Chemical Methods of Shade Measurement.

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Introduction.

The importance of light in the growth of plants has prompted many investigations into its accurate measurement (Stern, 1962). In measuring the shade offered by shade trees in tropical crops such as coffee and tea, it is desirable that a large number of simultaneous light measurements be made over a large area, and hence any method must be reasonably cheap and easy to apply. As the shade at any site varies throughout the day, any measuring device must be integrating. A set of tubes containing a photosensitive chemical satisfies these requirements.

Of the many photochemical processes known (Kistiakowsky, 1928) several have been applied to light measurement. Dore (1958) and Friend (1959) used solutions of anthracene in benzene and Pearsall and Hewitt (1938) utilized acid solutions of potassium iodide. In the latter method 2 per cent. potassium iodide was mixed with 1.15 per cent. sulphuric acid and, after exposure to light, the iodine liberated was determined by titration with sodium thiosulphate. A modification of this method was investigated for possible application to the measurement of the shade given by shade trees in coffee plantations.

POTASSIUM IODIDE METHOD OF SHADE MEASUREMENT.

On exposure to sunlight, potassium iodide in aqueous solutions undergoes decomposition to iodine. This reaction has been discussed by McCrae (1923) from a chemical viewpoint, and also by Braid (1923). It is catalysed by sulphuric acid and the amount of iodine produced when this catalyst is absent is difficult to estimate quantitavely by titration with thiosulphate. However, if strong solutions are used, the yellow colouration (due to the liberated iodine) can be accurately measured colorimetrically at a suitable wavelength.

Initially 30 per cent. aqueous solutions were used, but 10 per cent. and 20 per cent. solutions were later investigated. Tubes of 20 ml. capacity and fitted with plastic screw-top lids containing plastic covered foam liners were filled with the solution, placed in shallow cardboard boxes (three per box) and covered with a series of standard 'shades' made from white cheese cloth or green savlon shade cloth. These boxes were placed in the sun and one bottle removed from each at the end of three, four and five hours. One box was left uncovered to represent 100 per cent. transmission of full sunlight and six others were covered with shades transmitting from 26 to 90 per cent. full sunlight (26, 30, 52, 66, 80 and 90 per cent.). Readings, in foot-candles, were made at 10 minute intervals with an E.E.L. lightmeter for the total period of exposure and the amount of light falling on each bottle estimated.

After exposure the tubes were allowed to cool to 25 degrees C. and the contents filtered directly into a spectrophotometer cell and the transmittance measured at 410 mu on a Beckmann DU spectrophotometer, using distilled water as a standard.

In other experiments longer exposure periods were used and the same procedure was repeated for 10 and 20 per cent. solutions. In one series of experiments sets of bottles containing 10, 20 and 30 per cent. solutions were exposed for the same period under the same set of 'shades'.

Calibration.

On five days and at one-hourly intervals from 9 a.m. to 3 p.m., the transmission of the standard 'shades' was measured with the E.E.L. lightmeter. The target was inserted in the box at the same level as the bottles and a sunlight reading made. The shade was placed in position, the reading noted, and the shade then removed and a further sunlight reading made. When the original and final sunlight readings were identical the result was recorded. For the same hour on the various days, it was found that the transmission of a particular standard was always within 1 per cent. of the mean for that standard at that hour. (For a mean of 90 per cent. the readings varied from 89 per cent. to 91 per cent.) However, the general pattern throughout each day was for the transmission of each shade to increase to a maximum at mid-day and then to decrease in the afternoon. With some shades the variation was as much as 8 per cent. (i.e., from 46 per cent. at 9 a.m. to 54 per cent. at noon). As the greatest amount of light was incident in the middle of the day the standard shade value used was the mean of values obtained from 10 a.m. to 2 p.m.

