

STUDIES ON TEA AND DROUGHT 1. SOME OBSERVATIONS ON DROUGHT EFFECTS ON PHYSIOLOGY OF TEA

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The severe drought experienced in early 1992 afforded an opportunity to undertake intensive studies on drought damage to tea. In this study, some of the physiological changes associated with drought damage in tea have been examined.

Root starch in affected and healthy plants from two agro-ecological regions was estimated and compared while recovery from pruning was followed in relation to drought damage and root starch.

Results showed that root starch decreased with increasing severity of drought damage with only traces in bushes that succumbed to the drought. The rate of recovery from pruning depended on the initial reserves and bushes with starch levels above 10-15 % recovered satisfactorily while those with below 5 % recovered poorly. In young tea, healthy plants had only 3-4 % root starch whereas affected plants had only a trace. The conducting tissues were imperfectly developed in drought affected young plants.

INTRODUCTION

The severe drought experienced in early 1992 caused widespread concern among tea planters warranting the adoption of measures to alleviate drought damage in tea plantations. Little research has been done on drought damage in tea in the tea producing countries. In recommending remedial measures reliance had always been placed on general principles rather than on experimental evidence. The remedial measures adopted were related to either the reduction of water loss by plants through transpiration or to ensure retention of sufficient soil moisture for plant survival during droughts. The short and long-term measures recommended for drought include the following cultural practices (Visser and Kehl, 1956):

1. Thatching new clearings with Guatemala or mana grass to prevent evaporation of soil water.
2. Removal of excessive foliage of shade trees by lopping so as to cut down transpiration losses and consequent drain on soil moisture.
3. Cutting back at the very commencement of a drought of green manure bushes like *Crotalaria*, *Tephrosia* and *Stylosanthes* which compete with tea for water.
4. Cutting down transpiration of tea by keeping as much shade as is essential to prevent exposure to sun. In this way extra water loss due to increased temperature and light intensity would be avoided.

5. Maintaining a good draining system to retain soil moisture.
6. Improving soil organic matter in order to increase the water holding capacity of the soil.
7. Planting of wind belts to reduce the enhancing effect of strong and desiccating winds on transpiration losses.
8. Planting of drought resistant/tolerant clones.

Water stress in tea can affect physiological processes in many ways. Although the effects of water deficits on such transpiration and growth have been investigated and well documented, the specific sequence of associated physiological changes have not received sufficient attention and is still only imperfectly understood.

Not much work has been done on the extent to which water deficits developing during a prolonged drought affect photosynthesis and food storage in tea. Survival during drought could largely depend on stored food, essential for the metabolic activities in living cells of the plant. Carbohydrates form the food of tea plants and their presence is probably closely related to growth and survival. In this preliminary investigation, we have attempted to assess the root starch levels of mature and young tea affected by the prolonged drought experienced in early 1992 and the extent of their recovery.

MATERIALS AND METHODS

Experiment 1. Effects of drought damage on root starch in mature vegetatively propagated (VP) tea

This study was carried out on mature clonal tea, in two agro-ecological regions, where drought damage was extensive, one representing the up-country, conducted at a) St.Coombs Estate and b) Mattakelle State Plantation, Talawakele (1382 m amsl) and the other, in the Uva region, conducted at Battawatte State Plantation, Passara (1400 m amsl). At St.Coombs and Mattakelle Estates the drought lasted from January to mid-April 1992 (mean monthly rainfall of 6 mm), while at Battawatte it commenced in late June and continued until September (mean monthly rainfall of 19 mm). The degree of drought damage suffered by the mature tea fields was classified as follows:

1. Bushes unaffected (healthy).
2. Partial defoliation but frame alive.
3. Complete defoliation but frame alive.
4. Complete defoliation and frame dried up.

The worst affected was the clonal tea in the final years of a pruning cycle. We selected 3 to 5 bushes at random from each of the categories (1), (2) and (4) above for collection of root samples. From each bush, 3 segments of root, each 1.5 to 2.0 cm in diameter and 8-10 cm in length were severed after exposure. The first sample was taken in late April 1992 when the drought effects were very evident on the bushes.

