SPECTROSCOPIC ANALYSIS OF SOIL COLOUR

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A knowledge of soil colour is useful both in practical agriculture and soil science. The colour of a soil is the most easily recognisable of all its characteristics and is frequently a significant criterion of the properties and agricultural value of the soil. The black and red soils may be mentioned as examples. The greater the number of properties with which colour can be correlated, the more is the knowledge gained of the soil. This means that soil colour should be studied objectively. In order to do this we must have (i) methods for the precise definition and measurement of soil colour in terms of strict physical standards, and (ii) a knowledge of the origin, composition and properties of the different soil groups for the interpretation of soil colour on an objective basis.

At present, the method available for measuring soil colour is that of the Munsell system and consists essentially in matching or duplicating the colour of the soil under investigation, with that produced by rapidly rotating a circular disc on which are exposed segments of discs of standard colours. This system is an improvement over the simple visual description of colour for the subjective study of soil colour but is not useful for its objective study.

We have fairly accurate methods for ascertaining the composition and properties of soils and there have been a few reports on the relationship between the visual colour and the composition of the soils.

Soil Colour and Composition

Leather[7] and Annett[1] attributed the colour of the black cotton soils of India to titaniferous magnetite and humus while Harrison and Ramaswami Sivan[5] held that the black colour was due partly to humus and partly to hydrated double silicates of iron and aluminium. Utescher[10] considered that the content of ferrous oxide (FeO) had no influence on soil colour and that the colour of a soil depended on the silica-ferric oxide ratio (SiO_2 : Fe_2O_3) in the hydrochloric acid-soluble portion of the soil. He stated that his results confirmed the view first put forward by Ganssen, namely, that with six molecules of silica for one of ferric oxide a grey soil might be

expected, with two molecules of silica for one of ferric oxide the soil would be dark brown, and that between these two extremes the soils would range between greyish brown to yellowish brown, a red coloration being the result of less hydration. Bal[2] attributed the black colour of the soils of the Central Provinces to a peculiar type of humification in base saturated soils. Hock[6] studied the behaviour of humus extracts of soils on exposure to the light of the mercury vapour lamp and found differences which permitted distinction between black soils and brown and grey-brown soils of Russia and Germany. From investigations on the humus content of a large number of soils of U.S.A., Gillam[4] reported that although the pigment content and humus colour was the greatest for Chernozem soils, followed in order by grey-brown forest soils, red, yellow and laterite soils, the pigment fractions isolated from soils of the different groups were remarkably consistent in chemical and physical properties. According to Utescher (*loc. cit.*) the coloration given by humus is generally masked by that resulting from the silica-ferric oxide ratio. Beck[3] reported that the removal of free ferric oxide had no effect on the yellow colour and considered that iron silicates were of minor importance. Roychoudhri[9] analysed black and red soils derived from the same geological formation and found the red soil to have more of free ferric oxide (Fe_2O_3) and the black soil more of silica (SiO_2). This is in agreement with Ganssen's view quoted by Utescher (*loc. cit.*). Thus, the meagre information that is available is incomplete and conflicting and there is need for a satisfactory method of defining and measuring soil colour and for the objetive study of soil colour.

METHODS AND MATERIALS

Colour is the manifestation of the result of interaction between matter and light and the colour that we see is the result of electronic and atomic motions in the molecules of the body. There is absorption of light at the surface of the body and re-emission or reflection in a definite manner. The visual colour of a body is determined by the light which comes from the body to the eye. Applying this to soil, it follows that the colour of a soil is determined by the group of wave-lengths of light that are absorbed and reflected.

The use of the spectrophotometer appeared to offer an accurate means for analysing and measuring soil colour. The preliminary work was done with Nuttings Spectrophotometer. The arrangement for absorption was suitably altered for reflection by means of two plane mirrors. The results obtained with this equipment were subsequently compared with those obtained by the G.E.C. Recording type of Photoelectric Spectrophotometer.

