

*INTERPLANTING IN TEA: 2—THE INTERACTION OF SHADE WITH FERTILIZER APPLICATIONS

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Introduction

Walter (1950), Portsmouth (1951), and Visser and Kehl (1956) used an ecological argument in favour of the use of shade in tea, namely that tea is a "shade-loving" plant, because the tea in its natural habitat grows under shade.

However, man has rarely paid much heed to such crude ecological arguments in the development of his crop plants, or he would not cultivate his soil, weed his crops, or apply manure to them. This is also true for tea; the conditions under which it is commercially grown today are very different from those of the tea growing in the forest, for it is pruned, plucked, manured, and cultivated.

Accordingly, the habit of the tea tree has been fundamentally changed by its artificial conversion into a leaf-producing bush. Therefore, it may well be asked whether it is necessary, or under what conditions it is useful, to give a poor imitation of one single aspect of a forest, namely, by sparsely interplanting the tea with shade trees.

The shade question is not new but it has recently come into the limelight again. De Weille (1959) in Indonesia discussed shade trees especially in connection with blister-blight control and concluded "that shade removal can be carried out and there is no need to fear any damage by sun or wind". Wight (1959 a, b, c), in a series of articles, extensively reviewed the work done in Assam, demonstrating the complex nature of the interaction between shade and fertilizer application and the importance of differences in reaction of different *agrotypes* of tea. On the whole, Wight's observations indicate that the use of *Albizzia chinensis* shade trees under Assam conditions is to be favoured for both agricultural and economic reasons.

Lately Child (1960), in East Africa, reviewed many of the historical data on the shade-tree tradition, as well as observations made on the effect of shade trees in Kenya and Nyasaland. He reached no conclusions but indicated "the danger of making or of accepting dogmatic assertions" on the shade question.

I have recently discussed several aspects of shade trees, cover crops, and weeds, in relation to soil moisture, mobilization of and competition for nutrients, and organic matter (Visser, 1961 a): In the present paper I review and discuss the influence of shade *per se* and its relation to fertilizer applications.

2. Shade and manuring with special reference to nitrogen

The majority of experiments on shade and manuring have been carried out by the Tocklai Experiment Station over a period of 30 years. In order to distinguish

the effects of shade itself from effects of shade plus root competition acting together, bamboo screens were used and compared with normal shading by growing trees. The experiments indicated that generally the interaction between nitrogen and shade is the more important one.

Table 1 gives two examples derived from graphs (of different trials) given by Dutta, Basu and Sharma (1953) and Wight (1959b) on the effects of natural and of artificial shade in relation to increased nitrogen applications.

TABLE 1.—Annual yield of tea (in lb. per acre) under natural shade (*Albizia chinensis*) and artificial shade (screens, giving 50% light intensity) as affected by nitrogen application (Assam).

Tea planted in 1932; *Albizia chinensis* in 1942.

1	2	3	4	5
Period	Treatment	Zero N	90 N	Gain due to N
10 years (1942-'51)	Shade trees	900	1120	+220
	No shade	752	1084	+332
	Gain due to shade	+148	+36	

Tea planted in 1920; screens erected in 1951

1	2	3	4	5
Period	Treatment	Zero N	80 N	Gain due to N
7 years (1951-'57)	Screens	790	790	0
	No shade	480	880	+400
	Gain due to shade	+310	-90	

Table 1 shows that the shaded tea was more productive than the unshaded when no nitrogen was given (Columns 3); but with 80 lb. or 90 lb. N, the unshaded tea was about the same as the shaded. The effect of N was thus far more beneficial with unshaded tea than with shaded (Columns 5). With 80-90 lb. N, the unshaded tea had caught up with the shaded; the results suggested that with still more N, unshaded tea would gain still more and give a higher ceiling to the crop.

In a sense, shade thus appears to be equivalent to a certain amount of nitrogen, in these two cases about 30 to 60 lb. N per acre. In another long-term trial initiated by Cooper (Wight, 1959a) shaded tea without nitrogen was found to yield nearly as much as unshaded tea which had received on an average 84 lb. N yearly.

The influence of shade *per se* has been investigated at Tocklai in many other trials both on unmanured tea (Wight, Barua, Green & Barua, 1958; Barua 1956, 1957 and 1960) and in the presence of different dosages of nitrogenous fertilizer at varying light intensities (Dutta & Heath, 1954; Dutta & Basu, 1956, 1957; Dutta, Basu & Sharma, 1958). These trials showed basically the same results as those presented in Table 1, namely that the yield of the tea depends both on the shading density and the nutrient supply (soil fertility).

Shade-tree and nitrogen effects have also been investigated by the Tea Research Station in Nyasaland, the results being given in Tables 2 and 3 (Anon. 1954, 1955, 1956, 1957, 1958, 1959 and 1960).

TABLE 2.—Annual yield of mature tea (lb. per acre), unshaded and shaded by *Albizzia gummifera*, with and without nitrogen (Nyasaland)

Tea planted in 1932, *Albizzia gummifera* in 1949.

Treatments	Period I: 52/53—55/56			Period II: 56/57—58/59		
	Zero N	80 N	Gain due to N	Zero N	80 N	Gain due to N
Shade trees	510	629	+119	755	907	+152
No shade	342	602	+260	672	1039	+367
Gain due to shade	+168	+27		+83	-133	

TABLE 3.—Annual yield of young tea (lb. per acre) under different shade-tree species (similarly manured) (Nyasaland)

Tea planted in 1951, trees in 1952.

Treatments	Period I: 1953/54—55/56		Period II: 56/57—58/59	
	Yield	Gain due to shade	Yield	Gain due to shade
No shade	305	—	1,185	—
<i>Grevillea robusta</i>	336	+31	1,045	-140
<i>Albizzia gummifera</i>	336	+31	856	-329
<i>Gliricidia maculata</i>	280	-25	778	-407

Table 2 shows the same tendency as was observed in the Tocklai trials, namely that shaded tea gives a higher yield than unshaded tea in the absence of nitrogen, but that nitrogen applied to unshaded tea increases its yield more than that of shaded tea. The yields of the manured tea over the first period of 4 years are about the same, irrespective whether or not shade is present, while that of unshaded tea over the second period—at the end of which the shade trees were ten years old—was significantly higher than that of shaded tea. This is presumably due to the fact that as the trees grow older, the light intensity under them is reduced and competition increases. In this experiment shade trees were about equivalent to 40–50 lb N.