The sampled roots were immediately brought to the laboratory, washed, separated into bark (all tissues outside the cambium) and wood. Only the wood, which contains a major portion of stored starch, was used for the analysis of starch. The wood was cut into small pieces and placed in an oven at 80°C for overnight drying. The dried samples were then ground in a Wiley grinding mill using 40 mesh sieve and the fine root powder collected for starch extraction.

Analytical procedure

1. One of the dried powdered root sample was extracted for half an hour with 25 ml of 80% methanol, and the contents centrifuged for 15 min. and the supernatant containing the soluble sugars discarded. The residue was further extracted twice with 25 ml portions of 80 % methanol to remove traces of sugars.
2. The residue was extracted with 25 ml of 1% HCl in 80% methanol for half an hour, the contents centrifuged and the supernatant discarded. The residue was washed twice with 25 ml portions of 80% methanol to remove traces of HCl in the residue. This procedure results in the solubilization of starch.
3. The residue was quantitatively transferred into a 100 ml conical flask using 25 ml of hot water and the contents heated on a steam bath at 100°C for half an hour with occasional shaking. The contents were centrifuged while hot and the supernatant collected. The supernatant contains the hot water soluble starch. One ml aliquot of the supernatant was diluted to 50 ml with warm water, treated with 2 drops of I/KI₂ and the blue colour so developed was read in a spectrophotometer (Model Shimadzu) at a wavelength of 660 nm, after setting the blank to zero.

Experiment 2. Recovery from pruning in relation to drought damage and root starch

Field No. 6D of Mattakelle State Plantation planted with clone Norwood 2 (N 2) was selected as the drought damage was severe with more than 80% of the bushes completely defoliated. It was estimated that even the remaining bushes had only about 10-30% of the initial foliage. Among those defoliated, some had dried up completely, while in others the basal frame and a few branches were still alive.

As the rains commenced around late April/early May 1992, the dead bushes were uprooted and the vacancies planted with clone N 2. Those partially defoliated and a few that were alive were pruned in mid-May at 50-55 cm (20-22") and allowed to recover. One week prior to and again at 50 and 90 days after pruning, the storage roots from the healthy and drought affected bushes were sampled for analysis as in Experiment 1. A count of the recovering healthy shoots and the number of leaves on each shoot was also made at 50 and 90 days from prune.

Experiment 3. Root starch in young tea during drought

A young tea field (Field No. 2A, Mattakelle Estate) with clones TRI 2025 and DT 1, centered and brought into plucking in late September 1991, had suffered heavily during the drought. The plants had been yielding well until the beginning of the drought but thereafter declined drastically. As the drought progressed, more than 70% of the

bushes of clone DT 1 completely defoliated and many dried up. Clone TRI 2025 was less affected. Some of the affected plants of DT 1 which had some foliage recovered to some extent with the rains but the new foliage became yellow, followed by defoliation. On the other hand, there were others of both TRI 2025 and DT 1 which withstood the drought and recovered very well producing vigorous shoots. Root samples were collected from both clones showing different degrees of drought damage for starch analysis, as in Experiment 1. As there were visual differences in the shoots of affected and healthy plants, the shoots were sampled (2nd to 3rd internodes from apex) for anatomical studies.

RESULTS

Experiment 1. Effects of drought damage on root starch in mature vegetatively propagated (VP) tea

At both Talawakele and Passara there was markedly less root starch in affected plants compared to healthy plants (Table 1). Thus, in all the clones tested in this study, while the healthy plants contained root starch ranging from 30 to 55% on a dry weight basis, partially defoliated and completely defoliated plants had about 10-16 and 2-4% starch respectively.