The latter work was done by one of us at the Ordnance Laboratories at Cawnpore. We are grateful to the authorities of those laboratories for the facilities and assistance so readily given us. The results with the two instruments agreed, with the exception that in the reflection curves towards the ends of the visible region, the results with the Nuttings Spectrophotometer were less reliable.

Natural uncultivated or virgin soils with and without different treatments such as ignition, addition of organic matter and leaching, and among components of soils ferric salts prepared in different ways were examined with the aid of the spectrophotometer. The samples of soils examined were the surface first foot soils collected from different parts of India for the comparative soil survey studies that have been in progress at this Institute. They were air dried, crushed and passed through 2 mm. sieve and the material that passed through was used for the spectroscopic study.

In Figs. 1 and 2 (Plate V) are presented the results obtained with the G.E.C. self-recording instrument. The ordinates (% reflectance) are the values for reflection compared with the reflection obtained with the standard magnesium carbonate block in the same region taken as 100. The abscissae represent the wave-lengths which are cut by the dotted vertical lines into the six colours of the visible spectrum (violet, blue, green, yellow, orange and red).

SPECTROPHOTOMETRIC ANALYSIS OF SOIL COLOUR

The following soils were submitted to colour analysis in their natural condition. The soils are listed according to visual colour groups, probable geological origin and the prevailing climatic factors, expressed as Meyer's factor, in that region (see Table I).

The results are presented in Figs. 1 and 2, (Plate V). The curves for the different soils are denoted by the simple numbers against them and correspond to those listed above. Some of the soils were also examined after submitting them to different treatments and they are denoted with the number and a letter indicating the nature of the treatment.

A after a number indicates ignited soil;

B after a number indicates that organic matter was incorporated into the soil (1·5% by weight of a mixture of powdered lucerne plant and calcium phosphate was added to some of the soils in petri-dishes suitably moistened and kept for two months with frequent stirrings);

TABLE I

Showing the soils analysed

No. of ref. given in Figs. 1 & 2	Name of the soil	General visible colour group	Chief geological region	Meyer's climatic factor
20	Surat	Black	Trap	202·4
21	Padegon	Do.	Do.	132·3
18	Labhandi	Do.	Cuddapah	237·2
22	Akola	Do.	Trap	141·0
17	Nagpur	Do.	Do.	225·0
19	Poarkhera	Do.	Trap surrounding Vindhyan	236·8
23	Koilpatti	Do.	Crystalline gneisses and schistose	154·6
5	Coimbatore	Red	Do.	162·0
3	Chandkuri	Do.	Do. & also Cuddapah	237·2
4	Ranchi	Do.	Do.	318·1
1	Taliparamba	Do.	Do.	753·9
2	Sirsi	Do.	Do.	666·5
9	Delhi	Orange brown	Transition	123·7
24	Makrera	Greyish orange brown	Do.	110·2
11	Karachi	Orange brown	Shales surrounding old deposit	35·8
6	Jorhat	Yellow	Alluvium	638·0
8	Waraseoni	Do.	Crystalline Aravalli	275·0
7	Dacca	Do.	Alluvium	505·2
15	Lyallpur	Pink	Indus Alluvium	60·8
16	Peshawar	Do.	Do.	69·2
14	Padrauna	Pinkish grey	Recent Alluvium	313·6
25	Berhampur	Do.	Coastal Alluvium	301·5
10	Lahore	Yellowish grey	Recent Alluvium	105·8
12	Haripur Hazara	Do.	Do.	74·3
27	Sakrand	Do.	Do.	32·7
13	Pusa	Whitish grey	Do.	207·9
26	Rangpur	Grey	Do.	686·3

C   after a number refers to the soil that was leached with water for a month with alternate drying and wetting;

D   after a number indicates addition of the leachate from C above. Numbers G 1 to G 5 refer to certain inorganic salts and will be explained later.

