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AN OVERVIEW OF TEA RESEARCH IN TANZANIA – WITH SPECIAL REFERENCE TO THE SOUTHERN HIGHLANDS

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ABSTRACT

The history of tea development in Tanzania from the early part of this century to the present is summarised. Average yields of made tea from well managed estates in the Mufindi district have increased from around 600 kg ha^{-1} in the late 1950s to 3000 kg ha^{-1} at the present time: by comparison, yields from smallholder farms have remained much lower, averaging only 400-500 kg ha^{-1}. There have been a large number of technical, economic and other changes over the last 30 to 40 years. The removal of shade trees, the use of herbicides, the application of NPK compound fertilisers, the introduction of irrigation (on some estates) and changes in harvesting policy have all contributed to the increases in yield. Financial and infrastructural problems have contributed to the low yields from many smallholders and others, and have limited the uptake of new technology.

The contribution of research is reviewed, from the start of the Tea Research Institute of East Africa in Kenya in 1951, through to the development of the Marikitanda Tea Research Centre in Amani in 1967; the Ngwazi Tea Research Unit in Mufindi (1967 to 1970, and from 1986), and lastly the Kifyulilo Tea Research Station, also in Mufindi in 1986. The yield potential of well fertilized and irrigated clonal tea, grown at an altitude of 1800 m, is around 6000 kg ha^{-1}. This potential is reduced by drought, lack of fertilizer, bush vacancies and inefficient harvesting practices. The corresponding potential yields at high (2200 m) and low (1200 m) altitude sites range from 3000-3500 kg ha^{-1} up to 9000-10000 kg ha^{-1} and are largely a function of temperature. The opportunities for increasing yields of existing tea, smallholder and estate, are enormous.

Tea production in the Southern Highlands of Tanzania is about to expand rapidly. Good, appropriate research is needed to sustain this development over the long term, and suggestions on how best this is done in order to assist the large scale producers as well as the smallholders, are discussed.

INTRODUCTION

The first experimental tea in Tanzania was planted in 1904 by German settlers at the Agricultural Research Station in Amani in the Usambara mountains, and at Kyimbila Mission in the Rungwe district in the Southern Highlands. Commercial tea production did not begin in Tanzania though until 1926, and in 1929 a land development survey commission recommended that tea should replace coffee in Mufindi and Tukuyu. Following the appointment of a tea officer, free seed was distributed to interested settlers during the period 1930 to 1934. A small tea factory was opened in Mufindi in 1930. By 1934, 1000 ha had been planted in Tanzania, and this produced 20 t of processed tea, of which 9.3 t was exported. The tea industry in Tanzania had begun (Carr *et al*., 1988).

The outbreak of the Second World War in 1939 led to the internment of many of the German settlers, and their estates and farms were taken over by the British Custodian of Enemy Property. In 1940 the Tanganyika Tea Company (a subsidiary of Brooke Bond Africa Ltd) having leased all `enemy' tea estates in Tanganyika, began to plant more tea in Mufindi, and to build a new factory. By 1950 annual production in the three main tea areas, Mufindi, Tukuyu and the Usambaras had reached about 900 t. In 1956 production in Mufindi alone was 1700t, and in Tukuyu 450 t.

At independence in 1961, tea production in the Southern Highlands was wholly in the hands of foreign companies and a few settlers. Smallholders began to grow tea soon afterwards, and by 1963/64 there were about 330 ha. The Tanzania Tea Authority was formed in 1968 and has two main functions, one of which is to manage the planting and processing of tea, principally in the smallholder sector. There are now about 28,700 farmers in Tanzania, with an average holding of only about 0.3 ha, who produce around 4000 t/annum of tea from about 9000 ha. In 1990 Tanzania produced a total of 18000 t of processed tea, from a planted area of about 19000 ha, making this country the third largest producer after Kenya (ca. 200000 t) and Malawi (ca. 40000 t). Zimbabwe produces a similar amount to Tanzania. About three quarters of the national crop (ca. 14000 t) is produced in the Southern Highlands from about 11000 ha of planted tea,. which is centred around factories in the districts of Mufindi, Njombe, Rungwe and Tukuyu (Table 1). Tea contributes directly to the livelihood of at least 150,000 people living in the Southern Highlands.

Tea is the third highest earner of foreign exchange within the agricultural sector, and it has recently been identified as a priority crop within the National Agricultural Research Masterplan.

Table 1. Production of made tea and areas of tea within the Southern Highlands (1990/91).

Region	**Operating Company**	**Factories**	**Production ($t\ y^{-1}$)**	**Area of tea (ha)**
Mufindi	Brooke Bond Tanzania Ltd[1]	Lugoda, Kilima, Kibwele	6644	3152
	Mufindi Tea Company Ltd	Itona	1617	
Njombe	Luponde Tea Estates Ltd	Luponde	380	2482
	Tanzania Tea Authority	Lupembe	973	
Rungwe	Tanzania Tea Authority	Mwakaleli, Katumba	2180	4036
Tukuyu	Tukuyu Tea Estates Ltd	Msekela, Chivanjee	2099	1530

1. Includes production from smallholders in the Mufindi district.

Production trends

A very large proportion of the estate grown tea was originally propagated from seed, and is therefore genetically diverse. Since about 1970 most new plantings and nearly all in-filling has been with clonal plants, either selected locally or imported from Kenya or Malawi. Nevertheless, the productivity of some well-managed tea estates in the Southern Highlands has risen considerably over the last 30-40 years, through improved agronomic practices and good management. This is illustrated by the records of Kilima Estate in Mufindi where average yields have increased from about 600 kg ha^{-1} in the late 1950s to around 3000 kg ha^{-1} at the present time (Figure 1). Indeed, it is reported by Hester (1991) that yields in Mufindi in 1952 averaged only 225 kg ha^{-1}.

In the smallholder sector by contrast, yields have generally remained low, at around 400-500 kg ha^{-1} due largely to financial and infrastructural constraints to production which have also limited the uptake of new technology. The same problems have also faced a number of private and publicly owned estates.