TABLE 1 - *Root starch (%) of the drought affected and healthy tea bushes (dry weight basis)*

<i>Location and clone</i>	<i>State of bush</i>		
	<i>Completely defoliated</i>	<i>Partially defoliated</i>	<i>Healthy</i>
St.Coombs Talawakele			
TRI 2024	4.30	9.75	31.00
TRI 2025	3.50	16.25	34.00
Mattakele S.P. Talawakele			
TRI 2023	3.25	13.18 *	43.00
TRI 2025	4.18	16.18 *	23.50
N 2	2.50	4.00 *	41.00
Battawatte S.P. Passara			
TRI 2025	4.50	13.45	55.00

* 50 % foliage defoliated * 90 % foliage defoliated

There were some differences in root starch content between locations. At Passara, there was about 55 % starch in the roots of healthy plants whereas at Talawakele it varied from about 23-43 % starch in the clones studied.

The partially and completely affected bushes of clone N2 at Mattakelle Estate contained 2-4% starch whereas a few which survived the drought without heavy defoliation contained as much as 40% starch.

Experiment 2. Recovery from pruning in relation to drought damage and root starch

The rate of recovery of the pruned plants varied and greatly depended on the levels of root starch at the time of pruning. Healthy plants with adequate reserves (>15-20 %) recovered satisfactorily (Fig. 1) while those with low starch reserves showed poor recovery (Fig. 2). Considering the root starch a few days before prune (Table 1) and 7 weeks after prune (Table 2) it was evident that in all the bushes there was a depletion of starch. In bushes badly affected, the starch level was as low as 1-3% and correspondingly the recovery was also poor. On the other hand, the healthy plants showed satisfactory recovery and also had 8-14% starch at the end of 7 weeks which became further reduced to 5-9% at the end of 12 weeks from prune (Table 2).

TABLE 2 - Recovery from pruning of drought affected plants in relation to root starch (clone N 2)

Starch (%)	Total No. of buds	No. of shoots with leaves				State of growth
		1-2	3-5	7-9	10-12	
<i>After 7 weeks</i>						
2.25	5	5	-	-	-	Bushes with poor recovery and few branches dead
2.25	28	19	9	-	-	Stunted growth, leaves with yellow margin
12.50	75	15	60	-	-	Satisfactory growth with healthy shoots
13.50	44	4	20	20	-	Satisfactory growth with healthy shoots
10.70	56	24	20	12	-	Satisfactory growth with healthy shoots
<i>After 12 weeks</i>						
1.78	1	1	-	-	-	No recovery, bush dried up.
1.25	3	3	-	-	-	Stunted growth, poor recovery and dieback
4.5	47	8	7	12	20	Satisfactory recovery with healthy shoots
8.5	135	30	10	65	30	Vigorous growth with healthy shoots

Experiment 3. Root starch in young tea during drought

With the onset of the intermonsoonal rains in late April there was some regrowth in the drought affected young plants but the growth was stunted. In addition, at a later stage their foliage became yellow and the shoots had very short internodes with thin diameter (Figs. 3 and 4). The affected shoots snapped off easily. On the other hand the healthy plants produced shoots with good foliage, long and thick internodes and were difficult to break.

Compared with mature tea, 3-4-year-old plants had low root starch. Healthy young plants of both, TRI 2025 and DT 1 had about 2-4 % starch whereas in the drought affected young plants there was only a trace.

A transverse section of the drought affected and healthy shoots close to the apex (2nd to 3rd internode) showed poor and irregular development of xylem and phloem tissues in drought affected shoots with even the size of the individual xylem cells being smaller compared to that of healthy shoots (Fig. 5a and 6a). On the other hand, the conducting tissues of the healthy shoots were well developed with large xylem vessels with more thickened walls (Fig. 5b and 6b). The number of xylem and phloem cells formed from the dividing cambial cells were also more in the healthy plants compared to those affected.

DISCUSSION

In this paper, which forms the first of a series on the effects of drought and tea we looked into some physiological changes that take place in tea plants during drought.

The damage caused to tea during drought was variable even in the same tea field with certain sections being affected while others remained healthy irrespective of clones. This indicates that even in the same clone, plants vary in their ability to resist or tolerate drought damage for some reason or other. It is therefore important to identify those physiological factors which may be associated with drought resistance/tolerance properties in tea.