Table 3 demonstrates a similar effect on young tea of the age of the shade trees. During the first period—at the end of which the trees were five years old—the effects of the trees were small (of the order of 8–10%). During the second period of three years, all shade-tree species depressed yield, particularly *Gliricidia* and *Albizzia*. These trees had by that time formed a closed canopy, so that competition for light occurred and, especially in the case of *Albizzia*, competition for moisture too (Anon. 1960). The fact that yield was depressed least by *Grevillea* is probably due to the fact that this tree neither provides such a heavy shade as *Gliricidia*, nor competes so severely for moisture (and nutrients) as *Albizzia*.

Another example of the effect of shade on nitrogen responses is given in the form of a graph which presents the summarised results of two manurial trials carried

out by the Tea Research Institute of East Africa (Kericho) and the Tea Research Institute of Ceylon (St Coombs). At each location the nitrogen responses in the one experiment were investigated on tea under *Grevillea robusta* and in the other trial in the absence of shade trees. The Kericho trial represents yields over a 4 year cycle (Goodchild, 1956; Goodchild and Foster-Barham, 1957, 1958, 1959, 1960). The St Coombs trial without shade represents average yields over the 2nd cycle—20 to 40 lb. N—and 4th and 5th cycle—40 to 80 lb. N (Eden, 1949b); the figures relating to shade present yearly averages of the 3rd and 4th cycle of an experiment initiated by Eden (1941, 1943).

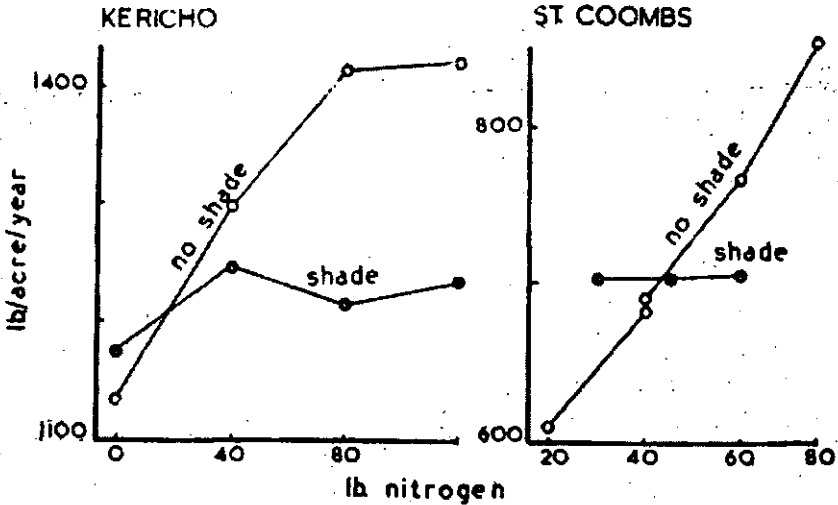


Figure 1. Nitrogen responses of tea under *Grevillea robusta* trees and of unshaded tea—Kenya and Ceylon

Although Figure 1 presents data from two different trials, they allow a qualitative comparison. It is shown that the trend is the same as mentioned before, namely that unshaded tea responds better to nitrogen than shaded tea. The yields of the unshaded tea increase linearly with the nitrogen dosage up to 80 lb per acre in both instances. The yield of the shaded tea, on the other hand, is not much affected by the nitrogen dosage.

The observed interaction between shade and manurial application is a general one and it applies to other crops that are traditionally shaded, such as cacao.

Table 4 represents the results obtained by Cunningham and Lamb (1958, 1959) in Ghana on 10-year old cacao, unshaded and shaded, unmanured and manured over the last three years with N, P, K and Mg.

TABLE 4.—Annual yields of cacao (lb./acre), unshaded and shaded by *Gliricidia maculata*, with and without fertilizer (Ghana)

Treatment	No fertilizers	NPKMg	Gain due to fertilizer
Shade trees ...	615	869	+254
No Shade ...	1,079	1,574	+495
Gain due to shade ...	-464	-705	

It will be seen from Table 4 that the unshaded cacao yielded markedly more than the shaded, even in the absence of manuring. This indicates both a high soil fertility and shade so heavy as to limit nutrient uptake. Again responses to manuring were higher without than with shade. Comparable trends were also observed in Trinidad on a spacing-cum-manuring trial, unshaded and shaded by shade trees (Havord, Maliphant & Cope, 1954, 1955; Maliphant, 1959a) and in a manurial trial in which young cacao was grown under light intensities varied by means of bamboo screens (Evans & Murray, 1952; Murray 1953, 1954, 1955a, 1958). It appeared from the latter experiment that with light intensities less than 50%, light was limiting yield; with more than 50% light there was a drop in yield of the unmanured plots but an increased yield of the manured plots indicating that then nutrient availability was limiting yield. In this trial the cacao trees in the early stages after planting grew better under shade than without.

TABLE 5.—Annual yield of cacao under shade (*Erythrina poeppigiana*) and artificial shade (screens, giving 50% light intensity) with and without fertilizer (Trinidad).

Yield in lb./acre (6th crop year)

Treatment	No fertilizer	NPK	Gain due to fertilizer
Shade trees ...	924	1,215	+291
No shade ...	610	1,488	+878
Gain due to shade ...	+314	-273	

Yield in No of pods/12 trees (4th Crop year)

Treatment	No fertilizer	NPK	Gain due to fertilizer
Screens ...	66	114	+ 48
No shade ...	26	152	+126
Gain due to shade ...	+40	-38	

Table 5 is an example of the trends of young cacao some years in bearing. It presents the results of two treatments—not manured, and manured with NPK—of the trial under shade trees (Maliphant, 1959a) and of the trial under screens (Murray, 1955a) respectively.