The contribution of research to the increases in productivity on the better commercial estates are considered in this paper, whilst the constraints faced by smallholders and others are also highlighted, and quantified.

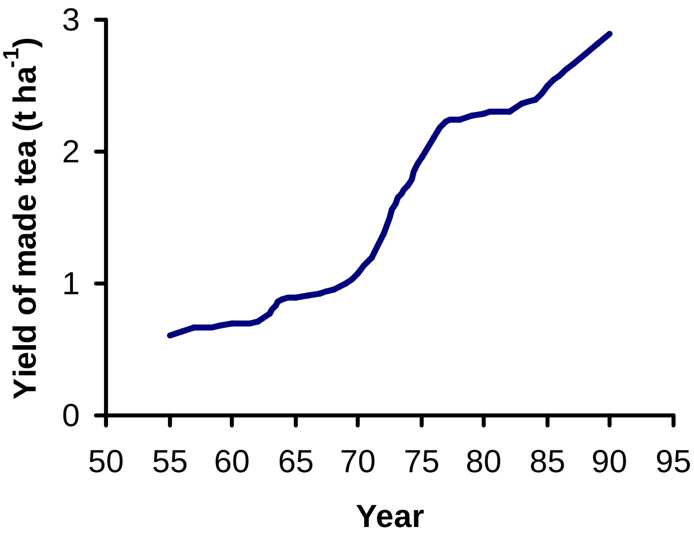

Figure 1. Annual yields of made tea per hectare from Kilima Tea Estate, Mufindi, from 1995 to 1990.

RESEARCH REVIEW

Tea planters the world over bring with them the experiences they have gained elsewhere where climatic, soil and other conditions may vary considerably. This has been true in Tanzania as much as elsewhere, and continues to this day. Until they, and their advisers, have been convinced by the results of research undertaken locally, or by the experience of their neighbours, that new production techniques are superior in crop and financial terms to those that they are used to then, for defendable reasons, they will continue to do what they know best and avoid taking unnecessary risks. The tradition within the tea industry of `visiting agents' appointed by head office travelling the world and transferring knowledge from one country to another, has also sometimes acted as a brake on local innovation. `Standing orders' issued from a head office, perhaps several thousand kilometres away from the sites of production, have also been responsible for restricting new thinking in the tea industry. Smallholders have perhaps not been constrained in the same way, although many will have learnt their trade whilst working on nearby commercial estates. This built in conservatism within the tea industry is something which research and educational establishments have long been trying to overcome. In Tanzania, particularly in the Southern Highlands, there is perhaps at last a sign of progress.

Tea Research Institute of East Africa

Organised research work into tea was first initiated in East Africa as a subsidiary division of Brooke Bond (Africa) Ltd in 1949. The scope of this department was expanded by the formal inauguration in 1951 of the Tea Research Institute of East Africa (TRIEA) as a company supported with funds derived from a compulsory cess levied by the joint Tea Boards in Kenya, Tanganyika and Uganda on producers. The Tanganyika Tea Board contributed 15% of the annual budget, which corresponded to the proportion of crop produced in Tanganyika compared with the total in the three countries.. Initially the headquarters of the TRIEA was at Kimugu Estate in Kericho, Kenya, but moved to a new site on Timbilil Estate in 1959. In the same year a small sub-station was opened at Amani in Tanganyika.

In 1967 the development of a field station in Tanzania began at Marikitanda, Amani in the Usambara Mountains (O'Shea, 1968). At about the same time the TRIEA also leased a small area of tea on Ngwazi Estate in Mufindi on which to conduct basic studies on the soil/plant/water relationships of tea, a 3-year project funded in part by the then UK Ministry of Overseas Development (Carr, 1968).

During the early years the TRIEA concentrated on plant establishment and improvement, crop nutrition and weed control; including some basic studies of the responses of tea to shade. Replicated field trials were established at sites in each of the three countries including several in the Southern Highlands. These were looked after by the estates concerned, with field recorders responsible for applying the fertiliser to the experimental treatments, and for recording the harvested weight of fresh leaf from individual plots. These data were then forwarded to Kericho, Kenya for analysis and interpretation by the senior scientists responsible. The annual yields from each of these experiments were reported routinely in Annual Reports, copies of which were sent to each estate. Occasional advisory visits were also made to each tea district in East Africa by the senior scientists (of which there were only 3 or 4). Technical courses were held in Kericho, Kenya including the occasional specialist conference. In 1965 the first edition of an advisory book entitled `Tea Estate Practice' was published. This brought together the collective results of experiments, and the experience of scientists and growers, on which general advice on all aspects of tea management in the field was given. The TRIEA at this time did not conduct research on tea processing. A second edition of Tea Estate Practice was published in 1966; it was later (1969) renamed as the Tea Growers Handbook to highlight the increasing role that smallholders were playing in the tea industry in East Africa. Routine soil, and later leaf, chemical analytical services were provided to growers, but samples had to be sent to Kenya. Root samples were also analysed for total carbohydrate content. In 1964 tea clones became available for commercial release and cuttings were sold by the TRIEA to growers, including those in Tanzania.

