A SIMPLE CHEMICAL LIGHT-METER FOR USE IN FORESTS

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SUMMARY: A modification of Heinicke's method for measuring light by the photo-decomposition of uranium salts is described. Partially masked glass tubes of uranyl nitrate/oxalic acid solution are exposed to light for several days and the decomposition, shown to be linearly dependent on the amount of light received, is found by titration. Tests in artificial light and natural forest show that the method is applicable to a wide range of light intensities. It is simple and cheap enough for extensive use in ecological investigations.

INTRODUCTION

Natural light is difficult to measure because it can fluctuate so widely and so quickly. Photo-electric light-meters have been much used in ecological work (e.g. Blackman and Rutter 1946); they are readily available and are accurate within their working range, but are expensive, their range does not reach full daylight and, being virtually instantaneous in measurement, they are fully subject to the momentary vagaries of natural light intensity.

Long-acting, cumulative, photochemical light-meters (e.g. Friend 1961) are more suitable for ecological work where even daily fluctuations in light intensity are usually an embarrassment and what is wanted is a measurement, not of intensity, but of differences in total light quanta received at different points or times. We have adapted one type of photo-chemical meter for use in New Zealand forests where the range of intensity is extreme and the mosaic of intensities is complex, thus making multiple measurements (and cheapness) essential. In particular, we have been concerned to produce a meter which would work in heavy shade. No attempt has been made to take account of differences in spectral composition, despite their possible importance in explaining plant distributions, since this is a separate problem common to almost all types of light-meter.

The original method was developed by Heinicke (1963), based on work by Atkins and Poole (1929), for measuring light in the canopy of a Canadian orchard where light intensity was about half full sunlight. It involves the photolysis of uranyl oxalate in aqueous solution in the presence of excess oxalic acid and, according to Atkins and Poole, the rate of decomposition is independent of the excess oxalic acid concentration and of the presence of air and is almost independent of temperature within the normal outdoor range. We used uranyl nitrate instead of sulphate, which is not readily available in New Zealand, a simpler and more rapid titration method and variable masking of the container to increase the range of light intensity for which the meter will work.

METHODS

(a) *Technique*

Exposure tubes were uniform 19 × 150 mm. test-tubes painted aluminium over a black undercoat except for a clear window encircling the tube, 1, 2, 4, 8, or 12 units wide. The unit of width is 0.5 inch, the width of a single strip of Sellotape applied before painting and afterwards removed. Each tube was closed with a rubber bung, pierced by a capillary tube to allow gases to escape, and contained 20 ml. of uranyl oxalate stock solution. This solution, stored in the dark, consists of 6.3 g. oxalic acid and 5.1 g. uranyl nitrate per litre of distilled water, giving the molar excess of oxalic acid required to keep the reaction velocity constant (Atkins and Poole 1929). The tubes were left exposed for a period dictated primarily by experience but generally about a week. During exposure to light the uranyl oxalate is capable of absorbing photons to become activated, and then decomposes (Gaertner and Kent 1958):

$$UO_2(C_2O_4) + 2H^+ \dashrightarrow UO_2^{++} + H_2C_2O_4$$

$$\downarrow h\nu$$

$$UO_2(C_2O_4)^* + 2H^+ \rightarrow UO_2^{++} + CO_2 + CO + H_2O$$

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After exposure, the remaining oxalate in the 10 ml. of solution is estimated by titrating against 0.025N potassium permanganate solution in a flask containing 10 ml. of 25% sulphuric acid and c. 100 ml. of boiling water, until a faint pink colour persists:

$$2KMnO_4 + 8H_2SO_4 + 5UO_2(C_2O_4) \rightarrow$$
$$2MnSO_4 + 8H_2O + 10CO_2 + 5UO_2(SO_4) + K_2SO_4$$

No water bath is needed provided the titration is done quickly, but if the temperature is allowed to fall below 80°C. an insoluble precipitate is formed and the titration is ruined. The difference between this titration and that of an aliquot of the unexposed stock solution represents the light absorbed.

(b) *Trials*

Linearity of response to different quantities of light was demonstrated in a series of experiments involving a total of 20 tubes exposed for different periods and with various window sizes to fluorescent light at a constant intensity of c. 300 f.c. (Fig. 1).

