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AN APPARATUS FOR THE INSTANTANEOUS MEASUREMENT OF THE RELATIVE LIGHT INTENSITY

by

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I. Introduction

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Light intensity measurements have had an importance in forest stands particularly in relation to the characterization of the light conditions below the canopy. They so can lead to a better knowledge of the local ecology and of the bio-climatological conditions, and furthermore to the analysis and better planning of stand treatment and regeneration. Different methods of measurements have been developed and according to the set purpose, absolute or relative measurements are used.

As the absolute light conditions below the canopy are directly related to the actual light condition above the canopy or in the open, the two sets of measurements below and above the canopy must necessarily also be related to each other. This can be done either by calculating the mathematical relation between the two sets of measurements or by directly measuring the lower light intensity (under canopy) as a percentage of the higher light intensity (above canopy).

Relative light measurements present a great advantage, they are less liable to accidental fluctuations within a very short time and they allow an effective comparison between different places, especially between different stand densities. Direct or indirect relative measurements are especially succesful for the characterization of light conditions below the canopy of forest stands or at different levels, for the elaboration of light intensity maps in forest

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stands, as well as for the investigation of the eventual relation existing between given light conditions and different stand characteristics such as yield, increment and basal area.

Different methods used for relative light measurements are described everywhere (Fairbairn 1958, 1961; Naegeli 1940; Shipman 1954; Brechtel 1962; Roussel 1953).

Synchronized observations below the canopy and in the open can in fact be obtained by two persons who make readings at specified time intervals and who therefore used a prefixed time-scheme or a known sound signal. Such a method of measurement however supposes the existence of a free space or an open field, easily accessible and immediately adjacent to the forest sample plot.

The open space available for such reference measurements must cover a considerable area as the measurements in the open must be done at a distance from the forest margin equal to three or four times the maximal tree hight at the moment.

Where there is no such open field area available near the forest stand, the reference measurement have to be made immediately above the canopy of the plot for example by means of a mast.

It is, in conclusion, also possible, to calculate relative light intensity conditions going out from results given by integrating light apparatus or by recorders placed above and below the canopy. It was however found by Geiger 1961, Sauberer and Haertel 1959, Mitscherlich et al. 1965, 1966, 1967, Burschel and Schmaltz 1965, that with the decrease of the light intensity in the open, the relative light intensity increases. So that for example on some day at the same place in a forest stand different relative light intensities can be noticed according to the course of the light intensity in the open. This inverse relation may be explained by the fact that direct radiation is more intensely reflected than the diffuse light. Hence it becomes necessary to make reservations concerning the relative values obtained by calculation departing from totalized measurements.

It is a fact that in nearly all current methods, these relative values must be calculated a fairly long time after the basic measurements were taken. It is often unavoidable to use series of absolute measurements taken by different persons, and this will always be a disadvantage. At the same time it is also disadvantageous because faulty measurements cannot be recognized on the spot, so that after all series of observations are useless.

The use of a certain number of instruments, however of the same type and identical in general terms, leads to insecurity as to the real value of relative data, as these so-called « identical instruments » are never absolutely identical, especially in regard to their sensitiveness.

Thus Brechtel 1962 stated a number of important disadvantages belong to the fact that the calculations of relative light intensity values were made some time after the moment of measurement. Taking all this in consideration, he constructed a simple apparatus by which it was possible to read instantaneously the relative light intensity in a forest stand.

As it was desirable from our point of view out, to facilitate the operational part of the apparatus by Brechtel, we constructed an analogical apparatus based on a different principle. Describing both the principles all becomes clear.

2. **Principle of the apparatus**

2.1. *The Apparatus by Brechtel 1962*

Figure 1 gives a schematic survey of the principle of the apparatus in question. Two photo-elements F_1 and F_2 are respectively above and below the canopy. As the switch S_1 is in the position 1 the microampère meter (A) with a scale varying from 0 to 100 indicates the current of the photo-cell F_1. By means of a potentiometer R_v the value 100 is adjusted. When S is in the position 2, the photo-current of the second cell (F_2) being indicated, the relative light current can immediately be read in percent of the previous one and this for the same position of the potentiometer.