In order to determine the concentration of iodine corresponding to a particular reading on the spectrophotometer, a very dilute solution of iodine in 20 per cent. potassium iodide was prepared. 1, 2, —9, 10 ml. aliquots of this solution were made to 100 ml. with 20 per cent. potassium iodide and given the arbitrary concentration units, 1, 2, —9, 10. It was found that Beer-Lambert's Law was obeyed and standard 0 (20 per cent. solution of potassium iodide) had a transmittance of 100 per cent. and a solution of concentration 10 a transmittance of 16 per cent. at 410 mu. The sensitivity of this method is clearly shown as standards 1, 2 and 3 did not give a distinct colour with starch indicator.

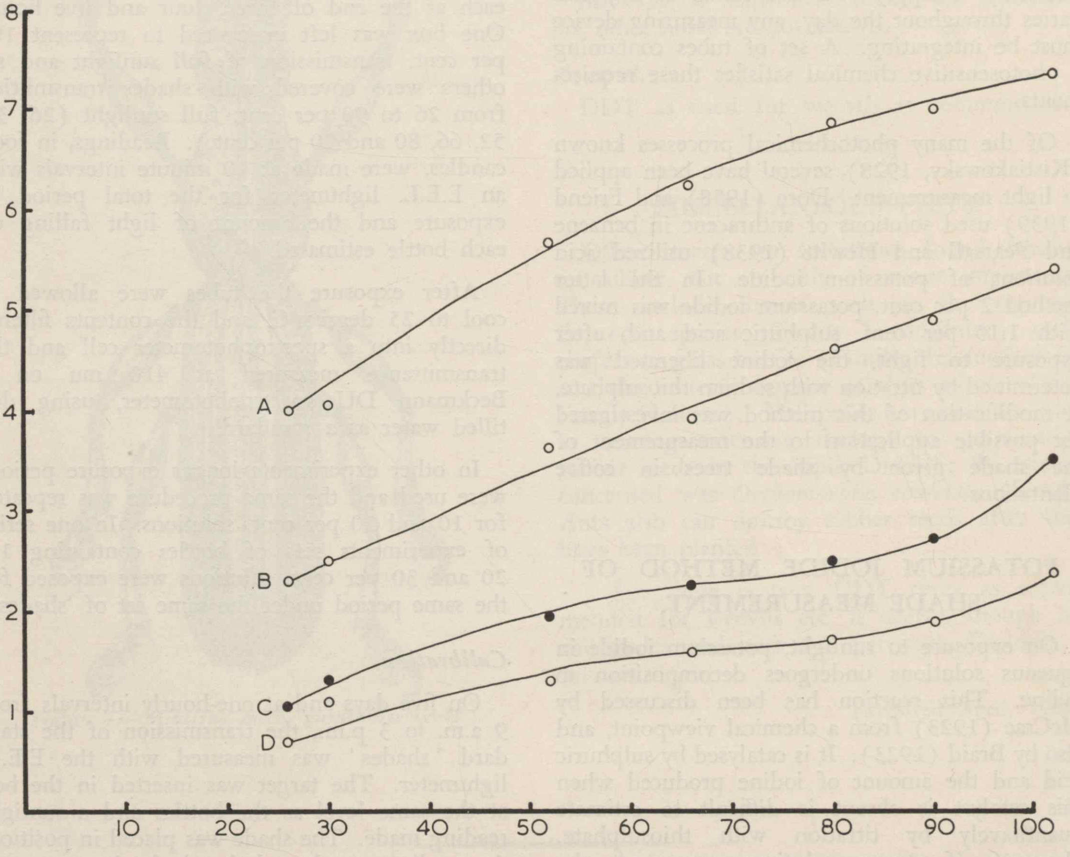

Figure 1.—Variation in the concentration of iodine produced by varying intensities of sunlight. A, B, D represent experiments with 30, 20, 10 per cent. (respectively) potassium iodide in which the full sunlight was 40,000 foot-candle-hours. C is the curve from an experiment utilising 10 per cent. potassium iodide, in which full sunlight was 48,000 foot-candle-hours.

Results.