An examination of the curves in Figs. 1 and 2 shows that the objective colour of a soil consists of all the continuous colours of the visible spectrum and is not so simple as the subjective colour which is capable of being represented by only three primary colours. At the same time, the curves of objective colour for all the soils (leaving the ignited ones which are marked A on the group) are all similar indicating certain general characteristics—(1) similarity in the nature of the soil colour components in every case, in

spite of the fact that these soils appear unrelated on the basis of their subjective colour (as for example the red soil is subjectively unrelated to either the black or the yellow soil), and (2) the increase in the proportion of reflection with increasing wave-length for all the soils.

The objective colour of the red soils is distinguished by high reflectance values in the orange and red regions, the gradual increase in reflection with wave-length upto the green region, followed by a steeper rise in the yellow and then a moderated rise from orange onwards and a general tendency to a sigmoid curve with high values of reflection for orange and red, as will be seen from the curves for the soils of Chandkuri, Sirsi, Taliparamba and Coimbatore (curves Nos. 1, 2, 3 and 5 in Fig. 1). The ignited soils have the same trend but with a more pronounced S-shape in their curves.

The typically yellow and the orange yellow soils of Waraseoni, Jorhat, Dacca, Delhi and Karachi (Nos. 6, 7, 8, 9 and 11) tend to give double sigmoid curves with two humps, one in the middle of the blue region and the other in the green, giving high values of reflection from yellow onwards.

The pink soils of Lyallpur and Peshawar (Nos. 15 and 16, Fig. 2) have both the above features.

The black soils of Nagpur and Koilpatti (Nos. 17 and 23, Fig. 1), Poarkhera, Surat and Akola (Nos. 19, 20 and 22, Fig. 2) have almost a steady rise with the minimum and maximum amounts of reflectance between 10 and 20%.

The grey soils of Haripur Hazara, Berhampur, Rangpur and Sakrand (Nos. 12, 25, 26, 27) behave like those of the above group but with the difference that the reflectance values are higher (about 15–30%).

Figs. 1 and 2 show also the effect of the different treatments to which the soils and the salts were subjected.

Curves of the ignited soils marked A, have very much lower red reflectance values leaving their violet reflectance almost unchanged. The effect of incorporating organic matter in the soil (curves marked B) could more easily be seen in Chandkuri soil (B) by a depression in the red reflectance of about 3% than in the Coimbatore soil (5 B) or the Waraseoni (8 B). The effect of leaching soils from Akola, Padegon, Nagpur and Poarkhera (22 C, 21 C, 17 C and 19 C) and adding the leachete from the Akola soil to Waraseoni soil (8 D) and that from Nagpur soil to Coimbatore soil (5 D) has not produced any significant changes. In the case of prepared standard salts G 3 which is in effect iron silicate changed on ignition its curve (see G 3 A) which more or less resembles that for iron oxide or that for G 1 indicating thereby that it is decomposed to ferric oxide.

The soils thus far considered are what may be characterised as mineral soils and contain small but varying amounts of humus. The next step in the study was the differentiation between the organic and inorganic components of soils in relation to soil colour.

Soil Organic Matter in relation to Soil Colour

A red soil from Naduvattam, a black one from Moyar and a lighter black soil and a yellowish brown from Mansong were studied. The humus pigment was extracted according to the method of Gillam (*loc. cit.*) and the extracts were suitably diluted to obviate differences due to concentration arising from the differences in the humus contents of the soils. The absorption curves obtained are reproduced in Fig. 3, Plate VI. No. I H is for the red soil at 1.4×10^4 times the dilution of the amount in that soil, No. II H is for the black one from Moyar at 7.8×10^4 dilution, No. III H is the lighter black from Mansong at 4×10^4 times dilution and No. IV H is the brown soil from the same place at 10^4 times dilution. The scale is in wavenumbers and each strip of spectra is greater than the top strip by a density value of 9.1.

These curves indicate that the humus of differently coloured soils has almost the same kind of pigment which in ordinary concentrations absorbs completely the violet and blue radiations. However, the red and yellow soils on account of the relatively lower amount of pigment, reflect some light in the longer side of the blue. Thus the reflection spectra of soils in the violet, and in many cases in the blue does not appear to be influenced by the humus pigment and would appear to indicate the unveiling of the inorganic components that may be attributed to soil colour.