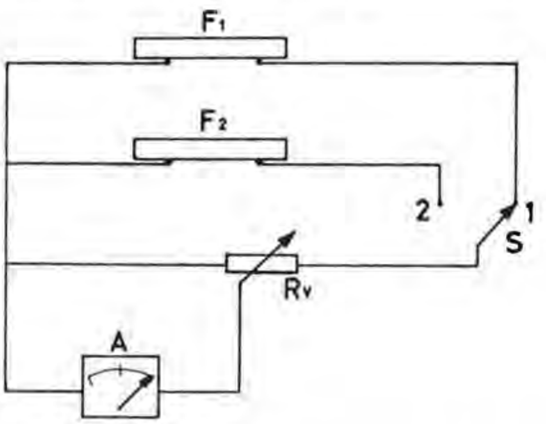

Fig. 1. The principle of the relative light intensity meter constructed by Brechtel 1962.

2.2. *The Principle of a Relative Light Intensity Instrument with Compensating Circuit*

Two photo-cells respectively above (F_1) and below the canopy (F_2) are connected in opposition (Fig. 2). As F_1 produces a greater current than F_2 and as these photo-currents are anti-currents in a closed circuit, there is a differential current indicated on the μA meter (A). Turning the linear potentiometer (R_V) in the correct position, the differential current can be compensated or reduced to zero, so that no current flows through the μA-meter. The pointer is at zero on the scale of the μA-meter with a central zero position. The adjustment of the potentiometer indicates a value that corresponds to the relative light intensity.

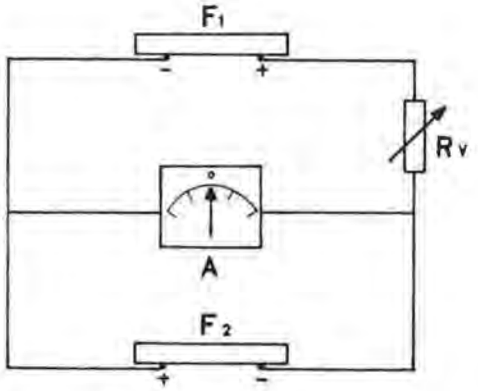

Fig. 2. The principle of a relative light intensity meter with compensating circuit.

2.3. *Theoretical and Pratical Approach to the Calibration*

In fig. 2 each photo-cell can be considered as a D.C.-generator with a current I, an e.m.f. E and a resistance R.

The relation between these quantitives for the two selenium photo-cells are respectively :

$$I_1 = \frac{E_1}{R_1 + R_v} \quad (1) \qquad \text{and} \qquad I_2 = \frac{E_2}{R_2} \quad (2)$$

Reducing the differential current to zero by varying the potentiometer, both above mentioned relations (1) and (2) become equivalent :

