MEASUREMENT OF CURED TOBACCO LEAF COLOUR

By B. J. CRACK, M.Sc.* and F. CHIPPENDALE, M.Agr.Sc.†

SUMMARY

The Hunterlab and Hilger and Watts colour meters were used to measure cured tobacco leaf colour as an aid in experimental work on cultural and curing problems.

Both gave a satisfactory measure of colour, permitting variations to be interpreted on two-dimensional diagrams.

The leaf condition known as "flatness" was interpreted as comparatively low saturation of hue, and in psychophysical terms as comparatively low purity of dominant wavelength.

I. INTRODUCTION

The quality of manufactured tobacco is determined by a number of characteristics which render the product attractive to the consumer. These include physiological strength, aroma, flavour and colour. The grading, appraisal and buying of leaf are based on a number of readily observable physical characteristics from which the quality is judged by the experienced assessor. The buyer is also influenced by those characteristics such as texture and elasticity which concern particularly the manufacturer. Such characteristics as body, grain, texture and lustre are discussed by Barnard (1960).

Although a particular colour in itself may not be a prerequisite for smoking satisfaction, certain other quality factors are inferred from colour both by consumer and by manufacturer. Colour is the most readily observed property on the sale floor and the effect of colour, particularly unsatisfactory colour, is most important. The psychological effect is that the experienced assessor carries in his mind the memory of a range of colours acceptable or unacceptable. His experience correlates these with certain other properties determining quality. Furthermore, the system of grading in use in Australia over a number of years as outlined by Marks (1943) uses colour as a factor in defining a grade, although in grading and assessing, characteristics other than colour are also taken into account. Under the selling system in the United States of America, colour has been shown by Free, Weybrew, and Monroe (1953) to account for about 65 per cent. of the observed variation in selling price.

* Formerly Soils Technologist, Queensland Department of Agriculture and Stock

† Officer-in-Charge, Plant Nutrition Section, Queensland Department of Agriculture and Stock

Watkins and Hassler (1962), in reporting an investigation into causes of tobacco discolouration, commented that the market value of flue-cured tobacco depends to a large extent on its colour because correct colour assures the buyer that a crop has not been grossly mismanaged. Nickerson (1946) discussed the general application of colour measurement to the grading of agricultural products. It is not suggested that a system of grading based on instrumented colour measurement be established, but the importance of colour in tobacco is evident.

The need for precise colour measurement becomes important in experimental work. It would enable a measurable comparison to be made between treatments, both cultural and curing, and also allow comparisons between different crops and seasons. This need became evident in Queensland investigations into inferior quality leaf, described as "flat". This term came into common usage, particularly in the Burdekin area, about 1960. The term lacked any true definition and in fact was and is used with different meaning by various people associated with the industry. The term has been equated with other descriptive but equally indefinite terms such as "faded," "washed out," and "dull." Another descriptive term applied to extreme cases is 'mousy." It was hoped that precise colour measurement would assist in comparisons in experimental work and would also allow of some definition of the appearance characteristic known as "flatness". Attempts to use a colour atlas such as the Munsell Colour Charts were not successful, as it was found that the entire range of tobacco colours was comparatively small. Investigation was made into the use of photoelectric instruments to measure tobacco leaf colour.

II. PSYCHOLOGY AND PHYSICS OF COLOUR

The eye can distinguish small differences in colour but colour memory is not precise; hence, for comparisons over a period, or for fading, some form of instrument measurement becomes desirable. The physical basis of the colour of a non-luminous body is the radiant energy reflected in the different wavelengths of the spectrum and the composition of this can be measured with a spectrophotometer. However, the eye does not take into account the various wavelengths in the light received and can distinguish only differences in dominant or average wavelength, luminance and purity. These and related properties of a reflecting surface are referred to respectively as hue, lightness (or value), and saturation (or chroma). These three dimensions may be arranged in a psychological colour solid (Figure 1) in which the vertical axis represents lightness (from black to white). Direction from the axis corresponds to a particular hue and distance from the axis represents saturation.

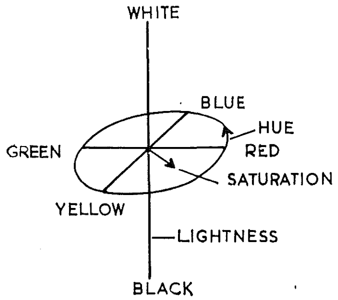

Fig. 1.—Psychological colour solid.

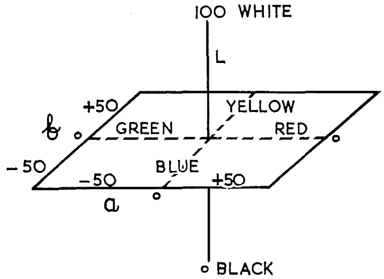

Fig. 2.—Psychophysical colour solid Cartesian co-ordinates. (After Hunter.)

The eye is a trivariant receptor and normal colour vision is three-dimensional, based on photosensitive pigments in the retina. For colour matching, a mixture of three primary colours can provide a match for any colour. Thus varying amounts of three primary stimuli to the eye can provide most colour matches and this is the basis of the tri-stimulus system of colour measurement. There are a number of theories on the interpretation of the trivariance of vision, among the best known being that of Young-Helmholz. The Hering theory is a psychological concept which proposed sensations arranged in opposing pairs to distinguish light-dark, red-green and blue-yellow. Any colour definition requires three terms, one defining lightness or luminous reflectance and two describing colour quality in terms of hue and saturation, dominant wavelength and purity, or amounts of red-green and blue-yellow. This latter way of describing chromatic differences in terms of opposing pairs is demonstrated in Figure 2, a psychophysical colour solid using Cartesian co-ordinates. The lightness scale is unchanged from that shown in Figure 1. The horizontal "a" axis measures red (+) and green (—) and the "b" axis has yellow (+) and blue (—).