It can be seen from Table 5 that the interaction between shade and fertilizer application with respect to cacao is the same as that observed for tea (*see* Table 1), irrespective of whether the light intensity was reduced by shade trees or by screens. In both instances, shade significantly increased yield in the absence of fertilizers but decreased it when N, P and K were applied. The gains due to fertilizer applications were about three times as high for unshaded cacao as those for shaded cacao.

A recent review by Dierendonck (1959) refers to experiments carried out in Central and South America which indicate the existence of a similar relationship between shade and manuring with coffee as found for tea and cacao. Yield responses to fertilizers, particularly nitrogen, by unshaded coffee were observed to be much higher than corresponding responses under shade.

3. Shade and manuring, with special reference to phosphate and potash

As regards shade and phosphate applications, a negative interaction has been found in several trials carried out by the Tocklai Experimental Station (Dutta & Heath, 1954; Dutta, Basu & Sharma, 1958; Wight, 1959a & c). It appeared that phosphate increased the yield both under natural and artificial shade, while decreasing it in full daylight. Wight (1959a, 1959c) suggested that the phenomenon is perhaps in some way connected with mycorrhiza, as their development may be affected by the light intensity as shown by Björkman (1942) for *Pinus* and *Picea*.

On the other hand, the relation between shade and phosphate may have other causes, though not necessarily related to shade trees, as inferred by Dutta *et al* (1955 & 1956) because the interaction was also negative under artificial shade. It seems possible that the depressing effect of increased phosphate is partly associated with weed growth—particularly in the case of annual pruning—for weed growth is reduced by shade and greatly enhanced by phosphate (Eden, 1944, 1949a; Visser, 1961a).

These suggestions do not explain why a positive response to phosphate was found in an *unshaded* long-term trial at St Coombs (Eden, 1949b) and a negative response in *shaded* tea at Passara (Eden, 1949a; Portsmouth, 1954; Visser, 1957). Likewise, phosphate under shade had not a positive effect in all trials carried out in Tocklai; e.g. in a trial with different shade-tree species, phosphate (or potash) had no effect on yield either in the presence or the absence of nitrogen (Dutta & Heath, 1954; Dutta, Basu & Sharma, 1959).

Responses to phosphate in experiments carried out in East Africa (Eden 1953, 1954; Goodchild, 1955, 1956, 1957; Goodchild & Foster-Barham, 1957, 1958, 1959, 1960) were very small whether or not the tea was shaded; in two shaded trials, phosphate increased yield by 2 and 5%, in two unshaded trials by 1 and 1.5%.

In experiments on young cacao on Trinidad with and without shade trees (Maliphant, 1959a), and under varying light intensities obtained by screens (Murray, 1954, 1955), phosphate responses were on the whole higher for unshaded than for shaded cacao.

With respect to potash applications and shade, it was found that potash responses of cacao under shade trees were higher than those of unshaded cacao (Havord, Maliphant & Cope, 1955; Maliphant, 1959a); while potash applied to cacao under screens increased the yield above 50% light intensity and had its maximum effect at full sunlight (Murray, 1954, 1955a). The effect of potash on the yield of tea in trials carried out in East Africa was negligible, irrespective of the presence of shade trees. In the Tocklai experiments too, no interaction between shade and potash application was found.

It is evident from the foregoing that there is no clear-cut relation between shade on the one hand and potash and phosphate responses on the other. Undoubtedly both soil conditions and the amounts and the proportions of the fertilizer mixtures play an important part. When mineral supplies are adequate, manurial effects may be absent irrespective of shade; the effects may even be negative, if an abundance of one mineral leads to a decreased availability of the other.

On the whole, it would appear that nitrogen is the most important element in relation to light intensity and is probably in most instances the limiting factor rather than potash and phosphate. It seems likely that these latter nutrients (and others) will become limiting only if their availability in the soil is limited (or unbalanced) and nitrogen requirements are satisfied.

4. Effect of shade and fertilizer application on the composition and characteristics of leaves

4.1. MINERAL COMPOSITION.—As regards the percentage mineral content, Blackman and Rutter (1947, 1948, 1949) made an extensive study of bluebells (*Scilla non-scripta*). They found that shading increased the percentage contents in the leaf of N, P and K, the last being most affected. In all but one instance, the effects of increased nutrient supply on the percentage content of any of the elements were of much the same magnitude at all levels of light intensity. The exception was in one trial where the effect of additional potash decreased with reducing light intensity.

Leaf analysis of young cacao in trials under artificial shade (Murray, 1953) and under natural shade (Maliphant, 1959b) showed that light intensity markedly affects mineral levels in the leaf. The overall effect of shade was to increase the levels of N and particularly that of K. However, similar levels in unshaded plants could be produced by additional applications of N and K.

In Murray's trial the percentage P-content was not much affected by either light intensity or phosphate application. In the experiment by Maliphant, phosphate fertilizer markedly increased leaf P-content in the absence of shade. In this trial nitrogenous fertilizer depressed the P-content and potash decreased the N-content of the leaf more markedly in the absence of shade than with shade. Results similar to those of Murray were also obtained by Tanada (1946) for coffee seedlings grown under different light conditions in water cultures. It was found that N and K contents of shaded leaves were much higher than those of unshaded leaves, while P-contents were little affected by the light intensity. Dierendonck (1959), in a review of the effect of shade and manuring on coffee, concluded that leaf-nitrogen levels of unshaded coffee can be potentially as high as, or possibly higher than those of shaded coffee when sufficient nitrogen is available in the soil.

Barua (1957) found in tea artificially shaded by screens that the percentage N-content of plucked shoots significantly increased, though the increase was small, with reduced light intensity. Neither the dosage rates (75 and 150 lb N) nor their interaction with light intensity had significant effects.

It would appear that the tendency of unshaded plants to contain a lower percentage of minerals than shaded plants is mainly an indication of the insufficiency or lack of balance of the nutrient supply in relation to the increased demands of the more rapid metabolic processes in the plant.

