5 | 0.65 | 4.61 |
| Post-monsoon | MP | 5.9 | 5.0 | 4.4 | 5.1 | 0.29 | 2.15 |
| | YP | 4.6 | 4.9 | 4.7 | 4.7 | 0.68 | 6.42 |

MP = Mature plant; YP = Young plant

Leaf Water Potential (ψ_l)

Leaf water potential was observed lowest in April and high in June and August (Table 12 and Figs. 15 & 16). Moderate range of potential was found in October and December. February showed higher leaf water potential than April, but lower than all other months.

In all the cases, Barnockburn-157 showed highest leaf water potential, while Tukdah-78 showed lowest potential. In mature plants, the annual range of leaf water potential in Barnockburn-157,

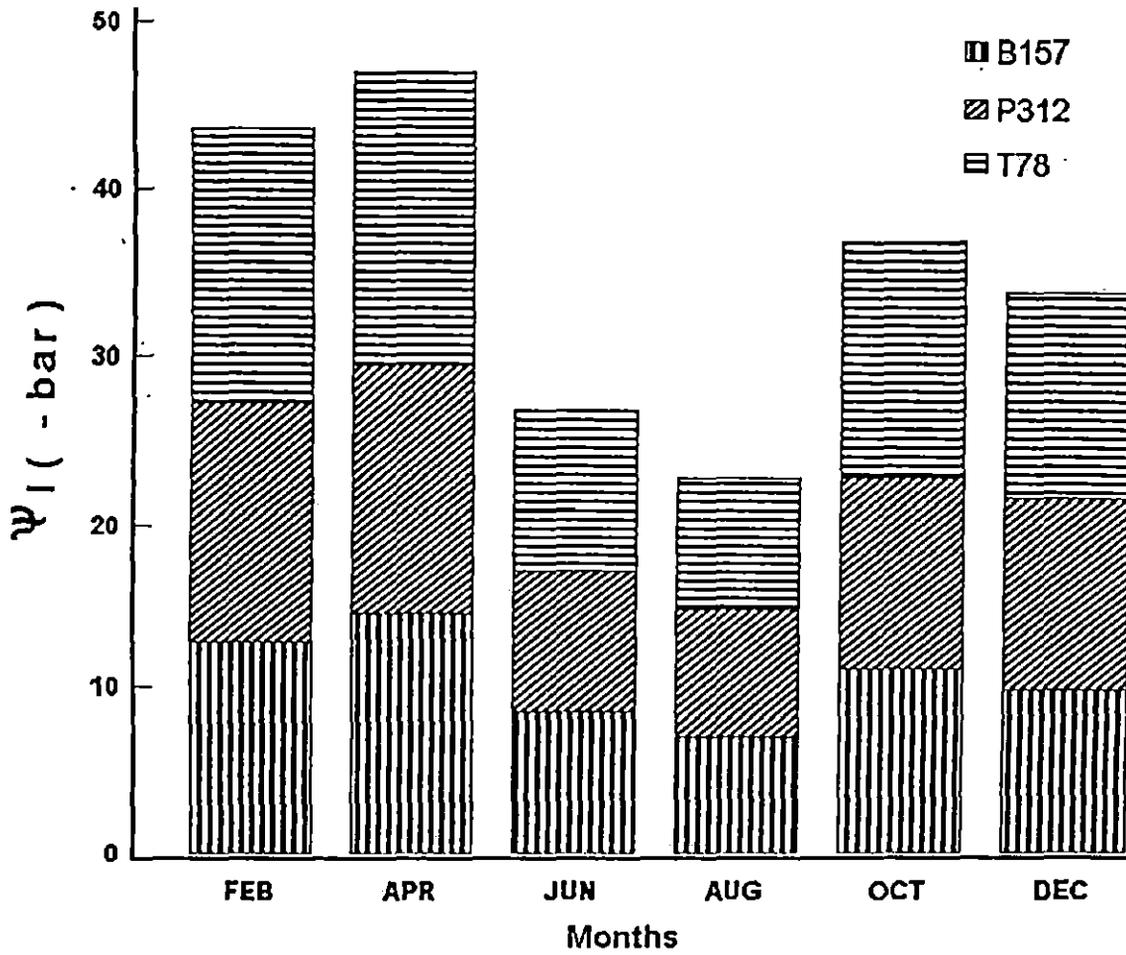


Fig.15, Status of Leaf Water Potential in young plants.

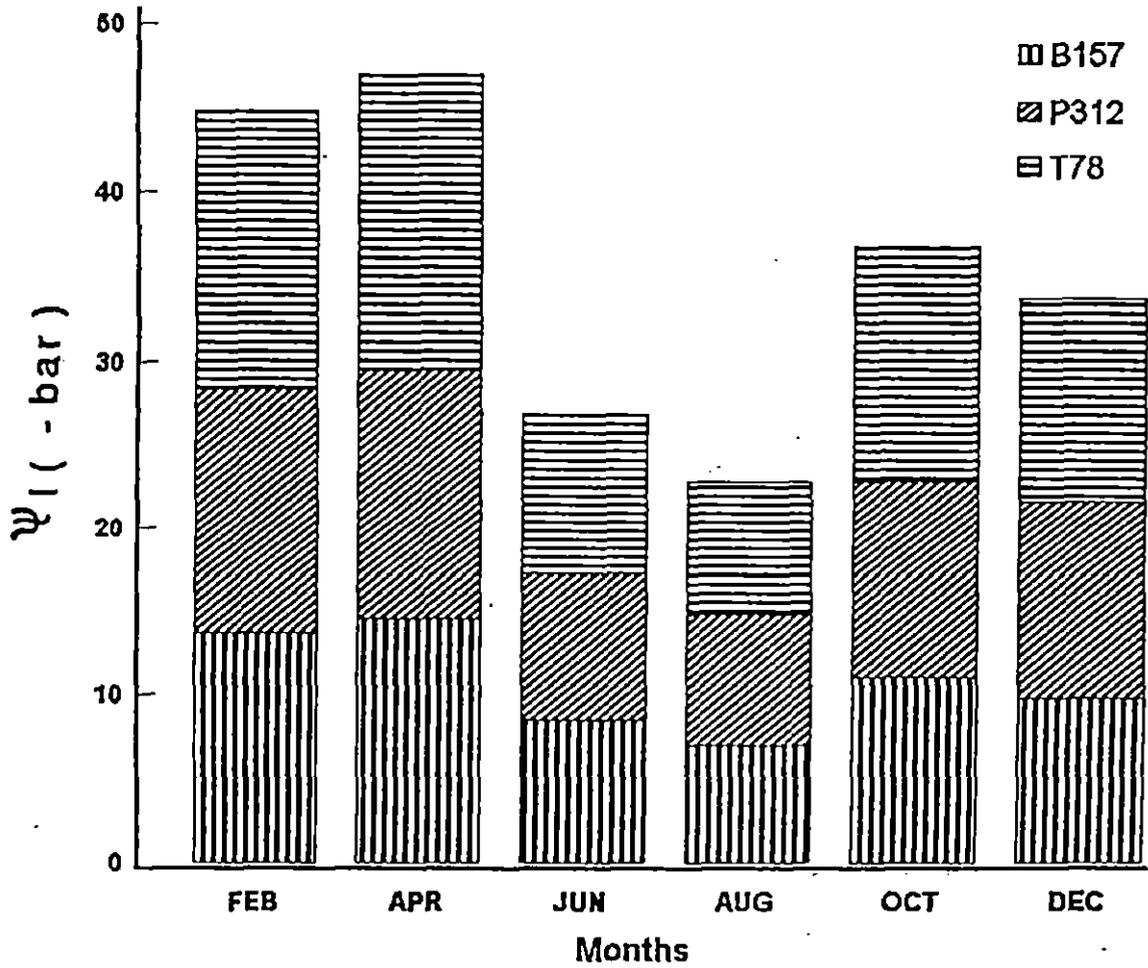


Fig.16. Status of Leaf Water Potential in mature plants.

Phoobshering-312 and Tukdah-78 was -8.0 to -13.9, -8.7 to -15.7 and -9.3 to -17.0 bar respectively; while in young plants the range was -7.0 to -14.5, -7.7 to -15.0 and -8.1 to -17.5 bar respectively.

The difference in plant age (of 5 years) had no effect on the rate of leaf water potential.

Table 12 : Status of leaf water potential (-bar) in experimental plants

| Month | Plant age | Variety | | | Mean | LSD P=0.05 | CV % |
|----------|-----------|---------|------|------|------|---------------|---------|
| | | B157 | P312 | T78 | | | |
| February | MP | 13.6 | 14.8 | 16.5 | 15.0 | 1.92 | 2.43 |
| | YP | 12.7 | 14.6 | 16.3 | 14.5 | 3.20 | 5.97 |
| April | MP | 13.9 | 15.7 | 17.0 | 15.5 | 2.70 | 2.31 |
| | YP | 14.5 | 15.0 | 17.5 | 15.7 | 2.23 | 8.60 |
| June | MP | 8.5 | 8.7 | 9.9 | 9.0 | 2.17 | 9.70 |
| | YP | 8.5 | 8.7 | 9.7 | 9.0 | 1.05 | 7.87 |
| August | MP | 8.0 | 8.9 | 9.3 | 8.7 | 0.92 | 4.09 |
| | YP | 7.0 | 7.7 | 8.1 | 7.6 | 1.69 | 5.80 |
| October | MP | 12.2 | 13.0 | 14.2 | 13.1 | 2.64 | 5.23 |
| | YP | 11.1 | 11.7 | 13.9 | 12.2 | 2.27 | 6.56 |
| December | MP | 11.5 | 12.3 | 14.3 | 12.7 | 2.23 | 9.04 |
| | YP | 9.8 | 11.8 | 12.1 | 11.2 | 2.61 | 4.46 |

MP = Mature plant, YP = Young plant

Leaf Temperature (T_L)

Leaf temperature was found highest in April, closely followed by June and lowest in February (Table 13 and Figs. 17 & 18). During October and December, moderate range of leaf temperature was noticed.

Phoobshering-312 showed higher leaf temperature than other two genotypes. In mature plants, the annual range of leaf temperature of Bannockburn-157, Phoobshering-312 and Tukdah-78 was found to be 17.4-28.7°C, 16.8-29.0°C and 17.2-28.2°C respectively, while in young plants the range was 18.8-30.3°C, 18.2-31.2°C and 18.4-28.6°C respectively.

There was hardly any difference in leaf temperature owing to difference in age.

Table 13 : Status of leaf temperature (°C) in experimental plants

| Month | Plant age | Variety | | | Mean | LSD P=0.05 | CV % |
|----------|-----------|---------|------|------|------|---------------|---------|
| | | B157 | P312 | T78 | | | |
| February | MP | 17.4 | 16.8 | 17.2 | 17.1 | 1.16 | 4.32 |
| | YP | 18.8 | 18.2 | 18.4 | 18.5 | 1.70 | 1.69 |
| April | MP | 28.7 | 29.0 | 28.2 | 28.6 | 1.07 | 2.14 |
| | YP | 30.3 | 31.2 | 28.6 | 30.0 | 1.73 | 3.62 |
| June | MP | 27.8 | 28.6 | 28.1 | 28.2 | 2.05 | 1.43 |
| | YP | 29.9 | 30.6 | 28.2 | 29.6 | 2.54 | 3.49 |
| August | MP | 27.3 | 28.2 | 27.7 | 27.7 | 1.18 | 4.18 |
| | YP | 26.3 | 26.6 | 26.5 | 26.5 | 3.80 | 6.62 |
| October | MP | 26.9 | 27.2 | 26.7 | 26.9 | 1.60 | 2.16 |
| | YP | 25.1 | 25.6 | 25.0 | 25.2 | 2.17 | 4.02 |
| December | MP | 23.9 | 22.5 | 22.0 | 22.8 | 1.11 | 1.23 |
| | YP | 21.0 | 20.6 | 19.4 | 20.3 | 1.41 | 2.92 |

MP = Mature plant, YP = Young plant

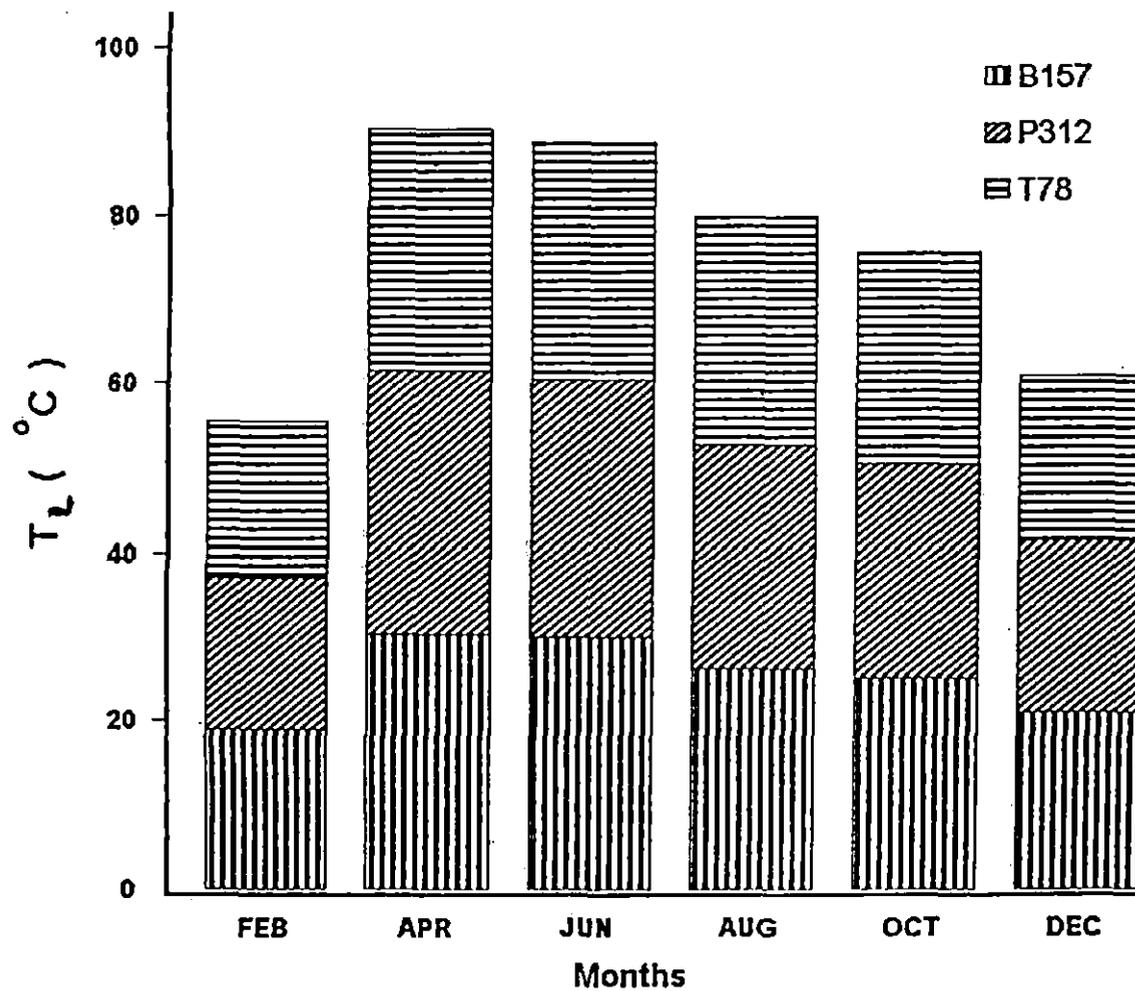


Fig.17. Status of Leaf temperature in young plants.

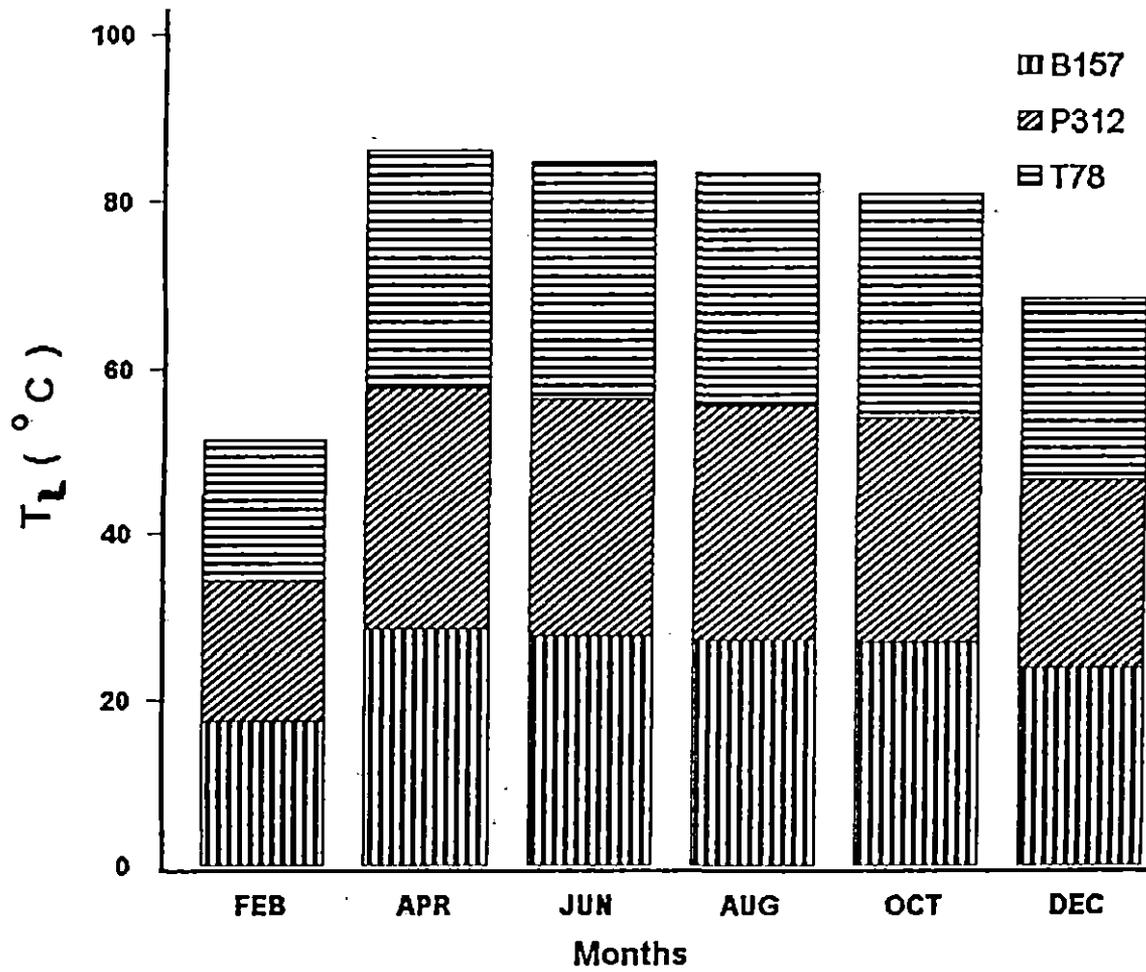


Fig.18, Status of Leaf temperature in mature plants.