The TRIEA Annual Reports for 1963, 1964 and 1965 listed 13 experiments which were being conducted in Tanzania at that time. These included an experiment with magnesium (labelled T24, Herkulu Estate, West Usambaras), fertiliser placement at planting (T23, Kiganga Estate, Tukuyu; T25, Musekera Estate, Tukuyu), and a number of different factorial NxPxK (and sometimes S) trials, including T2 (Kivere Estate, Mufindi), T3 (Luhota Estate, Mufindi), T4 (Ngambo Estate, Amani), T6 (Kwankoro Estate, Amani), T11 (Lugoda Estate, Mufindi), T13 (Kilima Estate, Mufindi) and T19 (Mwitika Estate, Tukuyu). There were also two shade x nitrogen experiments (T8, Monga Estate, Amani; and T14, Kinoga Estate, Mufindi) and one bringing-into-bearing experiment (T7, Ngambi Estate, Amani). A TRIEA field officer responsible for these experiments was based in Mufindi until 1965. The conclusions reached from the work in 1964 were as follows (TRIEA Annual Report, pages 55-56):

> "Fertiliser and shade experiments have confirmed the value of applying at least 80 lb N acre^{-1} (90 kg ha^{-1}) in mature tea in all districts and have indicated the need for a reduction in shade in fields receiving this rate of application. Responses to phosphate fertilisers have been greater in Mufindi than elsewhere, and there is an indication that optimum responses will be obtained when the phosphate application is combined with high application rates of nitrogen. A significant response to potash has now occurred at Amani. In this area potash deficiency is sufficiently widespread for potash treatment to be generally recommended. Potash deficiency has been recognised at Lupembe, and in parts of Mufindi though no responses to application of potash have yet occurred in the Mufindi experiments; this may reflect considerable variations in the local soil conditions. A new NPK experiment has been laid out at Lupembe.
> A response to gypsum, applied in the planting hole, has been obtained in an experiment at Tukuyu."

It must be noted that the best yields of processed tea recorded in any of these experiments were only about 1300-1500 kg ha^{-1} (experiment T2), whilst several had yields as low as 350-700 kg ha^{-1} (T4, T8, T11, T13). There were obviously major limiting factors, other than those being tested. One clue is perhaps given by the large response to the addition of leaf litter (from *Grevillea* shade trees and from tea) to plots. Yields were increased from 818 (without) to 1400 kg ha^{-1} (with), which was by far the largest response to any treatment combination in these experiments, which were being undertaken when weed control using herbicides (paraquat and simazine) was being introduced into tea as an alternative to the use of jembes. The eradication of couch grass, reduced damage to the tea bush frames (resulting in improved ground cover), minimal surface root disturbance and the retention and incorporation of leaf fall and prunings in the soil, together resulted in a major change to the physical and nutrient status in the surface soil layers, and hence to the availability of phosphate and potassium fertilisers in the acid soils (Wilson, 1972).

Tea Research Institute - Marikitanda

The TRIEA sub-station at Amani never became fully operational, and in 1965 the Governing Body agreed to the establishment of a new Tea Research Centre in Tanzania. Eventually a 20 ha site was chosen at Marikitanda in the Amani district of the East Usambaras (alt. 1050 m). In 1967, following the arrival of Piers O'Shea, the first officer-in-charge, development began. The hilly site had a history of previous cultivation under coffee and cinchona (both with *Grevillea* shade), and, from 1958 to 1965, as a tea nursery. The secondary bush was cleared and in the following years a number of field experiments were established, principally clonal field trials, crop establishment and crop nutrition experiments (O'Shea, 1968). The site at Marikitanda was deliberately chosen as a place to study the nutrition of tea grown on eroded and leached soils. By the end of 1971, 10 ha of trials had been established. These included: mulch in young tea (T43, T50), forms of nitrogen (T39), soil mixtures in polythene sleeves (T35, T45 and T47), bringing into bearing (T41), clones x magnesium (T44), sulphur (T53 and T56), fertiliser in the planting hole (T55), vegetative propagation (T62), and later NxPxK x mulch factorial (T66), replanting (T68), plucking surface (T54), *Armillaria* control (T61), forms of mulch (T72) and pruning systems (T76).

The results of these experiments are variously summarised in Annual Reports of the TRIEA from 1970 onwards, with consolidated reports on specific issues as follows: Mulching experiments (TRIEA, 1971, 1974 and 1979); soil mixtures (TRIEA, 1970); bringing into bearing (TRIEA, 1972); *Armillarea* control (TRIEA, 1974); NxPxK x mulch (TRIEA, 1977); replanting (TRIEA, 1977); pruning systems (TRIEA, 1979) and sulphur (TRIEA, 1974).

One of the most important observations to emerge from this work was the important role of mulch together with a balanced NPK compound fertiliser had on the establishment and development of young tea plants on these debilitated soils.

In addition to these experiments, a number of clonal field trials were established (labelled C.F.T.M.) in 1967, 1968 and 1970. Annual yields from each of these trials were summarised in the TRIEA Annual Reports for 1975 and 1979. Clones labelled with the prefix 200 were selected at Amani or Marikitanda. Clone 31/11 was grafted as a scion on a number of clonal rootstocks in 1974. By this time, about 1/4 million clonal plants and cuttings had been released to the industry from Marikitanda, mainly to the Southern Highlands.

Experiments which were continued or were initiated elsewhere in Tanzania during the 1970s included two height reduction pruning trials which began in 1974 in Mufindi (T65, Lupeta Estate; T67, Kilima Estate), and a nitrogen experiment in 1977 also in Mufindi (T60, Matagutu Estate). Experiment T13 (NxP) continued on Kilima Estate in Mufindi until 1988, but the other field experiments were abandoned over the years. From 1967 to 1979 when the Tea Research Institute of East Africa formally split up the meteorological data for Marikitanda were always reported in the TRIEA Annual Reports.

After 1979 Marikitanda came under the control of the Tanzanian Ministry of Agriculture and Livestock Development. During the next 10 years or so little new work was started, but routine recording of the experiments continued. A nitrogen (as NPK) experiment (T91) was initiated at Marikitanda in 1983, and another (T82) at Maruku (Bukoba district) in 1981. A plucking interval study (T83) was also started in Maruku in 1987. Three new clonal field trials started at Marikitanda in 1979, 1980 and 1985. The future management of this research institute is now under review.

