CHAPTER 5

GENERAL DISCUSSION
The tea plant \textit{Camellia sinensis (L) O. Kuntze} is a perennial mesophyte. It requires soil condition, neither with too excess nor with too deficit in water for its maximum growth and productivity. Under natural conditions, the maximum potential of horticultural and agronomic crops is seldom attained, because of the limitations on morphological, physiological and metabolic processes imposed by environmental stresses, mainly drought and waterlogging (Krizek 1981, 1984, Stavarek and Rains 1984).

Water stress develops either as a result of limited water supply to the soil, or, due to excess soil water that reduces oxygen availability and increases anaerobic toxins—thus causing reversible or irreversible changes to the plant systems (Kaufman 1981, Syvertsen 1985). Harmful effects of water stress on the physiology and biochemistry of plants have been increasingly documented (Kozlowski 1976, Hook and Crawford 1978, Brouwer and Wiersum 1978, Mussell and Staples 1979, Turner and Kramer 1981). In a comparison of the two forms of water stress, namely drought and waterlogging, the single most important factor limiting productivity and crop yield on a world-wide basis is drought (Hanam 1972, Turner and Kramer 1981).
The knowledge of plant-water interactions with atmospheric and edaphic conditions is of paramount importance for execution of the plant improvement programmes in general and for improving plants' adaptation to water stress in particular. To varying degree, the responses of the tea plant to water stress, as a whole, can be expressed at four levels: (a) Developmental or anatomical, (b) Morphological or structural, (c) Physiological, and (d) Metabolic or biochemical.

The morphological responses of the tea plant to water stress can be judged from its effects on various components of growth. From our studies, it has been noticed that both deficits and excess of water in the soil medium, induced considerable effects on growth performances of leaf, stem, and root. The inhibition of leaf growth in tea as a result of water stress was reflected in the observed reduction of leaf blade thickness, leaf area, and number of new leaves formed. The reduction in total leaf area in response to water stress could be attributed to the reduced area and number of new leaves formed, accompanied by simultaneous increase in leaf dropping. At first, the physiologically older leaves were shed, which might be due to accelerated senescence induced by water stress. Secondly, even the relatively younger leaves were also shed, which might be attributed to the hastening in the formation of abscission layer. This effective reduction in total leaf area due to water stress may decrease the leaf area index and may be accountable for reduction in total dry
matter production via photosynthesis by the plant. Thus, water stress has often been considered to reduce photosynthesis and growth mainly by reducing leaf area and stomatal opening (Slatyer 1971). Low leaf water potential and loss of turgor below a certain threshold value under water stress condition are attributed to a reduction in leaf initiation, cell enlargement and division and hence reduced leaf area (Boyer 1968, Green et al. 1971, Kirkham et al. 1972). The increase in leaf area by increased production of leaves by crops is important, because it represents higher photosynthetic area for productivity. Hence, the reduction in leaf area may be one of the main causes for frequently reported crop suppression under situations of drought and waterlogging in tea.

As in other plants, the first visible symptom in the tea plant caused by water stress is leaf wilting. Wilting was eventually accompanied by leaf drooping to various degrees, depending upon the intensity of stress. The failure of turgor maintenance due to imbalance between absorption and loss of water, resulted in the progressive changes in the leaf angles in both drought and waterlogged conditions in tea. Leaf rolling and orientation following inception of wilting may be one of the plants' inherent strategies to reduce radiation load and may, at least to some extent, be attributable to decreasing transpiration rate. Wilting and rolling of leaves have some important biological implications on plant growth processes. The stomata usually close during early stages of
water stress, often long before visible wilting occurs and remain closed during continued drought (Kozlowski 1972).

Both drought as well as waterlogging inhibited apical, lateral as well as radial growth of the stems in tea. This reduction in extension growth of the stem together with inhibited leaf growth may account for the decrease in total dry matter production and yield of the over ground parts of the tea plant during periods of water stress. It is an established fact that apical, radial and reproductive growth of shoot in a tree is highly correlated with environmental water stress (Zahner 1968). Since, the harvestable material in tea constitutes a small proportion of growth and the components of yield are the rate of growth of shoots, the size and weight of shoots at harvest and the number of shoots per unit area of plucking table (Squire and Callander 1981), the normal growth of the over ground parts in general and that of the shoots in particular is very important in order to sustain higher yield. The size and number of shoots are the main components of yield. Differences in yield between clones and seedling varieties in tea are largely caused by the differences in the number and size of the developing shoots (Toyao 1965, Amma 1971).

Under pot-study conditions, water stress inhibited root growth in tea, which could be seen from the observed reduction in depth and volume of the root system, depth of
the effective root zone and the number of primary roots. However, under field conditions, the pattern of root growth differs. Under condition of drought, roots tend to go deeper into the soil in search of water, because in the surface soil water becomes sparsely available to the roots. On the other hand, under waterlogged situation, the root growth becomes stunted and slow and the proliferation of the roots tend to be limited on the surface layer of the soil. In severe cases, the main roots tend to move upwards probably in search of oxygen, because oxygen availability is the main limiting factor for growth in waterlogged soil.