NET PHOTOSYNTHESIS AND INDIVIDUAL WEATHER PARAMETERS

(a) Air temperature and Net photosynthesis

Influence of ambient temperature in different months on the rate of net photosynthesis of mature and young plants is depicted in Figs. 19 and 20 respectively. It can be seen that the influence was similar in mature and young plants. High temperature existed during April, June and August but lowest rate of net photosynthesis was observed during April. This denotes that suppression of net photosynthesis in April is due to some other factors. Comparatively low rate of net photosynthesis was observed during February when the ambient temperature was lowest. In the months of October and December when the air temperature was moderate, highest rate of photosynthesis was observed.

(b) Photosynthetic photon flux density and net photosynthesis

Influence of photosynthetic photon flux density in different months on the rate of net photosynthesis of mature and young plants are presented in Figs. 21 and 22 respectively. It can be seen that the influence was similar in mature and young plants. Very high photon flux density was noticed in April and October but just contrasting picture emerged as far as the rate of net photosynthesis is concerned. While in October, photosynthesis rate was highest, it was lowest in April. It denotes that photon flux density is not a limiting factor in a singular form, other factors are involved in diminishing the rate of net photosynthesis in April. The effect of photon flux density does not seem to be promising if the rate of net photosynthesis in June and August is compared. In August, photosynthetic photon flux density was lowest and in June and rate was quite high, but net photosynthesis was almost at par.

(c) Sunshine hour and net photosynthesis

Influence of sunshine hour (bright sunshine) in different months

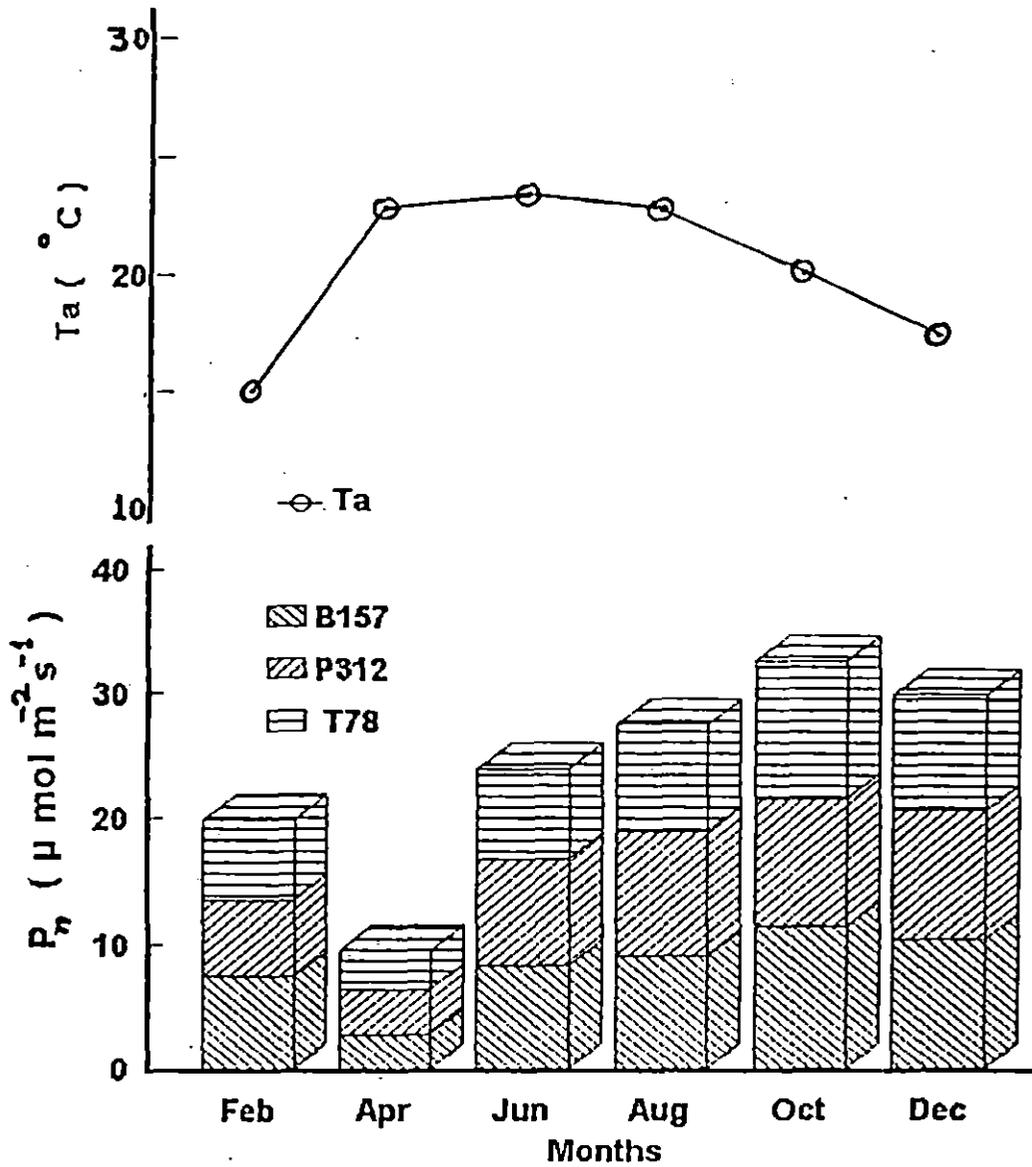


Fig19. Influence of ambient temperature ($^{\circ}\text{C}$) on the net photosynthesis ($\mu\text{mol m}^{-2}\text{s}^{-1}$) of mature tea plants during different months.

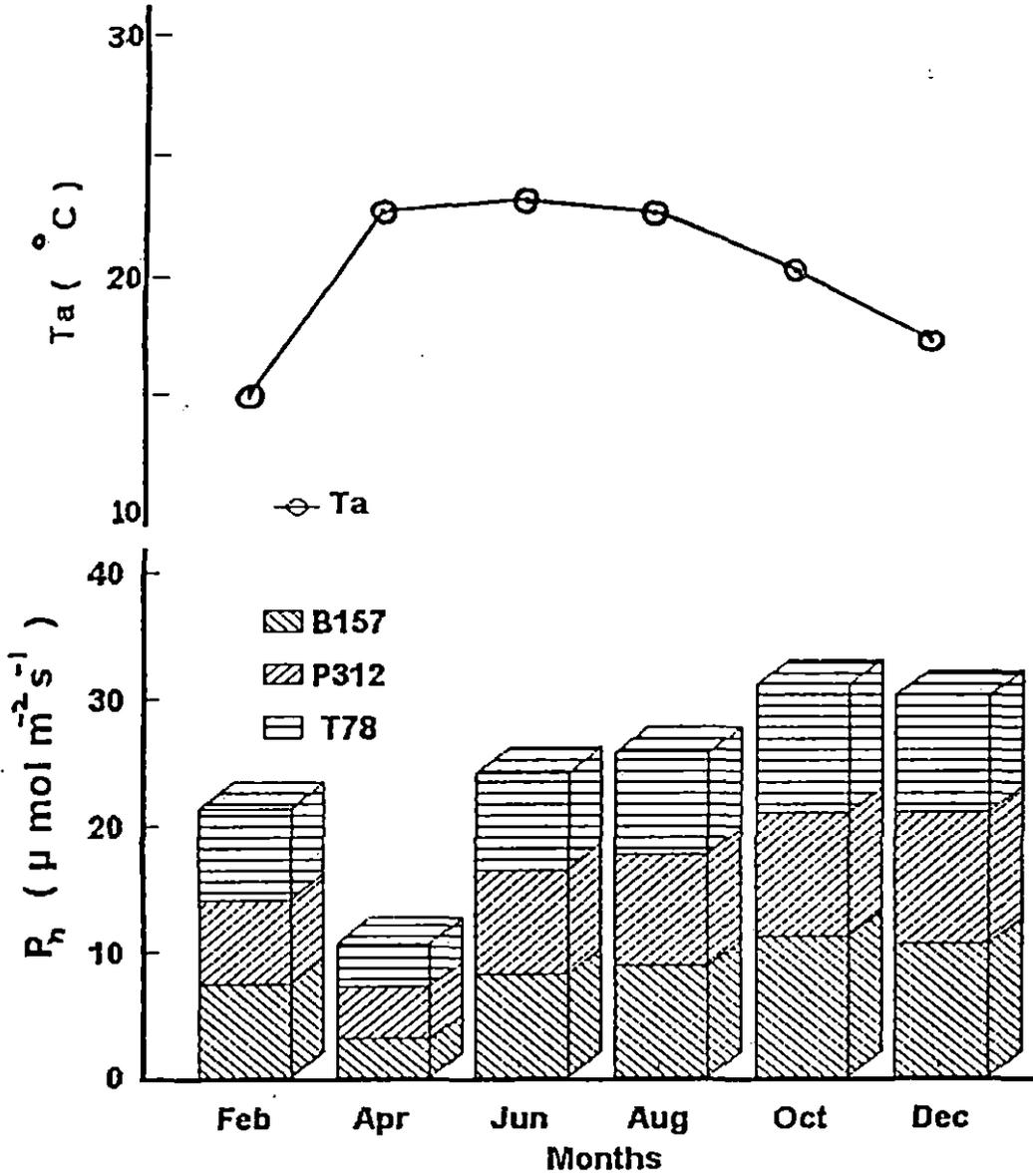


Fig20, Influence of ambient temperature ($^{\circ}\text{C}$) on the net photosynthesis ($\mu\text{mol m}^{-2}\text{s}^{-1}$) of young tea plants during different months.

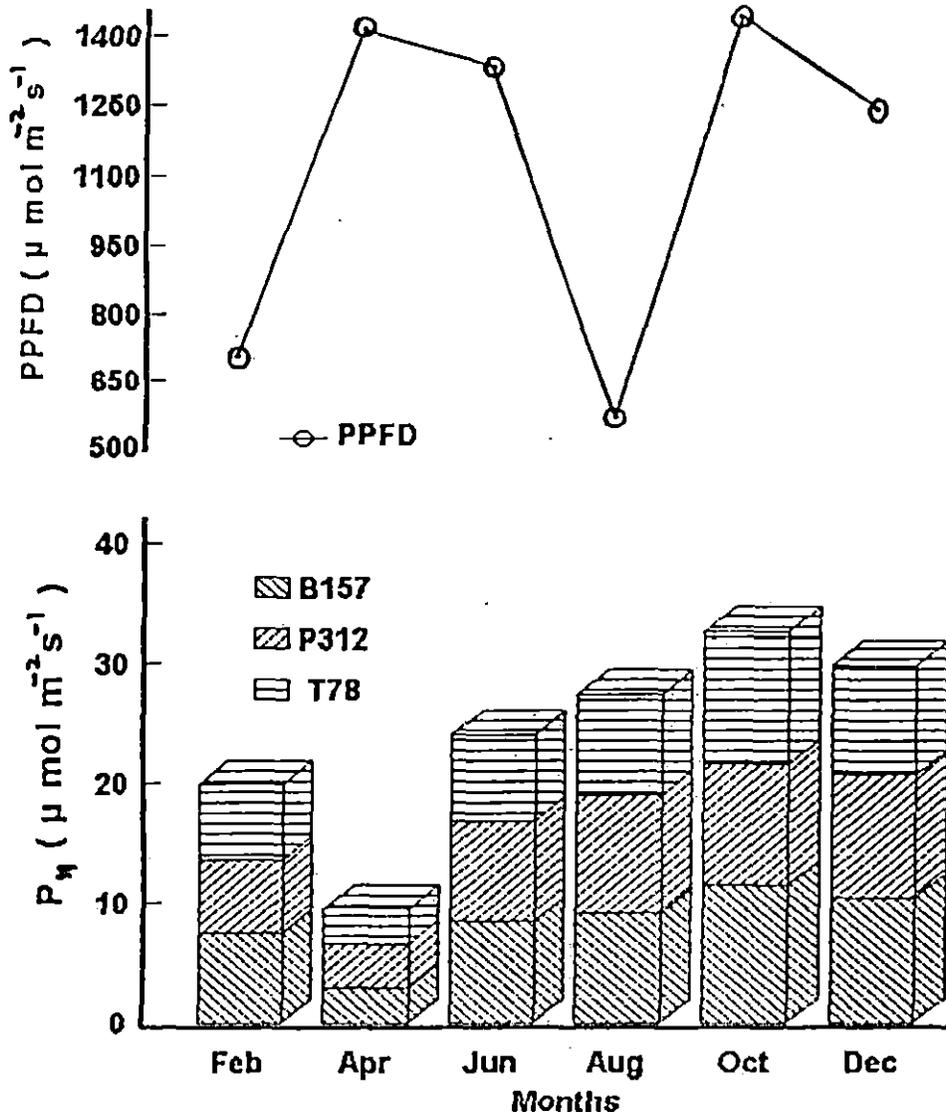


Fig. 21. Influence of photosynthetic photon flux density ($\mu \text{mol m}^{-2} \text{s}^{-1}$) on net photosynthesis ($\mu \text{mol m}^{-2} \text{s}^{-1}$) of mature tea plants during different months.

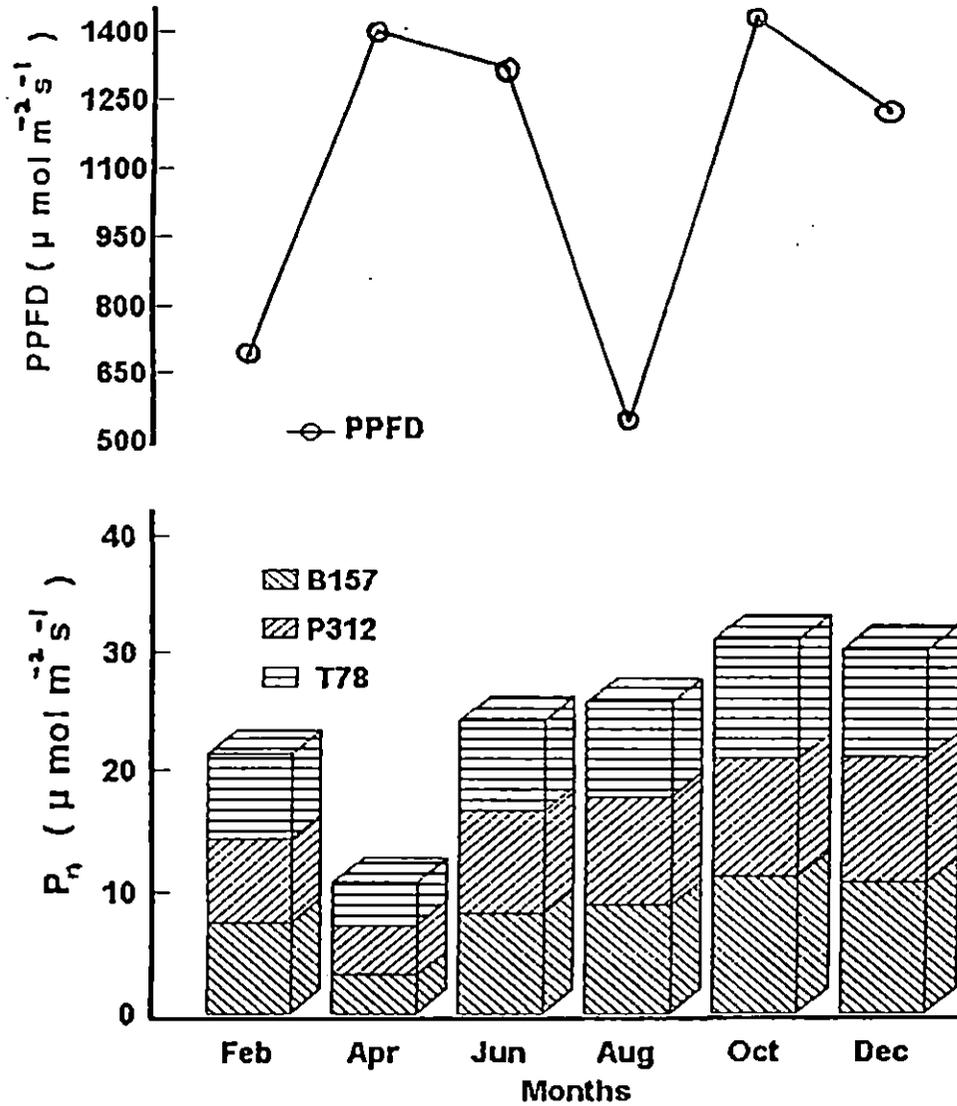


Fig. 22. Influence of photosynthetic photon flux density ($\mu\text{mol m}^{-2} \text{s}^{-1}$) on net photosynthesis ($\mu\text{mol m}^{-2} \text{s}^{-1}$) of young tea plants during different months.

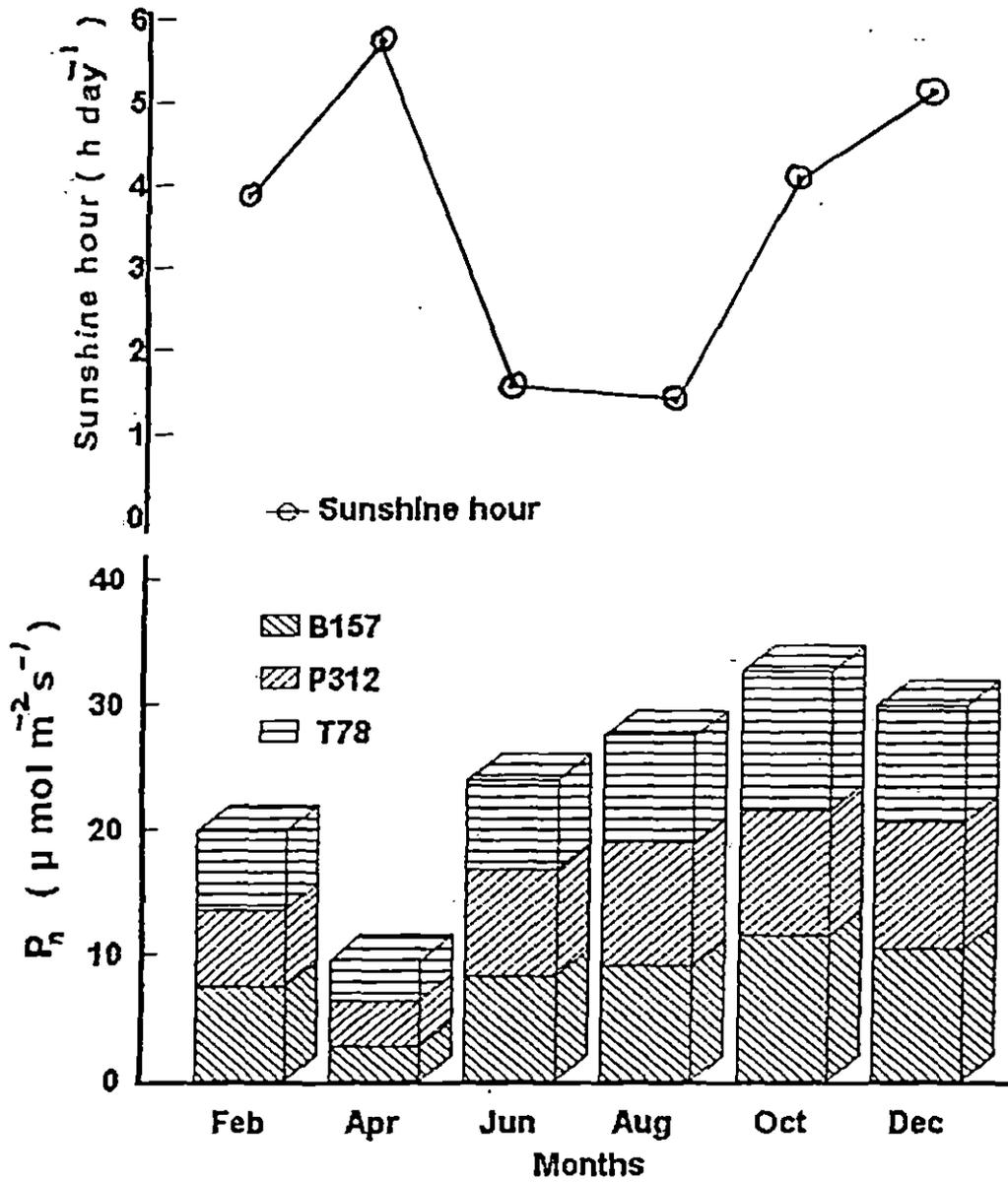


Fig.23. Influence of sunshine hour (h day⁻¹) on net photosynthesis (μmol m⁻² s⁻¹) of mature tea plants during different months.