Ngwazi Tea Research Unit

Between 1967 and 1970 fundamental studies into how the tea bush responds to climate and the availability of water were carried out on a small (4 ha) area of tea planted close to a lake on Ngwazi Estate in Mufindi. The climate at Ngwazi (alt. 1800 m) is characterised by a warm wet period from November to April, a cool and dry season from May to August, followed by a warm dry period from September through to the start of the rains. To this extent, it is typical of many other parts of the Southern Highlands of Tanzania, although rainfall can be locally variable, whilst temperature is largely a function of altitude. The sequence and duration of the wet and dry seasons, and the range of temperatures represented during the year though, meant that Ngwazi Estate, which is about 16 km north west of the main tea growing areas in Mufindi, has provided an excellent outdoor laboratory where fundamental studies can be undertaken on the water relations of the tea plant, including responses to temperature. In addition, practical information on the commercial value of irrigation, for example, can also be obtained. Thus, in the three year period 1967 to 1970, a series of experiments were carried out on the irrigation and water requirements of tea. These included identifying the limiting soil water deficits, and yield response to water for mature seedling tea (labelled N1); studies on how water and temperature influence the components of yield of clonal tea (N2); the yield response of clonal tea to irrigation and nitrogen (N3 and N4); the effects of shelter from wind on the yield and water use of tea (N5); and factors influencing root growth (N6). In addition, some detailed studies of the water relations of the tea plant were initiated. This work was responsible in part for the commercial introduction of irrigation on all the tea estates in Mufindi during the next 10 years or so (Hester, 1971); it also provided a basis for beginning to understand the basic mechanisms by which the tea plant responded to its environment, above and below ground. This was essential if the results were to be extrapolated with confidence to other tea areas within east Africa where the intensity and duration of the dry season, the depth and available water capacity of the soils, and prevailing temperatures varied.

Early in 1970 the Ngwazi Tea Research Unit was closed, and the key staff transferred to the TRIEA headquarters in Kericho, Kenya for the next phase of the 5-year project. The results of this work can be found in the Annual Reports of the TRIEA for 1966/68, 1968/69 and 1970. Many have also been published in the international scientific literature (Carr, 1970; 1971a & 1971b; 1972; 1974). One unexpected observation was the effect of shelter from wind with *Hakea saligna* hedges on the yield and water use of tea. The experiment was based on Kilima Estate, Mufindi close to the escarpment edge. Contrary to expectations at the time, shelter from wind <u>increased</u> the water use of tea during the dry season in unirrigated tea, although there was a net benefit from shelter during the rains (Carr, 1971a; 1985). Such a result does though have a scientifically sound explanation, and can be predicted from first principles. Rarely though has it been observed in field experiments anywhere else in the world. For unirrigated tea, these results led to a rethink on the commercial value or otherwise of *Hakea* hedges.

The results of the irrigation experiments also suggested that the yield potential of tea grown in the Mufindi district was a long way above the commercial yields being obtained at the time; there were obvious cumulative benefits from irrigating unshaded seedling tea, supplied with adequate quantities of NPK fertiliser, even when the tea was in the sixth year of the pruning cycle. For clonal tea, yields in excess of 4000 kg ha^{-1} were obtained, about three times the commercial estate yields being obtained at the time. New yield targets were being set for managers. The results also suggested that rates of fertiliser application could be substantially increased (from 100 to 300-400 kg N ha^{-1}) in well irrigated tea. The results of similar irrigation experiments being carried out in Malawi though gave very different results from those in Mufindi. These differences could be explained on the basis of the large saturation deficits of the air experienced during the dry season in some years in Malawi which restricted shoot extension rates even when the soil was wet, but not in Mufindi (Carr *et al*., 1987).

A number of factors were therefore beginning to come together during this period from the mid-1960s to the mid-1970s. The introduction of herbicides; the removal of shade trees; the use of NPK compound fertiliser (rather than sulphate of ammonia); a recognition of the role of irrigation. Collectively these factors were responsible for the increases in yield which occurred throughout the 1970s and into the 1980s on Brooke Bond Tanzania Estates (Congdon, 1991). Other growers though were constrained by a shortage of cash, labour and the difficulties in obtaining expensive inputs.

By the mid-1980s, it looked as though the commercial yields had reached a plateau of around 2500 kg ha^{-1} (Figure 1). The pressure though was still on to reduce the unit costs of production, and this could be best done by increasing yields from existing tea. The two most expensive inputs were irrigation water and nitrogen fertiliser. Silsoe College was invited by Brooke Bond Tanzania Ltd to undertake a statistical analysis of long-term commercial yield data to try to identify the optimum levels, and to see if there were opportunities to raise yield further in a cost-effective way. This request eventually led to a project which was jointly funded by the UK Overseas Development Administration (they had originally funded the earlier work at Ngwazi), Brooke Bond Tanzania Ltd and the Tanzania Tea Authority. Later, Mufindi Tea Company joined the consortium. The project immediately had a wider brief and this included doing a similar statistical analysis of commercial yield data for sites elsewhere in east Africa (in Kenya and Malawi) and from Tukuyu (Stephens *et al*., 1988; Carr and Stephens, 1991). The data were not always easy to interpret, and because of this it was decided to initiate an irrigation x nitrogen field experiment at Ngwazi. After an interval of 16 years, research at Ngwazi had begun again. This new experiment (labelled N9), based on the line-source technique, has allowed a large number of treatment combinations to be tested in a relatively small area of clone 6/8. In the six years since 1986, response functions to water and to nitrogen have been developed which can be used to quantify either the yield lost as a result of drought in different areas of Tanzania (and elsewhere), or to predict the likely benefits from irrigation in yield and cash terms (Figure 2). At the same time, new yield targets have again been set for commercial growers, of 5000-6000 kg ha^{-1} from well irrigated (500-700 mm per season) and fertilised (ca. 300-350 kg ha^{-1}) clonal tea (Stephens and Carr, 1989, 1991a, 1991b). The results of this experiment also suggest the yields that can be achieved in the Southern Highlands with low (no irrigation, 100 kg N ha^{-1}) input systems of production (1200-1500 kg ha^{-1}), declining eventually perhaps to 300-500 kg ha^{-1} if no fertiliser is applied. The same experiment has also advanced our understanding of how weather influences the rates of development and growth of individual shoots and hence yield (Stephens and Carr, 1993a; 1993b). Knowledge of this type can be used to optimise harvesting practices, for example by predicting harvest intervals in terms of phyllochrons, estimated from measurements of air temperature (Burgess and Myinga, 1992).