For good root growth, tea soil should be deep and well drained. A high ground water table impedes aeration and root growth, resulting into a shallow root system, a shortage of nitrogen and thus a poor yield; and during the dry season only a limited amount of water can be stored in the shallow root zone and the crop suffers from drought (Vander Laan 1971). However, the waterstress-induced reduction in root growth observed in tea, is important from the view point of maintaining optimum root: shoot ratio for proper growth of the tea plant.

Root and shoot growth are interrelated, since the stress which limits shoot activity, can induce a decrease or cessation of shoot growth (Hogd-kinson and Becking 1971). As an approximation, the root:shoot ratio is often used to
estimate relative absorption - transpiration capacities (Pallardy 1981). In tea, it was observed that root:shoot ratio was increased under water stress conditions. However, as compared to drought, it was observed to be reduced in waterlogged condition. This indicates that under soil moisture deficits, although the shoot growth was suppressed, the root growth was favoured. But in case of waterlogging, the extent in both the cases of root and shoot growth was relatively less. Under waterlogged condition, there was more inhibition of root growth as compared to drought. Because, in addition to stress resulted from water excess under waterlogged situations, the roots are exposed to the toxic substances released from the anaerobic condition of the root zone. Limitation of root growth causes reduction in total absorbing surface of the plant and thus disrupts the uptake of nutrients and water to the plant body.

The water balance of plants depends not only upon leaf characteristics that may influence loss of water, but also on attributes of the stems and roots which influence water uptake, transport and storage (Doley 1981). The reduction in the leaf blade thickness resulting from shrinkage caused by internal plant water stress, was associated with the observed reduction in the thickness of palisade and spongy parenchyma, area of xylem and phloem and xylem : phloem ratio in the leaf mid-rib and volume and area of vascular elements in the leaf petiole. It has also been noticed
that the area of xylem and phloem, xylem : phloem ratio in stem and root sections were found to be significantly reduced in both drought and waterlogging. The extent of reduction was more under waterlogged condition than under drought. Further, the roots were more affected compared to stem, so far as the vascular elements were concerned.

The leaves are the sources of energy and the factory for food manufacture for plants and the roots supply the necessary ingredients like water and nutrients in order to keep the factory running. Water is absorbed through the roots, crosses a membrane barrier at the endodermis, moves into the xylem of the roots, and then moves upwards through the xylem of the main stem, branches and petioles and finally through the vascular elements of each leaf (Hinckley et al. 1981). Zimmermann (1978) envisaged that the conductivity of the xylem supplying water to a unit mass of leaves (leaf specific conductivity) varied greatly due to variations in vessel diameter and the pattern of water flow and gradients of water potential throughout a tree crown favour the main stem in situation of severe drought. Hence, any disorders in the developmental process together with shrinkage and disruption of the vascular tissues resulting from water stress might account for commendable hindrances in the path of translocation and distribution of assimilates from leaves to different plant parts and also for water and nutrients from roots to leaves.
The significant reduction in the total volume of vascular elements in the leaf petiole in response to water stress, indicates that it may form a bottle-neck for translocation of water, nutrients and metabolites in and out of leaves. Our results show that as compared to drought, the vascular elements in all the components studied were affected more in waterlogged condition. Due to low oxygen availability, the root environment becomes anaerobic, producing toxic substances which are harmful for root growth and this may be attributable for reduction in vascular areas. Thus, our observations reveal that water stress may impose a major constraint in absorption, transport and translocation processes by impairing the xylem and phloem conduits in tea.

Water stress either directly or indirectly influences many important physiological processes in plants (Hsiao 1973, Kozlowski 1968, 1972, 1976). Significant reduction in translocation was brought about in tea by water stress imposed by drought as well as waterlogged soil conditions which could be assessed from the pattern of fixation and distribution of $^{14}$C-assimilates. With decrease in stomatal conductance, fixation of ratio active carbon was reduced significantly as compared to unstressed control plants. Thus, in tea water stress inhibited the movement of $^{14}$C-photosynthates, lowered the velocity as well as the amount of transport and simultaneously decreased the distribution of $^{14}$C-photosynthates from the fed leaves to different plant parts. In pot-
conditions, both drought as well as flood conditions caused maximum set-back to the roots as compared to the other parts of the plant body. Our results indicate that so far as the fixation of $CO_2$ and translocation of photosynthates were concerned, the performance of clone TV18, categorised as drought tolerant, was relatively better than that of the drought susceptible clone TV21 under both drought and waterlogged conditions.

Since, the long distance transport of assimilates from the site of assimilation to the point of utilization, the loading and unloading of the sieve elements, and the velocity of assimilate movement in the sieve tubes are the phenomena of translocation, an effect of water stress on any one of these processes will be apparent as an effect on overall translocation (Begg and Turner 1976). A number of workers have reported that water stress decreases translocation, fixation and distribution of metabolites (Roberts 1964, Plant and Reinhold 1965, Hartt 1967). These results lend support to our findings in tea.