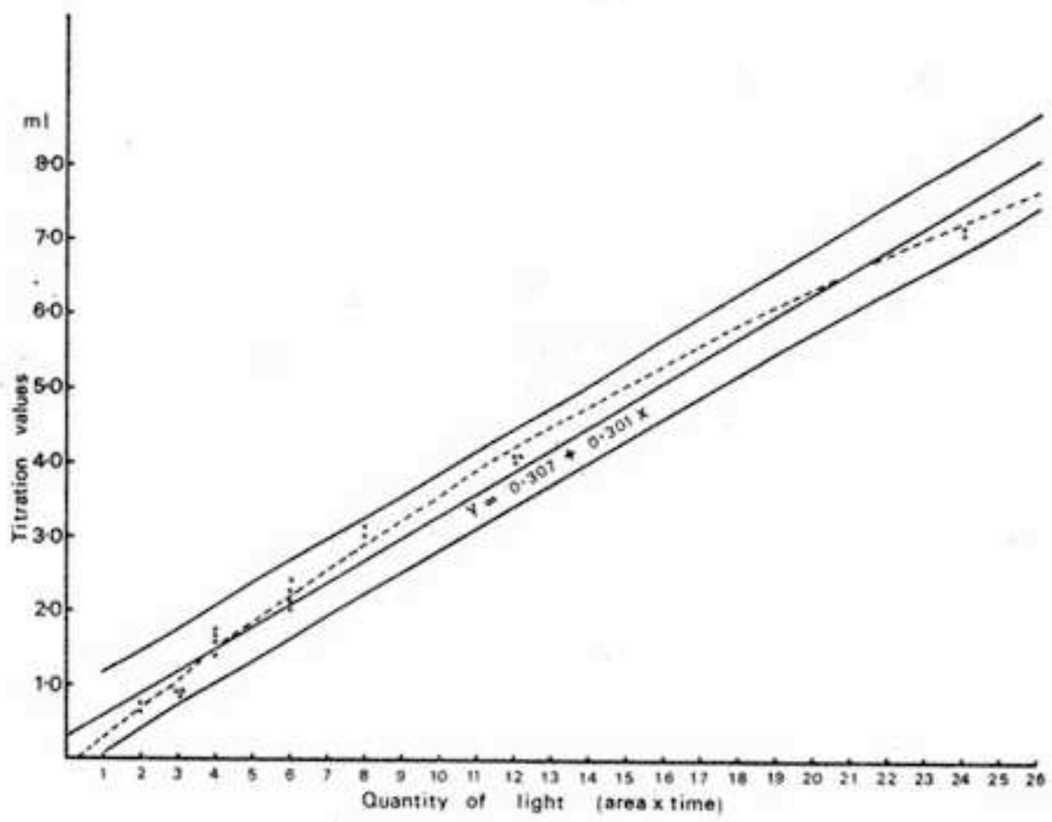

FIGURE 1. *Relationship between (X) quantity of light received (area of exposure window × days exposed) and (Y) subsequent titration values (ml. less of permanganate solution needed, compared with unexposed controls). 20 tubes in artificial light intensity of c. 300 f.c.*
Continuous lines = linear regression ± 95% C.I.
Interrupted line = curvilinear regression:
$Y = 2.6065 + 0.4064(X - 7.6500) - 0.0041(X^2 - 97.7500)$,
fitted by least squares to same data.

The quadratic curve, also plotted in Figure 1, gives a significantly better fit but lies wholly within the 95% confidence limits for the straight line, at least in the range of values tested. This result was further confirmed in various levels of natural daylight, but there is some evidence that the curvature of the line becomes rather more pronounced at very high intensities, as in bright sunlight.

The straight line relationship, although clearly to be expected, is important since it permits a very wide range of light intensities to be measured within the same titration range, the effects of different sizes of exposure windows and different exposure times being fully predictable.

A second set of tests was then undertaken to find out whether the method would be feasible in the field. From among many tests made to investigate the distribution of light intensity round tree trunks in forest, the most replicated data are from 12 locations (3 random sites within each of 4 sample areas, roughly N., S., E. and W.) on a single trunk of *Podocarpus ferrugineus*, at 15 ft. from the ground but still within the canopy of shrubs and small trees, the relics of cut-over podocarp forest on the valley floor in Leith Valley, Dunedin. In four separate tests, a tube was hung upright against the trunk at each location, and 3–4 control tubes similarly placed on the north side of a telegraph pole in a clearing nearby. After the experience of previous tests it was possible to choose apertures for the tubes which would allow harvesting of all tubes at roughly the same stage. This made subsequent titration easier. The results of the four trials as percentages of full daylight (i.e. of the mean titration value of the control tubes on the telegraph pole) are given in Figure 2. Clearly they produce a reasonable picture of the sort of change in quantity of light which one might expect round a tree trunk in forest. They conform quite closely to a quartic curve and the best fourth order polynomial fitted by least squares is also plotted in Figure 2. Such curves are notoriously difficult to interpret in ecological terms, but in this instance the relationship is probably to be interpreted as fortuitous, resulting from its very close similarity to a cosine curve (even though the quartic curve is actually a slightly better fit than the best fitting cosine curve) and each light value obtained is thus an angular function of aspect.