Inorganic Components of Soil Colour

The observation that variations in the reflectance in the violet region and to a less extent in the blue are not due to the organic pigment of the soils and the absence in soils of coloured inorganic salts, other than iron salts, in amounts sufficient to colour the whole soil mass indicated the study of iron silicates that may be expected to form and exist in the soil under different conditions. Accordingly the following salts were prepared and their reflection spectra are given numbered G 1–G 5 in Figs. 1 and 2:—

G 1 is ferric hydroxide precipitated from a solution of ferric sulphate with ammonia and washed as the extreme case of alkali leached ferric silicate.

G 2 is ferric hydroxide complex prepared as in (G 1) but by interaction between a large excess of sodium silicate over ferric sulphate to represent incomplete stage of leached ferric silicate and alkali retention.

G 3 is ferric silicate prepared by interaction between ferric sulphate and sodium silicate in proportions to give a salt of the formula $Fe_2(SiO_3)$, and the soluble portion washed out with water.

G 4 is ferric silicate prepared with a large excess of ferric sulphate over sodium silicate to represent incomplete leaching on the acid side.

G 5 is the precipitate obtained from a mixture of ferric sulphate and sodium silicate in solution and acidification as the extrme case of acid leached ferric silicate.

On the classical view of Oswald, the colour of the common iron salts is due to the Fe ion. There is evidence in literature (*cf.* Mellor's *Treatise on Theoretical and Inorganic Chemistry*, Vol. containing Fe, Vol. 12, 1932) to show that the changes in the colour of iron in combination are due to changes in (i) hydration, (ii) particle size, or (iii) electric charge on the iron clusters. With hydration as with the electric charge on iron, either the competition with attractive forces of water to iron causing hydrates of the electrostatic repulsion between electrically charged iron is brought into play which opposes the crystal forming forces (or the attractive force of iron to iron) and which therefore reduces the particle size of the iron cluster. The changes in colour due to changes in hydration or charge, are therefore attributable to changes in particle size which can directly charge its colour (see E. F. Holden, R. Bradfield and others quoted by Mellor, *loc. cit.*). Such changes are reported in literature in the gradual hydrolysis of ferric chloride, where the extent and conditions of hydrolysis determine the charge, hydration and size of the iron cluster and hence its colour. The same can be pictured during the hydrolysis of ferric silicate (which is a salt of a weak base and a weak acid) in presence of either an acid or a base, wherein the salts G 5 and G 1 can be produced. There is therefore justification for picturing the changes in colour on the state of hydrolysis of iron silicate, as gradual and continuous. This view derives support from the curves G 1, G 3 and G 5 in Fig. 1. All the curves show an increase in reflection with an increase in wavelength and with a steep rise in the green yellow region. G 1 which would be the end-product of hydrolysis under alkaline conditions of G 3 or from silicate, has a smoother curve with the above features, while G 3 has a greater steep and showing towards the red end a suppressed S or sigmoid shape; on the other hand for G 5, the S shape while still suppressed, is more pronounced than in G 3 with an additional but very small S shape in the earlier part of the curve.

Comparing these curves with those of the soils, the curves of all the soils are either similar to these three (G 1, G 3 and G 5) or take intermediary

shapes, indicating the essentially continuous change that is responsible for all these curves. The curve for Coimbatore (5) is in intermediary shape between G 1 and G 3 but mostly towards G 1. Curves for Sirsi (2), Taliparamba (1), Chandkhuri (3) and Kanke (lower No. 4) are gradual variations from G 1 towards the shape of G 3. Similarly Labhandi soil is variation from G 3 towards G 5, while Waraseoni soil (8) is a much farther variation in the same direction towards the shape of G 5. From a similar comparison of all the soil curves, it can be considered that G 1 and G 5 constitute limits for the changes in G 3 and cover the entire scope of variations present in the soils studied here. Thus it is possible to get the curves of these soils by interpolation between G 1 and G 3 or G 3 and G 5, or conversely to express the values of reflection as made up of the constituents G 1, G 3 and G 5. This is possible only in the violet and to a less extent in the blue region, where the humus studies showed that it is not responsible for the changes in soil colour in this region.