A directly proportional relationship between the concentration of iodine produced and the amount of light initiating the reaction was not obtained. The results for several typical experiments are shown graphically (Figure 1) and it can be seen that there was a consistent relationship for solutions exposed at the same time. Graphs A, B, D show the results of an experiment in which solutions of 30, 20 and 10 per cent. potassium iodide respectivly were exposed at the same time under the same shade coverings. In this experiment 100 per cent. sunlight was 40,000 foot-candle-hours. Graph C shows the results of an experiment using 10 per cent. potassium iodide solution for which 100 per cent. sunlight was 48,000 foot-candle-hours.

For convenience of calculation when a large number of determinations is made, a calibration curve relating the transmittance of each iodine solution (as read from the spectrophotometer) with the transmission of the standard shade which covered this solution (100 per cent. shade) can be drawn. These curves are the inverse of the types shown in Figure 1.

SHADE MEASUREMENT IN COFFEE PLANTATIONS.

A field test was performed at the Highlands Experiment Station at Aiyura in the Eastern Highlands. Four experimental blocks were used :—

A6 : An entomological block with single stem coffee pruned to a height of 5 ft. 6 in. It was divided into four plots (1, 2, 3, 4) in two of which (1, 4) the *Albizia stipulata* shade had been thinned to give approximately half the shade cover of that in the other two (2, 3).

C6 (Fig. 2) : A shade, spacing, pruning trial utilizing two types of shade tree (*Albizia* and *Casuarina*), two types of pruning (single stem and multiple stem) and three triangular spacings (7 ft., 8 ft., and 9 ft.). This block was divided into 48 plots, eight of which were utilized in the light measurement determinations. The 7-foot spacing plots were omitted because of the difficulty in moving between the bushes to distribute the bottles and all multiple stem plots (where the coffee was up to 12 feet high) were also omitted because of mechanical difficulties in bottle suspension. The plots within this block are distinguished by subscripts. Thus the eight plots measured in C6 are denoted C_1 - C_8.

D6 : A duplication of C6.

A10 (Fig. 4) : A fertilizer trial with uniform *Albizia stipulata* shade over single stem coffee ranging in height from five to six feet.

Method.

Two methods were investigated : The anthracene method as used by Friend (determination of the anthracene concentration at 400 mu on a BECKMANN DU spectrophotometer) and a second method utilizing a 30 per cent. aqueous solution of potassium iodide. Bottles similar to those already described were used for all measurements.

Small wire cradles (Plate I) were suspended from the coffee bushes (in blocks A6, C6, D6) or shade trees (in block A10) with jute or

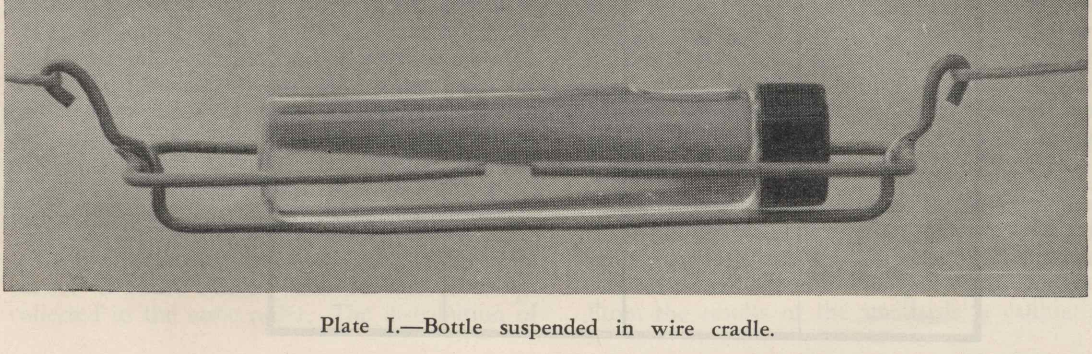

Plate I.—Bottle suspended in wire cradle.