$$\frac{E_1}{R_1 + R_v} = \frac{E_2}{R_2} \quad (3)$$

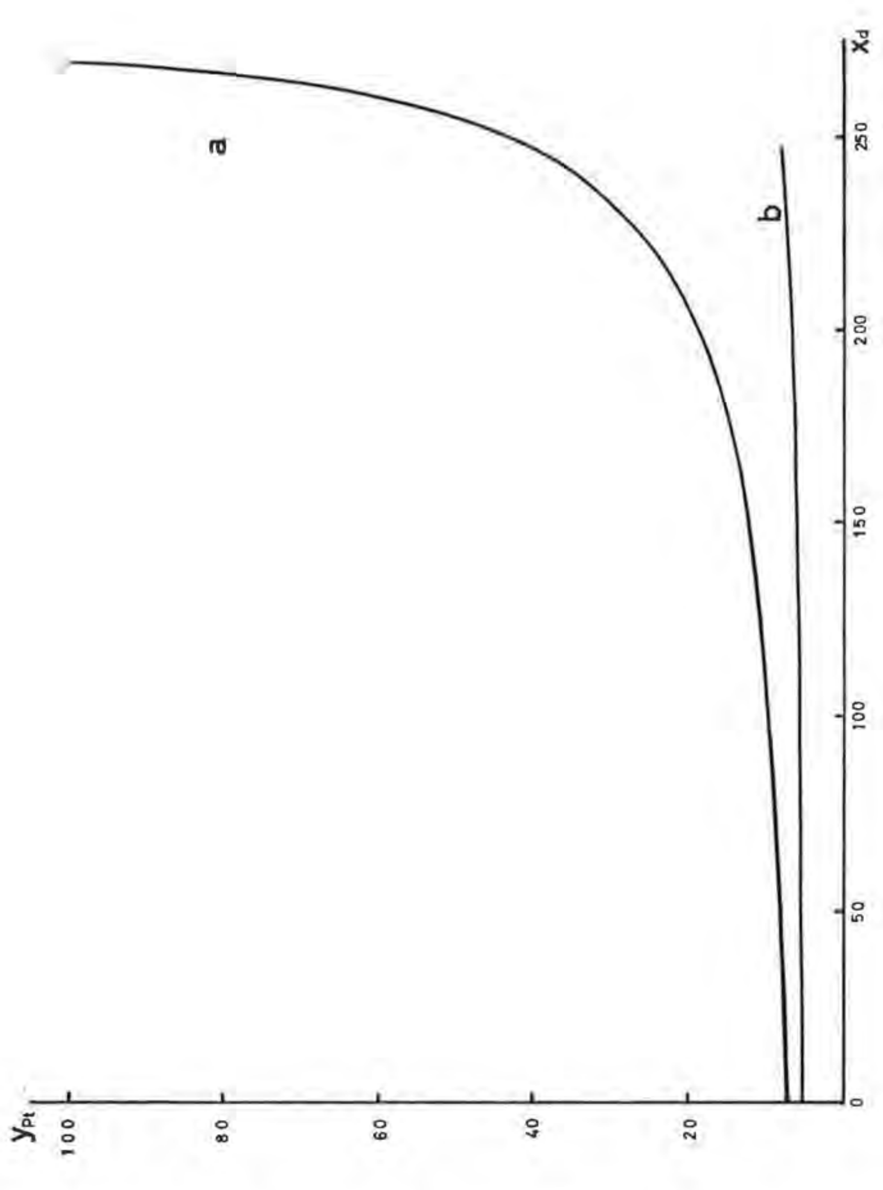

Fig. 3. The relation-curve between the position of the potentiometer in degrees (x_d) and the relative light intensity in percent transmittance (y_{pt}) for the A- and the B-scale.
The equation for the A-scale is :

$$0{,}000996\ x_d - 0{,}000497\ x_d\ y_{pt} + 0{,}141571\ y_{pt} = 1$$

The proportion of the e.m.f. E_2 and E_1 is decisive for the proportion of the light intensities below and above the canopy.

The relation (3) may be written as :

$$p = \frac{R_2}{R_v + R_1} \tag{4}$$

The value of the proportion p can vary between one and zero.

For each value p there is a corresponding value for R_v varying between zero and infinite.

The internal resistances R_1 and R_2 of the two photo-cells are different because they change with the received light intensity. For different external resistances varying between 15 and 1.500 Ohm of a selenium photo-cell, it was possible to relate the absolute light intensity and the internal resistance. It was found that for an increased absolute light intensity, the internal resistance decreases. That is why the internal resistances R_1 and R_2 vary according to the change of the light intensity.