QUANTITATIVE EVALUATION OF THE INORGANIC COMPONENT OF SOIL COLOUR

It has been shown thus far that (1) the humus pigment does not appear to be responsible for variations in soil colour in the violet and the blue and any small variations are masked by the influence of the inorganic components, and (2) there is close agreement between the reflectance curves for the soils and the prepared salts.

Swampy and forest soils and the contribution of ferrous iron to soil colour have not yet been investigated. These have been expressly excluded from the scope of the present study which is confined to natural, virgin surface soils of the plains and in which conditions favourable to reducing reactions do not prevail. Having regard to these, it would be instructive to calculate and compare the values for reflectance in two different regions of the spectra for the standard salts and the soils given in Figs. 1 and 2. To do this it is necessary to make a simplifying assumption that, acidic and basic hydrolysis could not have occurred together in the soil without mutually interacting to produce either a net basic or acidic reaction.

The pink soils do not appear to permit this assumption. Leaving them out of consideration for the present, and if the assumption just now suggested is valid for the other soils, the calculated values for the reflectance of a soil should agree with the values for either G 1 and G 3 or G 3 and G 5.

On this basis, the calculated values for total reflection in the violet (the area enclosed by the curve on the x-axis in that region) was proportionately split either into G 1 and G 3 or G 3 and G 5 components. Similar figures for the blue are also obtained.

The method of calculation is shown below :—

Let X 1, X 3 and X 5 be the percentage of G 1, G 3 and G 5 components making up the colour of the soil and let R 1, R 3 and R 5 be the reflection values of G 1, G 3 and G 5 and r the reflection value of any one soil. Then solving by the assumption made, the equations—X 1 + X 3 = 100, and X 1 R 1 + X 3 R 3 = r, we get the value of X 1 and X 3. Similarly for the values of X 3 and X 5 we get them by solving the equations—X 3 + X 5 = 100, and X 3 R 3 + X 5 R 5 = r.

DETAILS OF CALCULATION OF THE INORAGNIC COLOUR COMPONENTS OF SOILS

1. If the colour component is all G 3 only and contains no other component, the reflectance of that soil in the violet must be 202·4 in the violet and 749·0 in the blue.

2. If for a soil the values are less than the above values in their respective regions, it means that either in part or in full G 3 is replaced by G 1, which has lower values than G 3 itself namely 121 in the violet and 385 in the blue.

2 (*a*). If G 3 is completely substituted by G 1, the fall in reflectance value in the violet = 202·4—121 = 81·4.

Thus if the fall in violet reflectance of soil from 202·4 is 81·4, it means the colouring matter has 100% G 1 and no G 3 at all.

2 (*b*). Similarly if the fall is zero (*e.g.* Padegon soil), it means the colouring matter has 0% G 1 and 100% G 3.

2 (*c*). But for intermediate values of fall between zero and 81·4 it means that the % of G 1 is also intermediate between zero and 100%.

e.g.—Surat has a value of 198 in the violet and therefore the fall = 202·4—198 = 4·4.

If the fall is 81·4, the G 1% in the colouring matter = 100% but when it is 4·4 as in Surat, $G 1\% = \dfrac{100 \times 4·4}{81·4} = 5·4\%$ and the rest, *i.e.*, 94·6% is the % of G 3 in the Surat soil.

3. Similarly for another soil instead of a fall in the violet reflectance, suppose there is a rise over 202·4.

Then it means that G 3 either in part or in full is replaced by the G 5 which has higher values, namely 514·8 in the violet and 2107 in the blue.

3 (*a*). For complete substitution of G 3 by G 5, the rise in the violet value = 514·8—202·4 = 312·4.

3 (b). But for Poarkhera soil the reflectance value is 253·0 in the violet. Therefore the rise = 253–202·4 = 50·6 only.

When the rise is 312·4%, G 5 = 100% and when the rise is 50·6 as in Poarkhera soil, G 5 = 100 × 50·6/312·4 = 16·2% and the rest 83·8% is the % of G 3 in the Poarkhera soil.