In earlier attempts to define colours, the tri-stimulus primaries R, G and B were used but this gave rise to some negative values. A new system of co-ordinates was evolved such that the spectrum locus would fit entirely within positive co-ordinates. This is the C.I.E. (Commission Internationale de L'Eclairage) system as proposed in 1931 and described by Judd (1952) and Wright (1958), with the primary tri-stimulus values represented by X, Y and Z. In photoelectric tri-stimulus colorimeters, the filter systems are selected to correspond as closely as possible to the X, Y, Z ranges defined by the C.I.E. standard observer for a standard light source. The chromaticity co-ordinates (x, y) defining colour quality can be computed from the measured tri-stimulus values by the formulae $x = \frac{X}{X + Y + Z}$; $y = \frac{Y}{X + Y + Z}$. The eye shows maximum sensitivity to approximately 550 mμ, the maximum of the relative luminosity curve, and this corresponds to the Y filter of C.I.E. system. This Y value is taken as a measure of luminous reflectance. Thus in the C.I.E. system a colour is defined in terms of the Y tri-stimulus value and the chromaticity co-ordinates (x, y).

III. INSTRUMENTS USED

The major part of the initial tobacco colour measurement work described here was carried out using the Hunterlab Model D25 Color and Color Difference Meter. As described by Hunter (1958), this instrument has three vacuum phototubes each with separate tri-stimulus filter. Each filter has spectral distribution close to one of the tri-stimulus functions of the C.I.E. standard observer. The phototube chamber is thermostatted for stability. Incident light is reflected back perpendicularly to the photodetectors. The luminous reflectance value varies solely with the Y tri-stimulus reflectance and is measured on the L scale. However, the chromatic scales "a" (red-green) and "b" (yellow-blue) give values adjusted by the analog circuit of the instrument and corrected for specimen reflectance and by the uniform color scale factors. In this system a colour is defined by L, a, b, values, which are considered to be more directly correlated with the visually perceived attributes of colour than are the X, Y, Z tri-stimulus values. Standard Illuminant C was used throughout. The L, a, b values can be converted to C.I.E. X, Y, Z values by the factors given by Hunter (1958):

$$Y = (0\cdot01L)^2$$

$$X = 0\cdot9804 \quad (Y + \frac{0\cdot01\ a\ L}{175})$$

$$Z = 1\cdot181 \quad (Y - \frac{0\cdot01\ b\ L}{70})$$

Colour was also measured on a number of selected samples using the Hilger and Watts Colourmeter J40, also using Illuminant C and measuring directly in C.I.E. X, Y, Z tri-stimulus values. As previously described, chromaticity co-ordinates (x, y) are simply computed from these values.

IV. PROCEDURE

All work was carried out on cured leaf. Initially the work on whole-leaf samples was undertaken in an endeavour to determine colour differences due to different treatments in an experimental crop. Each sample consisted of 10 leaves taken at random from the cured leaf of each experimental plot for a particular harvest.

A leaf segment 2 in. square was cut from each of the 10 leaves in a sample and these segments were mounted on a card. The Hunter instrument used had the exposure head mounted with the window facing down, and the card with the mounted segment upward was held in place against the window, using a "Lab Jack".

For the work on powdered material, a sample consisted of 8–10 leaves. The midribs were removed and the laminae dried overnight at 65°C. This dried material was ground in a Braun mixer and passed through a sieve. For colour measurement, the powdered material was placed in a sample holder having a 2-in. square window of $\frac{1}{16}$-in. optical glass. The back of the sample holder was held in place by a spring clip, thus providing constant compaction of the sample.

Investigations were made into:—

(*a*) The effect of particle size on readings. Powdered samples prepared as described above were passed through 1-mm and 0·5-mm sieves respectively and colour readings made. Some samples of powdered, unsieved material were also measured.

(*b*) The effect of powder compaction. Readings were made on uncompacted powders and on powder under different compacting pressures.

(*c*) Instrument stability and accuracy of results. A number of readings were made using different subsamples of the one powder. Such replicated readings were undertaken for a number of different powdered materials. The precision of the instrument has been established using ceramic plates, and standard errors obtained are quoted by the manufacturers. The procedure described here was used to determine the reproducibility of results, which in this case would depend not only on instrument precision but on homogenity of the powdered material and on sample mounting.

(*d*) Colour measurement of powdered samples of leaf from the main Queensland growing areas selected to provide a range of leaf quality. A few samples of imported United States Mahogany leaf were also measured. Before preparation, leaf comprising each sample was rated for colour quality by three observers experienced in tobacco appraisal.

Ratings used were:—

1: Good to satisfactory average leaf colour.

2: Some flatness or undesirable colour evident.

3: Definite flatness or inferior leaf colour.

Actual commercial grades were also given to the leaf samples.

The powdered material was passed through a 1-mm sieve.

(*e*) The variation in colour within a graded lot. Readings were made on a number of separately prepared samples from each of several carefully graded lots. From each grade, six subsamples each of 8-10 leaves were selected and powdered. These grade lots did not represent different grades from the one crop but were from three different crops. The samples A1 and A2, B1 and B2, and C1 and C2 respectively represent two subgrades of a farmer grade.