For the above mentioned reasons the theoretical calibrations by calculation of the relation (4) are far from easy, so that the practical way is necessary. The practical calibration was done as follows. A given proportion of the light intensities on the two photo-cells in a compensating circuit of the apparatus implicates a specified value and a position of the potentiometer (R_v). The position of the potentiometer may be read in degrees on a graduation and is an indication for the relative light intensity (figure 3). It is found that the relation between the position of the potentiometer in degrees (x_d) and the relative light intensity in percent transmittance (y_{pt}) is hyperbolic. So the curve of the A-scale calibration is a perfect hyperbola with the equation :

$$0{,}000996\, x_d - 0{,}000497\, x_d y_{pt} + 0{,}141571\, y_{pt} = 1$$

2.4. *Practical Design*

The figure 4 shows the practical outline of the apparatus. In order to have some control over the value of relative light intensity in practical situations it was desirable also to create with the same apparatus a possibility for absolute light intensity measurements.

The tumbler-switch S_2 leaves a choice between the absolute and the relative measurements. The absolute measurements above or below the canopy (switch S_5) may be read on the scale of the

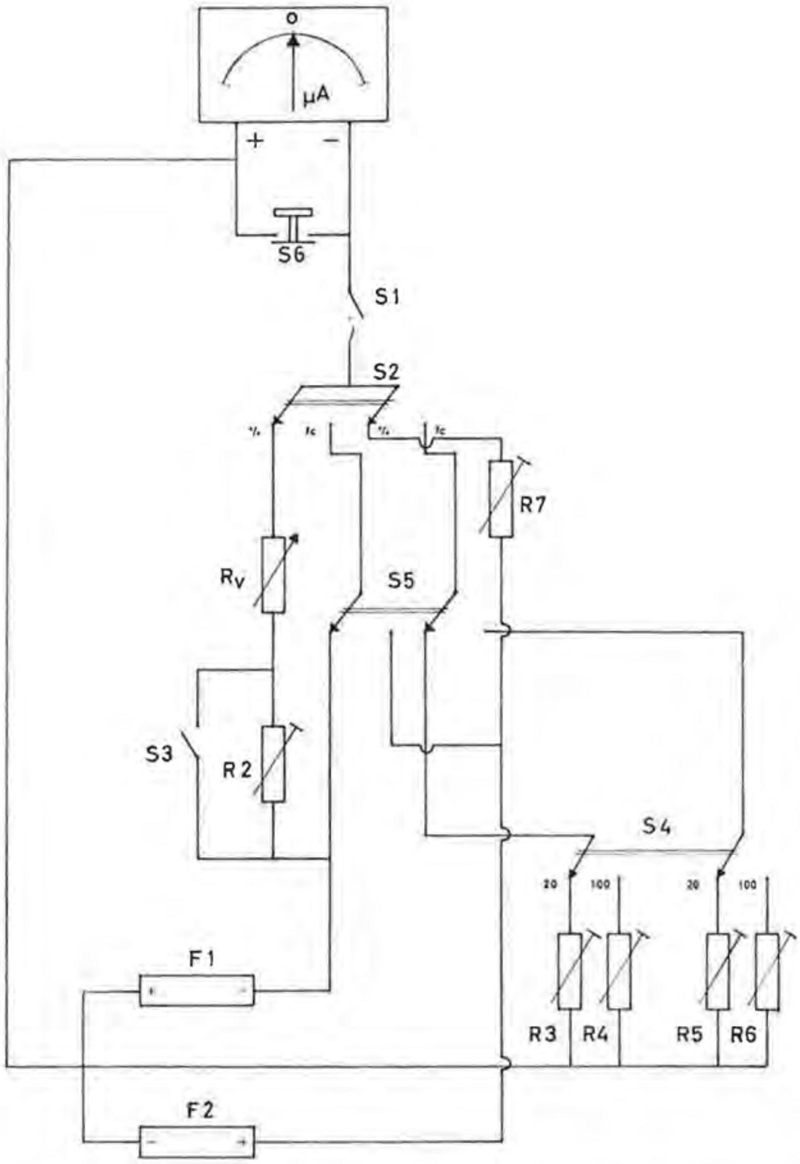

Fig. 4. The practical outline of the relative light intensity meter with compensating circuit and with possibilities for absolute measurements.