Water deficit in the soil is the main factor causing damage to tea during drought. The relation between photosynthesis and water deficit is well known and has been studied extensively (Verduin and Loomis, 1944; Ashton, 1956; Gist and Mott, 1957). With increased water deficit stomates are virtually closed to a point when photosynthesis is limited significantly. Several workers have shown that photosynthetic rates decrease rapidly or approach zero when wilting commences. Thus under prolonged drought conditions when photosynthesis becomes almost zero, the living tissues of the plant have to depend entirely on the accumulated reserves for sustenance obtained by energy generated from respiration. In fact, it has been reported that in tea, under normal conditions more than 60 % of the starch synthesised by the plants is utilized in respiration (Rahman, 1988).

In tea, more than 90 % of the reserves (starch) are generally found in the storage roots and when the plants begin to tap the root reserves for respiration and other metabolic activities as happens during a drought, the root reserves would gradually deplete with time until the plants become photosynthetically active again. Plants which have higher initial root starch may have sufficient reserves to go through the drought

without showing adverse drought damage while plants with low root starch may be those that succumb to drought, as a result of starvation.

The finding that the drought affected plants had very low root starch compared to healthy ones serve to emphasize that the starch was getting gradually depleted for various metabolic activities in the living cells (Experiment 1, Table 1). It is not uncommon to find soil and ambient temperatures in tea areas rising to 35° to 40°C during the day in dry months which would further increase metabolic activities, particularly respiration, thereby depleting the starch reserves faster.

The influence of water deficits on carbohydrate status of plants during drought has been studied by several workers in other crops. The accelerated conversion of starch to sugars during water deficits has been reported (Wadleigh and Ayers 1945; Eaton and Ergle, 1948; Woodhams and Kozlowski, 1954). It has been shown that increased amyolytic activity is involved in the disappearance of starch during drought. Breakdown of complex starch into smaller sugar molecules during drought was also reported in tea (Manivel, 1992).

As the water deficit in the soil increased and desiccation of the plant organs, continued, there would have been a progressive loss of dry weight through continued respiration; overall crop production becoming significantly low. Finally, when critical levels were reached individual cells and tissues began to die. This might have been the reason for the tea plants showing scorched symptoms and defoliation in many of the drought affected tea areas.

With the onset of the rains following the drought, when the water supply was resumed, the recovery took several days. Where there was less damage associated with sufficient starch in the roots (above 15-20 %) recovery was satisfactory, but those affected with low reserves (< 3%) showed poor recovery and sometimes even the emerging buds aborted subsequently. Plants which contained around 5% starch showed some recovery but the growth was stunted. According to Manivel (1992) recovery after water stress depended greatly on the root reserves.

It is in this context that plantations are advised to carefully plan out fertilizer applications following a drought to avoid further damage to plants already affected by drought. Since the root starch levels were found to be less than 3% in the defoliated but alive plants (Table 1), fertilizer application should be delayed until they develop sufficient foliage and are ready to absorb the applied nutrients. An early untimely application, when the plants do not have sufficient foliage will only result in rapid exhaustion of already depleted root starch and make them more vulnerable to death. In addition, direct toxic effects of absorbed fertilizers can also cause scorching and defoliation of leaves.

Plants with more than 75% defoliation and those defoliated but still alive deserve some attention. When these plants recover during the favourable period we have seen them regenerating buds at various levels on the frames starting from below, making the growth uneven as far as the plucking table is concerned. In order to avoid this situation, we have tried pruning those drought affected bushes and found the recovery uniform and satisfactory. As long as these plants have above 10-15 % starch



Fig. 1 – *Plant (clone N 2) with high root starch showing good recovery from drought following pruning.*



Fig. 2 – *Plant (clone N 2) with low root starch showing poor recovery from drought following pruning.*

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Fig. 3 – *Recovery of drought affected young tea (clone TRI 2025).*