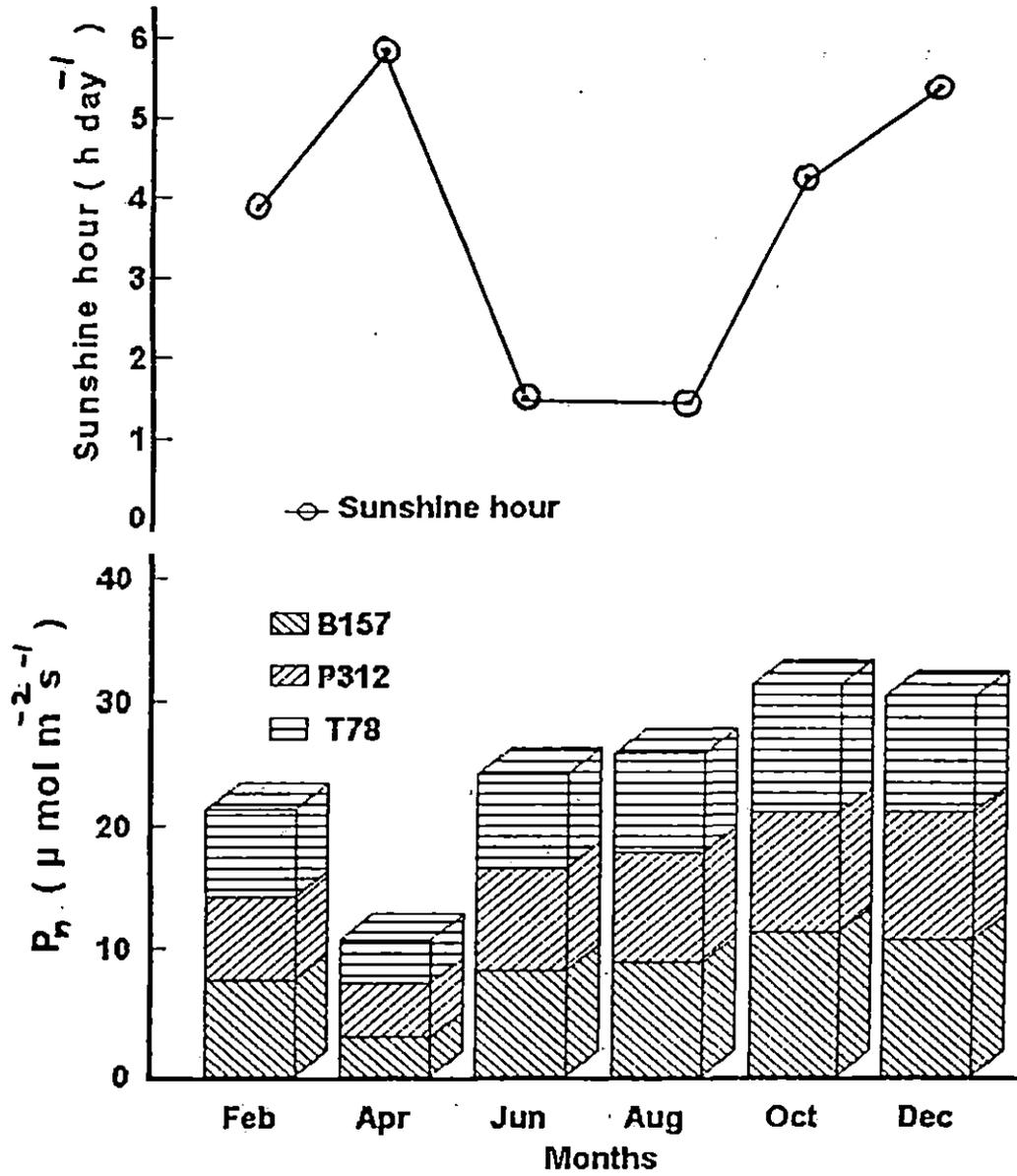


Fig.24 Influence of sunshine hour (h day⁻¹) on the net photosynthesis (μmol m⁻² s⁻¹) of young tea plants during different months.

on the rate of net photosynthesis of mature and young plants is presented in Figs. 23 and 24 respectively. It can be seen that the influence was similar in mature and young plants. Highest sunshine hour was observed in April, the month which saw lowest rate of net photosynthesis. Sunshine was moderate in October and December when the photosynthesis rates were very high. Low sunshine was observed in June and August when moderate rate of net photosynthesis accrued.

(d) Relative humidity and net photosynthesis

Influence of relative humidity in different months on the rate of net photosynthesis of mature and young plants is presented in Figs. 25 and 26 respectively. It can be seen that the influence was similar in mature and young plants. In the month of April relative humidity \bar{w}_s^a lowest and so was the rate of net photosynthesis. During February, when the relative humidity percentge \bar{w}_s^a little higher than April but lower thn all other months, the rate of net photosynthesis was low. During June and August very high humidity was observed, net photosynthesis was moderate. In October and December, when moderate relative humidity existed, very high rate of net photosynthesis was noticed.

(e) Wind velocity and net photosynthesis

Influence of wind velocity in different months on the rate of net photosynthesis of mature and young plants is presented in Figs. 27 and 28 respectively. It can be seen that the influence was similar in mature and young plants. From the figures it can be ascertained that the effect of wind velocity on net photosynthesis is not consistent. During April and June, wind velocity was very high but in April, the rate of net photosynthesis was lowest while in June it was moderate. In the months of February, August, October and December - wind velocity was almost at par but net photosynthesis varied widely during these months.

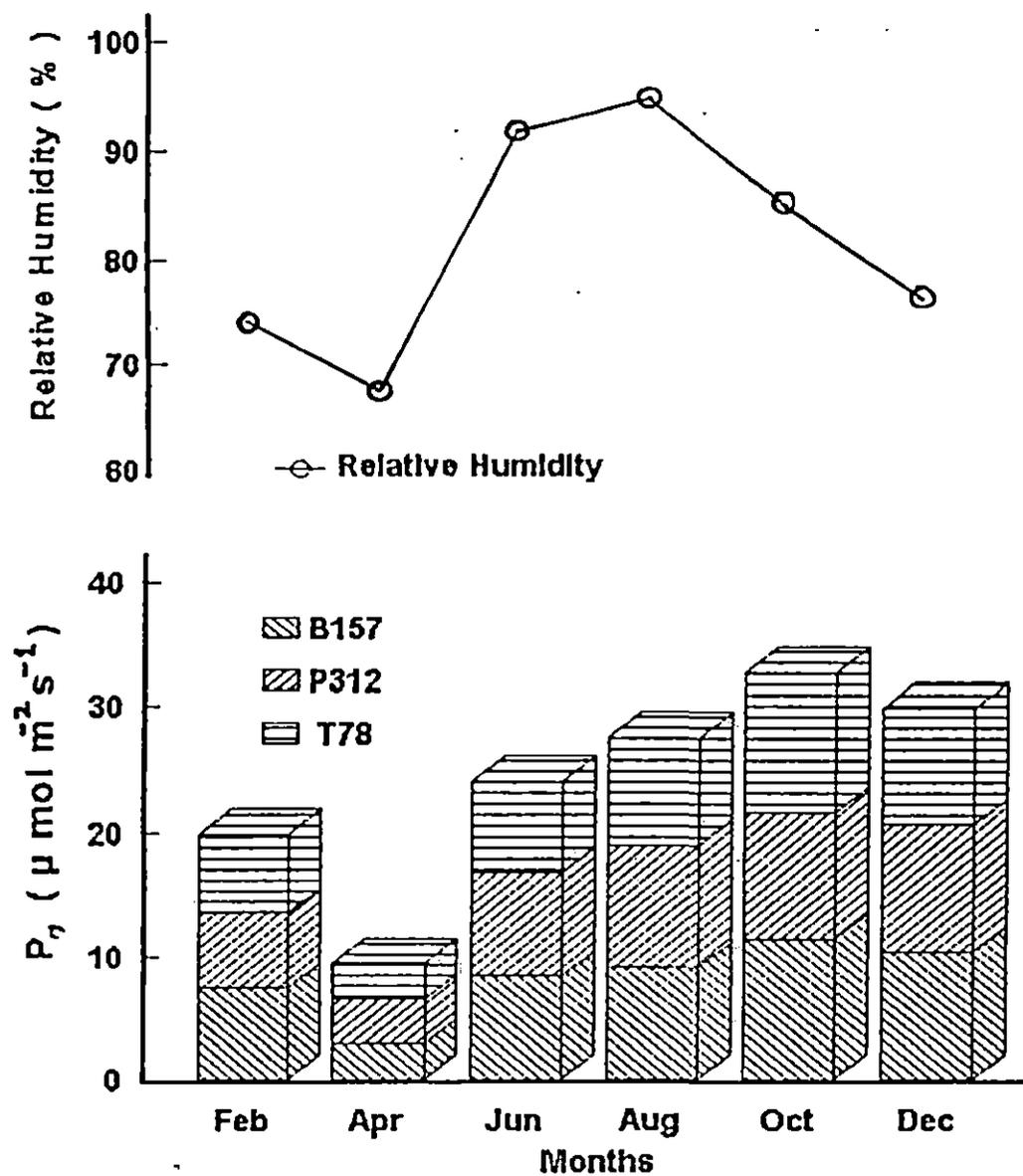


Fig.25 Influence of relative humidity (%) on the net photosynthesis ($\mu\text{mol m}^{-2} \text{s}^{-1}$) of mature tea plants during different months.

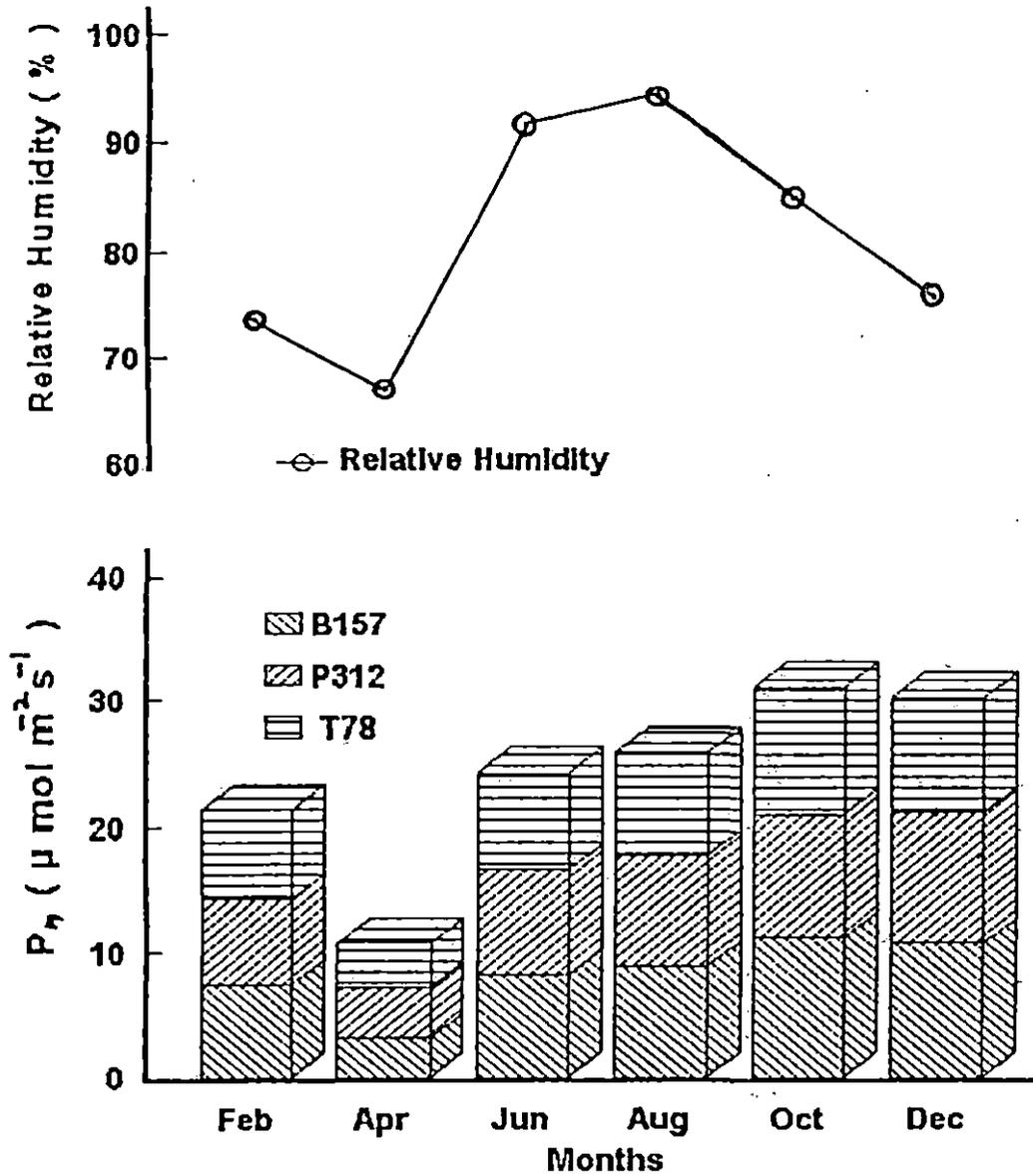


Fig.26 Influence of relative humidity (%) on the net photosynthesis ($\mu\text{mol m}^{-2}\text{s}^{-1}$) of young tea plants during different months.

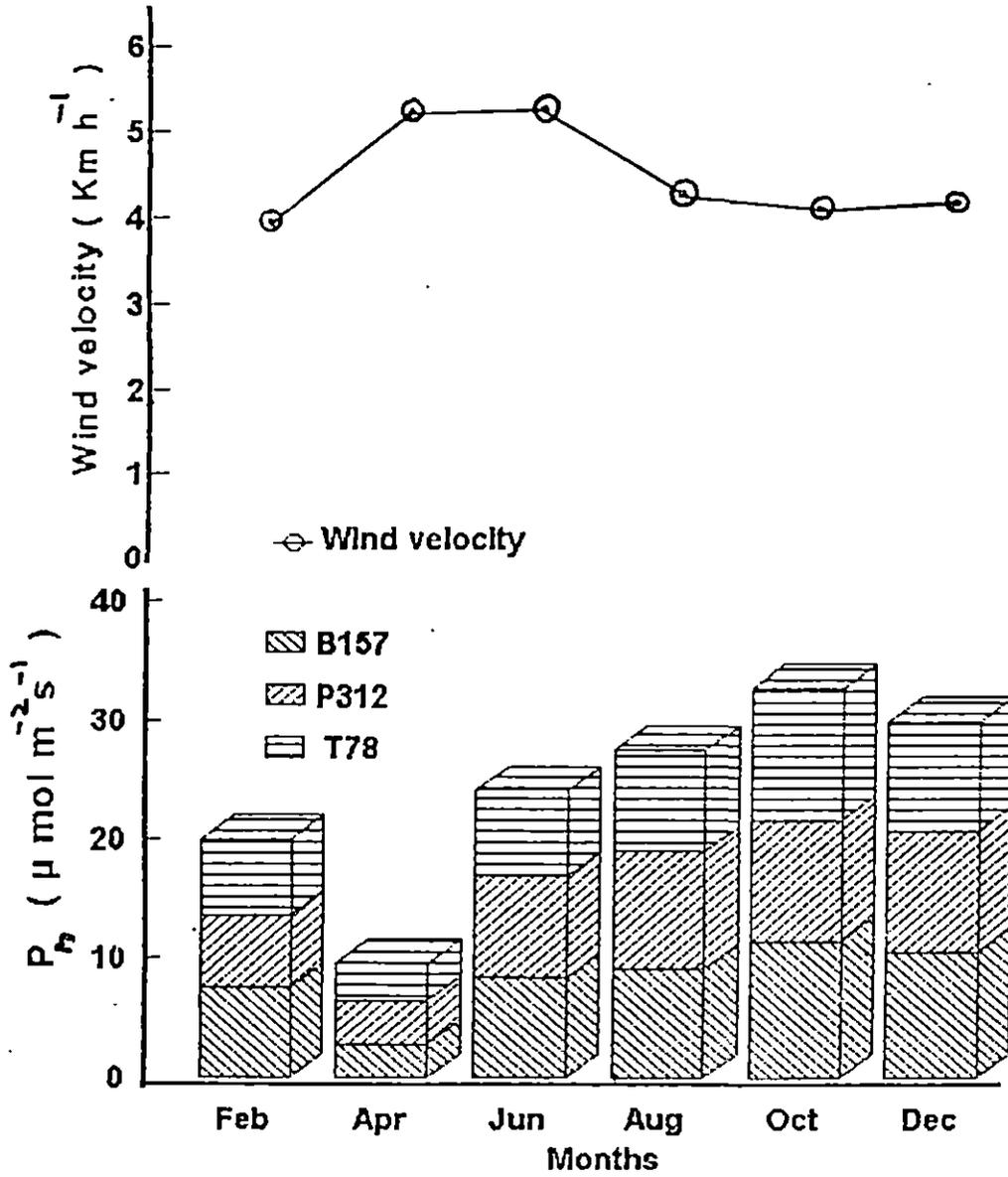


Fig.27. Influence of wind velocity (Km. h⁻¹) on net photosynthesis (μ mol m⁻² s⁻¹) of mature tea plants during different months.