4.2. LEAF CHARACTERISTICS AND QUALITY.—With regard to the influence of light on the leaves, it appears that increased light intensity generally reduces leaf size (Murray 1953; Visser 1960) increased leaf thickness (Visser 1961b), and may also increase dry matter percentage (Murray, 1953, Barua 1957), though no such increase occurred in our experiments with tea (Visser, 1961b). Observations of De Haan (1949) on cropshoots of shaded and unshaded tea plants in pots showed that the total number and total weight of the shoots harvested from unshaded plants in comparison with shaded plants increase, while individual shoot-weight decreases with time. The shoots of the unshaded plants appeared to be shorter and tended to become dormant sooner than shoots of shaded plants. It was further observed that shaded plants tended to produce as much or more during the dry season, but less during the wet season than unshaded plants.

Acute nitrogen deficiency as indicated by the yellow flush of the unshaded plants is likely to have been partly responsible for the observed tendencies. De Haan

remarked that the effect of light is strongly dependant on soil fertility; plants on fertile soil react better to full sunlight than those on poor soil.

The influence of light intensity (40, 50, 100%) and of nitrogen (75 and 150 lb.) on the component parts and nature of cropshoots were investigated by Barua, Dutta and Gogoi (1958). The treatments had some effect, but the observed differences were so small that it seemed unlikely that they would have influenced the grades and appearance of made tea.

Tests were carried out at Tocklai during two seasons on the characteristics and valuation of unshaded and shaded (by screens) tea (Dutta & Heath, 1954; Dutta & Basu, 1957). No differences were found as regards quality, briskness, colour of the tip, and appearance of the made tea. In one of the tests, strength and colour of the liquor were greatly improved by shade, in the other test only the colour of the liquor improved while colour of the infused leaf was significantly better for teas grown under full light. The valuation of the made teas was the same, irrespective of shade, during both seasons.

Similar tests on the influence of the nitrogen level—0 and 100 lb N in one and 0, 40 and 80 lb N in another trial—showed no differences in the valuation of the made teas in relation to the rate of nitrogen application (Dutta *et al*, 1954 & 1957).

According to Gokhale (personal communication) previous tests done at Tocklai showed that nitrogen doses higher than 100 lb per acre decreased quality, but the possibility that this was caused by the fact that nitrogen applications only (and not those of P and K) were increased, may not be excluded. Keegel (personal communication) has no reason to assume that the relatively high nitrogen doses (in proportion to P and K) as applied in Ceylon have any effect on quality, but little is known for applications greater than 100–120 lb. per acre.

5. The influence of the removal of shade on yield

The effect of shade removal is of practical importance because it arises when old shade is removed and the field is left unshaded either permanently or temporarily until the newly-planted trees have formed a canopy again.

This problem was investigated in a trial by Evans and Murray (1952) and Murray (1953, 1954, 1955a) earlier referred to (*see* p. 117) and in which young cacao was grown at varying light intensities (obtained by screens) and different manurial treatments. Provision was made in this experiment for the removal of the shade on half the plots, which was done at the beginning of the 4th year after planting (Murray, 1955a). It appeared subsequently that the responses to shade removal were greater where the initial shade over the plots had been greater. The yields of plots previously shaded to allow 15, 25, 50 and 75% light intensity were on an average (all treatments) 108, 88, 71 and 51% higher respectively than those of their still shaded counterparts. The absolute yields of the previously shaded plots receiving a balanced NPK mixture were 35% (averaged for 15 and 25% L.I.) and 24% (averaged for 50 and 75% L.I.) higher than the yield of equivalently manured plots which remained unshaded throughout. This increase in yield following shade removal in comparison with permanently unshaded plots indicates that under the improved light conditions use is made of soil reserves or mineral reserves in the plant, accumulated during the shade period.

The amount of increase in crop was related to the mineral nutrition of the plant. Plants previously heavily shaded showed a response to nitrogen on removal of shade; plants previously growing at high light-intensities showed little response

to nitrogen, but a marked response primarily to potash, secondarily to phosphate. Murray (1955a) attributed the significance of this difference in response to nitrogen to the better growth and subsequent self-shading of the unshaded plants. Further, after nitrogen requirements are satisfied, the availability of other elements may become limiting.

A trial on the influence of shade removal on tea was carried out in Indonesia by Vink (1953). In this case an area of a field heavily shaded by *Leucaena* species was divided into four half-acre blocks, receiving the same manure and of which the shade trees were felled or lopped so as to provide 4 treatments; A=no shade (all trees removed), B=light shade, C=medium shade and D=heavy shade (all trees left) giving light intensities (measured by Van Emden & Laoh, 1953) of 100, 60, 39 and 18% respectively. Before shade was removed the blocks were pre-plucked for about 4 months and they gave similar yields per block. The subsequent yields obtained after partial or entire removal of the shade are presented in Figure 2.

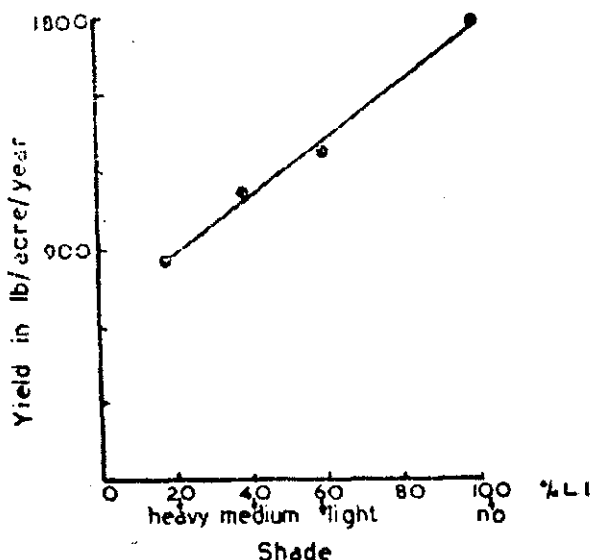


Figure 2. The effect of partial or entire removal of shade on tea yield (Indonesia)

Figure 2 shows that the yield increased in linear proportion to the increased light intensity. The complete removal of the shade approximately doubled the yield. The graph also suggests that yield increases will be greater when the light intensity before shade removal had been lower (as shown for cacao).