4. Similarly the % of the components G 1, G 3 and G 5 in the colouring matter of a soil can be calculated from the values of the rise or fall in the blue reflectance values. They were calculated and the two sets of values were compared.

The results are given in Table II below:—

Table II

Comparative values of reflectance in standard salts and soils

Soil and its visual colour	Violet reflection in planimeter units	Blue reflection in P.U. units (P.U.)	Calculated composition of iron pigment from violet			Calculated composition of iron pigment from blue		
			Ferric oxide G 1%	Silicate G 3%	Silicate acid leached G 5%	Ferric oxide G 1%	Silicate G 3%	Silicate acid leached G 5%
Standard Salts—								
G 1	121·0	385·0	100	..	..	100	..	..
G 3	202·4	749·0	..	100	..	..	100	..
G 5	514·8	2107·0	..	..	100	..	..	100
Black Soils—								
Padegon	202·4	750·6	..	100	..	..	99·5	0·5
Akola	233·2	882	..	90·1	9·9	..	90·2	9·8
Surat	198	763	5·4	94·6	..	..	98·96	1·04
Koilpatti	277·2	966	..	76·0	24·0	..	84·0	16·0
Nagpur	237·6	966	..	88·7	11·3	..	84·02	15·98
Poarkhere	253·0	994	..	83·7	16·2	..	81·96	18·4
Labhande	202·4	854	..	100	..	..	92·5	7·75
Yellow and Orange Yellow Soils—								
Waraseoni	277·2	1197	..	76·0	24·0	..	67·01	32·99
Jorhat	272·8	1120	..	77·5	22·5	..	72·68	27·32
Dacca	303·6	1302	..	67·6	32·4	..	59·28	40·72
Karachi	286·0	1162	..	73·2	26·8	..	69·58	30·42
Grey Soils—								
Makrera	237·6	862	..	88·7	11·3	..	91·66	8·34
Sakrand	365·2	1428	..	47·9	52·1	..	50·0	50·0
Lahore	321·2	1379	..	62·5	37·5	..	53·6	46·4
Haripur Hazara	321·2	1344	..	62·0	38·0	..	56·18	27·32
Pusa	404·8	1645	..	36·0	64·0	..	34·01	65·99
Berhampur	356·6	1288	..	50·7	49·2	..	60·3	39·7
Rangpur	343·2	1330	..	54·9	45·1	..	58·5	41·4
Padrauna	294·8	1029	..	70·4	29·6	..	79·4	20·6
Red or Brown Soils–								
Coimbatore	154·0	546	59·3	40·7	..	55·8	44·2	..
Sirsi	165·0	679	45·9	54·1	..	19·2	80·8	..
Taliparamba	184·8	721	21·6	78·4	..	7·7	92·3	..
Chandkhuri	171·6	679	37·8	62·2	..	19·2	80·8	..
Kauki (Ranchi)	193·6	784	10·8	89·2	..	..	97·4	2·6

The agreement in the calculated values from two independent premises namely, the reflectance values in the violet and blue regions is satisfactory in the sense that they emphasize the influence of the inorganic component as the determinant of soil colour. The agreement is particularly good for the black soils except for Koilpatti whose value for the violet region is more than that for its class value. The values for the blue region are however in conformity with expectation. In regard to red soils there is discrepancy in the two sets of estimates and the probable explanation is that they do not have the complete absorption in the blue region and therefore their blue values include the contribution due to humus while their violet values, as with the values in both the regions of other soils, do not include the humus pigment.

The broad conclusions from the investigations thus far made are that red soils are more alkali leached iron silicate, and black soils are those whose inorganic component corresponds more or less to iron silicate, while acid leaching of iron silicate leads to yellow and grey soils.