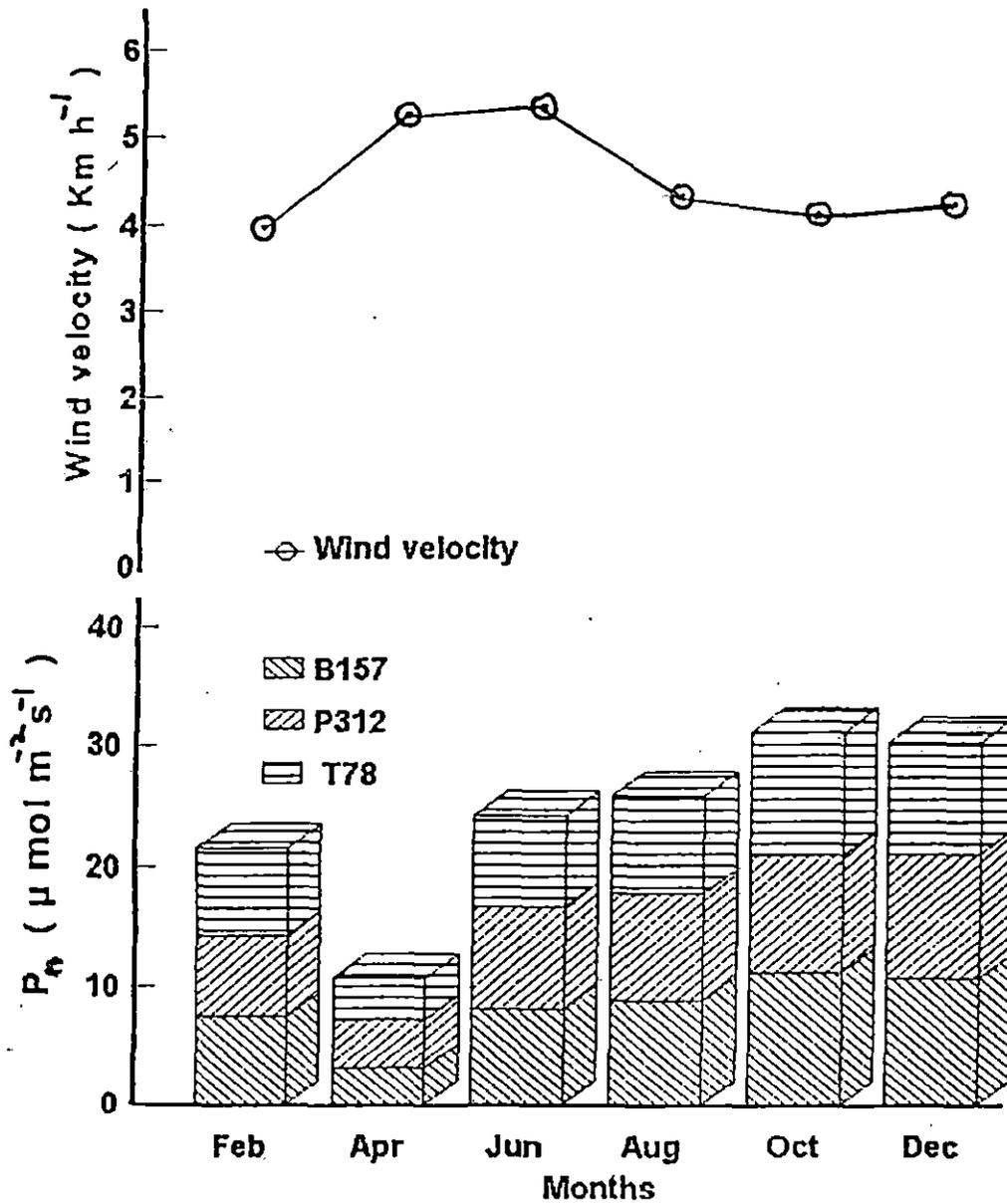


Fig. 28, Influence of wind velocity (Km. h⁻¹) on net photosynthesis (μ mol m⁻² s⁻¹) of young tea plants during different months.

RELATIONSHIP OF THE PHYSIOLOGICAL PARAMETERS

(a) Net photosynthesis and stomatal conductance

From the regression presented in Figs. 29 and 30 it is revealed that a strong positive correlation exists between net photosynthesis and stomatal conductance, in both mature and young plants. At lower rate of stomatal conductance, the rate of net photosynthesis was also lower.

(b) Net photosynthesis and stomatal resistance

From the regression presented in Figs. 31 and 32, it is revealed that a strong negative correlation exists between net photosynthesis and stomatal resistance. In case of young plants the relation was more negative and linear. At higher stomatal resistance the rate of net photosynthesis was reduced.

(c) Net photosynthesis and transpiration

A very strong linear correlation exists between net photosynthesis and transpiration (Figs. 32 & 34). In both mature and young plants, similar kind of trend observed. Higher the rate of transpiration, higher was the photosynthesis.

(d) Net photosynthesis and leaf water potential

Regression presented in Figs. 35 and 36 show that a positive but not very strong correlation exists between net photosynthesis and leaf water potential. The values are found scattered in the diagram. Similar kind of trend exists in mature and young plants. At lower leaf water potential, the rate of net photosynthesis was low.

(e) Net photosynthesis and leaf temperature

Weak negative correlation was observed between net photosynthesis and leaf temperature (Figs. 37 & 38). In case of mature

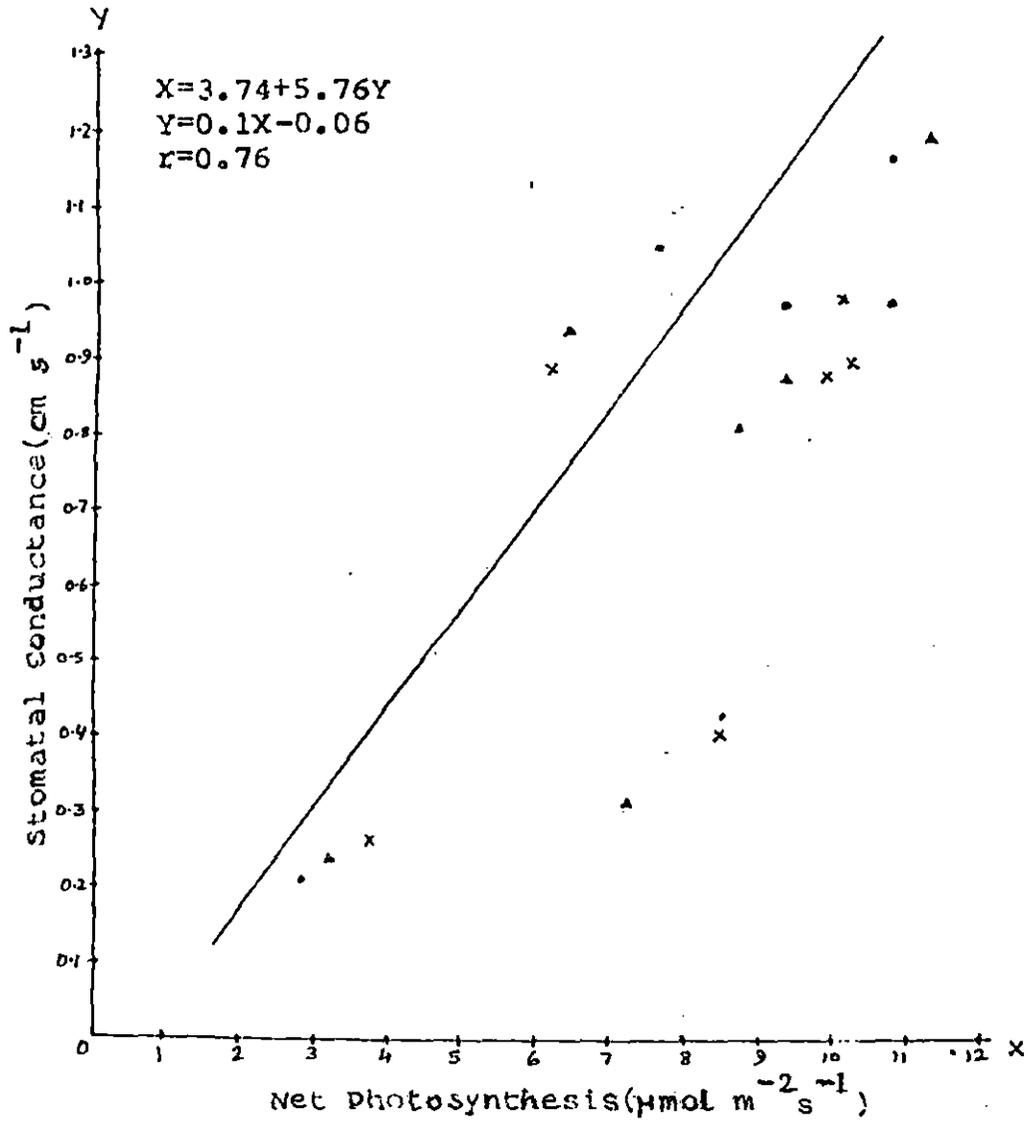


Fig 29. Relation between net photosynthesis and Stomatal conductance (o=B157, x=P312 and Δ =T78) Mature Plants.

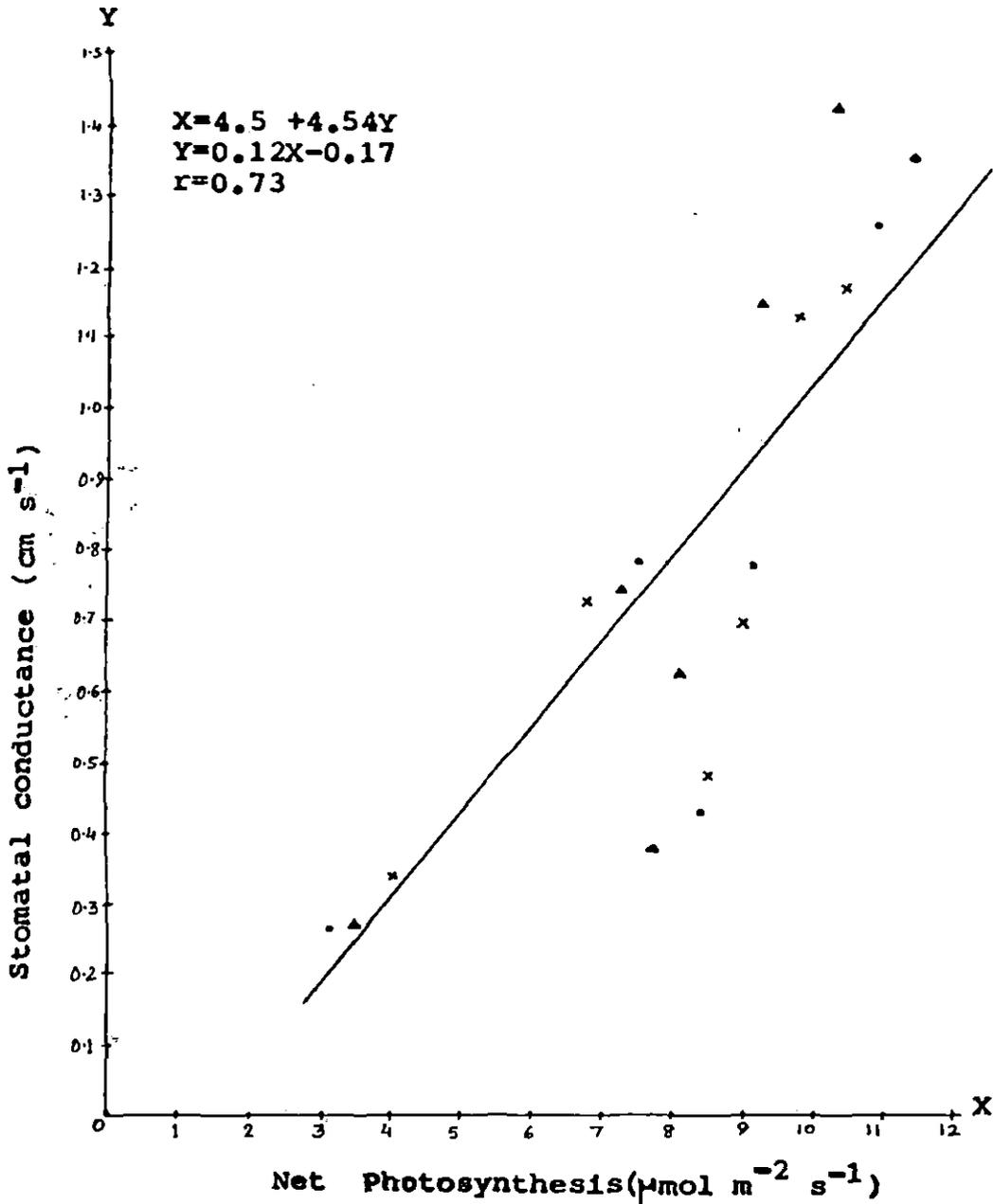


Fig.30. Relation between net photosynthesis and Stomatal conductance (o=B157, x=P312 and Δ =T78) Young Plants.

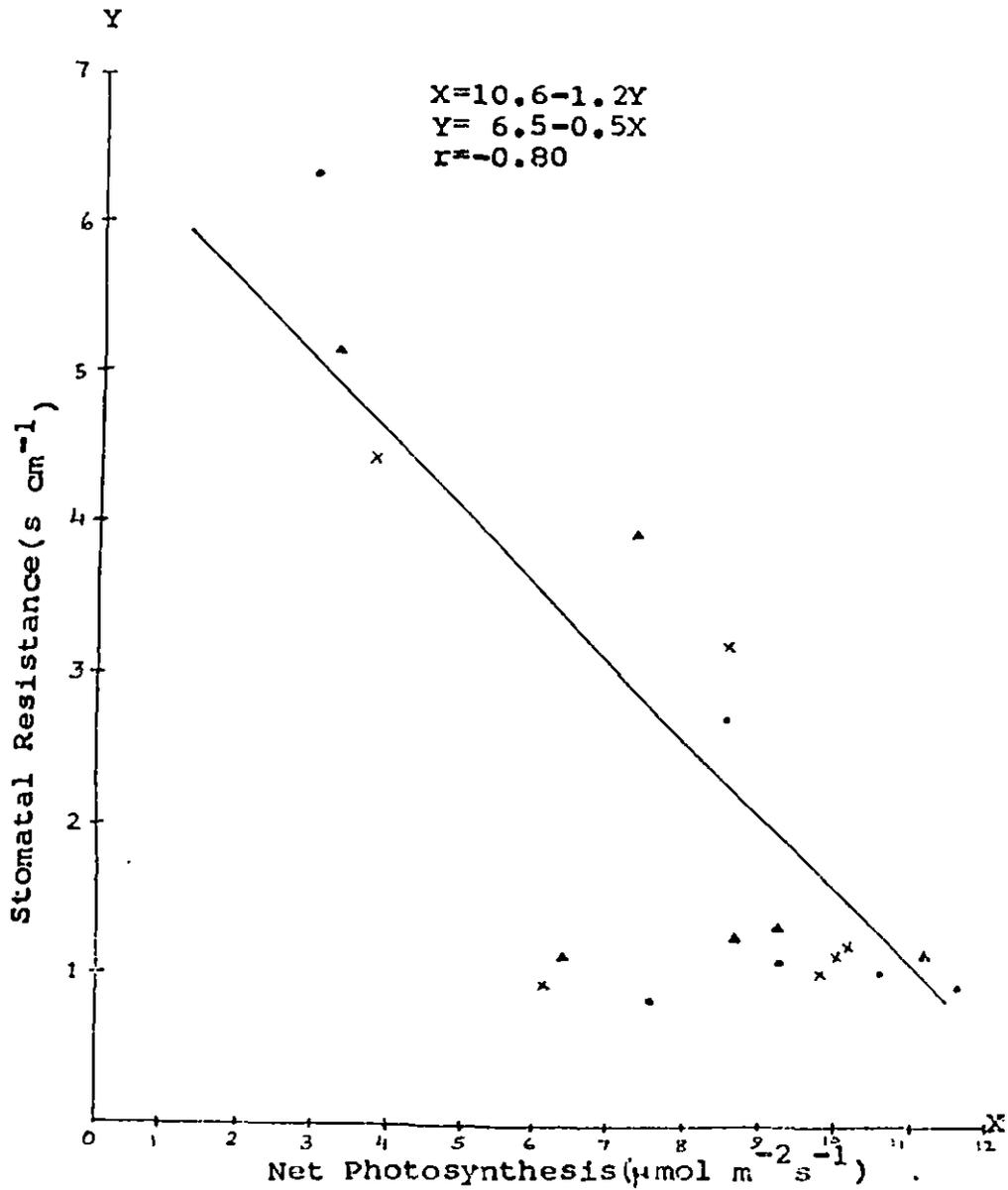


Fig.31. Relation between net photosynthesis and Stomatal resistance (\circ =B157, \times =P312 and Δ =T78) Mature Plants.

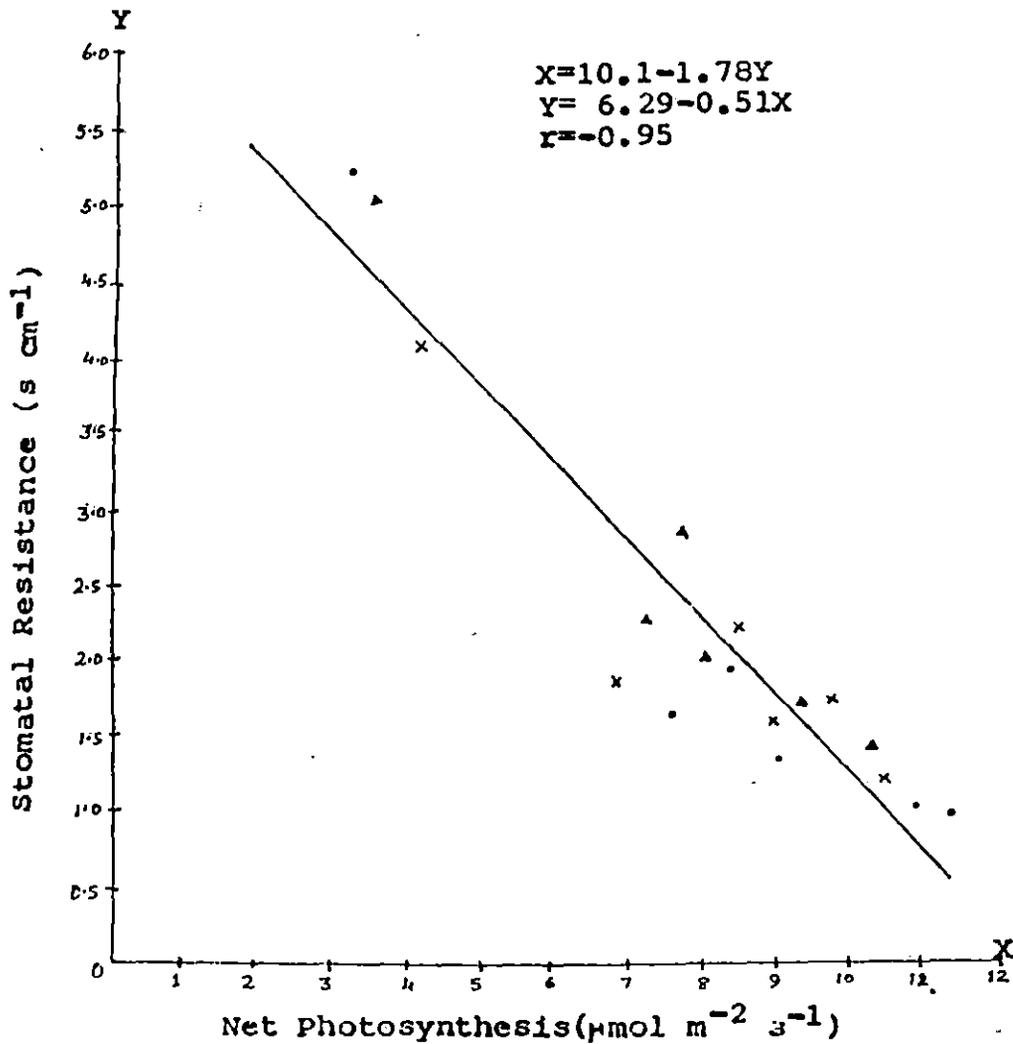


Fig.32. Relation between net photosynthesis and Stomatal resistance (•=B157, X=P312 and ▲=T78) Young Plants.