The observed inhibition in the fixation of $^{14}CO_2$ in leaves caused by water stress corroborated with significant reduction in the rate of photosynthesis observed in tea. However, Wardlaw (1968) attributed the decreased translocation rate to the reduction in photosynthesis under water stress conditions. Since stomata act as regulator for $CO_2$ exchange
as well as for water loss, water stress, sufficient to close stomata must also depress photosynthesis (Begg and Turner 1976). In tea, photosynthesis was reduced when shoot water potential fell below - 4 bars and stopped when it was around - 18 bars (Squire 1977). Thus, water stress cuts off gaseous exchange and decreases photosynthesis resulting into less dry matter production in tea (Williams 1971). As a result of this, total production of green leaf declines under severe situations of water stress. The comparatively higher photosynthesis exhibited by drought tolerant clone TV18 over drought susceptible clone TV21 might probably be attributed to the maintenance of higher turgor due to higher water potential of its leaves in water stress condition (Uprety and Sirohi 1985).

The increase in stomatal diffusion resistance with simultaneous reduction in rate of transpiration in response to water stress, confirms that like other plants the stomata of the tea plant also close or tend to close depending upon the intensity and duration of drought and waterlogged conditions. Among the two clones studied, TV18 being of Cambod origin and categorised as drought tolerant, exhibited relatively higher stomatal diffusion resistance, lower transpiration rate and consequently higher leaf water potential as compared to TV21, which is a relatively non-hardy clone possessing characteristics more towards Assam jat. Higher leaf water potential observed in clone TV18 is a reflection
of higher plant water status relative to clone TV21 under identical condition of soil moisture deficits. This might be a consequence of higher stomatal diffusion resistance accompanied by lower rate of water loss. Fordham (1971b) used stomatal behaviour as physiological indicators of moisture stress in tea. He found that stomatal opening was markedly reduced in tea during the dry season, when evaporation rates were high and it was greater on unirrigated plants. Similarly, Balasimha et al. (1988) observed that drought tolerant accessions of Cacao had strong stomatal regulations under water stress conditions.

As compared to the root part, the shoot part was more severely affected by water stress, which accounted for the increased root to shoot ratio in tea. Wilting and loss of turgor resulting from water stress caused loss of fresh weight, which was reflected in increased dry weight to fresh weight ratio under conditions of water stress. Ceulemans et al. (1979) found that among Azalea spp., the difference in behaviour to water stress was greatly dependent on root : shoot ratios. Winter (1971) opined that the availability of water to a plant influences its root : shoot ratio. Doley (1981) observed that species native to arid environments often have high root : shoot ratios, because the variations in depth, capacity for lateral root extension and degree of root ramification may significantly increase soil water availability to the plants (Pallardy 1981).
Floodwater sometimes overflows the tea plantations submerging the plants under water for varying durations. Following recession of the floodwater or due to heavy downpour of rain, the soil particularly in low lying areas frequently becomes saturated with water resulting into a waterlogged condition. Under both the situations, soil air space is replaced by water, rendering the soil incapable of oxygen replenishment, because of the slow diffusion of atmospheric oxygen into the waterlogged soil. Under both the incidents of waterlogged situation, accumulation of dry matter in various components of the tea plant decreased significantly. This decrease in dry matter accumulation under such environments could be inferred from reduction in specific leaf weight.

The results reveal that the condition of the tea plant becomes critical under entirely submerged condition. Under this condition, almost all the metabolic processes probably might come to a halt, since the entire plant was brought under anaerobic condition and became physiologically suffocated. Besides this, deposition of silt particles over both leaf as well as stem surfaces may cause much post-flood damage to the plants. Since, silting obstructs the normal functioning of the stomata affecting transpiration and photosynthesis. Moreover, the deleterious effects of post-flood atmospheric conditions like rising temperature may increase the leaf temperature to a critical level via their effect on the silt particles deposited over the leaves. In addition, silting
may also serve as a harbour for fungal diseases. Under partially submerged condition, only the root zone was subjected to anaerobiosis.

Reduction in specific leaf weight observed in both drought as well as waterlogged situations indicates that the production of dry matter via photosynthesis was limited as a result of water stress. The existence of a clonal variation in specific leaf weight implies that under identical situations of water stress, certain clones could exhibit relatively better efficiency in dry matter production than others did. The major impact of reduction in dry matter production in tea under waterlogged situation may be on decrease in yield. Harler (1966) suggested that rainfall exceeding 4500 mm is associated with decrease in yield in tea which is an apparent effect of waterlogging.