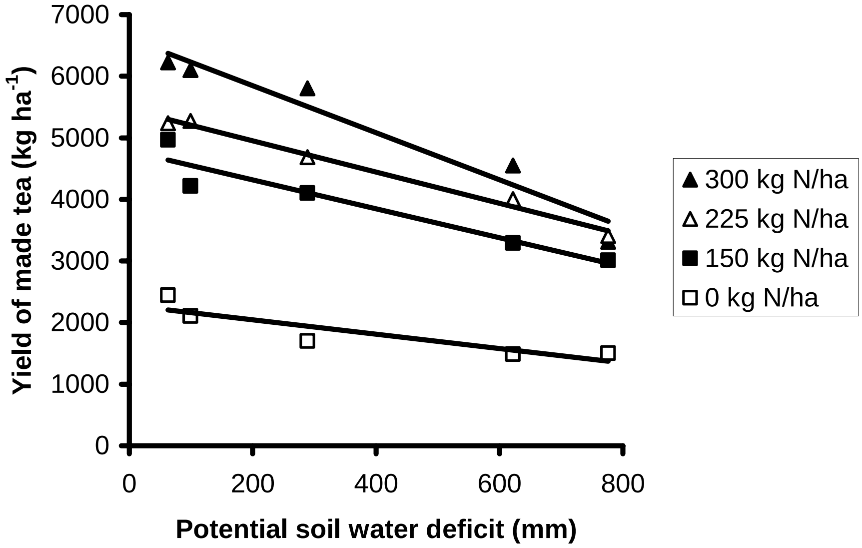

Figure 2. Yield responses of clone 6/8 to potential soil water deficit for four nitrogen treatments (Ngwazi Tea Research Unit, 1991/1992)

A fundamental philosophy behind the work is the need to try to ensure that field experiments not only provide results of short-term commercial value, but also that they contribute to the basic understanding of the mechanisms which control the responses (see Smith *et al*., 1993). Only in this way will it be possible to extrapolate results from one location to another, where the rainfall distribution is different for example, or where it is warmer or cooler, or to have a foundation of knowledge on which to begin to develop answers to the questions which growers will be posing in five or ten years time. Thus, advice can now be given on the yield increases to be expected by supplying additional irrigation water (up to 3 kg ha^{-1} for each mm of effective water applied), or by increasing the level of fertiliser in various combinations. This has already led in part to the yield/time curve continuing to rise, when it was feared that a plateau had been reached in 1985.

The results have also shown the yield levels that can be obtained from irrigated clonal tea, well supplied with fertiliser, in non-traditional tea areas such as the grasslands around Ngwazi estate or in the Njombe district. Major new developments are now occurring at both sites with big investments by Brooke Bond Tanzania Ltd, and the Commonwealth Development Corporation. In 5-10 years time there will be an extra 2600 ha of irrigated tea in the Southern Highlands producing up to 13 million kg of made tea per annum, equivalent to more than 70% of the current total national output. In addition, there will be improvements in the management of existing tea, as a result of using the experimental results to justify, for example, investment in irrigation schemes, including the construction of storage dams and new irrigation systems by Mufindi Tea Company (Weatherhead *et al*., 1990). Planting tea in the grasslands has the added advantage that it protects the remaining areas of rainforest. New large tea projects are also planned by the Tanzania Tea Authority in the Southern Highlands at Dabaga and Itambo.

The same research philosophy as that outlined above lay behind the planning and design of the second field experiment at the Ngwazi Tea Research Unit which was established in 1988, and labelled N10. This is a detailed evaluation of the response of six clones (chosen for particular scientific and commercial attributes) to drought (and irrigation) and to temperature. The clones are from Kenya, Malawi and Tanzania. The aim is to identify those cultivars which are most suitable for planting in the Southern Highlands, with or without irrigation, and at relatively high or low altitudes. The experiment is also providing information on the possible selection criteria for the next generation of clones. For example, the high yield of clone S15/10 (from Kenya) is associated with the large proportion of dry matter which is partitioned to the leaves and harvestable shoots, with correspondingly less to the structural roots, compared with other clones (Burgess, 1992). Similarly, the shoots of clone SFS 150 (from Malawi) are able to continue to extend at temperatures below the base temperatures of the other clones. Since it yields more than them during the cool season, it is probably suitable for high altitude tea areas such as Luponde Estate (alt. 2200 m). Recent analysis of earlier work at the Ngwazi Tea Research Unit showed for the first time, that there were quite large clonal differences in the responses of shoot extension to changes in temperature (Stephens and Carr, 1990).

Clone S15/10 yielded about 30% more than the other clones in experiment N10 when well watered. Indeed, yields of 3800 kg ha^{-1} were obtained from this clone in the third year after planting, and 5400 kg ha^{-1} in year four. Clone S15/10 also yielded slightly more than the others when only partially irrigated. On this basis, although the relative decline in yield was greatest with this clone, it could still be classified as drought tolerant. Surprisingly, clone 207 (originally selected on Luiga Estate in Mufindi) which is widely grown in the Southern Highlands on estates and by smallholders, yielded least when unirrigated, largely it appears because it is very susceptible to the fungal disease *Phomopsis theae*. This disease was first identified in Mufindi in 1963 (Hester, 1973) but since it can be controlled by irrigation (Carr, 1974), is no longer a major problem there. Clearly, it is still a problem for smallholders, especially those growing clone 207, without access to irrigation.