(*f*) Measurement of selected samples in the Hilger J40 Colourmeter. Powdered material was placed in a sample holder having a thin glass base, and opaque walls and cover plate. The detector unit in this instrument is movable and in this procedure was used with the window facing upwards, which enables the sample holder to be located on top of the detector.

V. RESULTS AND INTERPRETATION

(a) Whole-leaf Samples

A typical series of readings for one sample is shown in Table 1 with standard deviations respectively of L $\pm$ 2·25, a $\pm$ 0·25, and b $\pm$ 2·20. It was considered that these differences within a sample were greater than permissible to classify a sample accurately. Furthermore, reproduction of readings depended on exact repositioning of each segment under the specimen window and was not good. It was decided not to continue whole-leaf measurements but it may be possible to obtain useful information from such measurements for classification within the range of tolerance of normal commercial grading if this is desired in the future.

TABLE 1

WHOLE-LEAF MEASUREMENT. TYPICAL VARIATION OF HUNTER UNIT READINGS FOR LEAF SEGMENTS REPRESENTING ONE SAMPLE

Reading	1	2	3	4	5	6	7	8	9	10	Mean
L	57·6	59·4	57·3	57·2	53·8	57·5	55·8	58·7	53·4	52·4	56·31
a	2·4	1·7	2·4	4·1	3·0	3·3	3·3	3·1	2·0	3·8	2·91
b . . .	21·7	25·3	22·5	24·8	21·4	23·8	22·5	25·2	19·0	19·0	22·52

Standard Deviations: L = $\pm$ 2·25; a = $\pm$ 0·24; b = $\pm$ 2·20.

(b) Powdered Material

Effect of Particle Size.—Table 2 shows the effect of particle size on colour measurement. It will be noted that more light is reflected from the finer material but that the effect is not constant. All general colour measurements subsequently described were carried out on the less-than-1 mm fraction, but it is possible that the less-than-0·5 mm fraction would be preferable as this finer sieve excludes the small vein material, an amount of which is present in the 1-mm fraction. The unsieved sample is not satisfactory as the varied orientation of the larger particles may affect the results.

TABLE 2
EFFECT OF PARTICLE SIZE ON COLOUR MEASUREMENT (HUNTER UNITS)

Sample	Particle Size <1 mm			Particle Size <0·5 mm		
	L	a	b	L	a	b
1	55·8	3·5	26·4	56·2	3·0	26·0
2	60·3	1·6	26·7	61·3	0·9	26·1
3	52·9	4·4	25·7	55·6	3·5	26·7
4	51·9	5·0	25·4	53·7	4·5	26·0
5	46·4	6·3	21·8	47·7	6·2	22·4
6	53·8	3·6	25·4	55·8	3·0	26·1
7	58·0	2·8	27·4	61·0	2·0	27·9
8	53·8	3·5	26·6	55·6	2·7	27·2

Effect of Sample Compaction.—For the work reported here, a definite weight (2 g) of powdered sample was placed in the holder with the base held in position by a spring clip. Thus the sample was compressed against the glass although no actual measurement of the compressive force was made. A loose sample is unsatisfactory, but provided the sample is compacted, the actual pressure exerted does not appear to be critical. Table 3 shows a typical comparison between readings of compacted and loose material for two samples.

TABLE 3
TYPICAL COMPARISON OF READINGS (HUNTER UNITS) FROM LOOSE AND COMPACTED MATERIAL

Sample	Loose			Compacted		
	L	a	b	L	a	b
A	57·2	2·9	27·5	60·1	2·1	28·0
B	58·3	2·1	25·7	61·3	0·9	26·1

For any detailed and extensive work in tobacco colour measurement and definition, standards of sample preparation, particle size and compaction need to be set down.

Stability and Accuracy.—Both instruments were found to have satisfactory stability. For eight replicated readings on the Hunter instrument for each of four lots of powdered materials, average standard deviations were L $\pm$ 0·130, a $\pm$ 0·092 and b $\pm$ 0·076. For similar readings on the Hilger instrument, average standard deviations were x $\pm$ 0·0015 and y $\pm$ 0·0014. These variations are small and reproducibility of results was considered to be good.

Colour Measurement of a Range of Leaf.—Hunter units L, a, b were recorded for each of 200 powdered samples. As previously stated, the definition of a colour requires three terms: one quantity term (luminosity in L or Y) and two quality terms, either (a, b) chromaticness co-ordinates of Hunter or (x, y) C.I.E. chromaticity co-ordinates. However, such actual definition, being three-dimensional, cannot be conveniently used for comparisons or diagrammatic representation. Most colours investigated will vary both in chromaticness and in luminous reflectance and the actual size of a colour difference $\triangle E$ combining these variations is given in N.B.S. (National Bureau of Standards) units defined by Hunter (1942). Judd (1952) discussed this measurement and various formulae and factors for calculation of $\triangle E$ from the different co-ordinate systems. Such calculation would be of value in measuring fading, but for actual interpretation of tobacco colour measurements it is found that the plotting of two variables only will serve to characterize the important variations.

In Hunter units, "b" is a measure of yellowness and this hue is most important over the range of Australian lemon, bright and bright mahogany leaf. Figure 3 is a plot of Hunter unit L (lightness) against b (yellowness) for a range of 200 samples of cured leaf.