Fig. 4 – *Recovery of drought affected young tea (clone DT1).*

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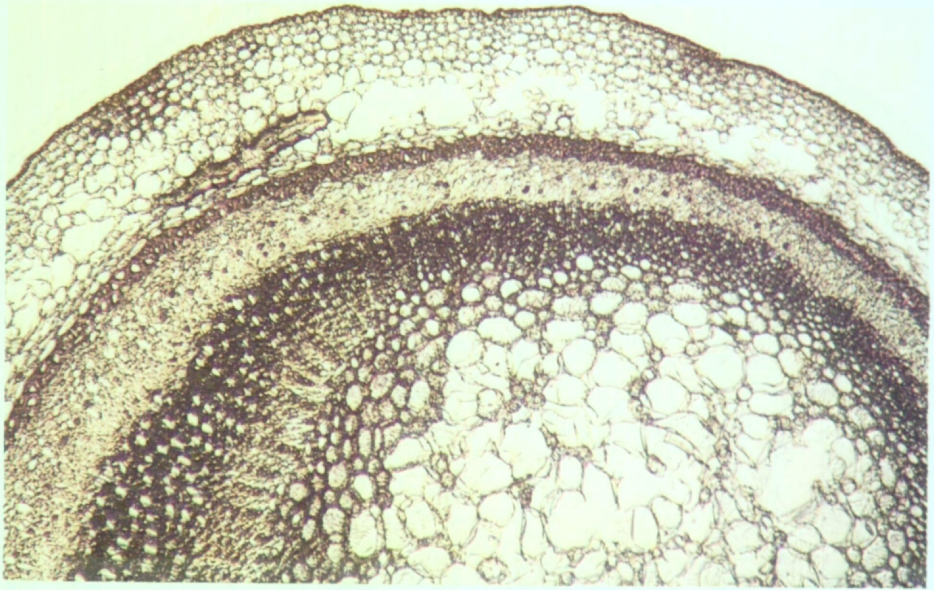


Fig. 5a – *Transverse section of stem from drought affected young tea (clone TRI 2025).*