The work at the Ngwazi Tea Research Unit is now entirely funded by the tea industry in Tanzania and managed by Silsoe College. In addition to the original members of the consortium, the Tanganyika Wattle Company at Njombe, and George Williamsons (Tanzania) Ltd (with an estate in Tukuyu as well as in the Usambaras) are now contributing to the cost of the work, including the foreign exchange component. Each member of the consortium is represented on a Management Board. Over the next four years, the work will be expanded to include fundamental studies of how different clones respond to mechanical harvesting, the development and evaluation of composite plants, and an experiment to determine the optimum plant density for areas which experience different levels of drought. Experiment N10 (comparison of clones) will continue, whilst experiment N9 (irrigation x nitrogen) will run until the response functions have stabilised. Tea quality evaluations will be initiated in order to give an estimate of total value, rather than yield only. There is a well equipped agro-meteorological station at Ngwazi with data for the periods 1967-1970 and from 1986 to the present.

Kifyulilo Tea Research Station

With the demise of the Tea Research Institute of East Africa in the late 1970s, and its subsequent consolidation as the Tea Research Foundation of Kenya in Kericho, Tanzania was left with little or no active research and virtually no infrastructure apart from what had been left at Marikitanda. The tea industry itself was also struggling during the 1980s as a result in part of national economic and individual financial difficulties. When it is difficult to get fuel or spare parts for the factory, research is perhaps not the most important issue. The problem remains though that when the upturn comes, people immediately want answers to problems. For example, which clone should we plant? It was when this vacuum existed that Silsoe College was first invited to work with Brooke Bond Tanzania Ltd to help to solve a specific problem. Soon afterwards though it became clear that if the tea industry was to expand, it was likely to be mainly in the Southern Highlands, and probably not in the north of the country.

It therefore seemed eminently sensible for the new "Tea Research Institute of Tanzania" to be based in the Southern Highlands, and not in the Usambara Mountains. In 1986 the last remaining German tea growers in Mufindi (Werner and Helga Voight) left Tanzania to return to Europe. The Government of West Germany donated the farm (Kifyulilo) to the Tanzanian Ministry of Agriculture and Livestock Development with the expectation that it would become the new centre for tea research in Tanzania. Since then, with support from the Government, and from the Tanzania Tea Authority, the Kifyulilo Tea Research Station has developed a programme of research, principally clonal field trials, crop nutrition studies and mechanical harvesting experiments. Laboratories and other facilities have also been developed slowly as funds became available. Kifyulilo is situated on the extreme western edge of the Mufindi escarpment, in an area of high rainfall and on steep slopes with soils that were derived under rainforest. It is only 20 km from Ngwazi Tea Research Unit, but soil and climatic conditions, particularly the duration of the dry season, are different (Stephens *et al.*, 1988). The National Tea Research Coordinator is the Officer-in-Charge of Kifyulilo, and as such is also responsible for field experiments conducted elsewhere in Tanzania, including those remaining at Marikitanda (T41, T60, T91 and T93 (zinc) and the clonal field trials) and at Maruku (T82, T83 and T85 (zinc)) (Ndamugoba, 1989).

In Mufindi, two clonal field trials (under irrigation) were started in cooperation with Brooke Bond Tanzania Ltd, on Luisenga Estate (in 1987) and on Luiga Estate (in 1988). On Livalonge Estate there is a zinc response trial on irrigated tea (T86). At Kifyulilo itself, new field experiments have been started to study the nutrition of mature seedling tea which has been starved of nutrients during recent years, this included a nitrogen trial (T90). New clonal field trials (rainfed only) have also recently (1989) been planted at Kifyulilo, and a museum of all clones known to be grown in Tanzania has been established, a very valuable national resource. There is also a zinc experiment, a mechanical harvesting trial and, on a neighbouring smallholder plot, a study of how best to weed and to infill tea with a large number of vacancies. A start has been made on selecting clones and on developing composite plants. Two experiments have also been initiated in the Tukuyu district (zinc, and NxK, both are sited on Rungwe Tea Estate). An agro-meteorological station is in the process of being established at Kifyulilo.

Although there are sometimes practical difficulties, every attempt is being made to ensure that there is good cooperation and liaison between staff at the Ngwazi Tea Research Unit and Kifyulilo Tea Research Station.

YIELD POTENTIAL AND CONSTRAINTS

The yield potential of any crop can be described by the function:

$$\text{Yield} = S \times f_S \times \varepsilon_S \times H$$

where S is the incoming total short-wave solar radiation (MJ m^{-2}), f_S is the proportion of this radiation which is intercepted by the crop (including that which is reflected upwards), ε_S is the efficiency of conversion of the intercepted radiation into dry matter (g MJ^{-1}), and H is the harvest index, or the proportion of the total dry matter which is partitioned into useful yield. In the case of tea the useful yield is the dry weight of the young shoots with usually two or three expanded leaves and an unopened terminal bud. Using values based on those recorded in experiments at the Ngwazi Tea Research Unit in experiments N9 and N10, for the high input treatments, the potential yield of processed tea from good clonal tea (typically clone 6/8) at an altitude of 1800 m is about 6000 kg ha^{-1} (Table 2).

Table 2. Potential tea yield at Ngwazi Tea Research Unit

Incoming solar radiation (S)	6700 MJ m^{-2}
Light interception (f_S)	0.95
Conversion efficiency (ε_S)	0.5 g MJ^{-1}
Harvest index (H)	0.19
Potential yield	**6,000 kg ha^{-1}**
Potential yield =	$S \times f_S \times \varepsilon_S \times H$

This is similar to the highest yield so far recorded in experiments from fully irrigated tea, well supplied with nutrients, and harvested at appropriate intervals (Figure 2). Using this approach as the basis for setting target yields for this altitude in the Southern Highlands it is possible, using the results from experiment N9 (Figure 2 and 3), to estimate the actual yields achievable if certain inputs are taken away (Table 3).

Table 3. Potential and actual yields of processed tea in the Southern Highlands of Tanzania at an altitude of 1800 m.