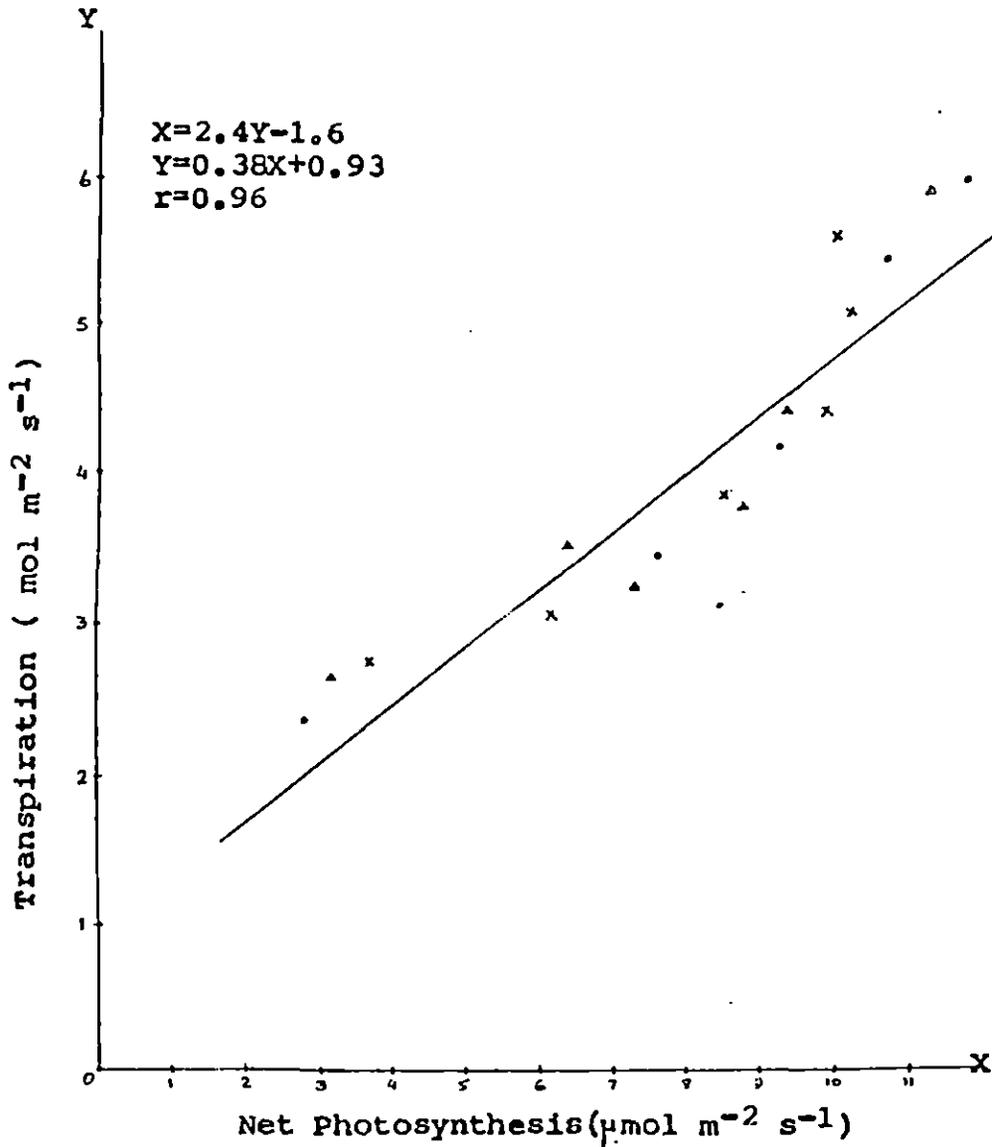


Fig.33. Relation between net photosynthesis and transpiration (o=B157, x=P312 and Δ=T78) Mature Plants.

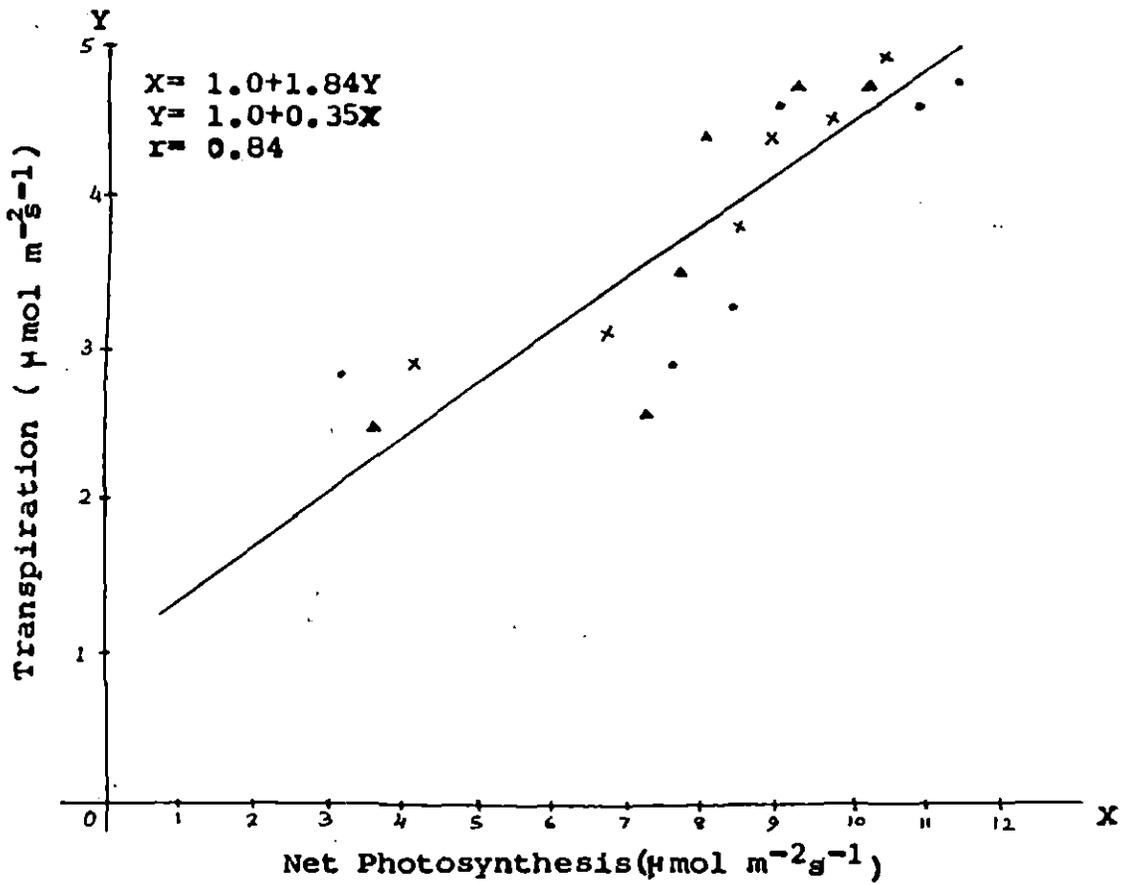


Fig.34. Relation between net photosynthesis and transpiration
 (\circ =B157, \times =P312 and Δ =T78) Young Plants.

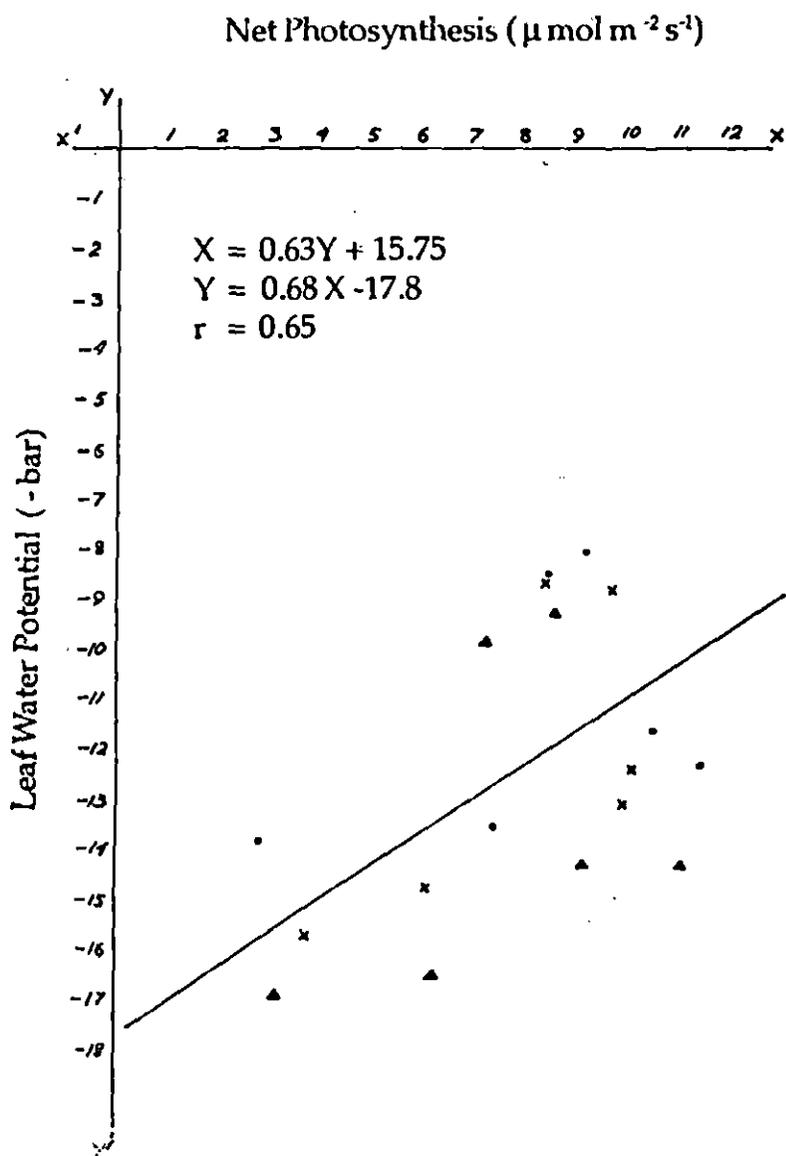


Fig.. 35. Relation between net photosynthesis and Leaf Water Potential (\bullet = B157, \times = P312 and \blacktriangle = T78) Mature Plants.

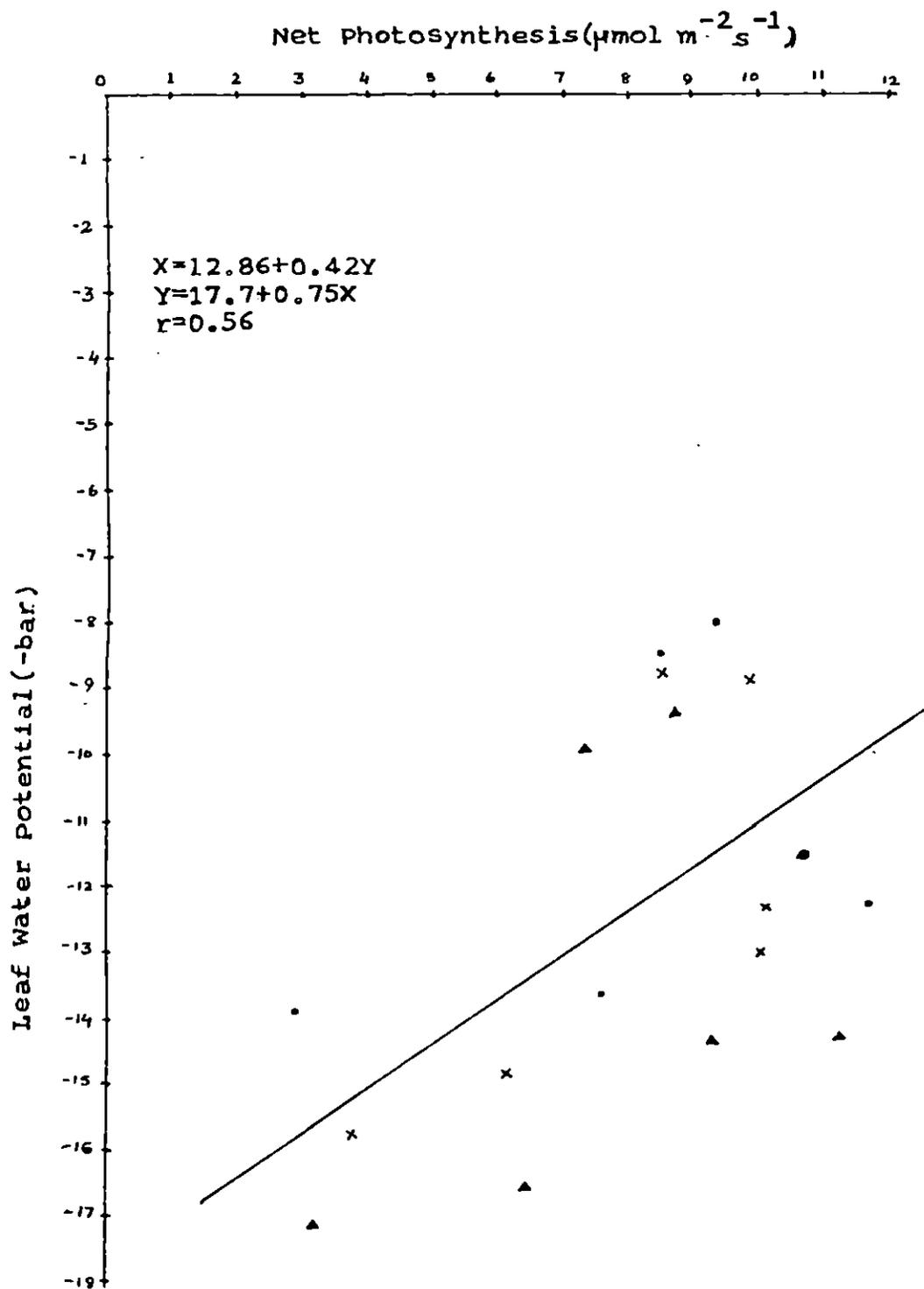


Fig. 36. Relation between net photosynthesis and Leaf Water Potential (.=B157, x=P312△=T78) Young Plants.

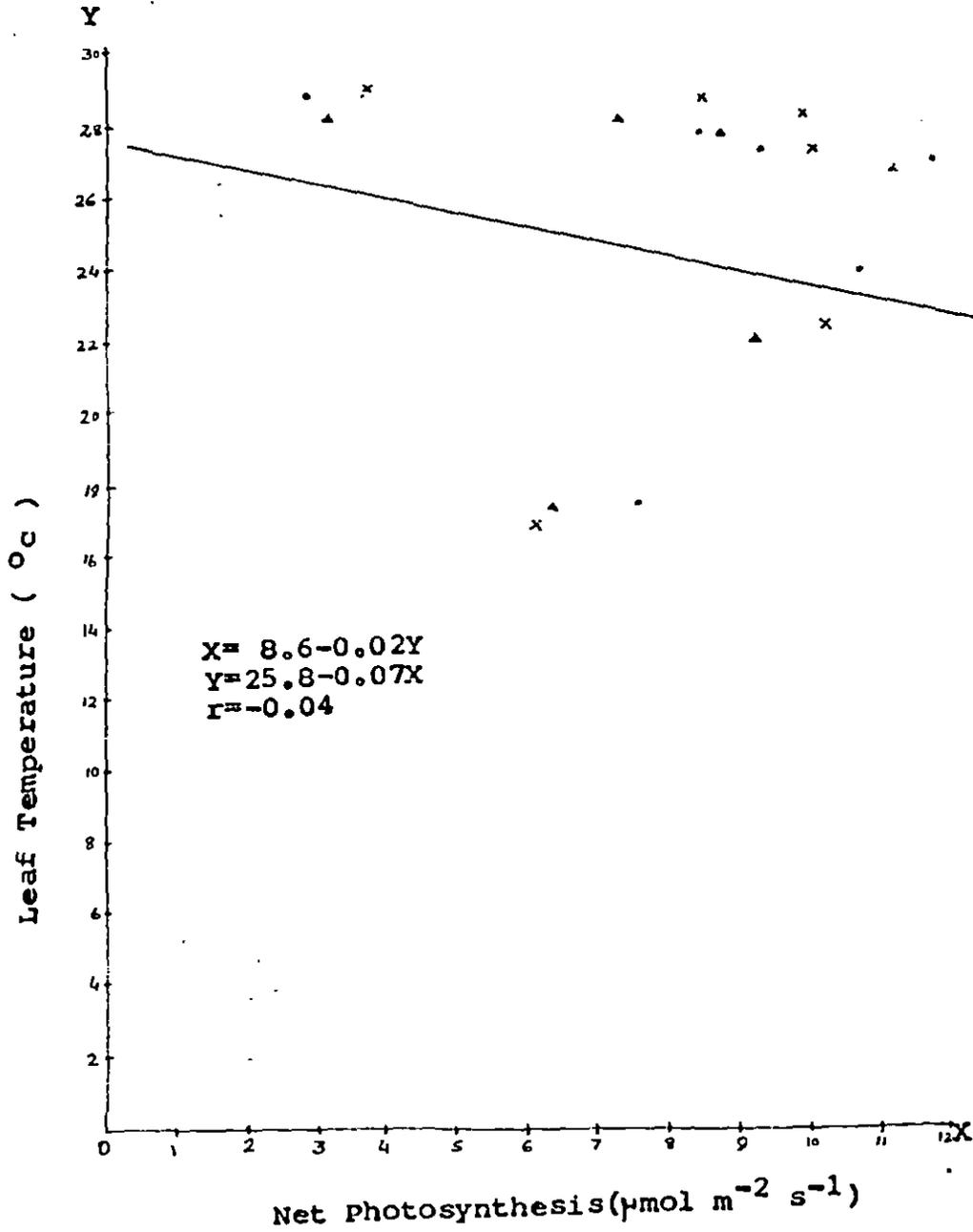


Fig.37. Relation between net photosynthesis and leaf temperature (o=B157, x=P312 and Δ =T78) Mature Plants.