Both the trials on cacao and tea confirm the practical experience of estates in Ceylon that marked yield increases can be obtained following shade removal. The question is, however, can this increased yield be maintained?

A partial answer is provided by another experiment carried out in Indonesia (Vink, 1953). This trial was laid out in mature tea and consisted of 8 blocks, each of 1½ acres. The medium to heavy shade, consisting of a mixed stand of *Albizzia falcata* and *Leucaena* species, was kept in 4 blocks and felled in 4 others (Jan. 1940). All blocks received only one manurial application of about 33 lb N and 40 lb P₂O₅ per acre in August 1940, and were plucked until June 1944 (Periods 1 and 2).

Thereafter, the field was rested until 1947 and then manured at 29 lb N + 17 lb P₂O₅ per acre per year. Experimental plucking was resumed from March 1949 until May 1950 (Period 3). At the end of this period most of the old *Albizia* shade was removed and replaced by new trees and dadap cuttings; manuring was stepped up to 120 lb N + 70 lb P₂O₅ per acre per year because the unshaded bushes showed signs of deterioration. Experimental plucking was done from November 1950 until February 1950 (Period 4).

TABLE 6.—*The long-term effects of shade removal on yield (lb./acre) of mature tea, as affected by under-manuring and resting (Indonesia)*

Period	Shaded	Unshaded	Gain or loss due to shade
1. April '40—Dec. '41 ...	613	1,057	-444 (73%)
2. March '42—May '44 ...	715	711	+ 4 (1%)
3. March '49—May '50 ...	1,017	952	+ 65 (8%)
4. *Nov. '50—Feb. '52 ...	1,209	1,062	+147 (12%)
Total ..	3,554	3,782	-228 (6%)

*"Shaded" plots during Period 4 were actually virtually unshaded as the old trees were felled just before plucking started.

Table 6 shows again a highly increased yield over the first year after shade removal (1), followed by a decrease in subsequent years (2) when shaded and unshaded tea yielded the same. After resting (3), the yield of the shaded tea was slightly higher than that of unshaded tea, which difference increased somewhat in the fourth period (4).

These trends are probably largely due to insufficient manuring, which had been virtually negligible in relation to the yields obtained during the first 10 years of the experiment. Under such conditions it is no matter of surprise that, over this period, shaded tea produced nearly the same yield as the unshaded tea. The nutrient requirements of the latter would have been much higher than those of the former, as all experiments so far described have shown.

The increased yield of the shaded tea as compared with the unshaded tea during the fourth period actually reflects the immediate effect of removing shade in the so-called shaded plot, as most of the shade had been removed at the start of this period. As the increased yields for the shaded and unshaded tea amounted to 18 and 12% respectively (period 4 versus period 3), one might say that two thirds of the increase was due to increased manuring and one third due to the removal of shade trees.

By and large, the indications are that the initial increased yield of the unshaded tea over that of shaded tea can be maintained if the tea is properly manured throughout. Improved light conditions will lead to a higher rate of metabolic activity in the plant, requiring a greater supply of nutrient.

6. Discussion

The foregoing review of experiments carried out on tea in particular, and also on cacao and coffee, leave not a shadow of doubt that shade and nutrient effects are interrelated phenomena. On the whole, it would seem that these traditionally shaded crops can produce higher yields in full sunlight than under shade trees,

provided the nutrient supply is increased. The depressing effect of shade trees on fertilizer responses is mainly due to the influence of shade *per se*; the trees as such play a secondary role.

The interrelation between light intensity and fertilizer responses is a fundamental physiological phenomenon as can be inferred from observations of White (1937) on cultures of *Lemna minor* grown at various light intensities and nitrate concentrations. It appeared that the optimal nitrate concentration rose with increasing light intensity and fell with decreasing light intensity, the optimal light intensity also decreased or increased with the level of the nitrate concentration. Similar observations were made by Murray (1954, 1955a, 1958) on artificially shaded cacao, while earlier it had been noted by Blackman and Rutter (1947) and Blackman and Wilson (1951b) in experiments with bluebell (and sunflower) that a marked interdependence existed between nutrient effects and shading, the nutrient effects being greatest at the higher light intensities.

Whether a plant will react favourably to shade or not is also dependant on the soil fertility, as is pointed out by Murray (1955b) with respect to cacao. In Grenada, on fertile soils and with generous manuring, high yields are obtained without shade—as was also observed by Cunningham and Lamb (1958, 1959) in Ghana; on the poorer clay soils of Trinidad, shade is necessary but yields are far lower. Likewise, Barua (1960) observed that although tea growing in (unmanured) good soil—as indicated by its nitrogen-status—produced the highest yields in full daylight, tea in (unmanured) soil of low fertility yielded best at a reduced light intensity.

It is thus evident that shaded plants have lower nutrient requirements, as is also suggested by the fact that shade has often been found to reduce nutrient absorption (derived from a literature review by Blackman and Rutter, 1949). The extent to which shade depresses nutrient uptake, notably that of nitrogen, may be linked with nitrogen availability. Both the observations of White (1937) with *Lemna minor* and of Gast (1937) with *Pinus sylvestris* showed that nitrogen uptake (and growth) at reduced light intensity is more depressed when the nitrogen supply is greater. This also offers a partial explanation for the observation that the optimal nitrogen application for shaded tea is very much lower than that for unshaded tea (Dutta, Basu & Sharma, 1958; Barua, 1956 & 1960).

Shade reduces photosynthesis and thus slows down the metabolism of the plant, with the result that less mineral nutrient is required per unit of time than when a plant is unshaded. Without shade, photosynthesis will be rapid and, if the minerals are not limited, a high metabolic rate can be achieved, leading to high yields. On the other hand, if the absorption rate of a plant is restricted by a limited or unbalanced nutrient supply and thus the increased demands of the plant cannot be met, internal deficiencies will occur. This is also substantiated by the fact that unshaded plants have often lower ash contents than shaded plants (Blackman and Rutter, 1949) and may show visible symptoms of deficiency. Consequently, due to the unbalanced metabolism of the plant, the yield (growth) will decrease, probably both directly and indirectly as the result of increased fall of deficient leaves.