S_1 on/out
S_2 f.c./%
S_3 A-/B-scale
S_4 20/100 f.c.
S_5 above/below
S_6 zero-set.

microampère meter which is calibrated by the resistances R_3, R_4, R_5, R_6 in an adjusted 20 or 100 f.c. full-scale, chosen by means of the tumbler-switch S_4.

The µA-meter is one with a central zero-position.

As for the absolute or the relative measurements, this was the best solution. For the absolute measurements the pointer moves to the right or to the left according to the concerned light intensity above or below the canopy.

As described in the principle for instantaneous measurement of relative light intensity (2.2) a linear potentiometer R_V (10 k Ω) had to reduce the differential current in the circuit.

To enlarge the range of measurements it was necessary to use a resistance R_2, so that two scales were available. The switch S_3 leaves a choice between an A or a B scale. Both these scales have a different range.

The connection of the two photo-cells (F_1 and F_2) with the apparatus is made by two wires of different length. The obtained differential resistance is reduced by an adjustment of the resistance R_7.

The push-switch S_6 serves as a zero-set for the µA-meter.

3. Operation of the apparatus

3.1. *Photo-cells*

The cells used for the apparatus are selenium photo-cells Dr. Lange S50. These cells are frequently used in Europe for light intensity measurements in forest stands and related problems (Brechtel 1962; Van Miegroet 1965; Mitscherlich et al. 1965, 1966, 1967), because their spectral sensitiveness covers that of the human eye and the concerned maxima of both curves coincide.

At the same time the photo-current rises proportionally with the light intensity. But this characteristic is linear only below the 1000 lux for an external resistance of 100 Ohm.

3.2. *Filters*

If the light intensity is above 1000 lux it is necessary to reduce them so as to obtain significant results with the selenium photo-cell.

There is a wide range of neutral density filters available. The Kodak Neutral Density filters have for example a range of filter densities varying from 80.0 to 0.010 percent transmittance. Normally one of these neutral filters is sufficient to reduce the light intensity beneath the limit.

A first rational condition concerning the operation of the apparatus is that the full light intensity in the open or above the canopy (E_{bo}) is greater than or equal to this in a forest stand (E_o).

$$E_{bo} \geqslant E_o \tag{5}$$

This first requirement is stated because of the environment of the measurements of relative light intensity.

Nevertheless by injudicious use of neutral filters, the read value of the light intensity below the canopy can be greater than that in the open, so that no relative value can be obtained.

The next condition is determined by the density of the filter used on the photocell in the open (F_{bo}).

As said the filter had to be able to reduce the intensity below 1000 lux. If a filter with a percent transmittance of 0.10 is used, the light intensity to measure may be at the most 10^6 lux. Using a filter of 1.0 percent transmittance, the intensity to measure must be less than 10^5 lux.

Depending on the light condition in the open — determined by the topographical and geographical place, the time, the weather, the nebulosity, the clouds, the season etc. and on the light conditions in the forest stand (that are, in addition to the causes already enumerated, now more specifically determined by the forest stand) the following situations are possible within the above mentioned requirements.

1. The light intensities respectively above and below the canopy are below 1000 lux.

$$E_{bo} \leqslant 1000 \text{ lux.}$$
$$E_o \leqslant 1000 \text{ lux.}$$

In this case the two photo-cells need no neutral density filter.

The relative light intensity which is read (E_{ra}) is equal to the real relative light intensity (E_r) :

$$E_r = E_{ra} = \frac{E_o \times 100}{E_{bo}} \tag{6}$$

2. The light intensity in the open is more than 1000 lux and the one below the canopy is less than 1000 lux.

$$E_{bo} > 1000 \text{ lux.}$$
$$E_o \leqslant 1000 \text{ lux.}$$

As said the photo-cell in the open needs a neutral density filter of a certain value (F_{bo} in percent transmittance).