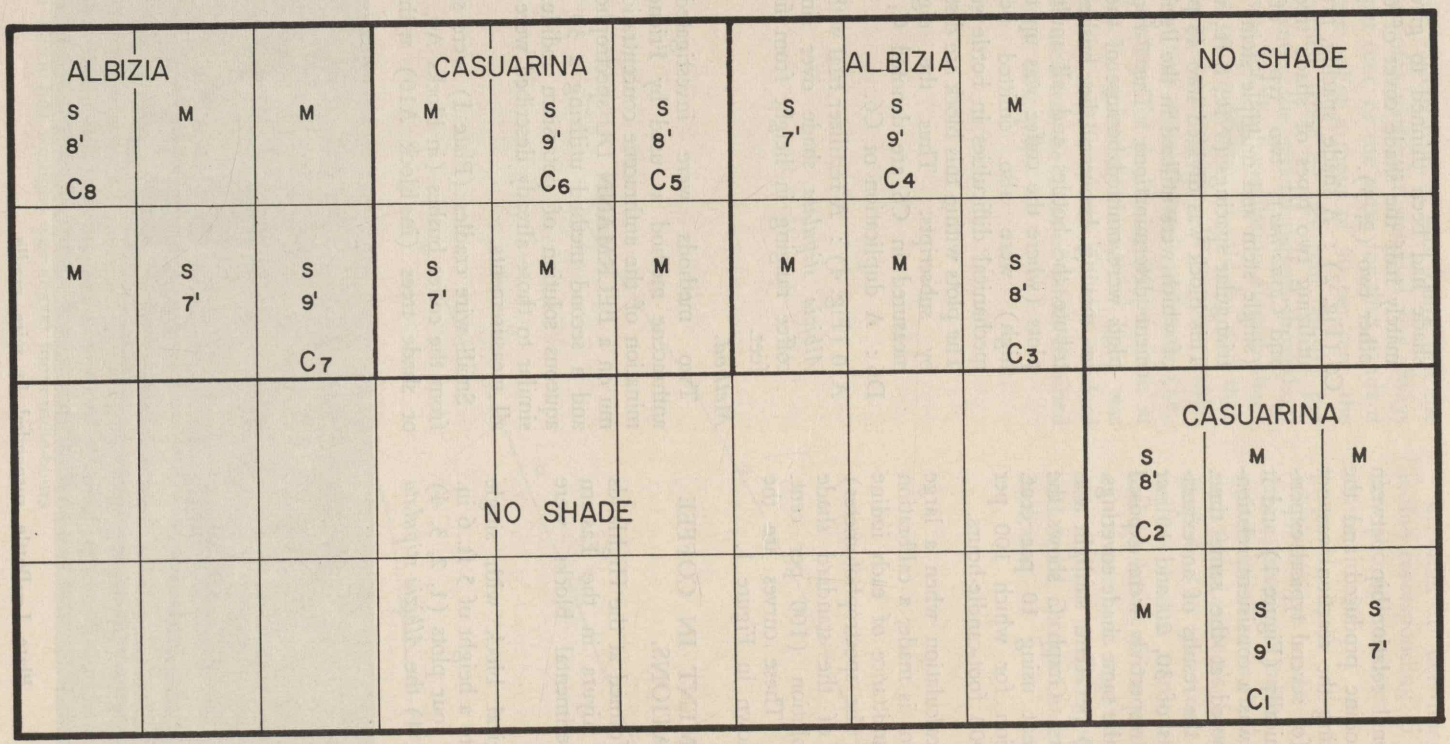

Figure 2.—Plan of Shade, Spacing, Pruning Trial C6, employing two species of shade tree : *Albizia stipulata* and *Casuarina* sp.

Three spacings : 7 ft., 8 ft. and 9 ft. triangular, and two pruning systems : Multiple Stem (M) and Single system (S). This trial is divided into 48 blocks, eight of which were used in the present work.

Plate II.—Block A10 with bottles suspended under *Albizia stipulata* shade.

binder twine (depending on the length of suspension). Where coffee bushes were utilized, approximately 6 ft. of jute twine was required to suspend the cradle in a north-south direction, equidistant from the two supporting bushes and about 5 ft. 6 in. from the ground. When shade trees were used, binder twine was used for the longer span (50 ft. between two adjacent trees) and the cradles were about 6 ft. from the ground (Plate II). The plan of cradle distribution is shown in Figs. 2, 3, 4. In each of the plots in the blocks C6 and D6 the distribution was as close as possible to that in plot C_6 (Fig. 3) (the plots were not all identical).