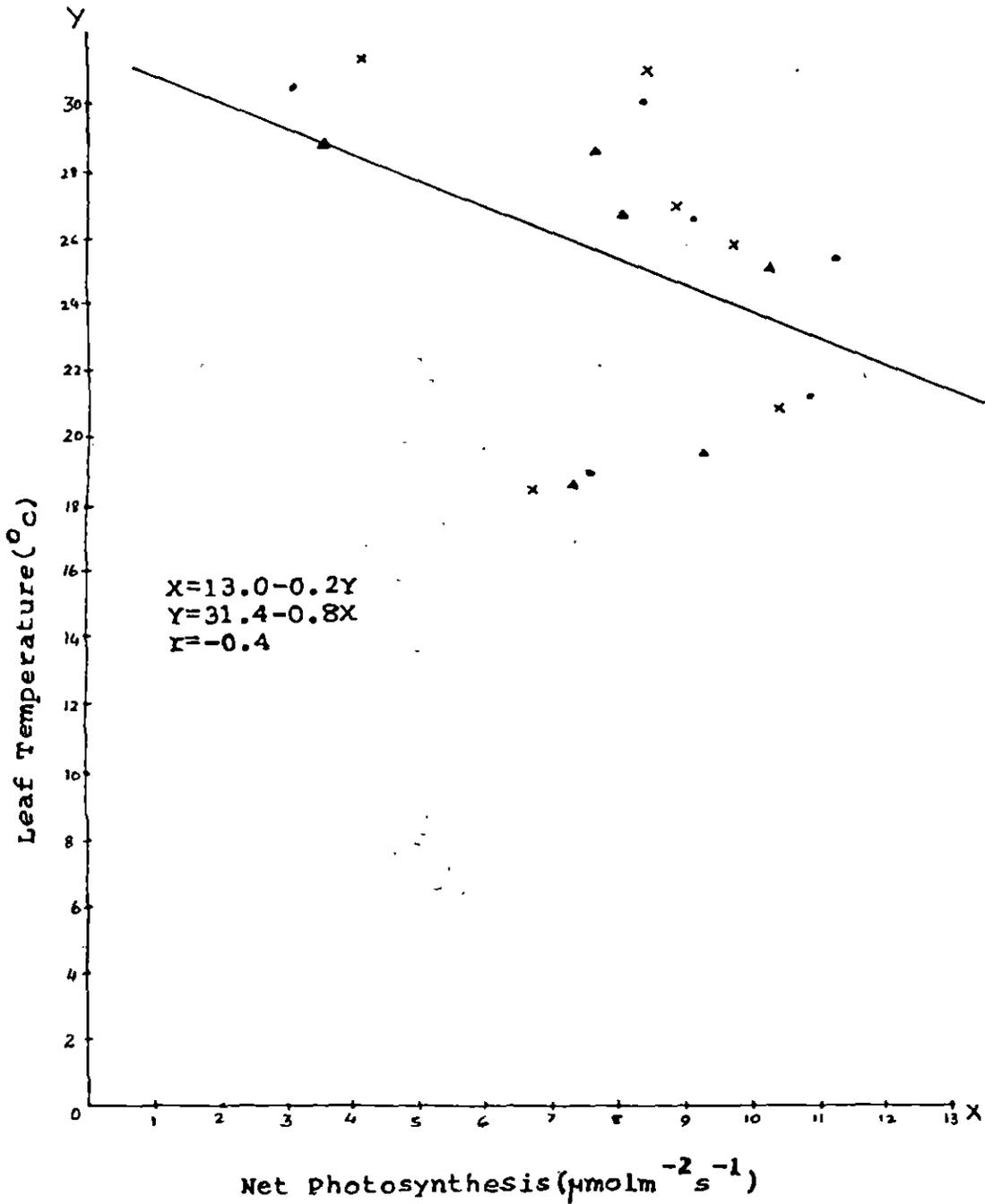


Fig. 38 Relation between net photosynthesis and leaf temperature (•=B157, x=P312 and Δ=T78) - Young Plants.

plants, the correlation was almost neutral. At very high leaf temperature the rate of net photosynthesis went down considerably.

EFFECT OF NUTRIENTS ON PHYSIOLOGICAL PARAMETERS

The rate of net photosynthesis, stomatal conductance and transpiration recorded during pre-monsoon, monsoon, post-monsoon and winter showed (Table 14) the following results.

(a) Net Photosynthesis (P)

In all the four seasons, the plants sprayed with phosphorus showed highest rate of net photosynthesis followed by sulphur treatment. There was no marked difference in the rate of net photosynthesis owing to the spray of molybdenum, potassium and zinc (Table 14). In pre- and post-monsoon, Bannockburn-157 exhibited highest rate of net photosynthesis among the three genotypes. In monsoon, Phoobshering-312 showed higher rate of net photosynthesis. In winter, except in sulphur treatment, Pboobshering-312 showed higher rate of net photosynthesis than other genotypes.

(b) Stomatal Conductance (gs)

In monsoon, the rate of stomatal conductance was found to be highest and lowest in pre-monsoon. In monsoon, post-monsoon and winter; sulphur treated tea plants showed highest stomatal conductance but in pre-monsoon, the rate was higher in molybdenum and phosphorus treatments. In post-monsoon and winter, Phoobshering-312 showed highest

of nutrient

| Potassium | |
|-----------|-------|
| B | C |
| 3.786 | 3.733 |
| 4.080 | 6.1 |
| 0.310 | 0.323 |
| 0.300 | 0.2 |
| 2.8 | 2.6 |
| 2.6 | 2.6 |
| 7.046 | 5.601 |
| 6.620 | 7.1 |
| 0.501 | 0.489 |
| 0.510 | 0.4 |
| 2.5 | 2.2 |
| 2.4 | 2 |
| 6.587 | 6.734 |
| 6.916 | 11.7. |
| 0.439 | 0.426 |
| 0.400 | 0.51 |
| 3.2 | 3.2 |
| 3.0 | 3. |
| 6.307 | 6.279 |
| 6.122 | 0.11 |
| 0.424 | 0.393 |
| 0.396 | 0.32 |
| 2.4 | 2.6 |
| 2.5 | 2. |

A = B157

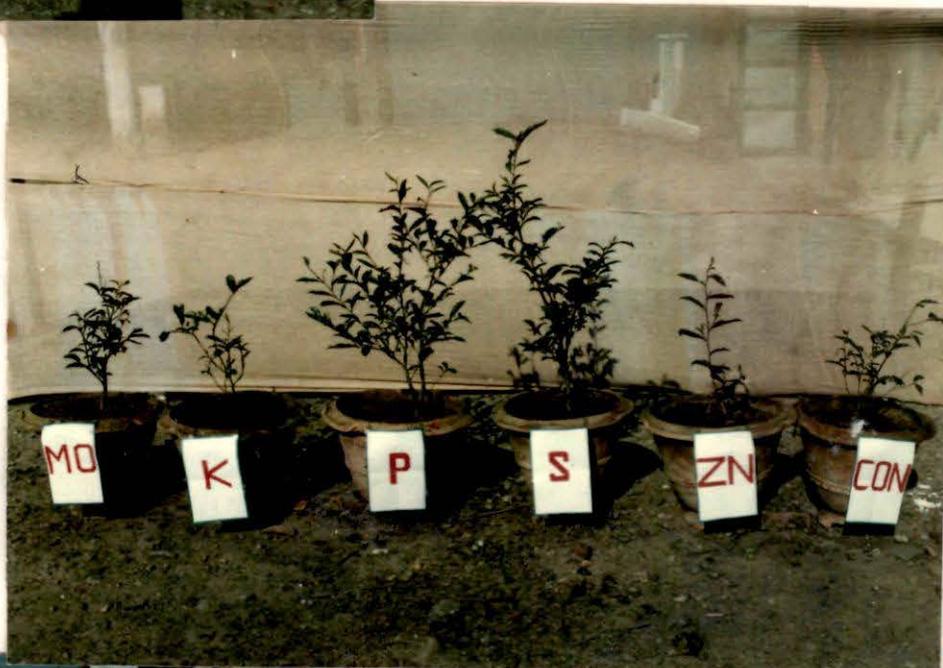
Table 14 : Effect of nutrients on physiological characteristics of three genotypes

| Season | Parameters | Molybdenum | | | | Potassium | | | | Phosphorus | | | | Sulphur | | | | Zinc | | | | Control | | | | CD (P=0.05) | | |
|--------------|----------------|------------|-------|-------|-------|-----------|-------|-------|-------|------------|--------|-------|--------|---------|-------|-------|-------|-------|-------|-------|-------|---------|-------|-------|-------|-------------|------|------|
| | | A | B | C | M | A | B | C | M | A | B | C | M | A | B | C | M | A | B | C | M | A | B | C | M | A | B | C |
| Premonsoon | P _N | 4.713 | 4.050 | 3.929 | 4.233 | 4.722 | 3.786 | 3.733 | 4.060 | 6.014 | 4.997 | 4.779 | 5.263 | 4.083 | 4.019 | 3.922 | 4.275 | 4.424 | 3.864 | 3.569 | 3.952 | 2.922 | 3.222 | 2.747 | 2.964 | 2.22 | 1.19 | 0.97 |
| | G _S | 0.424 | 0.297 | 0.290 | 0.340 | 0.260 | 0.310 | 0.323 | 0.300 | 0.271 | 0.456 | 0.276 | 0.334 | 0.371 | 0.266 | 0.167 | 0.260 | 0.190 | 0.301 | 0.320 | 0.300 | 0.250 | 0.240 | 0.250 | 0.255 | 0.08 | 0.09 | 0.13 |
| | E | 3.8 | 2.8 | 2.1 | 2.6 | 2.5 | 2.8 | 2.6 | 2.6 | 2.4 | 3.6 | 2.6 | 2.9 | 3.2 | 2.4 | 2.1 | 2.6 | 1.8 | 2.9 | 2.5 | 2.4 | 2.3 | 2.6 | 2.2 | 2.4 | 0.50 | 0.50 | 0.50 |
| Monsoon | P _N | 6.744 | 6.884 | 7.436 | 7.021 | 7.214 | 7.046 | 5.601 | 6.620 | 7.156 | 7.065 | 7.302 | 7.460 | 6.125 | 0.714 | 6.553 | 7.131 | 6.622 | 7.419 | 5.243 | 6.420 | 5.650 | 5.951 | 5.114 | 5.572 | 1.27 | 1.36 | 1.09 |
| | G _S | 0.371 | 0.372 | 0.677 | 0.473 | 0.564 | 0.501 | 0.489 | 0.510 | 0.454 | 0.437 | 0.371 | 0.421 | 0.201 | 0.904 | 0.540 | 0.575 | 0.357 | 0.577 | 0.307 | 0.414 | 0.319 | 0.474 | 0.260 | 0.351 | 0.23 | 0.27 | 0.27 |
| | E | 2.0 | 2.1 | 2.0 | 2.3 | 2.6 | 2.5 | 2.2 | 2.4 | 2.3 | 2.3 | 2.1 | 2.2 | 1.9 | 2.7 | 2.7 | 2.4 | 1.9 | 2.2 | 1.7 | 1.9 | 1.6 | 1.7 | 2.3 | 1.9 | 0.69 | 0.71 | 0.74 |
| Post monsoon | P _N | 7.491 | 7.256 | 7.445 | 7.397 | 7.426 | 6.507 | 6.734 | 6.916 | 11.730 | 10.004 | 0.334 | 10.202 | 10.616 | 9.116 | 7.650 | 9.130 | 6.470 | 6.460 | 6.755 | 6.564 | 4.126 | 4.070 | 6.423 | 5.142 | 2.00 | 2.41 | 1.20 |
| | G _S | 0.405 | 0.422 | 0.33 | 0.399 | 0.356 | 0.439 | 0.406 | 0.400 | 0.507 | 0.551 | 0.407 | 0.400 | 0.401 | 0.571 | 0.427 | 0.493 | 0.393 | 0.401 | 0.360 | 0.307 | 0.272 | 0.303 | 0.303 | 0.293 | 0.16 | 0.20 | 0.17 |
| | E | 3.4 | 2.9 | 3.2 | 3.2 | 2.7 | 3.2 | 3.2 | 3.0 | 3.0 | 3.0 | 3.3 | 3.6 | 3.6 | 4.2 | 3.6 | 3.0 | 3.2 | 3.5 | 3.1 | 3.3 | 2.1 | 2.5 | 2.5 | 2.4 | 0.74 | 0.74 | 0.94 |
| Winter | P _N | 4.512 | 4.765 | 5.519 | 4.932 | 5.779 | 6.307 | 6.279 | 6.122 | 0.157 | 0.631 | 7.096 | 7.961 | 7.665 | 7.479 | 7.031 | 7.392 | 5.760 | 3.519 | 5.153 | 4.013 | 3.241 | 3.349 | 2.705 | 3.090 | 1.09 | 2.00 | 1.74 |
| | G _S | 0.317 | 0.421 | 0.386 | 0.375 | 0.373 | 0.424 | 0.393 | 0.396 | 0.369 | 0.402 | 0.305 | 0.412 | 0.472 | 0.491 | 0.372 | 0.445 | 0.455 | 0.227 | 0.437 | 0.323 | 0.244 | 0.240 | 0.304 | 0.265 | 0.17 | 0.16 | 0.08 |
| | E | 2.1 | 2.3 | 2.3 | 2.2 | 2.4 | 2.4 | 2.6 | 2.5 | 2.4 | 2.9 | 2.6 | 2.6 | 2.7 | 3.0 | 2.9 | 2.9 | 2.0 | 2.0 | 2.9 | 2.6 | 1.7 | 1.8 | 2.0 | 1.0 | 0.71 | 0.67 | 0.45 |

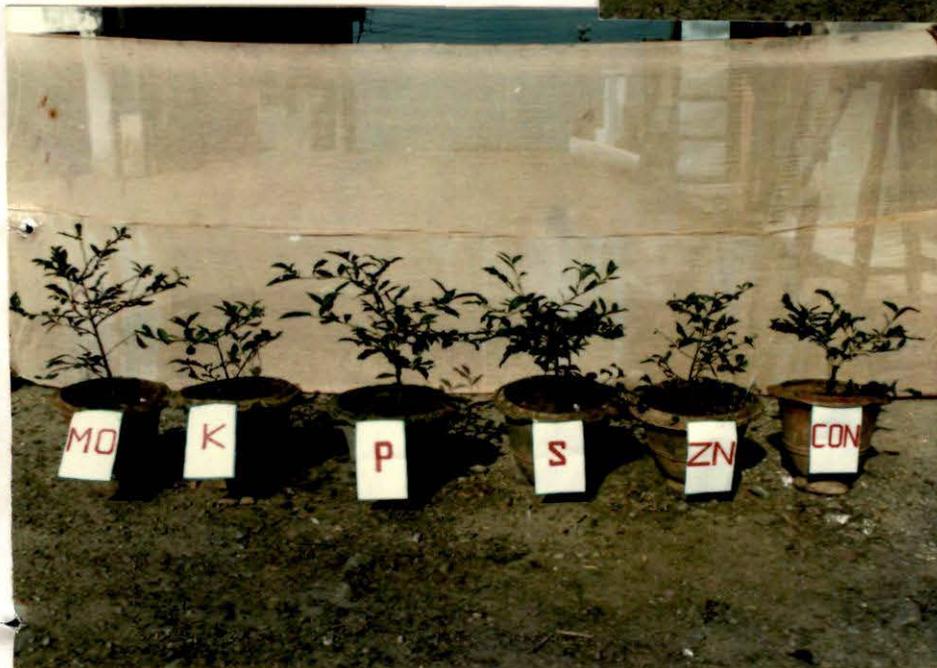
A = B157, B = P312, C = T78 and M = Mean



A



B



C

Fig.39 : Growth of plants belonging to Bannockburn-157 (A), Phoobshering-312 (B) and Tukdah-78 (C) effected by spray of molybdenum (Mo), potassium (K), phosphorus (P), sulphur (S), zinc (Zn) in comparison to untreated control (CON).

stomatal conductance in most of the treatments but in pre-monsoon and monsoon, no definite trend could be established.

(c) Transpiration (E)

In pre-monsoon, phosphorus treatments showed highest rate of transpiration while in other seasons, sulphur treated tea plants showed high rate of transpiration compared to other treatments. In post-monsoon and winter, untreated control plants showed lowest rate of transpiration. In pre-monsoon and monsoon, the transpiration rate was lowest in zinc treated and untreated plants. During pre-monsoon and post-monsoon, Phoobshering-312 showed high rate of transpiration in majority of the cases, while in monsoon, there was no definite varietal trend. During winter, Tukdah-78 showed higher transpiration rate in general.

(d) Girth and Height of the Plants

Data presented in Table 15 show that annual increment of girth was highest in phosphorus treated plants followed by sulphur treated

Table 15 : Effect of nutrients on annual increment of girth & height of three genotypes

| Name of nutrient (element) | Annual increment (%) | | | | | |
|-------------------------------|----------------------|------|------|-------------|-------|------|
| | G i r t h | | | H e i g h t | | |
| | B157 | P312 | T78 | B157 | P312 | T78 |
| Molybdenum | 48.7 | 28.0 | 48.8 | 50.7 | 41.7 | 53.5 |
| Potassium | 36.1 | 23.6 | 24.6 | 56.9 | 50.7 | 65.7 |
| Phosphorus | 87.8 | 56.4 | 70.7 | 106.9 | 106.9 | 84.8 |
| Sulphur | 75.0 | 42.9 | 61.0 | 79.2 | 77.1 | 66.1 |
| Zinc | 53.1 | 22.3 | 51.5 | 56.9 | 66.7 | 62.5 |
| Untreated Control | 19.7 | 20.9 | 17.5 | 32.7 | 35.4 | 49.4 |

plants. A general view of the morphological development of the pot plants after 2 years of planting is presented in Fig. 39. Health of the plants of all the genotypes treated with phosphorus and sulphur looks better than other treatments. As regards to girth of the plants in case of Bannockburn-157 and Tukdah-78, phosphorus treatment showed thickest stem followed by sulphur, zinc, molybdenum and potassium treatments in descending order. But in Phoobshering-312 after phosphorus and sulphur treatments, molybdenum spray yielded better result than potassium and zinc treatments.

In case of increment of plant height too, phosphorus and sulphur treated plants showed better results (Table 15). Height improvement due to potassium and zinc treatments was very close. Molybdenum treatment was not found to be suitable in increasing the plant height.

BIOCHEMICAL CHARACTERISTICS

(a) Total free amino acid

Pre-monsoon, monsoon and post-monsoon data of total free amino acid, presented in Table 16 show that during pre-monsoon, when droughty condition prevailed, higher accumulation of total free amino acid was recorded in all the three varieties. In monsoon, the content was lowest while in post-monsoon it was mediocre. The ranges of total free amino acid during pre-monsoon, monsoon and post-monsoon were : 1015-1995 $\mu\text{g/g}$, 252-755 $\mu\text{g/g}$ and 749.5-1131 $\mu\text{g/g}$ of fresh leaves respectively.