In popular colour terminology, for the higher lightness range, lower saturation is evidenced as paleness or greyness and increased saturation produces brightness. In the lower lightness range, the less saturated colours are dull and those more saturated are deeper. In tobacco colour measurements as plotted in Figure 3, those samples referred to as flat are shown to have comparatively lower "b" values for any given L. This means that they have lower saturation and less purity. Flatness is associated mainly with leaf in the Bright range of leaf classification and where samples of comparatively lower saturation occur in the darker Mahogany range they would be referred to as dull.

A discriminant analysis was undertaken on the data shown in Figure 3, using only two classes. Leaf with any flatness evident was classed as unsatisfactory. For the two variables L and b the function $T = -2L + 5b$ was found to give good discrimination between the two classes of satisfactory and unsatisfactory. The average standard error for T was $4 \cdot 225$. For a probability of misclassification of 5 per cent., a doubtful region existed for T between $T = 12 \cdot 79$ and $T = 15 \cdot 61$. This region of doubt is shown on Figure 3.

For $T > 15 \cdot 61$, samples can be classified as satisfactory, and for $T < 12 \cdot 79$ samples can be classified as unsatisfactory.

Although good discrimination was obtained using the two variables L and b, a significantly better discrimination was obtained using the three variables L, a, b.

Figure 4 shows the grouping of the samples in their commercial colour grades as an aid to general understanding of the colour grouping. It will be noted that there is considerable overlapping of the Bright and Mahogany grades. This is partly due to difference in individual opinion and the large tolerance in commercial grading and partly due to the influence of factors other than specific colour appearance in such grading.

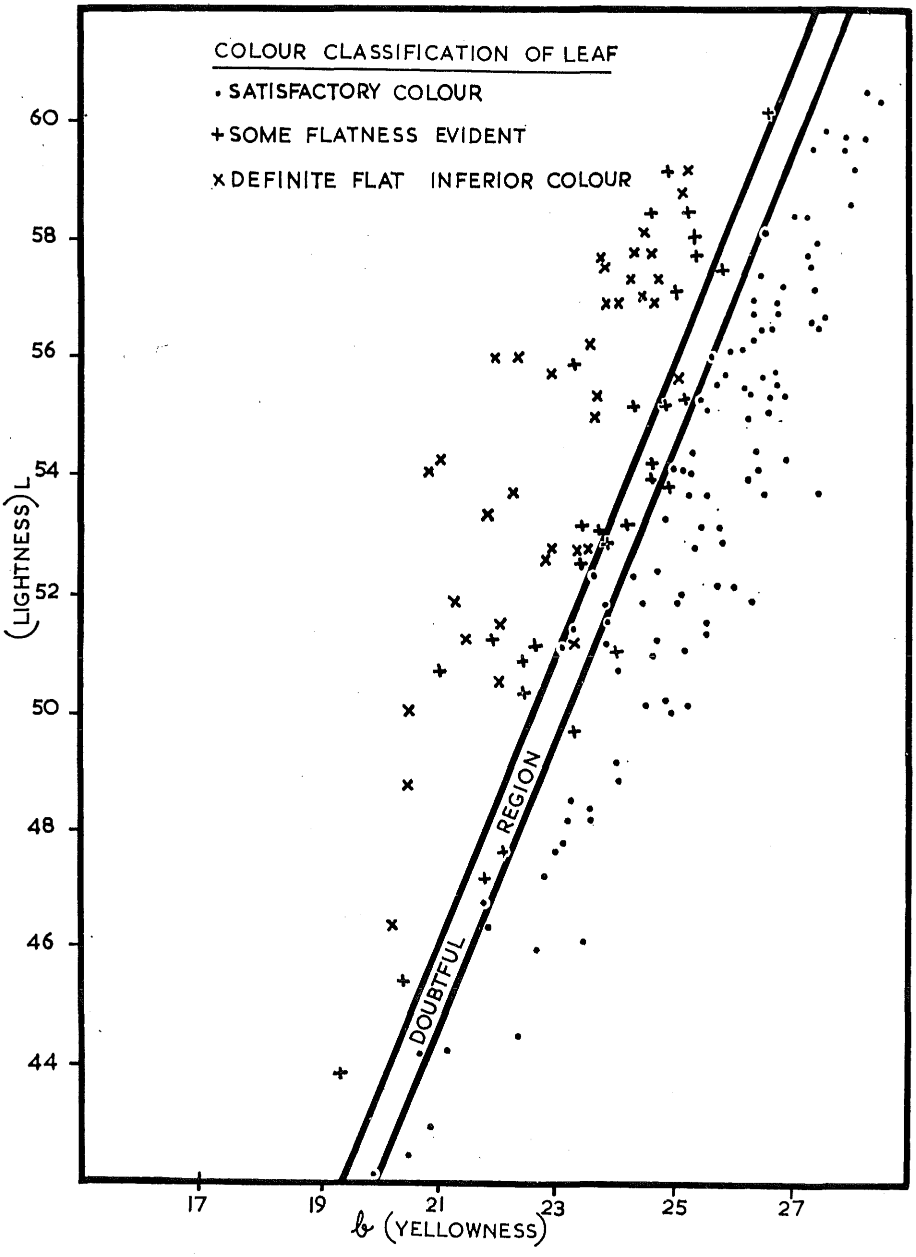

Fig. 3.—Plot of Hunter units (L, b) for a range of 200 classified tobacco leaf samples. This diagram also shows the region of doubt indicated by discriminant analysis of the data.