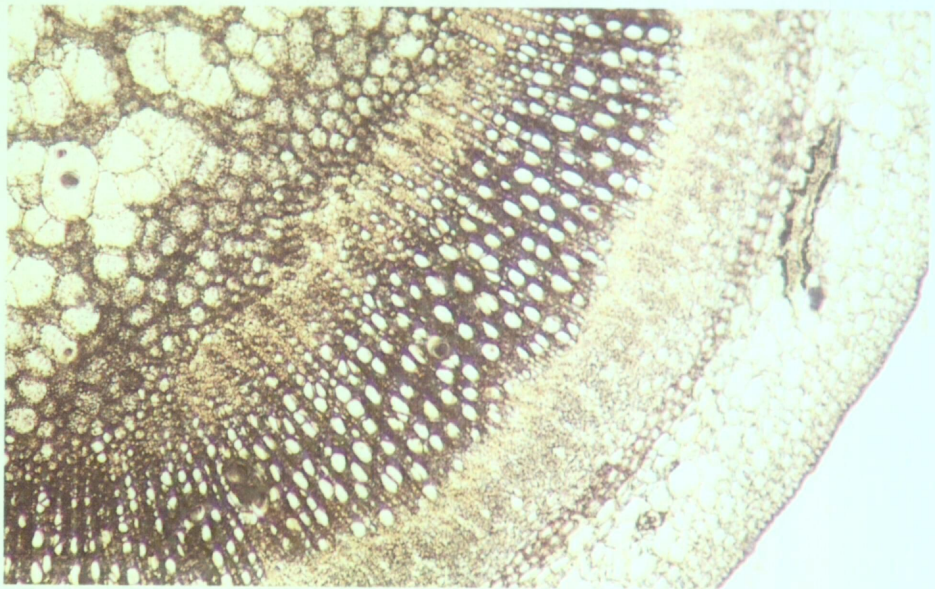


Fig. 5b – *Transverse section of stem from healthy young tea (clone TRI 2025).*

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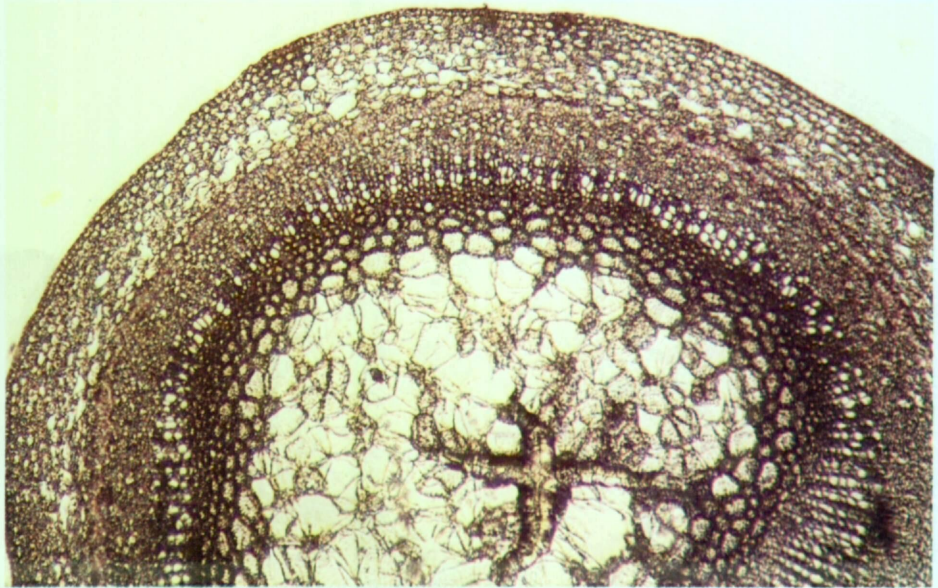


Fig. 6a – *Transverse section of stem from drought affected young tea (clone DT1).*

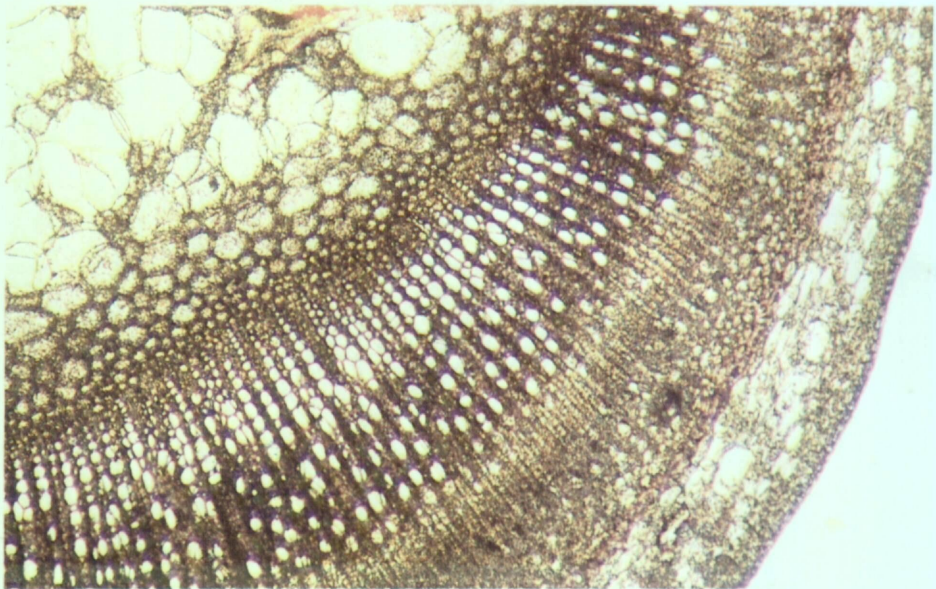


Fig. 6b – *Transverse section of stem from healthy young tea (clone DT1).*

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reserves and if they are pruned after a few showers of rain when soil moisture is not limiting, no adverse effects could be envisaged. Pruning at this stage has another physiological advantage. By pruning, a major portion of the living tissues, which otherwise depend on the limited reserves for their survival are removed, ensuring the slow depletion of starch and making it available for an extended period until sufficient foliage is developed by the plant.