In tea, the stomata closed to various degrees in response to different water stress treatments, depending upon the type of cultivars and duration and intensity of stress. Under waterlogged condition, the reduction in stomatal aperture area and perimeter was observed. Our findings reveal that certain tea clones are more sensitive to water stress than others. This differential response among different tea clones may be attributable to their differences in adaptation to conditions of drought as well as waterlogging. Thus TV1, a hardy Chinary clone, exhibited the lowest size of the stomatal pore.
in response to water stress, which is attributable to its better ability of drought tolerance. The variation in number of stomata per unit area observed in different clones and low stomatal frequency recorded in drought tolerant clone TV1, indicates that the stomatal frequency may also contribute, at least to a certain extent, for drought tolerance in tea. Carr (1971a) observed two types of tea differing in their size of stomatal apertures and responses to increases in sap tension. Water stress manifested as loss of turgidity in the stressed tissues can cause stomatal closure and decrease in transpiration and begins to remedy the cause of stress; and prolonged internal water stress must have an adverse effect on both the two aspects of yield in tea, viz. number and growth rate of shoots (Williams 1971). Probably due to stomatal closure, photosynthesis was also decreased in conditions of stress, resulting in less dry matter production. Thus decreased photosynthesis together with loss of turgor will affect the production of green leaf in tea.

Metabolic changes associated with water stress play the most important role in survival mechanism under conditions of environmental extremes and carry adaptive values, which favour the performance of the plant as a whole, during or after stress (Wyn Jones 1979, Stewart and Hanson 1980). Total chlorophyll and chlorophyll a : b ratio were reduced in water stress conditions in tea. This constitutes a very important factor in affecting the growth and yield under dry land farming.
conditions. Reduction in chlorophyll a : b ratio indicates that chlorophyll a is more sensitive to water stress than chlorophyll b in tea. Reduction in total chlorophyll, relatively to a lesser extent in clone TV1 and TRA/KP/37 shows that these two clones possess greater adaptability to waterlogged conditions as compared to the other clones studied. However, in this context it is worthy to mention that clone TV1 proved to be the best both in drought as well as in waterlogged situations in respect of the parameters studied here.

Reduction in chlorophyll content is one of several factors decreasing photosynthesis under water stress conditions and the synthesis of chlorophyll can be highly sensitive to low leaf water potentials (Hsiao 1973, Boyer 1976). Kozlowski (1976) observed strong correlation between ethylene concentration and chlorophyll break down under waterlogged situations.

The increase in the amount of total soluble sugars in leaf, stem and root of the tea plant indicates that the conversion of the simple sugars into complex carbohydrates was probably interrupted as a result of water stress. Since the seat of production of the soluble sugars is leaf, the amount observed was more in leaf and gradually it decreased towards roots while being translocated through the stem. As compared to the plants at field capacity, total starch content in tea roots was also significantly decreased under drought and
waterlogged situations. Water stress may have both qualitative and quantitative effects on plant constituents and probably the most direct effects are on carbohydrates through the inhibition of photosynthesis (Crafts 1968). In several plant species when subjected to water stress, Woodhams and Kozlowski (1954) noted the rapid conversion of starch to sugars which they attributed to high respiration in the stressed plants.

In response to soil moisture deficits, proline accumulated in leaves of several tea clones studied. On the other hand, among the clones, TV1 - a categorically drought tolerant clone exhibited relatively higher amount of proline accumulation in response to drought. Thus in tea, proline accumulation in response to soil moisture deficit may be associated with drought tolerance. Several investigators have reported that proline accumulates in leaves when subjected to drought and suggested that proline content is a measure of drought resistance (Barnett and Naylor 1966, Sing et al. 1972, Kaufmann 1972, Hurd 1976). They also observed cultivar differences in accumulation of proline associated with low water potentials. Naylor (1972) suggested that water stress leads to blockage of synthesis of some amino acids. However, too little is known about the relationship of proline to drought resistance mechanisms except its role probably in osmotic regulation.
Increased deposition of epicuticular wax content on leaf surfaces under conditions of drought may have some adaptive significance for drought tolerance in tea. Because, leaf wax provides the plants with a tool for minimizing water loss during periods of soil moisture deficits. This leads the plants to a condition of favourable plant water status and consequently delays turgor loss and wilting. The observed clonal variations and accumulation of relatively higher amount of cuticular wax content in leaves of categorically drought tolerant clones under conditions of drought provides sufficient grounds for assessing plants for drought tolerance on the basis of the amount of wax deposition. Larcher (1975) observed that during prolonged drought, the cutin and wax lamellae may further thicken, as more waxes are deposited on the leaf. Baker et al. (1975) opined that these wax deposits are ideally suited to suppress cuticular transpiration. However, the physiological reasons for deposition of epicuticular wax in response to drought is not clearly understood.

The studies on the plant water relationships of tea reveal that there exists a strong correlation among water potential, relative turgidity, stomatal diffusion resistance and transpiration rate. It also exhibited a relationship between rate of withering and leaf water content of detached leaves. Both leaf and shoot water potentials decreased when the tea plant was subjected to drought and waterlogged
conditions. However, the extent of decrease was dependent upon the intensity and duration of stress. Under conditions of drought, the decline in water potential was very quick, synchronising with the moisture status of the soil. But in case of waterlogging, the decline in water potential was not noticed for first few days. After about third week, wilting symptoms in leaves of the waterlogged plants were noticed, which could be characterised by a drop in leaf water potential. However, the expression of wilting symptoms in waterlogged plants was very slow and not as prominent as could be noticed in case of drought. It is certainly true that waterlogging causes wilting, especially if the stress is imposed rapidly and transpiration demand is high and under this situation the loss of water from the shoot exceeds the supply from the roots leading to a drop in leaf water potential and thus causes wilting (Bradford and Yang 1981). Like water potential, relative turgidity values also were reduced under drought and prolonged waterlogged situations. It has already been mentioned that the stomata close or tend to close during periods of drought and waterlogging. As a result of this, higher stomatal diffusion resistance was observed which was accompanied by lower transpiration rate.