SUMMARY

The preliminary investigations reported in the foregoing pages may be summarised thus:—
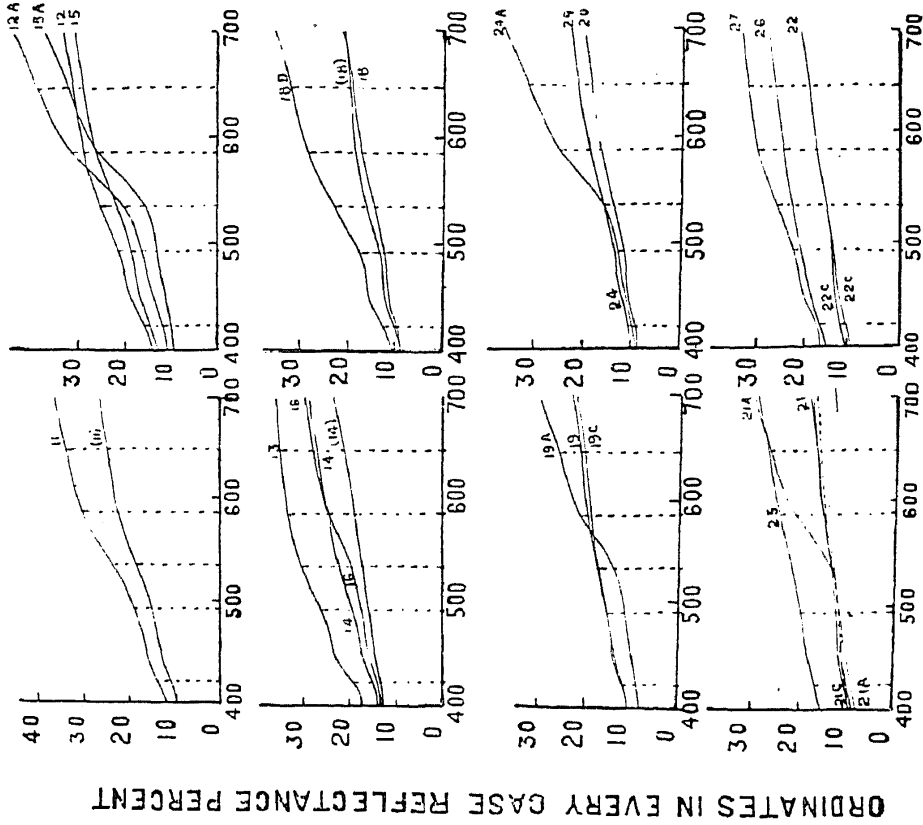
1. The colour factor of a soil has been so far not fully exploited in its relation to soil genesis and characteristics. This is because the understanding of soil colour has been imperfect.

2. The use of the spectrophotograph offers a new approach for the precise investigation of soil colour and for the correlation of soil characteristics with soil colour.

3. A study of the absorbed and dispersed light intensities of a soil has shown that soil colour can be investigated as a continuous variable.

4. The soil colour, as revealed by the colour analysis with the spectrophotograph, appears to be determined more by the inorganic components of the soil than by the organic.

It is to be hoped that this new and interesting approach introduces a new and more precise factor in explaining what soil colour is, to what extent it is due to absorption, to what extent it is due to scattering and reflection of light and in ascertaining soil genesis or formation under the influence of climate and geology. From the theories on the scattering of light, it may be possible to investigate the distribution of particle size and its effect, base exchange in relation to double layer of soil colloids or behaviour of soil colloids as acidoids, basoids and saloids.