In the mornings the numbered bottles were placed in the cradles and in the evenings collected in the same order. The distribution of bottles occupied about 15 minutes (three persons distributed 220 bottles). Initially the exposure period was from 8 a.m. to 5 p.m. but, as morning and evening shadows fell across the whole plot, it was considered that a more accurate measure of the effect of the shade pattern would be given when the sun was more directly overhead, and so the period from 9 a.m. to 3 p.m. was used in later trials. A set of bottles under standard shades (100 to 26 per cent. transmission of full sunlight) was exposed for the same period. Table 1 shows a comparison of the two exposure periods for block A6.

The bottles were allowed to cool to room temperature and the transmittance of the solutions measured (at 400 mu for the anthracene and at 410 mu for potassium iodide). From the results of the standards, a calibration curve was drawn relating the transmittance of the solutions to the relative light intensity (per cent. sunlight transmitted) under the corresponding shade covering. The percentage sunlight falling on each site over the exposure period was read from this calibration curve.

Table 1.

Shade measurement by the potassium iodide method on trial A6 over two different time intervals.

Plot.	Relative Light Intensity (per cent. Sunlight Received)	
	8 a.m.-5 p.m.	9 a.m.-3 p.m.
1	50	64
2	49	63
3	54	57
4	64	77
Av. A6	54	65

Each value for plots 1-4 is the average of 36 sites within each block. Plots 1 and 4 were designed to have approximately half as much shade as 2 and 3.

Discussion.

The results are shown in Tables 2 (C6 and D6) and 3 (A10). The value for each plot in C6 and D6 is the mean of nine sites (see Fig. 3) and that for each row in A10, the mean of 10 sites (Fig. 4).