The reduced light intensity above the canopy is to be indicated as :

$$E'_{bo} = E_{bo} \times F_{bo} \qquad (7)$$

The condition (5) becomes :

$$E'_{bo} \geqslant E_o \qquad (8)$$

Now the read relative light intensity (E_{ra}) is no longer identical to the real relative value (E_r) :

$$E_{ra} = \frac{E_o \times 100}{E_{bo} \times F_{bo}} = E_r \times \frac{1}{F_{bo}} \qquad (9)$$

Hence it appears :

$$E_r = E_{ra} \times F_{bo} \qquad (10)$$

Because F_b is given in percent values, the expression (10) can be written as follows : The real relative light intensity is fraction-part of the read value.

3. The light intensity in the open as well as the one in the forest stand is greater than the limit value. Both photo-cells require the use of neutral filters with values respectively as F_{bo} and F_o

$$E_{bo} > 1000 \text{ lux}$$
$$E_o > 1000 \text{ lux}$$

a) If the densities F_{bo} and F_o are different, than the relative light intensity is equal to :

$$E_r = E_{ra} \times \frac{F_{bo}}{F_o} \qquad (11)$$

b) If the used filters are identical, their proportion is one and the real relative light intensity is equal to the read value.

It is evident that this third case is the most common for relative measurements in forest stands.

The advantage of using neutral filters with different values of percent transmittance, resides in the fact that indirectly the reading possibilities on limited scales become enlarged. The following numerical example will well illustrate this :

$$E_{bo} = 100.000 \text{ lux} \qquad \text{and} \qquad E_o = 1500 \text{ lux.}$$

$$F_{b_o} = \frac{1}{100} \qquad\qquad F_o = \frac{10}{100}$$

Thus the read relative value is :

$$E_{ra} = 15\ \%$$

The real value :

$$E_r = E_{ra} \times \frac{F_{bo}}{F_o} = 15 \times \frac{1}{100} \times \frac{100}{10} = 1{,}5\ \%$$

3.3. *Reading-Scale*

On photo 1, showing the operational part of the apparatus, two reading scales are to be seen : The A-scale going from 100 to 8 percent transmittance and a B-scale from 8 to 5 percent transmittance. This double scale was necessary because of the possibilities of the material used in the construction of the apparatus. In the same way it was impossible to exceed the limit value of 5 percent.