The removal of shade from previously shaded plants has been found to lead to marked increases in yield, yield increases which were the greater as shade had been the denser. Apparently, the plants are then able to make use of mineral reserves available in the soil or in the plant.

It is evident from the complexity of the relation between shade and nutrient supply as discussed in the foregoing that the old fashioned "shade-loving plant" concept is not valid. Extensive investigations carried out by Blackman and co-workers have more than substantiated this. They found that the net assimilation

rate (rate of dry weight production per unit area) of the great majority of plant species investigated—among which were some with shady habitats—was limited by light, while reduced light always reduced the relative growth rate (Blackman & Black, 1959). Both Barua (1957) and ourselves (Visser, 1960, 1961b) found likewise with young tea plants that the net assimilation rate (and also growth when the nutrient supply was ample) increased with increasing light intensity.

Observations of Blackman and Wilson (1951a) as well as those earlier published by Blackman *et al* show clearly that plant species cannot be simply divided into "sun-loving" and "shade-loving" plants, merely because of their association with open or shaded habitats, but that much more specific criteria (as outlined by Blackman & Wilson, 1951b) are required.

In this context the conclusions reached by Blackman and Rutter (1950) from their studies on the so-called typical shade plant, bluebell, are of interest. "In woodlands, shade *per se* can only be regarded as an inimical factor; the prevalence of bluebell in deciduous woods is attributed to the absence of aggressively competitive species and more particularly to the protection provided by such habitats against grazing animals. Finally it is advanced that precisely the same factors operate in confining other species to woodland". We suggest that the tea bush found its habitat in forests for the same reasons. Apart from differences in soil fertility between forest and grass lands, the fire hazard in grass lands alone would have kept the tea out of it, while possibly also climatic differences may have an influence.

Experiments have not revealed any evidence that tea particularly likes shade; on the contrary there is ample justification for defining it as a "sun-loving plant".

7. Summary and conclusions

1. The experiments reviewed above show that responses to changes in fertilizer rates are less under shade than they are in full daylight. This has two aspects: (a) when shade is present, reduction in fertilizer rates has less detrimental effect on yield; and (b) when shade is absent, increase in fertilizer rates has more beneficial effect on yield. That is to say, if soil fertility and fertilizer applications are low, the shaded plant will tend to yield more; but with good soil and ample fertilizer, the unshaded plant will tend to yield more.

2. In a rough sort of way, shade can be said to be equivalent to a certain amount of fertilizer; the nitrogen-equivalent of shade may vary between 20 and 80 lb per acre. In general, the shade effect in terms of its equivalence to nitrogen (and other elements) will depend on both the shade density and the soil fertility. When the nitrogen availability (application) is low, nitrogen fixed by leguminous shade trees may also play a part. It would appear that nitrogen is the primary limiting factor for the growth and yield of unshaded plants; other nutrients, such as potash and phosphate, may become limiting as well, but probably only when nitrogen requirements are fulfilled.

3. With heavy shade or high soil fertility, it is to be expected that yield will become subject to diminishing returns much sooner, (*i.e.* at lower additional fertilizer rates) than when the shade is thin or the soil fertility is low; under good soil conditions, shaded tea may respond little to nitrogen because it is light and not nitrogen that it lacks, while at low soil fertility, responses of shaded tea may be linear up to a relatively high nitrogen level.

4. With poor soil conditions and a poor stand of tea, it is probable that the fertilizer application required to obtain comparable yields from unshaded tea would already be so high as to make any further increases in manuring uneconomic. Under such circumstances the presence of a good stand of shade trees is desirable, if not essential, from both agricultural and economic points of view. The same is true when a policy of moderate or low manuring is or has been adopted. Whereas without shade the yield would drop and the bushes deteriorate, with shade a moderate yield can be maintained. Probably the best and most economic way of improving poor tea fields that are lacking in shade and soil cover would be to re-establish or increase the shade.

5. It would be more profitable to remove the shade trees from good tea fields than from poor ones, as considerably less nitrogen would be required to obtain worth-while yield returns. In good fields the function of shade trees as providers of organic material is also less important than in fields with an inadequate cover. It must be noted that the yield response to shade removal is directly proportional to the original shade density, so that no great increases must be expected if the field was only thinly interplanted or the shade trees were frequently and severely lopped.

6. Disappointing results in the recent past, when on many estates shade trees were removed because of Blister Blight, were almost certainly due to the fact that manuring rates were low and by no means sufficient to meet the increased nutrient requirements of the unshaded tea. The logical consequence was that after the tea had exhausted available reserves, its yield decreased. There are good reasons to believe that the yield increase can be largely maintained if manuring rates are stepped up simultaneously.

7. There are indications that the characteristics of the tea—particularly leaf size, dry weight, ash content and quality—are to a greater or lesser extent influenced by the prevailing light intensity. However, the magnitude of the variations with light will probably be small if fertilizer applications are adequate. It is not known whether or not nitrogen application (with proportional amounts of P and K) exceeding 100 lb. per acre will affect quality.