Similar results have been obtained for trials on four other trees in the same stand of forest, but

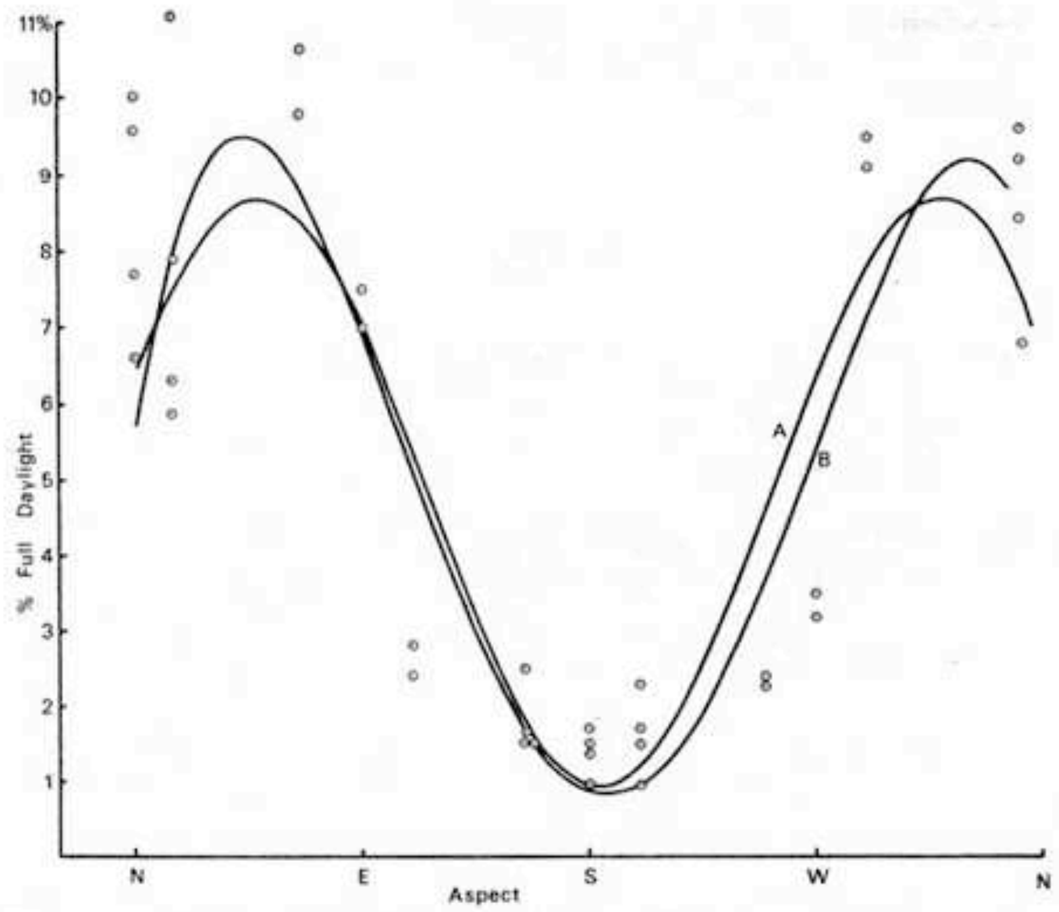

FIGURE 2. *Pooled field trials in canopy of forest on valley floor, Leith Valley, Dunedin, in June. Y = percentages of full daylight, i.e. of titration values for control tubes in adjacent open space, plotted against aspect (X).*
Curve A = best fitting cosine curve:
$$Y = 4.8010 - 3.8607 \cos(-1.3284X - 114.3307).$$
where X is in radians.
Curve B = Fourth order polynomial fitted to same data:
$$Y = 4.831 + 0.2105(X - 179.7) - 0.3321\times10^{-2}(X^2 - 0.4264\times10^5) + 0.1469\times10^{-4}(X^3 - 0.1143\times10^8) - 0.1955\times10^{-7}(X^4 - 0.3312\times10^{10})$$
where X is in degrees.