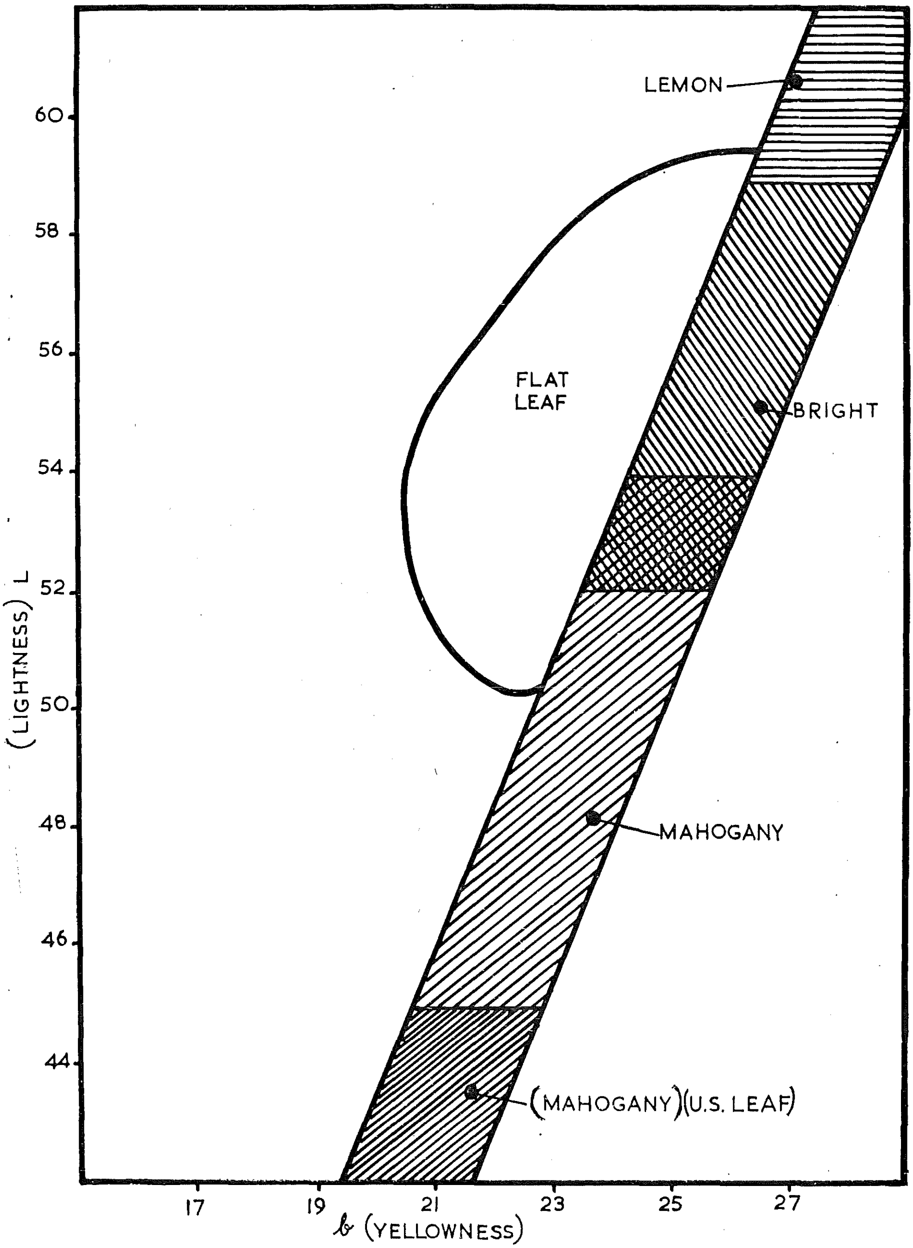

Fig. 4.—Range of commercial grades of tobacco leaf related to colour measurement for 200 samples (Hunter units).

The (L, b) plot distinguishes leaf of comparatively lower saturation in the yellow hue at the various lightness values and thus differentiates flat leaf. In some cases the apparent flatness is due to immaturity associated with plant starvation and false ripening. Greens or green cast may be evident also, but the flatness or paleness alone will be sufficient to categorize the leaf as unsatisfactory on the (L, b) plot. However, leaf may exhibit greenness and still appear bright. Although of unsatisfactory quality, such leaf will be grouped with good quality leaf on the (L, b) plot but can be detected on an (a, b) plot where low values of "a", (the red-green scale) will indicate greenness. Flat samples may also show low "a" values due to general low chromaticness, but if (a, b) values are plotted only for those samples placed in the satisfactory range in the (L, b) plot, samples showing greenness but not flatness will be characterized as shown in Figure 5.