Yield target	**6,000 kg ha^{-1}**
Drought	*(1,500)*
	4,500
Nutrient deficiency	*(3,000)*
	1,500
Incomplete ground cover	*(300)*
	1,200
Poor harvesting	*(600)*
Actual yield	**600**

Thus, assuming that the maximum soil water deficit (SWD) reached in the dry season is about 500 mm the total yield loss due to drought at 3 kg per mm increase in

the SWD is 1500 kg ha^{-1}. Similarly not applying nitrogen (as NPK 20:10:10) reduces yields at a constant rate of 10 kg per kg N below 300 kg N ha^{-1}. This represents a total yield reduction of 3000 kg ha^{-1}. When no fertilizer is applied, giving a net yield for unirrigated, unfertilised tea of about 1500 kg ha_{-1} , close to the value actually achieved in unshaded clone 6/8 tea, in the first year after pruning (Figures 2 and 3).
Similarly any loss in yield as a result of vacancies or incomplete ground cover will be directly proportional to the reduction in the amount of intercepted solar radiation. In this example it has been assumed that vacancies represent 20 per cent of the plant population, resulting in a further yield reduction of 300 kg ha^{-1}.

Finally yield can be lost as a result of irregular and erratic harvesting due to a range of extraneous social and economic factors, including delayed payments, lack of transport, shortage of labour or, in some cases, lack of factory capacity at peak times during the season. Assuming that this can represent a 50% yield reduction, the actual yield achieved is 600 kg ha^{-1}. This value is typical of that obtained on low-input smallholder farms in the Southern Highlands, and represents only 10% of the potential yield. The opportunities for increasing the yield from smallholder and estate tea which has already been planted is clearly enormous.

The example given in Table 3 refers to tea grown at an altitude of about 1800 m. Within the Southern Highlands tea is grown at altitudes ranging from 2200 m (at Luponde) to 1200 m (at Tukuyu). This can represent a difference of 5-6°C in the mean annual air temperature (Table 4).; Rates of shoot development (and extension) in tea can be described as a linear function of air temperature above a specified base temperature which can range from 8-13°C (Stephens and Carr, 1993a).

Table 4. Yield potential[a] at three sites in the Southern Highlands of Tanzania.

Site and altitude	**T_{mean}[b] (°C)**	**SRCs per year[c]**	**Annual yield (kg ha^{-1})**
Luponde (2200 m)	15	2	3500
Ngwazi (1800 m)	17	3.5	6000
Tukuyu (1200 m)	20	5.5	9500

a. Assumes no other major limiting factor such as very low or very high temperatures, dry air, dry soil or nutrient stress.
b. Annual mean air temperature.
c. Shoot replacement cycle (see text for details).

The time taken for an axillary bud released from apical dominance to grow to a harvestable shoot, with three expanded leaves and an unopened terminal bud, is known as the 'shoot replacement cycle' (SRC) and is measured in days. At the Ngwazi Tea Research Unit (alt. 1800 m) the typical duration of the SRC, for irrigated and well fertilized tea (clone 6/8) is about 60-70 days during the main growing season, increasing to 90-95 days in the cool season. Over the year as a whole about 3.5 shoot replacement cycles are completed. Using established relationships between shoot development rate and mean air temperature, the corresponding number of shoot replacement cycles which can be expected at Luponde (alt. 2200 m) is 2-2.5, increasing to 5.5 at Tukuyu (alt. 1200m). Since clones differ in their responses to temperature, this analysis is by necessity simplified. It does though give an indication of the potential yields which can be achieved at different sites within the Southern Highlands, when low temperature is the principal limiting factor. The analysis does not take into account any effect of temperature on the dry mass of a shoot, at the same stage of development, at harvest (Stephens and Carr, 1993b). It also assumes that there are no other major limiting factors such as frost (at Luponde), or high temperatures (>30-32°C) or dry air (saturation deficits > 2.3 kPa) at Tukuyu. The effect of temperatures on the inherent quality of the harvested leaf has also not been considered.

If tea production is to start to approach the target yields there are a number of socio-economic, technical and other innovations to be implemented. Under the first heading issues related to security of land ownership and incentives, including availability of credit, regular payments for green leaf, reliable transport, and adequate factory capacity during the peak seasons must all be addressed if smallholders are to take the crop seriously. On the technical side the sequence of innovations needed should begin with infilling vacancies with clones (which in turn will help weed control), improved nutrition (from a nominal 75 kg N ha^{-1} at present up to 300 kg ha^{-1} as NPK), improved harvesting (perhaps using mechanical aids if labour is short), water conservation (mulch in young tea, micro-catchments) and, for those with access to water, irrigation. The last requirement is probably any extension of the planted area, unless it is for a new grower. To facilitate these developments training at all levels, particularly perhaps the extension officers is essential.

THE FUTURE

A forward thinking and progressive industry needs good and relevant research support if it is to compete adequately in the international market place. The tea industry in Tanzania is no exception to this rule. An industry can live for a while on the cumulative results of earlier research, and perhaps the tea industry in Tanzania was able to profit from the work done by the old Tea Research Institute of East Africa during the 1960s and 1970s, particularly in the areas of crop improvement, crop nutrition and irrigation. But during the last 10 to 15 years, expectations have changed: what were acceptable yields in 1970 are no longer adequate. When the estate sector in Kenya can obtain average yields of around 3500-4000 kg ha^{-1} and smallholders average about 1000 kg ha^{-1}, Tanzania must be in a position to compete in terms of total value less costs of production, if it is to remain competitive. Where, for example, will the new clones or composite plants for the next century be coming from, or will Tanzania be dependent on its neighbours for planting material? Tea research in Tanzania must be developed quickly in a rational and sustainable way, and this might not necessarily be by creating another `Tea Research Institute' in the traditional mould.

The current constraints to tea production in Tanzania can be best summarised under three main headings:

1. Technical
2. Farming Systems
3. Training

For an industry to develop and to remain commercially viable, it must remain innovative and be prepared to test, validate and implement new ideas and techniques.

These will come largely from the results of strategic, *technically-based research*. The leaders in the industry will demand this.

At the same time, there are constraints to production which come within the *farming systems* sphere. This includes such things as: availability and cost of credit, labour and other inputs; the relationship between tea and other crops; methods and regularity of payment; availability of transport for green leaf etc. Similarly, if new ideas are to be implemented in commercially effective ways, there is a continuing need for *management* and *skills training* at all levels within the industry.