The studies of plant water relations can give a true picture of the plant water status and becomes of paramount importance in situations where water appears to be a limiting
factor for growth. The decline in total water potential ($\Psi_{t}$) can be ascribed to dehydration. Turgor potential ($\Psi_{p}$) quickly approaches zero, and the reduction in osmotic potential ($\Psi_s$) is due principally to water loss and the resulting passive concentration of cellular solutes (Hanson and Hitz 1982). The decrease in osmotic potential must therefore be largely due to active solute accumulation or osmotic adjustment and has a major consequence—the maintenance of leaf turgor, which has broad importance in controlling cell growth and maintaining structural integrity and gas exchange capacity in leaves (Hanson and Nelsen 1980, Turner and Jones 1981). Lahiri (1978) suggested that the study of plant water relations and its related physiological processes in dry areas may help us to formulate strategies for combating the stress imposed by drought to maximise the production.

Screening and selection of cultivars that can withstand the variable moisture stress situations is an important facet in the overall crop improvement programmes of tea research. But unfortunately, there are no simple laboratory techniques readily available for screening, nor any good selection criteria at our disposal for proper exploitation in breeding for plant improvement. Consequently, still we are to depend primarily upon some empirical methods of selection, where emphasis has been given on selection of clones merely based on field performances only.
We do not know the exact physiological and biochemical basis as well as the individual factors responsible for drought tolerance in tea. Hence in our studies, an attempt has been made to evaluate certain indices that can be used as selection criteria for drought tolerance in tea. The assessment of the parameters evaluated in relation to drought tolerance was based on comparisons between categorically existing drought tolerant and drought susceptible cultivars at Tocklai Experimental Station.

Lack of water has been a major selective force in plant evaluation and ability to cope with water deficits is an important determinant for crop distribution and productivity (Fischer and Turner 1978). Accordingly, an understanding of the mechanisms that confer adaptation to dry environments holds much theoretical and practical values (Hanson and Hitz 1982). While plants must passively withstand exposure to wide ranges of atmospheric and edaphic conditions, certain physiological processes and morphological characteristics provide marvellous buffering against environmental extremes (Kaufmann 1981).

Existence of a highly significant clonal as well as categorical differences between drought tolerant and drought susceptible clones with respect to most of the parameters studied has led us to think that drought tolerance in tea, to varying degrees can be ascribed to certain morphological,
physiological or biochemical attributes. From our studies, it is clear that most of the clones representing drought tolerant category could close their stomates earlier in response to the commencement of a droughty situation in the field. Stomatal diffusion resistance is important from the viewpoint of controlling water loss, especially under situations, where water is a limiting factor for growth. Hence, many plant physiologists and plant breeders think that the stomatal regulation by artificial means can be used as a tool for improving crop productivity through enhanced plant water status under situations of soil moisture deficits.

In tea, it has been observed that the increased stomatal diffusion resistance exhibited by drought tolerant category of clones was accompanied by simultaneous decrease in rate of transpiration. Plants with insensitive stomatal behaviour against soil moisture deficits have little adaptive values for dry land farming, although complete closure is not desirable under any circumstances. Because, it impedes the photosynthetic process and over-rules the transpirational cooling of leaves, which results into exorbitant rise in leaf temperature.

Under identical conditions of soil moisture deficits, the drought tolerant category of clones exhibited relatively higher water potential as compared to drought susceptible category. This property of the drought tolerant group of
clones was found to be associated with higher stomatal diffusion resistance and lower transpiration rate. Higher water potential exhibited by the drought tolerant category of clones is a reflection of higher plant water status, which they could build up through higher stomatal diffusion resistance under identical situations of soil moisture deficits in the field.

This enhancement of plant water status in drought tolerant tea clones could also be reflected through increased amount of moisture content per unit leaf area and relative turgidity of leaves measured. Under identical condition of soil moisture deficits, relatively higher specific leaf weight and dry weight to fresh weight ratio of leaves in categorically drought tolerant clones imply that the ability of a plant to accumulate dry-matter under unfavourable situations of moisture stress, constitutes a physiological attribute for drought tolerance in tea.

As compared to TV3, a drought susceptible Assam jat clone, smaller area and perimeter of the stomatal pore, lesser density of stomata and greater number of leaf hairs per unit leaf area observed in drought tolerant China hybrid clone TV1, may be responsible for observed reduction in transpiration loss and thus attributable for its superior drought tolerance.