References

- ANON. (1954). Annu. Rep. of the Tea Stations. *Rep. Dep. Agric. Nyasald. for 1952/53, Pt. 2: 12-20.*
- ANON. (1955). Annu. Rep. of the Tea Stations. *Rep. Dep. Agric. Nyasald. for 1953/54, Pt. 2: 51-64.*
- ANON. (1956). Annu. Rep. of the Tea Stations. *Rep. Dep. Agric. Nyasald. for 1954/55, Pt. 2: 30-40.*
- ANON. (1957). Annu. Rep. of the Tea Stations. *Rep. Dep. Agric. Nyasald. for 1955/56, Pt. 2: 42-65.*
- ANON. (1958). Annu. Rep. of the Tea Stations. *Rep. Dep. Agric. Nyasald. for 1956/57, Pt. 2: 60-110.*
- ANON. (1959). Report of the Tea Stations. *Rep. Dep. Agric. Nyasald. for 1957/58, Pt. 2: 81-104.*
- ANON. (1960). *Tea. Rep. Dep. Agric. Nyasald for 1958/59, Pt. 2: 91-114.*
- BARUA, D. N. (1956). Illumination and nutrients: yield equations. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1955: 38-40.*
- BARUA, D. N. (1957). Illumination and nutrients. Light intensity, assimilation rate, and yield of young tea plants. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1956: 34-51.*

- BARUA, D. N. (1961). Soil fertility and illumination response of tea bushes. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1959*: 64-68.
- BARUA, D. N., DUTTA, D. N. & GOGOI, B. B. (1958). Nature of the plucked tea shoot conditioned by shade and manure. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1957*: 69-75.
- BJÖRKMÄN, E. (1942). Über die Bedingungen der Mykorrhiza Bildung bei Kiefer and Fichte. *Symb. bot. Upsaliens*, 6: 1-190 (quoted from *Biol. Abstr.* 1946-no. 7878).
- BLACKMAN, G. E. & RUTTER, A. J. (1947). Physiological and ecological studies in the analysis of plant environment. II. The interaction between light intensity and mineral nutrient supply in the growth and development of the Bluebell (*Scilla non-scripta*) *Ann. Bot., Lond.* n.s. 11: 125-157.
- BLACKMAN, G. E. & RUTTER, A. J. (1948). III. The interaction between light intensity and mineral supply in leaf development and in the net assimilation rate of the Bluebell (*Scilla non-scripta*). *Ann. Bot. Lond.* n.s. 12: 1-26.
- BLACKMAN, G. E. & RUTTER, A. J. (1949). IV. The interaction between light intensity and mineral nutrient supply on uptake of nutrients by Bluebell (*Scilla non-scripta*). *Ann. Bot. Lond.* n.s. 13: 453-489.
- BLACKMAN, G. E. & RUTTER, A. J. (1950). V. An assessment of the factors controlling the distribution of Bluebell (*Scilla non-scripta*) in different communities. *Ann. Bot. Lond.* n.s. 14: 487-520.
- BLACKMAN, G. E. & WILSON, G. L. (1951a). VI. The constancy for different species of a logarithmic relationship between net assimilation rate and light intensity and its ecological significance. *Ann. Bot. Lond.* n.s. 15: 64-94.
- BLACKMAN, G. E. & WILSON, G. L. (1951b). VII. An analysis of plant environment, of net assimilation rate, leaf area ratio, and relative growth rate of different species. *Ann. Bot. Lond.*, n.s. 15: 373-408.
- BLACKMAN, G. E. & BLACK, J. N. (1959). XII. The role of the light factor in limiting growth. *Ann. Bot., Lond.*, n.s. 23: 131-145.
- CHILD, R. (1960). Problems of shade in tea. *Tea Rubb. Mail*, 83, no. 4298: 4
- CUNNINGHAM, R. K. & LAMB, J. (1958). Cacao shade and manurial experiments in Ghana. *Nature, Lond.*, 182: 119.
- CUNNINGHAM, R. K. & LAMB, J. (1959). A cacao shade and manurial experiment at the West African Cacao Research Institute, Ghana. I. The first year. *J. hort Sci.* 34: 14-22.
- DIERENDONCK, F. J. E. (1959). The manuring of coffee, cacao, tea and tobacco. *Centre l' Etude de l'Azote, Geneva, Pt. 2*: 23-55.
- DE HAAN, I. (1949). Physiology of leaf formation in tea (Dutch with English summary). *Arch. Theecult. Indonesie.* 16: 83-125.
- DE WEILLE, G. A. (1959). The adaptation of tea cultivation to the occurrence blister blight. *Arch. Tea Cult. Indonesia.* 20: 161-192.
- DUTTA, S. K. & HEATH, F. D. (1954). Agricultural Branch. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1953*: 7-34.
- DUTTA, S. K. & HEATH, E. D. (1955). Agricultural Branch. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1954*: 9-38.
- DUTTA, S. K. & BASU, S. (1956). Agricultural Branch. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1955*: 45-74.
- DUTTA, S. K. & BASU, S. (1957). Agricultural Branch. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1956*: 53-86.