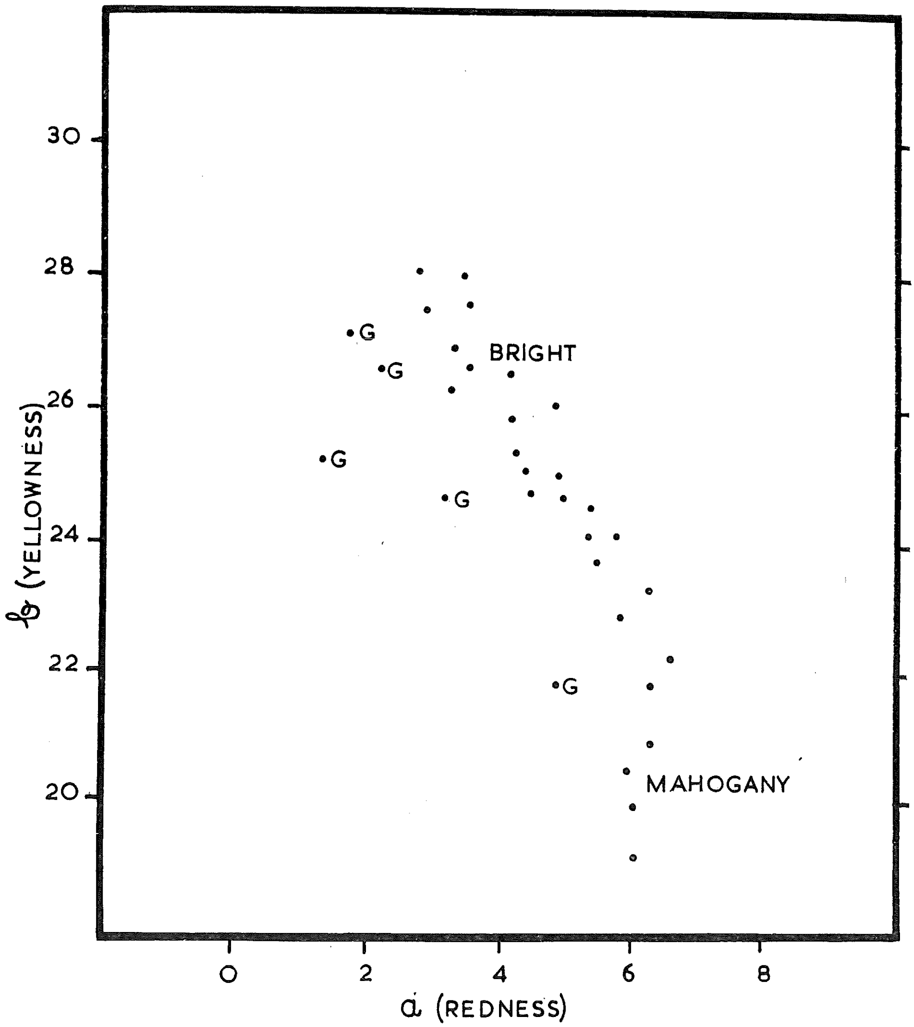

Fig. 5.—Plot of Hunter units (a, b) for a range of tobacco leaf indicating greens (G).

Sample Variation and Tolerance.—Because of the variations noted in the readings of whole-leaf samples, it was decided to investigate the range of readings on the Hunter instrument of a number of separately prepared samples from each of several carefully graded lots.

Figure 6 is the (L, b) plot showing the range of results obtained from each of these grade samples.

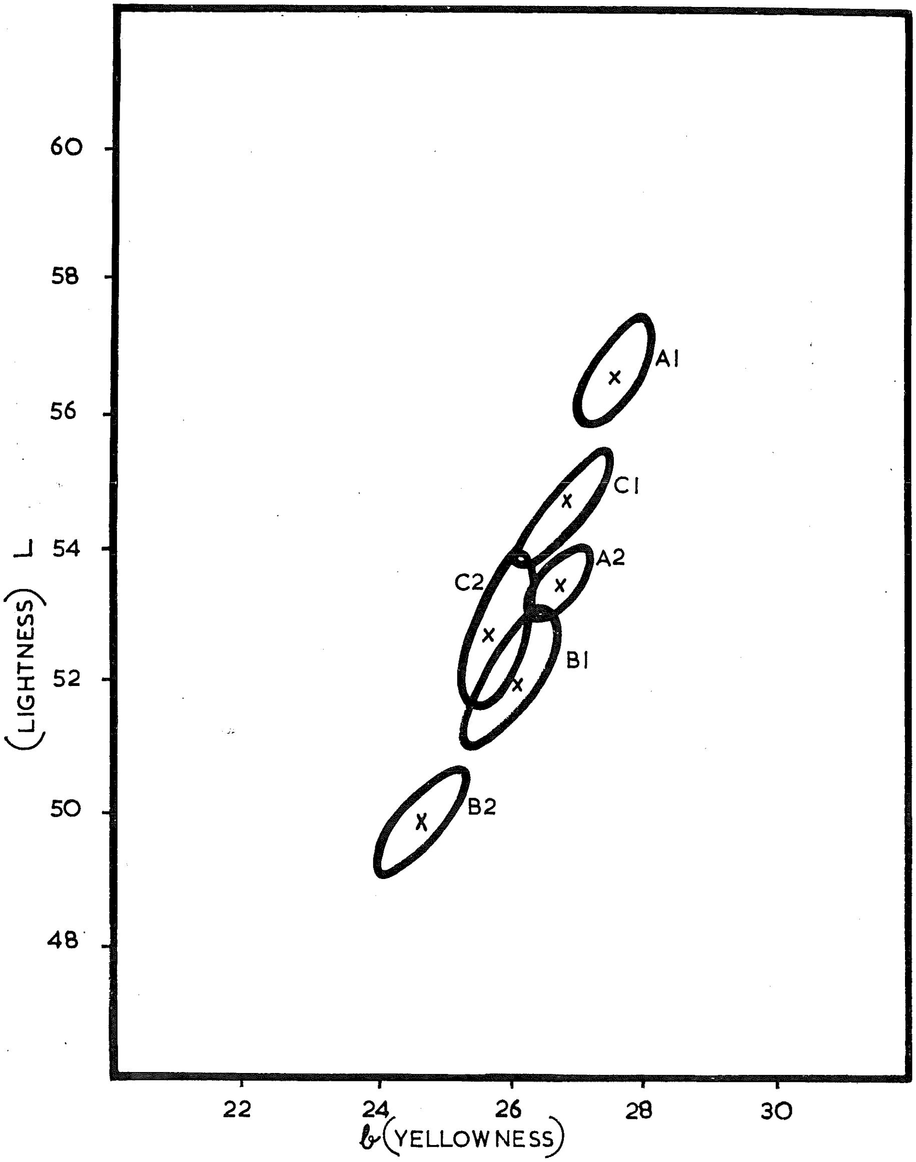

Fig. 6.—Variations within carefully graded lots (Hunter units). Each shaded area represents the range of readings of subsamples from that particular graded lot. The reading for a composite for each lot is indicated by X.