In this context, it should be mentioned that in tea most of the clones categorised as drought tolerant come from
Chinary origin with typically smaller leaf area. Hence, the smaller leaf area observed in certain drought tolerant clones under this study may, at least, partly be responsible for conferring drought tolerance through reducing total transpiring surface in tea.

Almost all aspects of plant growth are affected by water stress, among them the dry matter production that accounts for much of the production by agriculture (Haiao 1973). It is true that metabolism, transport, sensitivity to growth regulators, cell expansion, photosynthesis, root permeability, water relations, stomatal behaviour and morphology must all be taken into consideration and integrated to arrive at a definite conclusion of plant's adaptation to water stress (Bradford and Yang 1981). However, an assessment of the physiological responses of the tea plant to water stress is of utmost importance in order to identify traits, which could form a basis for the selection of drought tolerant clones. Sandanam et al. (1981) observed that among others, stomatal diffusion resistance and desiccation resistance are criteria, which could determine the efficiency in regulation of water loss when plants are subjected to water stress. They also found that drought tolerant clones had a higher relative water content for a given water potential as compared to the drought susceptible clones. In our previous studies also, it was observed that stomatal diffusion resistance may be used
as a parameter to screen the progenies for drought tolerance in tea (Handique and Manivel 1987). Stomatal diffusion resistance also showed an inverse relationship with rate of transpiration in tea. So while assessing drought tolerant cultivars, lower transpiration rate and lower rate of withering may also be considered as a parameter for screening.

Shoot water potential in mature tea bushes under moisture stress condition is an index of the plant water status and hence their ability to withstand drought (Handique and Manivel 1986). So, shoot water potential may be used for screening tea cultivars for drought tolerance. The results of our studies on stomatal diffusion resistance and water potential, based on a comparison between drought tolerant and drought susceptible groups of cultivars, yielded sufficient grounds in support of their use as indices for selecting drought tolerant cultivars in tea. Fordham (1977) used the changes in stomatal opening as physiological indicators of moisture stress in tea. Carr (1971a) and Williams (1971) recorded a linear correlation between stomatal aperture and leaf water status as revealed by pressure chamber technique and observed that some clones were more resistant than others to change in water status.

Knowledge of differences in osmotic and turgor potentials among and within species is useful in breeding for drought resistance (Parson and Hawe 1984). Two important
Determinants of the ability of a crop to yield well in drought are (1) its ability to tolerate a given plant water stress and (2) its ability to control build up of plant water deficits by stomatal closure (Jones 1977). The first one involves the investigation into biochemical level adaptation of organisms to environments. The second one involves the methods and the plants' own structural and physiological strategies for improving plant water status, basically the maintenance of higher water potential and relative turgor during periods of drought. Our investigations show that the leaf water status in tea, relative to a particular condition of soil moisture, could well be reflected by observing relative turgidity (RT) otherwise called relative water content (RWC) of leaves. Srinivas Rao (1986) and Boyer (1969) pointed out that RWC is perhaps the most widely accepted method of expressing the quantity of water in plant tissues and could be used as a measure of tolerance to stress. In our studies, RT exhibited a linear relationship with leaf water content. So drought tolerant cultivars exhibited relatively higher relative turgidity and leaf water content as compared to drought susceptible ones.

Comparative studies between varieties on photosynthetic efficiency and translocation under situations of soil moisture deficits carry adaptive values. In tea, between the two clones, the superiority in translocation and photosynthesis of the drought tolerant one over the drought susceptible one is an
added advantage for its adaptation under such conditions. More decrease in the area and volume of the vascular elements in stems, roots, petioles and leaf mid-rib as revealed by the anatomical studies together with the decreased absorption rate may be one of the reasons for reduced translocation of the drought susceptible clones. On the other hand, in the drought tolerant clones, comparatively higher photosynthesis under water stress condition may take place through the maintenance of higher turgor due to higher water potential of its leaves, as was observed in wheat varieties by Uprety and Sirohi (1985). Production of higher dry matter by drought tolerant category of clones under situations of soil moisture deficits could be seen in higher specific leaf weight recorded, as compared to the drought susceptible category.

It can be argued that for mesophytic plants some degree of internal water deficits is inevitable, so that the capacity to adapt metabolically to water stress is an essential condition for existence (Hanson and Hitz 1982). The increase in the amount of total soluble sugars and accumulation of proline in response to soil moisture deficits may be an indication of metabolic adaptation to water stress in tea. The relatively higher amount of proline accumulation in the drought tolerant clone TV1 over other clones studied, may constitute an attribute for its superior drought tolerance. This accumulated proline along with soluble sugars in tea might be involved in
osmotic adjustment during periods of drought. The high concentration of solutes found in plant cells creates the ultimate driving force i.e. osmotic potential that brings water into the plant from the soil (Boyer 1983). The decrease in osmotic potential must be due largely to active solute accumulation, or, osmotic adjustment has a major consequence in the maintenance of leaf turgor (Turner and Jones 1981). Active osmotic adjustment is important in drought tolerance, because it increases the water-absorbing power of the foliage, delays wilting and stomatal closure, and protects protoplasm from desiccation and coagulation (Levitt 1972). Thus like proline, the increase in sugar during drought, possibly resists desiccation of the protoplasm and thus cellular injury (Parker 1968, Koster and Leopold 1988).