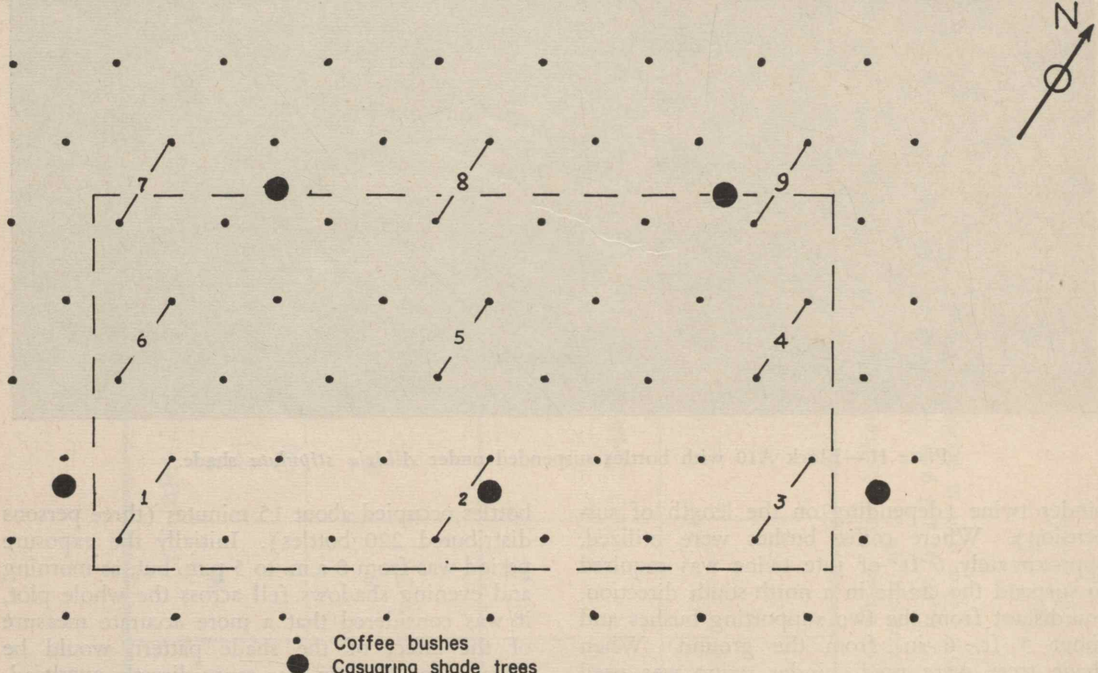

Figure 3.—Plan of C6 showing the position of measurement bottles. A similar pattern of bottle distribution and numbering was used in all blocks in C6 and D6 but the number and position of the shade trees varied from block to block.

There is good agreement between the two methods (correlation coefficient = 0.87) when whole plots are considered. There is less variability between the anthracene readings than for potassium iodide (least significant difference at 5 per cent. is 9.3 for potassium iodide and 7.1 for anthracene). There is considerable divergence between the values obtained on individual sites but this is readily explained by daily variation. The shade pattern over any site will be one of intermittent periods of full sunlight and some degree of shade. On cloudy days the times at which the clouds obscure the sun will alter the percentage light falling on any site. If clouds obscure the sun while the site is in full sunlight, the percentage sunlight received over the daily period will be less than if the times when the sun is obscured coincide with times when the site is heavily shaded. For a closer comparison of results, a number of experiments showing the daily variation for the one method is needed. This variation will be reduced when a number of sites is taken, however, and reproducible results should be obtained in experiments measuring the sunlight received over a whole block in one day.

The results show that while the *Casuarina* shade and the *Albizia* shade were fairly uniform in themselves they differed considerably from each other. This difference could be sufficient to alter the interpretation of the results which is based on the assumption that the shade is uniform throughout.

Table 3.

Results from the measurement of shade on the trial A10 (*Albizia stipulata* shade), showing the percentage of full sunlight received by each of the ten rows.

Row.	Relative Light Intensity (per cent. Sunlight Received.)	
	Kl Method.	Anthracene Method.
A_1	64	68
A_2	71	67
A_3	68	66
A_4	67	69
A_5	60	69
A_6	71	69
A_7	71	64
A_8	63	64
A_9	66	66
A_{10}	75	66
Av. A10	68	67

Each value is the mean of ten sites.

Table 2.

Results from the measurement of shade on the shade, spacing, pruning trials C6 and D6 by two methods (potassium iodide and anthracene), showing percentage full sunlight (100 per cent. shade) received by the various plots.

Block C6. Plot.	Relative light intensity (per cent. Full Sunlight).		Block D6. Plot.	Relative light intensity (per cent. full sunlight).	
	Kl Method.	Anthracene Method.		Kl Method.	Anthracene Method.
C_1	46	46	D_1	43	44
C_2	55	55	D_2	55	52
C_3	54	54	D_3	66	59
C_4	60	56	D_4	61	55
C_5	48	48	D_5	58	50
C_6	45	48	D_6	59	56
C_7	65	64	D_7	64	63
C_8	70	69	D_8	76	69
Mean C_1, C_2, C_5, C_6 (*Casuarina* shade)	49	49	Mean D_1, D_2 D_5, D_6 (*Casuarina* shade)	54	51
Mean C_3, C_4, C_7, C_8 (*Albizia* shade)	62	61	Mean D_3, D_4 D_7, D_8 (*Albizia shade*)	67	62
Mean C6 .... (C_1 - C_8)	55	55	Mean D6 .... (D_1 - D_8)	61	57

The results from A10 were very interesting as they showed fairly uniform shade throughout the block. It was thought that there may have been a significant difference between the shade in bushes close to shade trees and those midway between shade trees. There were also some areas (see Fig. 4) where the shade directly overhead was much less than in others. In fact, over a whole day and especially when the shade trees were tall and spreading, the direct shading of any bush was given by many shade trees some of which were distant from this bush. It is probable that in many plantations where an effort has been made to plant shade trees evenly the resulting shade is reasonably uniform despite variations in growth of occasional trees.