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REFLECTION SPECTRA OF SOILS

ORDINATES IN EVERY CASE REFLECTANCE PERCENT

ABCISSA IN EVERY CASE WAVELENGTH IN MILLIMICRONS

FIG. 2

REFLECTION SPECTRA OF SOILS

ORDINATES IN EVERY CASE REFLECTANCE PERCENT
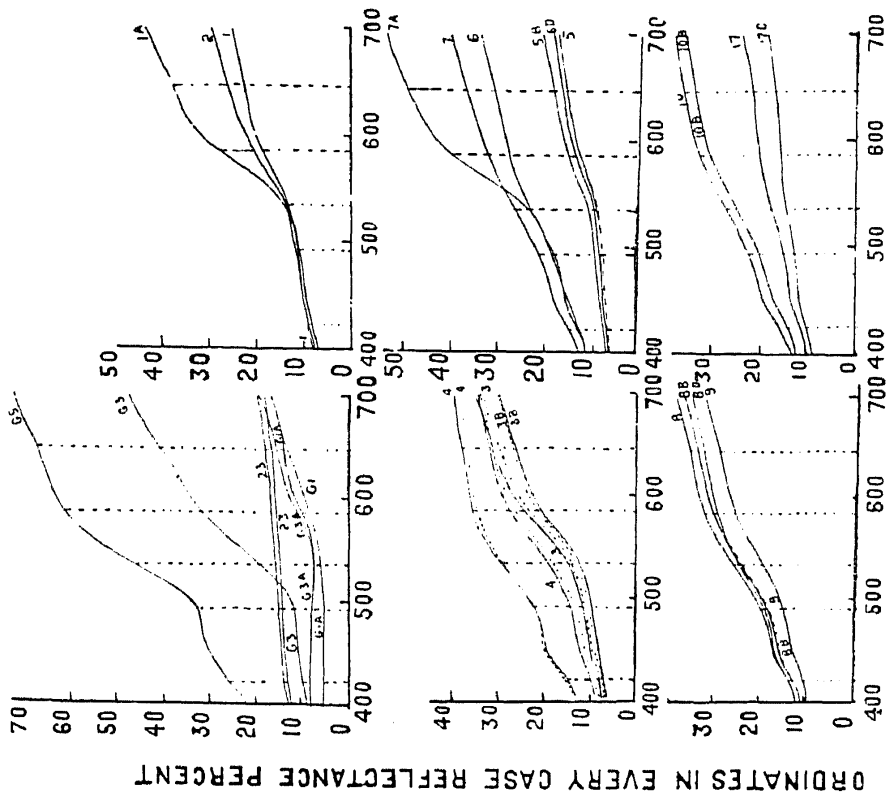
ABCISSA IN EVERY CASE WAVELENGTH IN MILLIMICRONS

FIG. 1

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ABSORPTION CURVES FOR HUMUS
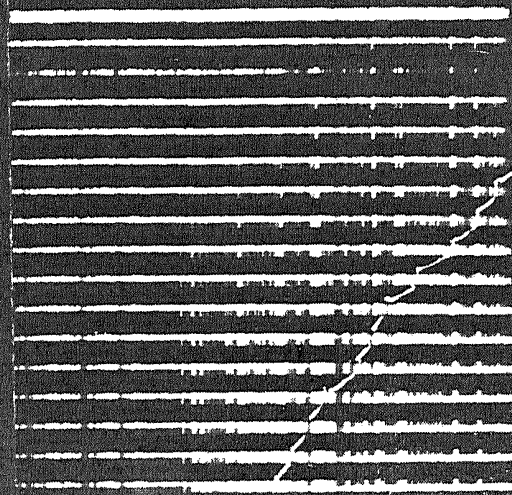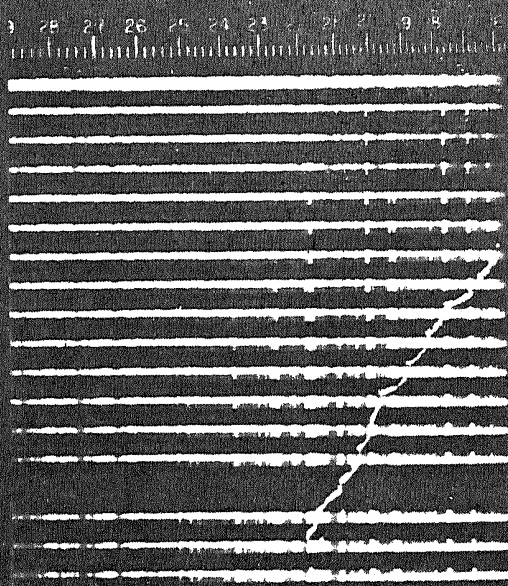
ABCISSA = WAVE NO. IN THOUSANDS Per Cm.