Recently, the possibility of using stress metabolites like ABA, Proline and Betaine as indicators of the water status of plants has been examined (Quarrie 1980). However, as such no satisfactory explanations have been put forward on their frequent association with water stress and cellular level mechanisms involved.

The observed clonal and categorical differences in deposition of epicuticular wax content in leaves of tea plants when exposed to drought may constitute an attribute for assessing relative drought tolerance in tea. The deposition of epicuticular wax plays an important role in reducing
transpiration loss and thereby facilitating build up of plant water status relative to a condition of soil moisture deficits. Sutter and Longhans (1979) recorded that the low survival rate of nonglaucous Carnation plantlets generated in vitro, may be explained by their lack of epicuticular wax content, which resulted in excessive desiccation when they were transferred from in vitro to the green house.

The degree of adjustability to water stress condition in tea may also depend on the plant's inherent ability to maintain the synthesis of other biochemical constituents like chlorophyll, starch etc. at a stable rate being less affected by water stress.

The existence of the differences in clonal responses to drought treatment, with respect to various growth parameters studied leads us to believe that the morphological adaptations of the tea plant to water stress must also be considered while selecting a cultivar suitable for plantation in areas prone to water stress. These include the effects of water stress mainly on dropping and drooping of leaves, leaf area, number of leaves, number and length of laterals, stem thickness, length and volume of roots, root : shoot ratios etc. Since, the tea plant is a sink-predominant crop, because, only the young shoots are harvested for making tea of commerce, the relative rate of production and growth of the young shoots on the plucking table bear adaptive values under situations of water stress.
Recovery from water stress is an important component of tolerance to water stress and represents the ability to regain physiological functions after either reversible strain (e.g., leaf wilting) or irreversible strain (e.g., leaf death) (Hinckley et al., 1981). Between the two clones studied, the drought tolerant clone TV1 exhibited a trend of quicker recovery in leaf water potential, stomatal diffusion resistance and transpiration rate over clone TV21, with categorically poor drought tolerance. Although, the recovery depends upon the intensity and duration of stress period, the quicker recovery potential of cultivars plays an important role in adaptation to water stress.

Antitranspirants: Soil loses water in order to meet the high evaporative demand of the atmosphere caused by the sun through evaporation from the soil and transpiration from the leaves. In India, the main source of rainfall is the monsoon climate. There exists several breaks of various durations in the monsoon, and in the winter season, very little rain is received which is also uncertain. Under these circumstances, the tea plants have to grow on stored soil moisture after the cessation of monsoon rains. Consequently, the tea crop is subjected to water stress due to receding soil moisture and rising temperature. Consequently, the growers will be left with two possible alternatives to feed back the tea plant with sufficient water so as to maintain them at relatively favourable plant water status for growth and productivity. They can either supply
the plants with sufficient water through artificial irrigation to meet the current demand, or, they can employ expedients to reduce the rate of loss from the foliage to the amount which the roots can extract from the soil (Winter 1971).

In recent times, increase in irrigated areas has partly changed this situation, but approximately 75% of the cultivation is still dependent on rainfall (Kumar and Sinha 1988). The supplementation of water through artificial irrigation does not seem to be economical because of the recurrence and magnitude of drought and its overlapping nature with the dormancy period (Saikia and Dey 1984). Moreover it is fully agreed that the internal moisture stress must be relieved in order to fetch the increased foliage production. But, since the tea is an extensive crop, the conventional way of avoiding stress and to meet the current water loss through evaporation and transpiration by full irrigation over the very large tracts of tea is obviously impracticable and is likely to be prohibitively expensive (Winter 1971). The alternative to frequent irrigation is the avoidance of internal stress by reducing transpiration.

Approximately 99% of the water taken up by the plant roots is transported to the atmosphere through the stomatal pores (Davenport and Hagan 1975). Therefore, it seems to be important to make necessary steps to reduce this significant
amount of water loss by controlling stomatal pores which will otherwise be lost through transpiration. Unfortunately, many of several approaches for reducing transpiration are only of limited applicability and therefore, research has been intensified to develop 'stomatal inhibitors' and 'film-forming compounds' generally known as 'antitranspirants' (Martin et al. 1984). The objective of using antitranspirants is to decrease irrigation water requirements and alleviation of internal water stress.

Among several chemicals evaluated Rallidhan (1000 & 2000 μg/ml), Antistress (300 μg/ml), PMA (25 μg/ml), ABA (25 μg/ml), CCC (500 μg/ml), ABA (10 μg/ml), PMA (10 μg/ml), Vapor Gard (2.5 & 5%) exhibited promising antitranspirant properties as compared to others investigated in tea.