COMPARISON OF THE TWO METHODS.

The potassium iodide method has considerable advantages, most of which are associated with the solvent used. The anthracene method requires large quantities of pure benzene. This is expensive and, in New Guinea, where transport is almost wholly by air, transportation of this solvent to and from the field is a major problem. There is considerable manipulation before each reading, and errors introduced by evaporation and during dilution can be significant. These disadvantages are avoided in methods using water as solvent. It was found that errors introduced by transferring the iodine solution directly to the spectrophotometer cell without filtration were small, and this modification enabled a large number of solutions to be measured very quickly.

The greatest advantage of the anthracene method is that it has a sounder theoretical basis for use under field conditions. The proportionality between total quantity of light, irrespective of time-intensity variations, and the logarithm of the residual anthracene concentration, means that a series of standards is not required and accurate comparisons of the total insolation in different localities can be made. The potassium iodide method is essentially an empirical one under field conditions and is limited to measuring the percentage shade given by the shade trees in any area.

Whereas the anthracene method is sensitive to light between 300 and 400 mu, McCrae (1923) has shown that radiation up to 590 mu will produce decomposition of potassium iodide although the most active region is below 500 mu. The merits of this added range are difficult to determine. In the absence of a method which is sensitive to the whole spectral range, or to the wavelengths predominantly associated with photosynthetic processes, the existing methods appear to be of equal merit from spectral range considerations, as they follow the assumption that the range measured comprises a fairly constant proportion of total sunlight.

Conclusions.

The small number of experiments performed limits definite conclusions. It appears that the potassium iodide method of measuring shade is quite valid empirically, and reliable results can be obtained. Because of the advantages already mentioned, this method would be preferable to the one using anthracene. Although the measurements for any one site are not satisfactorily consistent, comparisons between plots (by taking a mean, over say 10 sites) can be readily made. Comparisons between different localities would be unsatisfactory by the potassium iodide method.

An efficient method of bottle suspension has been demonstrated. This enables the widespread use of chemical light meters throughout a block. It is unsatisfactory for coffee more than about six feet high, and cumbersome where very close spacing of coffee bushes occurs. It is difficult to envisage any other satisfactory method under these conditions.

It is doubtful whether this type of light measurement will have general application throughout plantations. It is of little interest to a planter to know that 70 per cent. sunlight is the optimum condition for coffee on his plantation without knowing exactly how to produce this degree of shade. It could be used to test the uniformity of shade, but this could be estimated visually with sufficient accuracy for practical purposes.

This method should prove useful in experiments where accurate comparisons between blocks and assessment of the most satisfactory light conditions can be made. Present methods