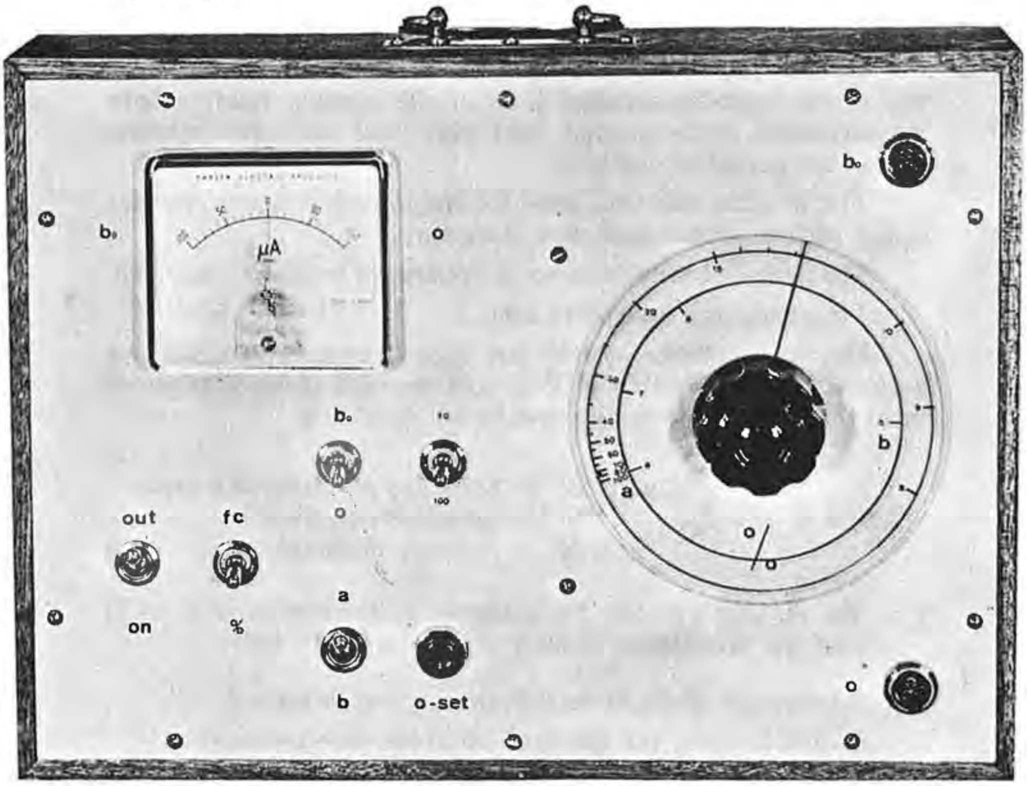

Photo 1. The operational part of the relative light intensity meter with compensating circuit.

As mentioned above (3.2) the correct use of neutral filters with different value can help to eliminate this deficiency. Because of the environment where the measurements were done, the photo-cells normally always need density filters, so that the filter-obligation is not a disadvantage. The most sensitive part of the scale is the lowest percent transmittance values.

Between 80 and 100 percent there is less sensitiveness, but considering the set purpose of measurements this is not so desired.

The difference in sensitiveness is obvious when looking at the curve of the scale calibration (fig. 3).

4. **The practical use of the apparatus in a forest stand**

Without reckoning the possibility of some raised objections as spectral sensitiveness of the photo-cells, the change of the spectrum after light-transmission through the leaves etc., some measurements were done with the apparatus in the experimental forest of the Department of Silviculture of Ghent at Gontrode.

On four places chosen at random, distinguished by a different size of the light-transmission level of the canopy, relative light measurements at the ground level were read every five minutes during the period of one hour.

The weather was very good for the intended measurements : sunny without clouds and very stationary.

The period of measurement was restricted mainly about noon.

The results are noticed in table 1.

For small samples (usually less than 30 observations) and for a probability of $P = 0.05$ or $P = 0.01$, on each place of measurement the value of the mean $\bar{x}$ will be between $\pm$ S'

where $S' = \frac{S}{\sqrt{N}}$ and S' = Standard deviation of a mean
S = Standard deviation
N = Number in sample.

t = the value of Fischer for n degrees of freedom ($n = N - 1$) and the probability levels $P = 0.05$ or $P = 0.01$

A statement of the fiducial limits is given in table 2.

As will be seen, the obtained intervals were satisfactory.

TABLE 1

A survey of the relative light intensity in percent transmittance on different moments and for different places, their mean value and the standard deviation on each place.

Place	The relative light intensity in % on successive moments with an interval of 5 min.													Mean values and Standard deviation
	0 m	5 m	10 m	15 m	20 m	25 m	30 m	35 m	40 m	45 m	50 m	55 m	60 m	
I 4	6.5	8.0	7.3	6.1	7.7	8.2	8.8	8.3	7.9	8.2	7.8	7.9	7.5	7.7 ± 0.7
H 9	2.3	2.2	2.5	2.4	1.8	2.8	2.7	2.7	2.2	2.1	1.9	1.8	1.7	2.2 ± 0.4
R 14	1.3	0.7	0.7	1.4	0.7	0.9	1.0	0.9	1.1	1.5	1.0	0.8	1.1	1.0 ± 0.3
A 19	13.0	12.5	13.0	13.5	11.0	11.5	16.0	10.5	14.5	11.5	11.5	11.5	11.2	12.4 ± 1.6

TABLE 2

The fiducial limits for different probabilities on different places

Place		Fiducial limits for the different probability (P)	
		P = 0.05	P = 0.01
I	4	7.7 ± 0.4	7.7 ± 0.6
H	9	2.2 ± 0.2	2.2 ± 0.3
R	14	1.0 ± 0.2	1.0 ± 0.2
A	19	12.4 ± 1.0	12.4 ± 1.4

Other positive considerations about the use of the relative light instrument may be summed up :

— Once the absolute light intensity above and below the canopy is approximately known, the right filters can be chosen. These absolute light measurements can be done grosso modo with the same apparatus.