The readings of the subsamples from each graded lot show considerable variation but it will be noted that the general orientation of each group is similar to the slope of the overall (L, b) scatter of Figure 3. Differences in luminous reflectance are comparatively large and in this regard the instrument is more sensitive that the eye. However, any important differences in colour quality, as shown primarily in this case by "b" reading, have been rejected by the eye in grading. It is not suggested that the variations shown were for samples grouped by the eye as indistinguishable, as even in careful grading a range of tolerance is implied. Figure 6 gives some idea of the grading tolerance and shows that more tolerance has been allowed by the observer in luminous reflectance than in colour quality. Within each group, the reading of a composite powder sample for that group is indicated.

Nickerson (1944) discussed the measurement and expression of colour tolerance. Any system of colour grading of agricultural products involves a tolerance. In the case of commercial grading for tobacco, this is wide and probably does not need to be closely defined. In the case of experimental work, closer limits need to be set. Colour difference, or in this case the range of tolerance, can be expressed as a single figure, $\triangle$E. However, as lightness changes are more acceptable than colour quality changes, such a single figure is not of much assistance. For both commercial and experimental work in tobacco, the relationship between L and b is most important and has comparatively low tolerance.

In the case of the (x, y) chromaticity diagram, the scale is not uniform in perceptibility, as shown by MacAdam (1942). Such relationships in perceptibility are important in determining and interpreting tolerances in terms of the (x, y) scale.

*Measurement using Hilger J*40 *Colourmeter*.—A selected range of 50 samples previously measured on the Hunter instrument were also measured on the Hilger J40 giving X, Y, Z tri-stimulus values. Such values can be converted to Hunter units and comparable discrimination was obtained when this was done.

However, the colour differences can be interpreted from a two-dimensional (x, y) chromaticity co-ordinate diagram.

Figure 7 shows the spectrum locus plotted on an (x, y) chromaticity diagram with the white reference point for C.I.E. Illuminant C. Radial lines from this point to the spectrum locus indicate dominant wavelength and distance along such radial lines represents purity. Such a diagram does not take into account luminous reflectance and therefore does not completely define the colour but indicates variations in the colour quality factors of dominant wavelength and purity, regardless of luminance. The spacing on this diagram is not related to

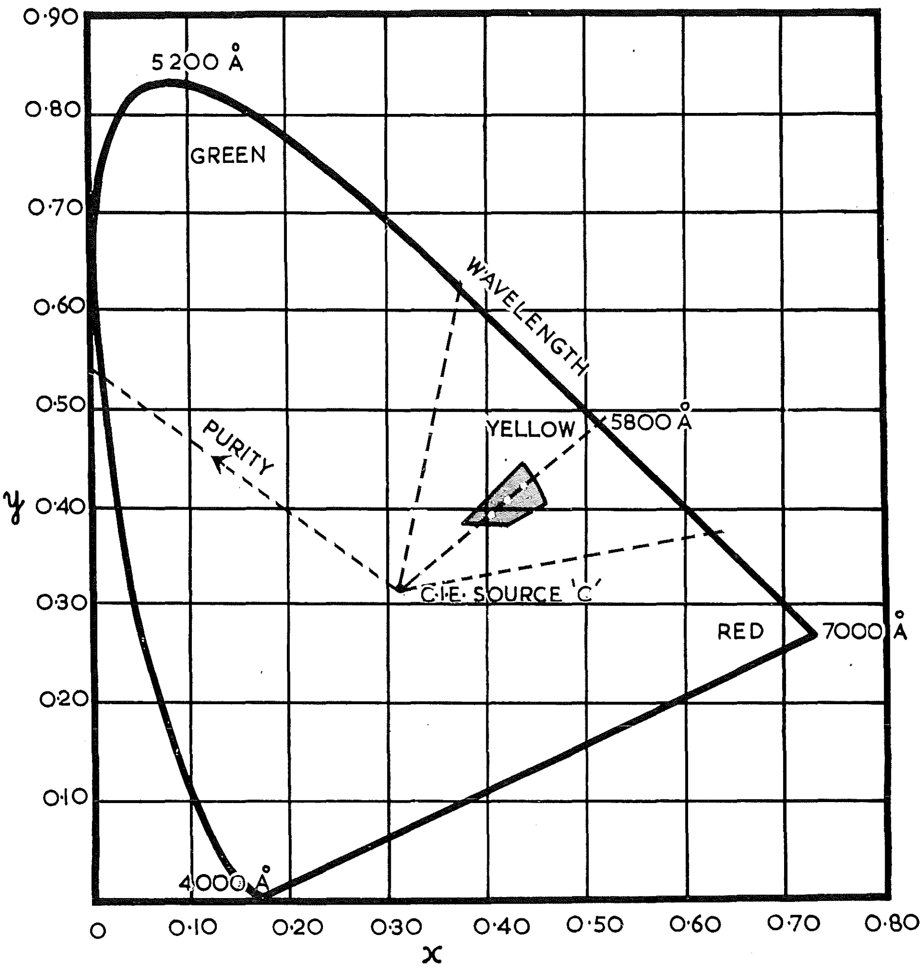

Fig. 7.—Spectrum locus plotted on (x, y) chromaticity diagram, indicating interpretation of dominant wavelength and purity. The range of the colour of tobacco leaf samples investigated is shaded.