Technical Research

Although the basic agronomy of tea production is relatively well understood, and reasonably well documented, there are still subjects of continuing concern. These include the development of new superior planting material (clones and/or composite plants) adapted to the diverse ecological areas within Tanzania. For this work to develop rapidly, fundamental studies are needed on the physiology of tea, and the genetic variability in responses to climatic and other variables. A full understanding of how these factors influence shoot growth, can lead in turn to improved harvesting policies and perhaps more effective use of labour. Tea nutrition, a major component of cost for all producers, is still not fully understood and fundamental studies leading hopefully to cost effective fertiliser policies is required for the major and minor elements. Will it always be necessary to keep repeating fertiliser trials around the country? Alternatives to inorganic fertilisers also need to be considered, such as the composts, and animal wastes being used on Luponde Estate, in that case to produce tea which meets the international criteria for organically grown produce.

Although fortunately there are no pests or diseases in Tanzania of major economic importance (except perhaps *Phomopsis theae* and *Armillaria mellea*), there is a continuing need to be vigilant, and the tea industry needs access to appropriate expertise. Witness a new unknown disease which is of increasing concern in Mufindi.

In the Southern Highlands, in particular, lack of rain and low temperatures are major constraints to high yields. Issues such as drought tolerance, the ability to grow at low temperatures, drought mitigation and irrigation are important to low and high input producers alike.

Developments in tea processing have largely come from the industry itself, particularly the private sector which, understandably, is not always keen to share this hard-won knowledge with organisations it may perceive to be competitors. A fundamental understanding of the chemistry of the tea manufacturing processes, and the ability to measure and control these processes in the factory, is needed if the industry as a whole is to compete in the world market, and to produce products of an acceptable quality for an ever changing and more discerning market. Such developments are occurring elsewhere in the world, including Kenya and Malawi. This work has to be linked with the inherent quality of the leaf provided from the field.

Farming Systems Research

Equal emphasis must be placed on the application and relevance of research to the different sectors of the tea industry. Although technical research can and should have a medium to long term perspective, the interpretation and application of existing knowledge has to match existing socio-economic conditions. For smallholders, tea is just one of several crops; how people allocate their time and invest often limited resources depends on many social and economic issues. For large sections of the tea industry, including the private and public sectors, large and small producers, there are many issues which fall into this category; for example, the question of incentives needed to attract pluckers in order to ensure that there is enough labour throughout the year (but not at the expense of food crops at home). If labour is not available, or smallholders have other demands on their time, there probably is a need for some form of appropriate mechanical aid, such as shears or blades, to increase labour productivity. There is an immediate need to undertake a survey of tea smallholders to identify the constraints to production which they recognise as being important, so that appropriate strategies to overcome them can be identified. These could be technical, social, financial or procedural.

With constantly changing costs of inputs, prices of tea and exchange rates, it is necessary to determine regularly the most cost effective management practices, so as to be able to answer the "what if" type of question. For example, "what if the price of tea falls by 20 per cent, is it still worthwhile applying x kg ha^{-1} of fertiliser?", or, "what if the premium for quality declines by 20 pence (TSh 150), is it still worthwhile harvesting `two leaves and a bud', or is it now better to go for quantity rather than quality and harvest more `three leaves and a bud?" Good data and modern computing skills are needed to be able to answer questions like this.

An industry supported research institute must be able to evaluate the applicability of the results of research in financial terms appropriate to the sector it is serving.

Training

Under this heading comes the whole question of technology/information transfer. It is of little value undertaking applied research unless the information can be communicated, adapted as necessary, and applied (either immediately or at an appropriate time in the future) in a practical way to the benefit of the industry, and the country. Communication (written, visual and verbal), management and technical skills need to be developed in staff working within the tea industry at all levels. This applies equally to research, extension and estate management staff. Research workers must be able to communicate their results either directly to growers, or to extension officers in language that can be understood, and not just to peer-group scientists.

It is also important that scientists submit their work for critical international evaluation in the scientific journals; industry and government can then have some faith that their researchers are good scientists.

Similarly, extension officers need to be able to communicate relevant and useful information directly to smallholders in easy to understand ways, and so earn the respect of the farmers through ability rather than through formal educational qualifications alone. People can be trained to do all these things, but first the training needs have to be identified in a systematic and action based way (Harding and Carr, 1991). Training therefore must be an essential third function of a research institute.

Research philosophy

Finally, it is not necessary for a Tea Research Institute to be large to be successful. Priorities for work need to be established early, and flexible systems developed which allow scientists and others to come together to work on specific projects for limited periods of time, depending on recognised needs. Experiments, wherever possible, should be designed to increase our scientific understanding of how a tea bush functions as well as providing answers to practical problems: these are not mutually exclusive objectives. Empirical experiments are usually of little long-term value to anyone, and commercial pressures to do work of this type must be resisted. Look to synthesise the results of existing (and past) experiments and attempt to identify mechanisms responsible for the observed effects, in order to predict what will happen elsewhere where the conditions may be different. Do a few experiments well: be prepared to stop experiments (something tea scientists find very difficult to do). Finally, research is not complete until the results have been published, *and* interpreted as clearly as possible for the benefit of tea growers.

Too often tea research is undertaken in isolation, geographically and intellectually. Not enough information is shared between countries, or between individuals working in different but comparable crops. A tea bush is a tea bush wherever it is grown (with relatively minor genetic differences); what we observe in the field is its response to physical, chemical and biological environments in which it is growing. These can now be described and quantified. It is no longer desirable or justifiable to keep repeating experiments in time or in space. We must be aiming to develop our understanding so that we can predict how the tea bush will respond to different conditions, and then to test whether these predictions are correct. The wide range of ecological conditions in Tanzania (and neighbouring countries) where tea is grown, provide an excellent outdoor laboratory in which to develop the approach and to set an example to the rest of the world.

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