— After the emplacement of the right filters on the photo-cells, the measurements can start in a quick tempo without difficulties.

— If it is prefered to move the photo-cell in the forest stand, someone may displace it, while the operator remains at the apparatus.

5. Conclusion

As it appears, it is possible to construct an apparatus for relative light intensity measurements, based on the principle of reduced currents in a compensating circuit.

Most difficulties arise from the potentiometer-calibration in percent transmittance values.

The correct use of the right filters allows an enlargement of the reading scale.

Direct and very good readings were made by right measurement conditions. This can also be said for routine measurements.

The apparatus lent itself particularly well to the making up of lightmaps and in general to the characterization of light conditions in forest stands.

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SUMMARY

An apparatus for the instantaneous measurement of the relative light intensity was constructed by Brechtel (1962). An analogical apparatus was built, from the same point of view, but on another principle. Namely two selenium photo-cells, connected in opposition, produce anti-currents in a closed circuit. The differential current is compensated or reduced to zero by a linear potentiometer.

The position of this potentiometer can be related to a value for the relative ratio between the light intensity above and below the forest canopy. The neutral density filters, which are necessary for the used photo-cells, can enlarge the reading scale, if they are chosen judiciously.

Some positive measurements were done in a forest stand. Generally the apparatus will give good results and will be easily used for the characterization of light condition in forest stands.

SAMENVATTING

Een toestel voor de onmiddellijke meting van de relatieve verlichtingssterkte onder het kronenscherm

Reeds door Brechtel (1962) werd een toestel vervaardigd waarmede rechtstreekse aflezingen van de relatieve verlichtingssterkte in bosbestanden mogelijk zijn. Uitgaande van dezelfde betrachtingen werd een gelijkaardig toestel gebouwd, gebaseerd op het volgende principe : twee fotoselenium cellen, tegengesteld geschakeld, leveren tegenstromen welke door middel van een lineaire potentiometer gekompenseerd worden of gereduceerd worden tot nul. De positie van de potentiometer is een maat voor de relatieve verhouding van de verlichtingssterkten respectievelijk boven en onder het scherm. De noodzakelijke neutrale densiteitsfilters voor de fotocellen kunnen, indien oordeelkundig gekozen, de afleesmogelijkheden op de relatieve schaal vergroten.

Richtinggevende metingen werden met het toestel doorgevoerd. Algemeen gezien zal het toestel grote diensten bewijzen bij de karakterisatie van lichttoestanden in bossen.

RESUME

Un appareil pour mesurer l'éclairement relatif instantané en forêt

Brechtel (1962) construisit un appareil pour mesurer l'éclairement relatif instantané en forêt. En visant le même but un appareil plus ou moins analogue fût construit selon le principe suivant : deux cellules photoélectriques, montées en sens opposé, produisent donc des contre-courants. Le courant différentiel est compensé ou réduit à zéro par un potentiomètre linéaire.

La position du potentiomètre indique la différence de l'intensité de la lumière au-dessus et au-dessous des cimes c.à.d. l'éclairement relatif.

Les filtres d'une densité neutrale, nécessaire à cause du milieu de mesure, donnent aussi l'avantage, s'il sont bien choisis, d'élargir l'échelle relative. Des mesures d'orientation faites avec l'appareil, démontrent qu'en général cette construction sera bien utilisable pour caractériser l'éclairement en forêt.