

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 CO_2 concentration, increases with temperature, (ii) if excessive accumulation of CO_2 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 Nothdurf, 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).