- DUTTA, S. K., BASU, S. & SHARMA, K. N. (1958). Agricultural Branch. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1957*: 76-114.
- DUTTA, S. K., BASU, S. & SHARMA, K. N. (1959). Agricultural Branch. *Rep. Indian Tea Ass. Sci. Dep. (Tocklai) for 1958*: 151-212.
- EDEN, T. (1941?). Report of the Agricultural Chemist for 1940. *Bull. Tea Res. Inst. Ceylon* no. 22: 53-62.
- EDEN, T. (1943?). Report of the Agricultural Chemist for 1942. *Bull. Tea Res. Inst. Ceylon* no. 24: 37-41.
- EDEN, T. (1944?). Report of the Agricultural Chemist for 1943. *Bull. Tea Res. Inst. Ceylon* no. 25: 38-45.
- EDEN, T. (1949a). Report of the Agricultural Chemist for 1948. *Bull. Tea Res. Inst. Ceylon* no. 30: 39-44.
- EDEN, T. (1949b). Work of the Agricultural Chemistry Department of the Institute, 1929-1948. *Monogr. Tea Prod. Ceylon* no. 1: 78 pp.
- EDEN, T. (1953). Agricultural Department. *Rep. Tea Res. Inst. East Africa for 1952*: 13-26.
- EDEN, T. (1954). Agricultural Department. *Rep. Tea Res. Inst. East Africa for 1953*: 15-31.
- EVANS, H. & MURRAY, D. B. (1952). A shade and fertilizer experiment on young cacao. *Rep. on cacao research 1954-1951. Imp. Coll. trop. Agric. Trinidad*: 67-76.
- GAST, P. R. (1937). Studies of the development of conifers in raw humus. III. The growth of Scots pine (*Pinus sylvestris* L.) seedlings in pot cultures of different soils under varied radiation intensities. *Medel. Statens Skogsforsokanst, (Stockholm)*, 29: 587 (quoted from Blackman & Rutter, 1949).
- GOODCHILD, N. A. (1955). Agricultural Department. *Rep. Tea Res. Inst. East Africa for 1954*: 15-29.
- GOODCHILD, N. A. (1956). Agricultural Department. *Rep. Tea Res. Inst. East Africa for 1955*: 14-25.
- GOODCHILD, N. A. & FOSTER-BARHAM, F. B. (1957). Agricultural Department. *Rep. Tea. Inst. East Africa for 1956*: 14-30.
- GOODCHILD, N. A. & FOSTER-BARHAM, C. B. (1958). Agricultural Department. *Rep. Tea Res. Inst. East Africa for 1957*: 17-28.
- GOODCHILD, N. A. & FOSTER-BARHAM, C. B. (1959). Agricultural Department. *Rep. Tea Res. Inst. East Africa for 1958*: 18-33.
- GOODCHILD, N. A. & FOSTER-BARHAM, C. B. (1960). Agricultural Department. *Rep. Tea Res. Inst. East Africa for 1959*: 19-30.
- HAVORD, G., MALIPHANT, G. K. & COPE, F. W. (1954). Manurial and cultural experiments on cacao. Part III. River Estate and Central Experimental Station, Centeno, Trinidad. *Rep. on Cacao Res. 1953, Imp. Coll. trop. Agric. Trinidad*: 80-87.
- HAVORD, G., MALIPHANT, G. K. & COPE, F. W. (1955). Manurial and cultural experiments on cacao. Part IV. The effect of fertilizers, shade and spacing on flowering, fruit-set and Cherville wilt. River Estate, Trinidad. *Rep. on Cacao Res. 1954, Imp. Coll. trop. Agric. Trinidad*: 58-64.
- MALIPHANT, G. K. (1959a). Manurial and cultural experiments on cacao. Part VII. River Estate, Trinidad: Shade, spacing, times and rates of fertilizer application. *Rep. on Cacao Res. 1957-58, Imp. Coll. trop. Agric. Trinidad*: 83-86.
- MALIPHANT, G. K. (1959b). The nutrition of cacao. Part II. Leaf nitrogen and phosphorus content. *Rep. on Cacao Res. 1957-58, Imp. Coll. trop. Agric. Trinidad*: 76-79.

- MURRAY, D. B. (1953). A shade fertilizer experiment with cacao. Progress Report (continued). *Rep. on Cacao Res. 1952, Imp. Coll. trop. Agric. Trinidad*: 11-21.
- MURRAY, D. B. (1954). A shade and fertilizer experiment with cacao. III. *Rep. on Cacao Res. 1953, Imp. Coll. trop. Agric. Trinidad*: 30-37.
- MURRAY, D. B. (1955a). A shade and fertilizer experiment with cacao. IV. *Rep. on Cacao Res. 1954, Imp. Coll. trop. Agric. Trinidad*: 32-36.
- MURRAY, D. B. (1955b). Climatic requirements of cacao with particular reference to shade. *Rep. Cacao Conf. London, 1955*: 17-22.
- MURRAY, D. B. (1958). Response of cacao to fertilizers, *Nature, Lond.*, **182**: 1613.
- PORTSMOUTH, G. B. (1951). The role of green manuring in the maintenance of the fertility of tea soils. *Tea Quart.* **22**: 97-101.
- PORTSMOUTH, G. B. (1954). Report of the Plant Physiologist for 1953. *Bull. Tea Res. Inst. Ceylon*, no. 35: 39-44.
- TANADA, T. (1946). Utilization of nitrates by the coffee plants under different sunlight intensities. *J. agric. Res.* **72**: 245-258.
- VAN EMBDEN, J. H. & LAOH, J. Ph. (1953). A method for measuring the density of shade (Dutch with English summary). *Arch. Theecult. Indonesie.* **18**: 223-237.
- VINK, A. P. A. (1953). Experiments and problems regarding manuring and shade in tea cultivation (Dutch with English summary). *Arch. Theecult. Indonesie* **18**: 33-91.
- VISSER, T. (1957). Report of the Plant Physiologist for 1956. *Bull. Tea Res. Inst. Ceylon* no. 38: 39-45.
- VISSER, T. (1960). Report of the Plant Physiologist for 1959. *Annu. Rep. Tea Res. Inst. Ceylon for 1959*: 67-90.
- VISSER, T. (1961a). Interplanting in tea: 1. Effects of shade trees, weeds, and bush crops. *Tea Quart.* **32**: 69-82.
- VISSER, T. (1961b). Report of the plant Physiologist for 1960. *Rep. Tea Res. Inst. Ceylon for 1960*: 79-89.
- VISSER, T. & KEHL, F. H. (1956). Drought. *Tea Quart.* **27**: 77-79.
- WALTER, T. E. (1960). Crop protection by modified agricultural methods. Part I. The control of shade. *Tea Quart.* **21** (4): 35-37.
- WHITE, H. L. (1937). The interaction of factors in the growth of *Lemna*. XI. The interaction of nitrogen and light intensity in relation to growth and assimilation. *Ann. Bot., Lond., n.s.* **1**: 623-647.
- WIGHT, W. (1959a). The shade-tree tradition in tea gardens of Northern India. I. The value of shade. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1958*: 75-98.
- WIGHT, W. (1959b). The shade-tree tradition in tea gardens of Northern India. II. The use of ammonium sulphate. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1958*: 99-122.
- WIGHT, W. (1959c). The shade-tree tradition in tea gardens of Northern India. III. Superphosphate and light intensity. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1958*: 123-150.
- WIGHT, W., BARUA, D. N., GREEN, M. Y. & BARUA, P. K. (1958). Botanical Branch. *Rep. Indian Tea Ass. sci. Dep. (Tocklai) for 1957*: 37-75.