As observed in normally pruned bushes, in the drought affected plants too there was rapid depletion of root starch for a time after pruning. At 7 weeks from prune, the healthy plants contained only 10-13 % starch whereas the affected plants had only traces (Experiment 2, Table 2). Further depletion followed at the end of 12 weeks, despite the plants producing 7-12 leaves on the growing shoots. This indicates that the assimilates 'currently' synthesised by the newly formed leaves were mobilized for recovery with little going for accumulation. This has been reported to be the trend even in normal healthy bushes during recovery from pruning (Nagarajah and Pethiyagoda, 1965). According to them it was only after 4 1/2 months that the root starch began to build up again in the roots.

In young tea the situation was different. According to our findings, unlike mature tea, the young tea accumulated only small quantities of starch in the roots (Experiment 3). It is possible that in young tea where the growth is generally vigorous, a major portion of the assimilates is utilized for growth leaving little for accumulation. Therefore any adverse conditions such as drought that affect photosynthesis would have a detrimental effect on the growth of these plants. The observation that there was poor growth in those plants associated with poor development of the conducting tissues such as xylem and phloem possibly indicates that the plants have been subjected to starvation due to inadequate supply of assimilates.

The fact that the mature and young tea that survived the drought contained more starch compared to drought affected ones (Experiments 1 and 3) indicates that root starch could possibly play an important role on drought resistance/tolerance in tea. The rapid breakdown of starch to sugar during drought could cause increased osmotic concentration of the cells to restore the water balance in the affected tissues or of the plant as a whole. The restoration of water balance may continue as long as the accumulated reserves last, after which the plants are subjected to desiccation and death. Since in young tea the root reserves are relatively low, these plants have to be treated differently by taking care to prevent depletion of root starch at least 2-3 months prior to drought. In other words, hard plucking, leaving insufficient leaves and high nitrogen application in new clearings 2-3 months prior to drought should be avoided. Further, practices such as bringing into bearing by 'cut across' and plucking them early before the onset of the drought should be avoided. Though we have not examined the extent of damage to young tea in other estates, the behaviour of drought affected plants in new clearings where they were 'cut across' in late August and brought into plucking in December 1991, clearly showed that such practices were detrimental to plant survival during drought. Bringing into bearing and plucking should preferably be done only with the commencement of intermonsoonal rains following drought.

The above findings emphasize the need for the adoption of certain useful practices that could help to minimise drought damage in tea. The information gathered from this study and that emerging from future studies, it is hoped will enable us to

better identify the possible physiological causes associated with defoliation and death of bushes during droughts enabling us to recommend remedial measures through appropriate cultural practices.

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REFERENCES

- ASHTON, F. M. (1956). Effects of a series of cycles of alternating low and high soil water contents on the rate of apparent photosynthesis in sugar-cane. *Plant Physiol.* 31, 266-274.
- EATON, F. M. and ERGLE, D. R. (1948). Carbohydrate accumulation in the cotton plant at low moisture levels. *Plant Physiol.* 23, 169-187.
- GIST, G. R. and MOTT, G. O. (1957). Some effects of light intensity, temperature and soil moisture on the growth of Alfalfa, red clover and birdsfoot trefoil seedlings. *Agron.J.* 49, 33-36.
- MANIVEL, L. (1992). Drought tolerance *vis-a-vis* starch reserves. Newsletter UPASI, TRI. 1 (2), 8.
- NAGARAJAH, S. and PETHIYAGODA, U. (1965). The influence of lungs on carbohydrate reserves and growth of shoots. *Tea Q.* 36, 88-102.
- RAHMAN, F. (1988). Physiology of the tea bush (A review). *Two and a Bud.* 35, 1-14.
- VERDUIN, J. and LOOMIS, W. E. (1944). Absorption of carbon dioxide by maize. *Plant Physiol.* 19, 278-293.
- VISSER, T. and KEHL, F. H. (1956). Drought. *Tea Q.* 27, 77-79.
- WADLEIGH, C. H. and AYERS, A. D. (1945). Growth and biochemical composition of bean plants as conditioned by soil moisture tension and salt concentration. *Plant Physiol.* 20, 106-132.
- WOODHAMS, D. H. and KOZLOWSKI, T. T (1954). Effects of soil moisture stress on carbohydrate development and growth in plants. *Am. J. Bot.* 41, 316-320.