Table 16 : Seasonal variation of total free amino acid
($\mu\text{g/g}$ fresh wt. of leaf)

| Seasons | Plant age | Variety | | | CD P=0.05 | CV % |
|--------------|-----------|---------|--------|--------|--------------|---------|
| | | B157 | P312 | T78 | | |
| Pre-monsoon | Mature | 1371.8 | 1302.5 | 1995.0 | 360.20 | 8.4 |
| | Young | 2284.5 | 1015.0 | 1480.0 | 289.03 | 7.0 |
| Monsoon | Mature | 448.8 | 405.7 | 755.1 | 180.32 | 5.6 |
| | Young | 275.1 | 252.1 | 596.9 | 71.90 | 10.7 |
| Post-monsoon | Mature | 871.8 | 696.0 | 882.5 | 97.39 | 7.6 |
| | Young | 1079.0 | 749.5 | 1131.0 | 178.72 | 10.2 |

Among the three clones, Tukdah-78 showed very high rate of total free amino acid, while it was lowest in Phoobshering-312 in all the seasons. In case of mature plants, in pre-monsoon total free amino acid

was significantly higher in Tukdah-78 than Phoobshering-312 and Bannockburn-157, where there was no significant difference between the content of Bannockburn-157 and Phoobshering-312. During monsoon, the total free amino acid content of Tukdah-78 was significantly higher than Bannockburn-157 and Phoobshering-312. In post-monsoon season, however, there was no significant difference between the amino acid content of the varieties. In young plants, in pre-monsoon and monsoon, same trend as mature plants followed, but in post-monsoon, there was no significant difference in the content of Tukdah-78 and Bannockburn-157 but content in Phoobshering-312 was significantly low.

In pre-monsoon and post-monsoon period, mature plants showed higher content of total free amino acid compared to young plants. In post-monsoon however, young plants showed higher accumulation.

(b) Proline

Pre-monsoon period showed very high accumulation of proline both in mature and young plants (Table 17). Lowest content of proline was noticed in monsoon and post-monsoon being mediocre. In pre-monsoon, monsoon and post-monsoon, proline content ranged between 1015-1995 $\mu\text{g/g}$, 30.71-58.28 $\mu\text{g/g}$ and 71.03-80.73 $\mu\text{g/g}$ of fresh leaves respectively.

Table 17 : Seasonal variation of proline ($\mu\text{g/g}$ fresh wt. of leaf)

| Seasons | Plant age | Variety | | | CD P=0.05 | CV % |
|--------------|-----------|---------|-------|-------|--------------|---------|
| | | B157 | P312 | T78 | | |
| Pre-monsoon | Mature | 159.0 | 138.2 | 144.8 | 52.69 | 5.9 |
| | Young | 223.5 | 139.0 | 170.5 | 84.00 | 4.1 |
| Monsoon | Mature | 35.6 | 30.7 | 58.2 | 17.59 | 6.2 |
| | Young | 52.1 | 50.5 | 58.3 | 20.55 | 9.2 |
| Post-monsoon | Mature | 71.0 | 76.8 | 81.7 | 5.37 | 2.1 |
| | Young | 80.1 | 80.5 | 80.7 | 3.92 | 2.9 |

Among the three varieties, Bannockburn-157 showed highest content of proline in pre-monsoon. In monsoon, Tukdah-78 showed higher content while post-monsoon all the three varieties showed proline content almost at par. Statistical analysis shows that in case of mature plants in pre-monsoon, there was no significant difference in proline content of different varieties, in monsoon, Bannockburn-157 and Phoobshering-312 showed significantly lower proline than Tukdah-78. In post-monsoon Bannockburn-157 showed significantly lower proline than Tukdah-78. In young plants, however, there was no significant difference in proline content among the varieties in any season.

(c) Ascorbic Acid

It can be seen from Table 18 that ascorbic acid content was little low in monsoon while in pre-monsoon and post-monsoon, there was not marked difference in ascorbic acid content. The content ranged between 39.4-51.7 mg/g. Among the three varieties, in mature plants, in

Table 18 : Seasonal variation of ascorbic acid (mg/g fresh wt. of leaf)

| Seasons | Plant age | Variety | | | CD P = 0.05 | CV % |
|--------------|-----------|---------|------|------|----------------|---------|
| | | B157 | P312 | T78 | | |
| Pre-monsoon | Mature | 51.7 | 49.9 | 51.0 | 1.04 | 0.61 |
| | Young | 51.2 | 49.7 | 50.7 | 0.97 | 0.61 |
| Monsoon | Mature | 44.3 | 41.1 | 46.7 | 4.17 | 2.21 |
| | Young | 41.2 | 39.4 | 41.8 | 2.97 | 1.01 |
| Post-monsoon | Mature | 50.7 | 47.0 | 50.2 | 4.64 | 1.81 |
| | Young | 48.0 | 44.8 | 46.7 | 2.68 | 1.71 |

the pre-monsoon season, Bannockburn-157 showed highest ascorbic acid content which was significantly higher than Phoobshering-312 but not than Tukdah-78. In monsoon, Tukdah-78 showed highest content which was significantly higher than Phoobshering but not than Bannockburn-157. In post-monsoon, there was no significant difference among the varieties, although Bannockburn-157 showed highest content. In case of young plants, in pre-monsoon, the same trend as mature plants followed. In monsoon, the same trend as mature plants, there was no significant difference among the varieties. In post-monsoon, the content was higher in Bannockburn-157 which was significantly higher than Phoobshering-312 but not than Tukdah-78.

(d) Total Chlorophyll

Data presented in Table 19 show that during monsoon, highest accumulation of total chlorophyll occurred in all the varieties while it

Table 19 : Seasonal variation of total chlorophyll (mg/g fresh wt. of leaf)

| Seasons | Plant age | Variety | | | CD P=0.05 | CV % |
|--------------|-----------|---------|------|------|--------------|---------|
| | | B157 | P312 | T78 | | |
| Pre-monsoon | Mature | 0.82 | 1.00 | 1.10 | 0.09 | 4.60 |
| | Young | 1.11 | 1.30 | 1.38 | 0.09 | 2.38 |
| Monsoon | Mature | 1.55 | 1.63 | 1.77 | 0.12 | 3.06 |
| | Young | 1.52 | 1.87 | 2.15 | 0.28 | 3.79 |
| Post-monsoon | Mature | 1.25 | 1.44 | 1.65 | 0.23 | 2.44 |
| | Young | 1.21 | 1.51 | 1.86 | 0.14 | 3.74 |

was lowest in pre-monsoon, post-monsoon, being mediocre. In all the cases Tukdah-78 showed highest content of total chlorophyll and Bannockburn-157 showed lowest. Among the three varieties, in mature plants in pre-monsoon and monsoon, total chlorophyll of Tukdah-78 was significantly higher than Bannockburn-157 and Phoobsering-312. In post-monsoon, the total chlorophyll content in Tukdah-78 was significantly higher than Bannockburn-157 but not than Phoobshering-312 but Bannockburn-157 showed significantly lower total chlorophyll than Tukdah-78. But in post-monsoon, the total chlorophyll content of Tukdah-78 was significantly higher than Bannockburn-157 and Phoobshering-312.

(e) Epicuticular Wax (EW)

In all the seasons, Phoobshering-312 showed highest content of epicuticular wax followed by Tukdah-78 and Bannockburn-157 (Table 20).

Table 20 : Seasonal variation of epicuticular wax (mg/g fresh wt. of leaf)

| Seasons | Plant age | Variety | | | CD P = 0.05 | CV % |
|--------------|-----------|---------|-------|-------|----------------|---------|
| | | B157 | P312 | T78 | | |
| Pre-monsoon | Mature | 0.058 | 0.074 | 0.067 | 0.005 | 4.26 |
| | Young | 0.060 | 0.075 | 0.063 | 0.009 | 5.13 |
| Monsoon | Mature | 0.031 | 0.039 | 0.031 | 0.007 | 12.35 |
| | Young | 0.033 | 0.039 | 0.033 | 0.006 | 11.44 |
| Post-monsoon | Mature | 0.052 | 0.066 | 0.058 | 0.007 | 4.55 |
| | Young | 0.049 | 0.061 | 0.056 | 0.007 | 6.75 |

Highest wax content was found in pre-monsoon and lowest in monsoon. Among the three varieties, in mature plants - in pre-monsoon,

the EW content of Tukdah 78 and Phoobshering 312 did not differ significantly but Bannockburn 157 showed significantly lower EW than Phoobshering 312. In monsoon and post-monsoon, Phoobshering 312 showed significantly higher accumulation of EW compared to Bannockburn 157 and Tukdah 78. While in pre-monsoon, there was no significant difference in EW content of different varieties. In post-monsoon, the EW content of Phoobshering 312 was significantly higher than Bannockburn 157 but not than Tukdah 78.

D I S C U S S I O N

Climate sets limits for crop production. The main climatic elements in agriculture are temperature, moisture, sunlight and wind. All crops have certain natural threshold limits of the climatic elements beyond which they do not grow normally. Plant growth is dependent upon all the factors that make up the environment. No particular level of one factor should be referred to as the optimum for growth of a species without specifying at least the approximate levels or conditions of the other important components of the environment (Griffiths, 1976). Characteristics of the plant or genotype, affect the way in which a crop will react to the environment. Many agricultural experiments are carried out that yield results of limited value because no consideration is given to important aspects of the environment, or no attempt is made to understand the interacting effect of culture method on yield (Williams and Joseph, 1976). The environment is of greatest importance in the life of the plant in as much as it is the cause of continuous response. Thus the plant places itself in specific position in relation to gravity and incident light and it continuously adjusts itself to water supply and light intensity through stomatal movements, readjustment of its chloroplasts etc. The same plant may exhibit very different behaviour in different environment (Went and Sheps, 1969). The external factors which influence the rate and efficiency of photosynthesis are light, temperature, humidity and carbon dioxide (Steward, 1960). Moyer (1965) referred that photosynthesis is influenced by all the environmental factors viz. temperature, moisture supply, relative humidity of the air, age of the leaf etc. Acclimation of plants to different light environments have profound influences on the structure and function of photosynthetic apparatus (Anderson and Osmond, 1987; Anderson et al., 1988). The main climatic variables influencing rates of shoot extension and yield of tea are temperature, rainfall, evaporation and the saturation deficit of the air and through their influence on plant and soil water deficits (Carr, 1972; Squire and Callandar, 1981; Stephens and Carr, 1990). Eden (1976) felt that it is difficult to specify the

ideal or the average climate that tea requires.

Temperature is a major factor for growth (Williams and Joseph, 1976). In temperate and subtropical regions of the earth, temperature constitutes a major limiting factor in crop production; in particular the low temperature which occurs in winter and early spring. On the other hand, in the humid tropical zone, it is very unlikely that temperature alone is ever a serious limiting factor in crop production. There are, however, special situation within the tropics in which temperature becomes important namely the cultivation in high altitude areas (Williams and Joseph, 1976). Carr (1985) suggested that even small variations (approximately 1°C) in air temperature can have pronounced effect on shoot extension rates. In general, mean minimum temperatures below 13°C are likely to bring about damage to the foliage and retardation of growth : Mean maximum temperature about 30°C are likely to be accompanied by humidities so low that a similar cessation of active development is inevitable (Eden, 1976). Because plants are not able to regulate their temperature effectively, their distribution, both on a worldwide and smaller ecological scale is strongly influenced by ambient temperature. Every plant has a optimal temperature for growth, and upper and lower limits, beyond which all growth stops. Because temperature effects metabolism, it also influences growth (Sutcliffe, 1977). It is interesting that temperature of tea is not very location specific, but it may vary genetically between cultivars under comparable conditions of growing (Banerjee, 1993). Tea exhibits a wide range of temperature tolerance and is cultivated from the humid equatorial regions to subtropical and temperature latitudes. High altitudes in the tropics and subtropics are also commonly cultivated with tea. Huang Shoubo (1989) reported that in China, optimum temperature of most tea varieties is in the range of 20-30°C. Hadfield (1976) found maximum CO₂ uptake at 30-35°C. Carr and Stephens (1992) noticed that rate of net photosynthesis falls off beyond 35°C. Temperature effects on leaf expansion often appear to be due to reduced cell expansion (Williams and Joseph, 1976). Effect of low temperature on plant growth is a reduction

in apical dominance and this seems to apply to temperate species as well as tropical species (Evans et al., 1964). Translocation of assimilates is also reported to be reduced by low temperature (Humphries, 1963), and this may be expected to affect photosynthesis through the accumulation of photosynthates at the primary reaction centres. A further general effect of low temperature in both tropical and temperate plants appears to be a change in the distribution of photosynthate between shoots and roots, the roots receiving proportionately more assimilates (Dobson, 1962; Evans et al., 1964). Barbora (1994) inferred that photosynthetic response to temperature was mainly due to change in mesophyll activity rather than stomatal conduct. Steward (1960) referred that temperature limits for photosynthesis in the intact cell are given on the one hand by the damage of essential structure due to disruptive crystal formation and on the other hand by heat denaturation of enzymes and structural proteins. But, according to Rosenberg (1974), the photosynthetic reaction is not strongly affected by the ambient temperature, as long as lethally high or low temperatures are not encountered.

In the present study, in April (summer) at higher air temperature (approx. 26°C), the rate of net photosynthesis was lowest. On the other hand, during June and August (monsoon), although the temperature was even higher than that of April, the rate of net photosynthesis ^{was} considerably higher than that of April (Figs. 18 & 19). During April, the light intensity was very high but during monsoon, the intensity was low. This result confirms the finding of Roberts and Whitehouse (1976) that at low light intensities, the photosynthetic rate is independent of temperature but at higher light intensities photosynthesis is affected by temperature. On the other hand, reduction in the rate of net photosynthesis in February (winter) is the result of low temperature encountered by the plants - when the soil moisture content was lowest and atmospheric humidity and light intensity were also low.

Leaf temperature is the passive outcome of the heat and mass exchange (Thom, 1975; Bött, 1983). Leaf temperature directly affects plant metabolic activities. Singh and Sahay (1992) observed that leaf

temperature above 35°C is too critical for photosynthesis. According to Carr and Stephens (1992) minimum leaf temperature necessary to initiate shoot extension is apparently 12°C and at leaf temperatures above 35°C, the rate of photosynthesis falls off quickly. McWilliam (1988) referred that the genotypes with the warmest leaves under water stress conditions are most resistant to drought than cool leaved genotypes.

In the present study, leaf temperature was found to have profound effect on the rate of net photosynthesis, there was sharp decline in net photosynthesis at higher leaf temperature. As reported by Singh and Sahay (1992), in the present study also, highest leaf temperature was observed under drought stress. Among the clones Phooobshering-312 showed highest leaf temperature during water stress period.

Light affects crop growth and production both through its use in photosynthesis and through photoperiodic reactions. Two aspects of photosynthetic light are of interest in studying crop production; the total amount of incoming light which is suitable for photosynthesis and the amount of light which is available to or can be utilized by the crop (Williams and Joseph, 1976). Moyer (1965) has reported that light intensity is one of the primary external parameters which control photosynthesis. Went and Sheps (1969) considered light as one of the most important parameters for photosynthesis because of its vital role as energy producer.

In the present study, high light intensity was to be a limiting factor only at high temperature and low atmospheric humidity. But when moisture was adequate, there was limiting effect of high light intensity. But at low intensity of light, the rate of net photosynthesis was reduced, although the moisture content and air temperature was quite high. Murty (1988) pointed out that reduction in photosynthesis under low light could be attributed to high stomatal resistance to CO₂ exchange. Voleti et al. (1991) reported that under low light, reduction in photosynthesis occurred, on the other hand, there is abundant

evidence that photosynthesis is inhibited due to high light intensity (Balasimha et al., 1991). Similarly, Chapman et al. (1988) observed that exposure of plants to high light intensities can reduce photosynthesis.

Humidity is of importance in tea physiology primarily because of its influence in determining the loss of moisture by evapotranspiration (Banerjee, 1993). The success of tea in high altitude sites partly appears to be related to the crops requirement for high moisture levels (Williams and Joseph, 1976). Kramer (1959) enlightened that water is an essential constituent of active protoplasm and is a reagent or reactant in various physiological processes including photosynthesis. According to Rosenberg et al. (1983) only 1% of the available liquid water taken by plants is actually involved in metabolic activities.

In the present study, low relative humidity was found to be the most important weather parameter in reducing the rate of net photosynthesis. In the month of April - air temperature, photosynthetic photon flux density, sunshine hour, wind velocity and soil temperature were very high but lowest was the rate of net photosynthesis, transpiration, stomatal conductance and leaf water potential. This is mainly because of lowest relative humidity and very low soil moisture. But present study has revealed that more than soil moisture, atmospheric humidity is important for physiological activity of the tea plants. Because soil moisture was very low in February too but the rate of net photosynthesis, stomatal conductance, transpiration etc. were higher than that of April. On the other hand, very high humidity also was found to affect the rate of net photosynthesis during monsoon. During post-monsoon, when the percentage of relative humidity was moderate, very high rate of net photosynthesis, stomatal conductance and transpiration was observed.

Many authors have referred that moisture is one of the most important parameters for physiological activity and growth of plants. It

had also been reported by various workers that low moisture is a limiting factor for physiological activity. Reduction of the photosynthetic rate as a result of moisture stress is well documented (Fry and Walker, 1964; Harris, 1973; Hsiao, 1973; Bielorai and Hopmans, 1975; Ackerson et al., 1977; Sung and Krieg, 1979; Ephrath et al., 1990). Kramer (1959) believed that reduction in water content usually reduces the rate of photosynthesis both because dehydrated protoplasm is less effective and because stomatal closure reduces the supply of CO₂. Slatyer (1973) reported that decrease in photosynthesis at high values of stress may be due to stomatal closure. Hutmacher and Krieg; (1983) commented that inhibition of photosynthesis by water stress may be attributed to both stomatal and non-stomatal factors depending on particular environmental conditions. Barbora (1994) inferred that water stress reduces photosynthesis due to stomatal closure. Munns and Pearson (1974) demonstrated that drought-induced reduction in translocation was proportional to the decline in photosynthesis because the amount of water actually needed for the photosynthetic process would be very little in comparison with the amount needed to maintain the living plant. Therefore, since long a deficiency of the supply of water actually needed for the photosynthesis in a direct manner, the indirect effects of a shortage of water could impair vital processes of the biological mechanism retarding photosynthesis (Devlin, 1978). Rosenberg (1974) reported that a shortage of soil water or atmospheric water stress on the plant will affect the efficiency of the photosynthetic reaction.

The role of atmospheric moisture (relative humidity), exclusively has been found to influence the physiological processes to a greater extent. Reduction in atmospheric humidity generally inhibit photosynthesis particularly when the availability of soil water is low (Schulze and Hall, 1982; Schulze, 1986; Korner and Diemer, 1987). Rosenberg (1974) reported that high atmospheric stress are expected to reduce photosynthesis probably by causing rapid evaporation from guard cells and causing stomata to close. Murthy (1995) remarked that tea

bushes are benefitted by high atmospheric humidity. He added that low humidity affects the physiological activities adversely by influencing the cell sap concentration. Mavi (1994) reported that water stress in the plant directly reduces the rate of photosynthesis because the dehydrated protoplasm has a lower photosynthetic capacity.