equal colour perception intervals. Figure 8 shows that small portion of the (x, y) diagram covered in the measurement of the tobacco samples investigated. A range of leaf, using the same colour rating as for Figure 3, was measured. In such a diagram it will be seen that for a particular dominant wavelength, flat leaf is shown to have comparatively lower purity. In this diagram it is also apparent that greens will be shown by their location on a dominant wavelength radial line of lower wavelength.

Munsell Notation.—Chromaticness charts are available for equiluminous colours to interpret and define (x, y) chromaticity co-ordinates in terms of the Munsell colour system. A different chart is necessary for each Munsell value

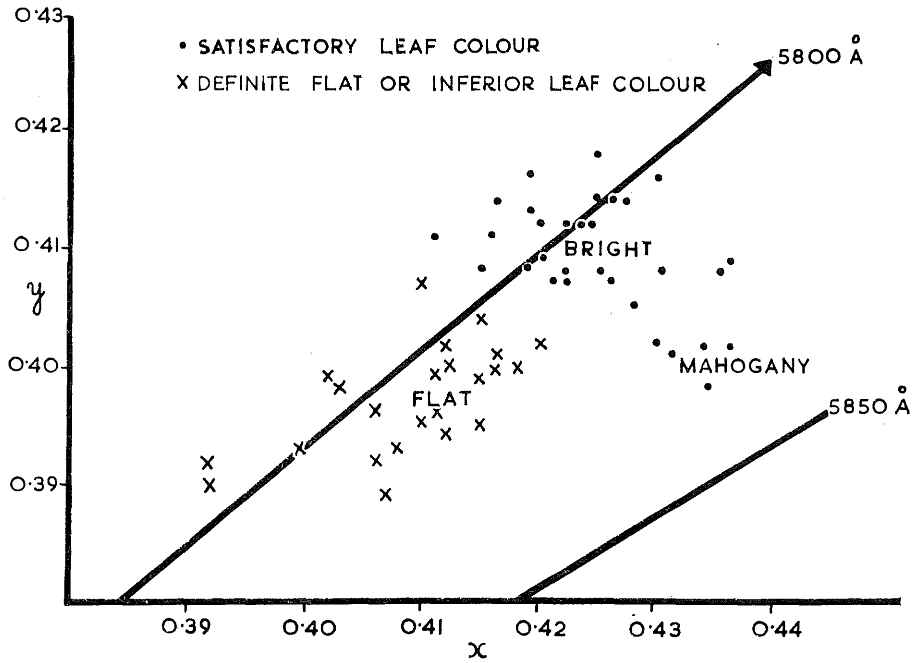

Fig. 8.—Portion of (x, y) chromaticity diagram for the range of tobacco leaf samples investigated. Co-ordinates are calculated from X, Y, Z readings made on the Hilger instrument.

and such charts and tables have been prepared by Newhall, Nickerson, and Judd (1943) for converting C.I.E. measurements to Munsell notation. Conversion of such measurements to Munsell units allows a better general understanding of the meaning of the measurements. Radial lines from the white point indicate hue, and distances from it as defined by the contour lines indicate saturation or Munsell chroma. Thus for any given luminous reflectance or Munsell value, such an (x, y) plot will define hue and saturation. In such a plot for a given luminous reflectance, flatness of leaf will correspond to lower saturation in the particular hue, a similar interpretation to that based on Hunter readings.

Munsell values (V) can be obtained from C.I.E. Y tri-stimulus value using tables given by Nickerson (1946). The Y values for the tobacco samples measured varied generally from $Y = 0 \cdot 20$ to $Y = 0 \cdot 40$, corresponding approximately to a range in Munsell value from 5/ to 7/.

Thus from X, Y, Z tri-stimulus values, (x, y) co-ordinates can be plotted and interpreted, and for given luminous reflectance or value, chromaticness can be defined.

VI. CONCLUSIONS

Either of the two instruments investigated will provide a satisfactory measure of cured tobacco leaf colour and an exact definition can be obtained in C.I.E. or related units.

For standardized conditions of sample preparation and reading, the range of satisfactory leaf colour can be established. Variations from this range can be defined and interpreted in terms of colour quantity and quality.

For a given value of luminous reflectance, flat leaf is shown to be comparatively lower in saturation of yellow hue than good quality leaf. In psychophysical terms, flat leaf is shown to be leaf of comparatively lower purity in the dominant wavelength.

Variations in tobacco colour can be shown and interpreted on two-dimensional diagrams.

VII. ACKNOWLEDGEMENTS

Thanks are due particularly to the management and laboratory staff of Taubmans Ltd., who made available the Hunter instrument over a prolonged period. The Hilger instrument was kindly made available by Watson Victor Ltd. Discriminant analysis of the data was provided by the Biometrics Branch of the Department, and various field officers assisted in the sampling. Thanks are also due to the various members of the tobacco industry who assisted in providing samples from sales floors.

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(Received for publication October 4, 1962)