These antitranspirants in tea when applied as foliar sprays, increased stomatal diffusion resistance, water potential, relative turgidity, specific leaf weight and finally water use efficiency in the treated plants as compared to the untreated ones under conditions of soil moisture deficits. Further it was observed that these chemicals reduced both transpiration and evapotranspiration rates and also the rate of withering in the treated leaves when subjected to soil moisture deficits.
The objective of reducing transpiration through application of antitranspirants may be sought primarily to improve plant performances by building up of plant water status, when soil moisture becomes a limiting factor for survival and growth, relative to a particular soil moisture status. The increased stomatal diffusion resistance in tea as a result of application of antitranspirants was inversely correlated with rate of transpiration, which ultimately helped the plants to build up favourable water status. This enhanced plant water status resulted in an increase in water potentials either in leaves or shoots and also in increased relative turgidity of leaves.

Conservation of soil water through reduced transpiration in the antitranspirant treated plants manifested in the decreased evapotranspiration rate (Davenport and Hagan 1975). Again, the improved plant performances could be observed in the higher specific leaf weight and water use efficiency. Water use efficiency and drought resistance are often taken closely as synonyms, although they are frequently unrelated (Hsiao and Acevedo 1974, Begg and Turner 1976). The foliar spray of antitranspirants is another approach to the improvement of water use efficiency of plants by virtue of reducing transpiration rate more than photosynthesis (Begg and Turner 1976).

The extension of these findings to the commercial gardens has revealed that the potentially effective anti-
transpirants can be successfully applied for alleviating the harmful effects of plant water stress during periods of drought. The assessment of the durability of these chemicals has shown that the lasting effect of these chemicals can be expected at least for one month.

However, while using antitranspirants, we should bear it in mind that they affect plant growth favourably by increasing plant water status, but adversely by reducing photosynthesis (Davenport et al. 1974). But since the antitranspirants are usually used in situations, where survival is the critical problem, any reduction in photosynthesis by these chemicals is of only secondary importance (Davenport and Hagan 1975). However, the perennials are less affected from decreased photosynthesis, because they have more food reserves as compared to the annuals.

One of several arguments against the use of antitranspirants is that the stomata of most crop plants close in response to water stress and consequently control their own internal water status. But such waterstress-induced defence strategies may not always be entirely adequate (Martin et al. 1984). Further, it is true that the complete closure of stomata is not at all desirable under any circumstance. Because, it will stop photosynthesis and will lead to excessive rise in leaf temperature. But, at certain critical value of leaf turgor, stomata may tend to close completely or
to a level, when the entry of CO$_2$ for photosynthesis will come to a critical point. Under such situations, antitranspirants reduce the hydro-active closure of stomata by increasing turgidity (Davenport and Hagan 1975). Thus, because of an improved leaf water potential, stomata may be more open beneath the antitranspirant film. Consequent to this, photosynthesis will be relatively increased, if the permeability of the films to CO$_2$ could be improved without impairing their resistance to water vapour loss (Davenport et al. 1974). Again, Shimshi (1963), Slatyer and Bierhuizen (1964) observed that under certain conditions, a decrease in stomatal conductance will reduce transpiration relatively more than photosynthesis and should increase water use efficiency. Finally, it has been suggested that, an ideal antitranspirant should be non-toxic, should persist for several weeks, should be cost effective and differentially permeable to CO$_2$ but impermeable to water vapour (Davenport et al. 1974, Martin et al. 1984).

Foliar application of Potash (K$_2$O) alone and in combination with Magnesium (MgSO$_4$) increased water potential, relative turgidity, specific leaf weight, and finally crop yield in tea. Application of potash for growth is a regular practice in the tea plantations. Several investigators also have documented the beneficial effects of potash application as a tool for controlling stomatal opening and economising water use by plants (Hafner 1971, Monard 1974, Saikia and
Dey 1984). The control of stomatal opening induced by potash application during periods of soil moisture deficits helped the tea plants to build up favourable water status which might have resulted into increased dry matter production and green crop as recorded.

Management of young tea under situations of drought appears to be a major problem and invites special attention of all concerned. Jalashakti, a super absorbent of water, alone or in combination with mulch, proved to be quite helpful in this respect. Before establishment and after planting, the young teas are more or less subjected to a transplanting shock. Under this situation, conservation of soil moisture and maintenance of favourable plant water status of the young plants are of urgent necessity to ensure good success in establishment of the young tea plants especially when soil moisture is a limiting factor.

Generally, 'transplant shock' occurs when water loss from leaves exceeds uptake through a damaged or pre-established root system (Davenport et al. 1972). As this chemical could enhance the water holding capacity of the soil, it could conserve soil moisture for sufficiently longer period, thereby delaying the depletion of available soil moisture and postponing the time for wilting incidents. Records of water potential showed that it could help in maintaining higher plant water status during periods of soil moisture deficits.
Hence it is felt that application of any material having property of water conservancy in the soil through increasing water holding capacity, together with mulch for decreasing evaporation from soil, may help bringing up the young tea plants in areas where water is a limiting factor. In supplement to this, the application of suitable antitranspirants may further alleviate the development of internal water deficit by virtue of enhancing relative plant water status.