Many authors have reported that irrigation plays an important role in combating moisture stress (Ali-Zade, 1950; Petinov, 1961). Stocker et al. (1954) suggested that strategic sprinkler of crops by overhead irrigation may be superior in terms of water used than furrow or ground irrigation. Fordham (1969) reported that internal water stress is reduced by ground irrigation but it does not have any lasting effect on temperature and vapour pressure of the atmosphere except for the short periods when water is actually being applied overhead. Lebedev (1962) reported that intermittent sprinkling of water was found to reduce temperature and increase humidity around tea bushes in Russia. An experiment conducted in Malawi showed that misting the tea in hot dry months removed adverse effects of dry air and allowed shoots to grow at the same rate as shoots growing at the same mean effective daily temperature in the rainy season (Tanton, 1982b).

In February, although the soil moisture was very low, relative humidity was higher than that of April. Subsequently, the rate of net photosynthesis was higher in February compared to April. The reason may be attributed to dew fall and foggy conditions prevailed during February. Griffiths (1976) reported that dew can be the source of important, although small amount of moisture. Went (1955) reported that water may also become available to plants as fog. Water which may not be measurable in conventional rain gauges becomes apparent as fog in forests.

Ranerjee (1993) reported that wind turbulence could be useful in reducing high temperatures which otherwise would adversely affect photosynthesis. However, direct effect of wind speed on physiology of growth and productivity of tea are not known. Mavi (1994) could not observe any positive correlation between the speed of wind and

photosynthesis. Kramer (1959) reported that wind usually causes increased transpiration because it removes water vapour from the vicinity of transpiring surfaces and produces a steeper vapour pressure gradient from plant tissue to air, but it also tends to cool leaves, thereby decreasing the steepness of the vapour pressure gradient. Williams and Joseph (1976) reported that air movement is an essential feature for plant growth. Rather low velocities of air movement, however, would be sufficient to ensure adequate air renewal at the leaf surface. In relatively still air, a linear relationship between net photosynthesis and the wind velocity can be established (Rosenberg, 1974). The present study reveals that high wind velocity does not always increase the rate of transpiration. In April (summer) when wind velocity was very high, the stomata was closed due to moisture stress, wind velocity had virtually no effect in raising the transpiration. Williams and Joseph (1976) reported that wind increases transpiration so that water deficits are liable to occur sooner and stomatal closure may then reduce photosynthesis. Secondly, renewal of air at the leaf surface will maintain the CO_2 concentration around the leaf at normal levels under conditions of rapid CO_2 uptake. With limiting moisture, wind may be expected to reduce photosynthesis, on the other hand, with a favourable moisture balance for the plant, wind is likely to increase photosynthesis.

In the present study, the rate of stomatal conductance increased and resistance decreased during droughty condition. No significant difference in stomatal resistance among the clone could be observed. Very little effect could be seen on stomatal conductance and resistance due to difference in age. Vankeulen (1981) suggested that photosynthesis controls stomatal conductance. With slowly imposed water stress, it may be the effect of water deficit in reducing net photosynthesis, that reduces stomatal conductance (Osmond et al., 1980). Fuentes and King (1989) observed leaf photosynthesis increased with increasing leaf conductance. Similar results were observed in the present study. Bansal and Nagarajan (1986) and Rao et al. (1988) reported reduction in

stomatal conductance due to water stress. Rajasekar et al. (1991) reported that higher stomatal resistance could affect gaseous exchange and consequently the rate of photosynthesis. Jones (1973) and Boyer (1976) referred that stomatal resistance is the principal limitation to photosynthetic CO₂. Gupta (1992) commented that high stomatal resistance in plants would be advantageous in water economy and drought resistance. Several scientists have attempted to select plant with high stomatal resistance (Miskin et al., 1972; Wilson, 1972). Rao et al. (1988) observed that stomatal resistance increased under water stress condition. Handique and Manivel (1990) also reported similar finding. Ephrath et al. (1990) found that stomatal resistance increased and photosynthetic rate decreased as a result of moisture stress. Coinciding with the finding of Rajkumar et al. (1993) no significant difference in stomatal resistance among the clone could be observed. Yang et al. (1990) found no significant relations between stomatal resistance and climatic variables. Finding of this study does not subscribe to the finding of Yang et al. (1990).

Reduced transpiration under water stress was also observed in this study. Studies showed that transpiration rate is directly proportional to plant production (Shih, 1985; Watts and Gotts, 1985). Fry and Walker (1964) found decrease in transpiration rate with increase in stress. Barry and Chorley (1968) reported that transpiration is controlled by the atmospheric factors which determine evaporation as well as by plant factors such as stage of plant growth, leaf area, leaf temperatures and soil moisture. He also reported that transpiration varies greatly with season. Blum and Sullivan (1986) reported that transpiration ratio under stress are lower for resistance than for sensitive genotype.

Crafts (1968) reported that decreasing water potential in leaves is known to reduce photosynthesis. Slavik (1965) pointed out that this is the result of three effects : (i) hydroactive closing of stomata

bringing about a reduced CO₂ supply, (ii) water stress in cytoplasmic ultrastructure affecting enzyme activity and (iii) dehydration of cuticle epidermal walls and cell membranes, reducing their activity for and permeability of CO₂. Rocha Neto et al. (1983) and Conceicao (1985) observed that photosynthesis decreased with low leaf water potential. Handique and Manivel (1986) inferred that drought tolerant clones consistently exhibited higher water potential. Parameshwara et al. (1988) found water stress lower the water potential values, but water potential of cold-stressed plants was not altered at all. Bunce (1990) observed that leaf water potential was lower when photosynthesis was reduced. Manivel and Handique (1983) inferred that there was no significant difference in water potential between the ages of plants. It has been established for a long time that low water potential causes metabolic imbalances within plants, cell elongation being one of the most sensitive portion (Slatyer, 1967; Hsiao and Acevado, 1975). Rao et al. (1988) reported that water potential decreased under water stress condition. In the present study also it was found that water stress reduced leaf water potential. Net photosynthesis decreased with low leaf water potential. Bannockburn 157 showed higher leaf water potential, hence, as per the inference of Handique and Manivel (1986), this clone can be termed as a drought tolerant clone. Coinciding with the findings of Manivel and Hnadique (1983), no difference in leaf water potential could be seen due to difference in age.

One of the major environmental factors to which plant responds, is mineral nutrition. Plant nutrition has been defined as the supply and absorption of chemical elements necessary for growth and metabolism. In the present study, among all the macro- and micro-nutrient sprayed on the young tea plants, phosphorus spray was found to be an excellent elevator of net photosynthesis. As a result of this, there was remarkable improvement of the girth and height of the plants (Fig. 41). Mann and Gokhale (1960) reported that phosphorus plays a major role in the growth of tea plants. Phosphorus plays a key role in DNA synthesis and indispensable for growth (Verma, 1993). Enhancement of leaf

photosynthesis by phosphate application was consistently related to non-stomatal factors as indicated by changes in the intercellular CO₂ concentration (Didier and El-Sharkawy, 1993). Phosphorus stress can limit photosynthesis when CO₂ and irradiance are saturating; possibly due to disruption of the leaf sugar partitioning and transport system (Pettigrew et al., 1990).

Sulphur spray was also found to be effective in improving the rate of net photosynthesis. Many authors have described the efficacy of sulphur in promoting physiological activities. Barua (1989) considered sulphur as an essential element for the growth of tea. Bhat and Ranganathan (1981) also reported that sulphur is an essential element for growth and productivity of tea plants. Sulphur is directly involved in the light reactions of photosynthesis and its deficiency reduces photosynthetic rates (Moyer, 1965).

As far role of potassium is concerned, it is said to promote the synthesis of ribulose biphosphate carboxylase, which in turn affects the rate of CO₂ assimilation. Potassium is important in the transport of newly formed and stored photosynthates (Shuman, 1994). Potassium fertilizers have been observed to increase the tolerance of tea plants to water stress (Barua, 1989). Plants with adequate potassium, lose less moisture because of the reduced transpiration rate. Potassium reduces transpiration through regulation of factors like leaf water potential, stomatal resistance etc. (Saikia and Dey, 1978). But in the present study, the role of potassium as a reducer of transpiration could not be established.

In the present study, zinc was not found to be useful in improving the growth of plants in the very early stage of life, although many authors reported very positive role of zinc. Sultana et al. (1978) reported that zinc is considered to be an essential for tea. Barbora et

al. (1993) reported that stomatal conductance and net photosynthesis are adversely affected by inadequate zinc.

However, the role of molybdenum in improving the physiological activities of young nursery tea plants could not be established in the present study, although it was found to be better than potassium and zinc spray.

In the present study, huge accumulation of free amino acid during water stress (pre-monsoon) is pronounced. Lowest content of free amino acid was observed in monsoon which indicates that when moisture is abundant the content of free amino acid is reduced. During drought there was 3.5, 3.5 and 2.6 times increase in the mean content of free amino acid in respect of Bannockburn-157, Phoobshering-312 and Tukdah-78, respectively in comparison to monsoon. In post-monsoon when optimum weather condition prevails as regards to atmospheric and soil moisture, the content of free amino acid attains a mediocre position. Among the three varieties studied Tukdah-78 which showed the highest content of free amino acid can be considered as a clone which can withstand physiological stress to a greater extent. Kathju et al. (1988) reported that water stress resulted in higher accumulation of free amino acids. Draper (1975) had also reported similar kind of finding. Levitt (1980) reported that even in the highly drought resistant creosote bush, total amino acid content more than doubled under moisture stress.

As far as proline content is concerned in the present study, proline raised considerably during droughty condition. This finding confirms the results obtained by various authors. Lowest content was found during monsoon. In drought, there was 4.4, 3.4 and 2.7 per cent increase in the mean content of proline in respect of Bannockburn-157, Phoobshering-312 and Tukdah-78 respectively in comparison to monsoon. Bannockburn-157 exhibited highest accumulation of proline during water stress period closely followed by Tukdah-78. Phoobshering-312 showed the lowest content.

Rajkumar et al. (1993) reported significantly high accumulation of proline content in tea leaves during moisture stress. Stewart (1973) reported that wilting causes a decrease in proline utilization by decreasing protein synthesis. Hanson et al. (1977) referred that proline accumulation is a sign of drought injury. Kathju et al. (1988) reported water stress resulted in higher accumulation of free proline. Jagtap et al. (1992) observed that water stress treatments with short spells significantly increased proline accumulation. Handique and Manivel (1990) observed higher quantity of proline in the leaves of drought tolerant clones. Accumulation of free proline in leaves due to stress in all the genotypes was observed by Bansal and Nagarajan (1986). Biswas and Chaudhuri (1986) observed that proline accumulates dramatically in water deficit stressed plants. Kathiresan (1987) also confirmed proline accumulation in plant, subjected to water stress. However, no relationship between accumulation of proline and drought was observed in wheat and soyabean (Sinha and Rajagopal, 1977; Guo et al., 1988).

In the present study, the content of ascorbic acid was low during monsoon but the accumulation of ascorbic acid during pre- and post-monsoon was almost at par. As a whole there was no high intensity fluctuations in the content of ascorbic acid owing to seasonal variations. These denoted that environmental factors do not influence the content of ascorbic acid in tea clones in this area in a big way. Jain (1994) has reported that ascorbic acid may function as a catalyst in photosynthetic phosphorylation. Devay (1965) concluded that since ascorbic acid is a co-factor for the enzyme glutathion reductase, new enzymes are synthesized at the low temperature which lead to an increase in the tissue content of ascorbic acid. Levitt (1980) reported increase in ascorbic acid due to water stress.

It was observed in this study that content of total chlorophyll went up considerably during monsoon and came down to lowest during water stress period. During monsoon, the chlorophyll content elevated 1.6, 1.5 and 1.6 times in respect of Bannockburn-157, Phoobshering-312, Tukdah-78

respectively in comparison to the content during drought stress. Chlorophyll content obtained mediocre position when moisture content was average. Lewandowska and Jarvis (1977) feel that photosynthetic efficiency of a crop may be indicated by the amount of chlorophyll. Rajasekar et al. (1991) reported that water stress leads to a decline in total chlorophyll in all the clones they studied. Biswas and Chaudhury (1986) and Jagtap et al. (1992) also reported similar finding. Reduced ability to form protochlorophyll was considered to be responsible for the inhibition of the development of chlorophyll under moisture stress (Hsiao, 1973). While Buttery and Buzzel (1977) and Antoszewski et al. (1989) reported high correlation of photosynthetic rate with chlorophyll content, Barman et al. (1993) could not find any direct correlation of that sort. Rajkumar et al. (1993) found no relationship between the amount of chlorophyll content and the photosynthesis of mature tea leaves. In the present study too, no perfect relation could be seen.

An enormous increase in epicuticular wax content was found during moisture stress period. Lowest content was noticed when moisture supply was abundant. The content of wax almost doubled in pre-monsoon (water stress period) in comparison to monsoon. Phoobshering-312 which showed highest content of epicuticular wax in all the seasons, can be considered as a suitable clone which can help in combating drought by reflecting the maximum quantum of solar insolation. Baker (1974) and Bengston et al. (1978) reported that water deficit increases the content of epicuticular wax in the plant. Many other authors have also reported high accumulation of epicuticular wax owing to water stress (Rajasekar, 1991; Voleti and Rajasekar, 1991; Rustogi and Barman, 1993). Premachandra et al. (1991) also observed leaf surface wax content increased with degrees of stress. Handique and Manivel (1990) who reported high quantity of wax in drought tolerant clones, suggested that deposition of wax may be correlated with reduction in transpiration rate and increase in stomatal resistance. Ziyad Mohammed et al. (1986) found higher content of wax in the drought resistant clones compared to drought susceptible clones. Excessive deposition of epicuticular wax in

Sorghum was found to increase leaf reflectance of visible and near infra-red radiation (Blum, 1975a), decrease net radiation in the field and decrease transpiration (Blum, 1975b). Ebercon et al. (1977) considered epicuticular wax as an effective component of drought resistance.

During the period of moisture stress, the content of total free amino acid, proline, epicuticular wax increased considerably, lowest content was found in monsoon. Although slight increase in the content of ascorbic acid was noticed in pre-monsoon, the overall data does not indicate high range of fluctuations in the content of ascorbic acid due to seasonal variation. Chlorophyll content increased during monsoon and decreased during moisture stress. Tukdah-78 showed highest content of total chlorophyll and free amino acid, while Phoobshe ring -312 showed high amount of epicuticular wax throughout the year. During drought the proline content of Bannockburn-157 was higher.

S U M M A R Y

The production of Darjeeling tea is almost constant i.e. 12-13 million kg. ha⁻¹ for the last 20 years. Many works were carried out in Darjeeling to find ways to enhance crop yield, combat the crop loss due to pest problems or improper management of soil nutrients. But there was hardly any progress in the eco-physiological studies in the hilly tea gardens of Darjeeling. Recently, it has been emphasised by eminent scientists that a major portion of the crop loss accrues, owing to physiological problems. Hence, it was endeavoured to study the physiological status of three major tea genotypes of Darjeeling under varied weather conditions at different seasons of a year. Apart from crop-weather interactions, the relations between various physiological parameters were also studied. Seasonal variations of anatomical and biochemical characteristics in tea plants were another aspects of this study. In addition, the role of few macro- and micro-nutrients in influencing physiological activities of tea plants was also studied meticulously. A gist of major findings of these experiments is listed below :

1. During drought stress most of the physiological characters viz. net photosynthesis, stomatal conductance, stomatal resistance, transpiration, leaf water potential are remarkably influenced by moisture deficit. Net photosynthesis, stomatal conductance, transpiration and leaf water potential were lowest during water stress while stomatal resistance was found to be highest. In droughty condition - the moisture stress, more specifically, atmospheric moisture stress was found to be the most promising limiting factor. Because during that period - temperature, sunshine hour and wind run were favourable. High-light intensity might also have limited the physiological activities, to some extent, because there are reports that under moisture stress, high-light intensity may retard the physiological processes.

2. Atmospheric moisture stress was found to play a more important role than soil moisture under droughty condition. Because in February (winter), soil moisture was found to be lowest but the physiological parameters viz. net photosynthesis, stomatal conductance, transpiration, leaf water potential showed higher values compared to April. The reason is that during February, the percentage of atmospheric moisture was higher than that of April, owing to foggy condition and dew fall. There are reports that fog and dew quenches the water requirement of plant to a considerable extent. In April, excessive evaporation from guard cells might have affected stomatal closure.
3. High percentage of moisture, heavy rainfall, low light intensity, low sunshine hour were found to limit the physiological processes. During June and August (Monsoon), the rate of net photosynthesis was lower than that of October and December (Post-monsoon) because of the aforesaid factors. Although in June and August - the air and soil temperatures were high, it could not influence the rate of net photosynthesis in positive direction.
4. Low temperature was another limiting factor for net photosynthesis. During winter, the rate of net photosynthesis was lower than monsoon and post-monsoon because of low temperature and of course, low moisture content.
5. The post-monsoon season was found to be most conducive for physiological activity. It showed high rate of net photosynthesis, transpiration, stomatal conductance etc. During post-monsoon, the light intensity was high, temperature was moderate, soil and atmospheric moisture were moderate, wind velocity was also moderate. This denotes that neither too high nor too low range of temperature, moisture, wind, sunshine hour etc. is suitable for optimum growth.

6. High-light intensity was not found to be a limiting factor as long as moisture content was adequate. During October, the light intensity was highest, while the rate of net photosynthesis, stomatal conductance and transpiration was also highest.
7. In terms with net photosynthesis - stomatal conductance and transpiration showed strong positive correlation. While weak positive correlation was found, with leaf water potential. On the other hand, net photosynthesis showed strong negative correlation with stomatal resistance and weak correlation with leaf temperature.
8. Among the three clones, Bannockburn-157 was found to have higher rate of net photosynthesis in most part of the year, while Tukdah-78 showed lowest rate. Under moisture stress, Bannockburn-157 exhibited lowest rate of net photosynthesis.
9. Bannockburn-157 showed high rate of leaf water potential throughout the year while the leaf water potential of Tukdah-78 was the lowest.
10. Although stomatal conductance, transpiration and leaf temperature showed seasonal variations, there was no marked difference among the three clonal varieties in respect of those parameters.
11. Difference in age of 5 years between the mature and young plants did not have any significant effect on any physiological parameters.
12. Foliar spray of phosphorus and sulphur on the potted young plants was found to increase the rate of net photosynthesis, girth and height of plants significantly compared to molybdenum, zinc and potassium spray. But the effect of nutrient spray of stomatal conductance and transpiration was inconsistent.

13. Under moisture stress - total free amino acid, free proline and epicuticular wax content showed enormous increase while there was marginal increase in the content of ascorbic acid. On the other hand, total chlorophyll content went down sharply during drought. During the rainy season just the reverse things happened.
14. Tukdah-78 showed highest content of total free amino acid and total chlorophyll content in all the three seasons studied, while Phoobshearing-12 showed highest content of epicuticular wax.
15. Under moisture stress, Bannockburn-157 showed highest content of proline, while in monsoon Tukdah-78 showed highest accumulation. During post-monsoon, there was no significant difference in the proline content of the three varieties.
16. The seasonal variation of ascorbic acid could not be ascertained, there was only marginal rise during drought.

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