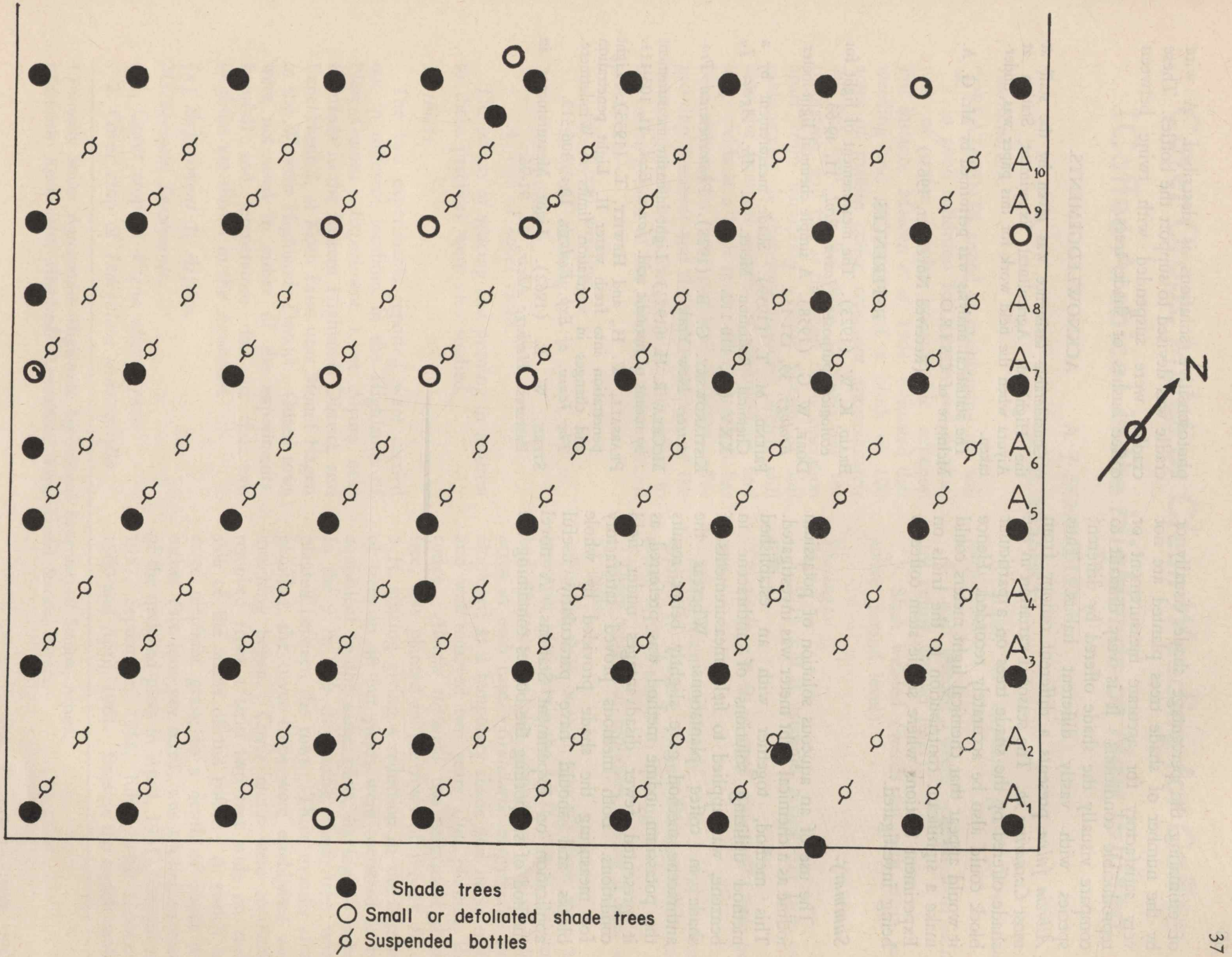

Figure 4.—Plan of the southern portion of A10, covering 900 coffee bushes.

of estimating the percentage shade visually or by the number of shade trees planted are not very satisfactory for accurate measurement or reproducible conditions. It is very difficult to compare visually the shade offered by different species with vastly different habits. Thus *Albizia fulva* presents a different canopy from most *Casuarina sp.* The seasonal variation in the shade offered by the shade trees on a particular block could also be accurately recorded. Hence it would appear that chemical light meters could make a significant contribution to the trials on Experiment Stations where single stem coffee is being investigated.

Summary.

The use of an aqueous solution of potassium iodine as a chemical light meter was investigated. This method, together with an established method utilizing solutions of anthracene in benzene, was applied to field measurements of shade in coffee plantations. Whereas the anthracene method gave slightly better results the potassium iodine method was preferred as it presented fewer disadvantages under field conditions. Both methods proved satisfactory for measuring the shade provided by whole blocks and should have particularly useful application on Experiment Stations. A novel method of supporting the bottles containing the photosensitive solutions is described. A wire cradle was devised to support the bottles. These cradles were suspended with twine between coffee bushes or shade trees.

ACKNOWLEDGEMENTS.

Considerable assistance was given by the staff at the Highlands Agricultural Experiment Station at Aiyura when the field work for this paper was undertaken.

The statistical analysis was performed by Mr. G. A. McIntyre of C.S.I.R.O.

(Received November, 1963.)

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