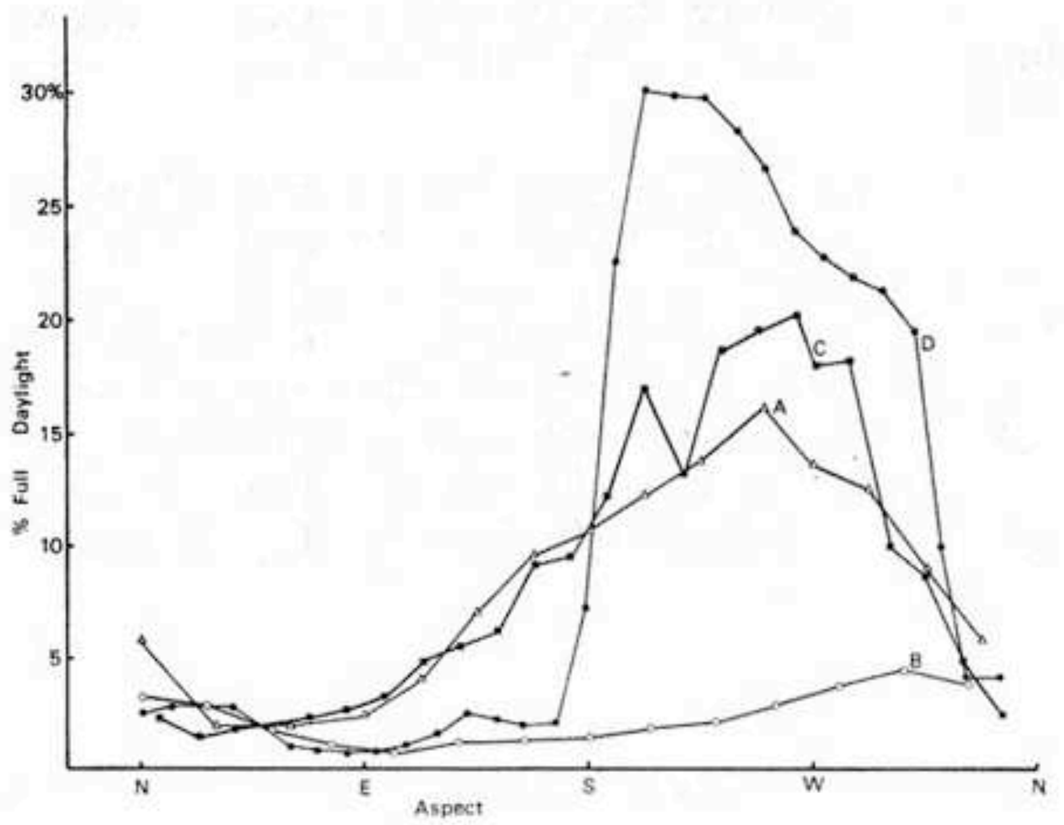

FIGURE 3. *Field trials on 4 trees (A–D), partly exposed to the west on hillside in Leith Valley, Dunedin. Percentages of full daylight, as in Figure 2, plotted against aspect.*

situated half way up the valley side, facing west. These results are plotted in Figure 3. They were obtained in the course of a study of correlation between cryptogamic epiphytes and environmental factors which will be the subject of a separate report; but the light data are relevant here in showing that the overall pattern is a consistent one and the method thus shows promise of being reliable, as well as cheap and easy. The differences between the four curves in Figure 3 are consistent with differences in the openness of canopy and shading by shrubs affecting the individual trees. The light maxima are recorded at the west rather than north, reflecting the difference in exposure compared with trees on the valley floor (Fig. 2).

DISCUSSION

The cheapness and simplicity of this method are evident. If some way could be found to assess the photo-decomposition automatically, without resort to titration, by far the most laborious and time-consuming part of the technique would be eliminated. As it is, preparing and analysing fifty tubes is one day's work.

The accuracy, that is repeatability, of the method has been tested as fully as the resources at our disposal permit, but further laboratory testing in a wide range of light intensities is desirable. Until the behaviour at high intensities has been more carefully established in artificial conditions, the meters cannot be considered reliable in full direct sunlight and, indeed, were not intended for it. Much more extensive data in artificial light would give a sounder basis for interpreting the variation found in successive measurements in natural conditions (Fig. 2). There seems to be a strong interaction between position and weather, the light readings taken at some sites being much more affected than others by the kind of cloud cover. With thinly-overcast skies, tubes in the forest interior may register higher values than in unclouded sunlight; presumably the result of a more diffuse and hence less directional illumination penetrating better into the parts normally shaded from direct sunlight.

The effectiveness of the light-meters, as would be expected, seems to be unimpaired by changes in temperature, and the salt concentration of the

liquid in the tubes has proved sufficient to allow them to be used in temperatures at least as low as 15°F.

The tilt at which these tubes are exposed might perhaps affect the results in the case of tubes receiving direct sunlight since the angle at which the sun's rays pass through the exposure window will determine, to some extent, the volume of solution receiving light; with narrow bore tubes the effect is likely to be slight even in full sunlight, and negligible in indirect light, but no tests of this have yet been made.

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