Netherlands Journal of Agricultural Science

VOLUME 11 NO. 5 NOVEMBER 1963

Statistical studies in detailed soil mapping; an aid in predicting the suitability of soils for crops by means of air-photo analysis

W. J. BRZESOWSKY

Soil scientist, Bennekom, Netherlands

Summary

A description is given of the procedure followed by the author in the assessment of the soil quality of lands under forest. Effective use could be made by a systematic photo analysis of the detailed information obtained in sample areas in regard to the significance of the soil-quality classification and to the relation between soil quality and terrain morphology.

1. Introduction

Systematic air-photo analysis has become an useful tool in modern soil surveys. Its efficiency has been generally recognized in semi-detailed and reconnaissance soil surveys (BURINGH, 1960).

The application of air-photo analysis in more detailed soil investigations has also advantageous aspects under certain circumstances (DE MEESTER, 1961; BRZESOWSKY, 1962). With the help of subsequent air-photo analysis, performed after the routine soil survey in the field, a final soil map can be produced of more detail than was originally aimed at during the soil-mapping stage of the field survey. This is largely due to more accuracy in the positions of the soil-mapping unit boundaries, to more variation in soil-mapping units and also to a smaller amount of impurities as usually present to a lesser or greater degree in the soil-mapping unit or classification unit. This can easily correspond to an enlargement of approximately two to three times of the scale of the originally planned field survey.

The efficiency of air-photo analysis depends very much on the use which is made of the physical, natural and cultural features as shown in the air-photo image such as terrain morphology, vegetation, land use and other phenomena.

The necessity of going into the field to classify and map the soils always remains, as the soil as such is not to be seen on air photos (VINK, 1962). Moreover it gives the soil surveyor the opportunity to correlate the soils with certain photo features, which in itself is an extremely important part of modern soil surveys.

Received for publication 28th April, 1963.

BURINGH (1960) has extensively described the various procedures for combining the field soil survey with the use of air photos and air-photo analysis. The main principle underlying this combination is to concentrate on detailed field and other investigations in sample areas and to extend the knowledge and experience to surrounding areas with the help of the information provided by the stereoscopic photo image. This is especially advantageous in areas which are not easily accessible or which are covered by dense forest vegetation as can happen in the more humid tropical zone.

Although a soil survey is the first important and necessary step in agricultural development, the second step, that is the soil-survey interpretation as part of land classification, is equally important (VINK, 1962), as it provides data which primarily concern the grouping of soils into suitability classes for a more or less specific use, or for improvement. It is considered that soil quality and soil/crop-response classification are also a part of this kind of soil grouping (KELLOGG, 1961).

In developing countries the need is usually present to obtain data for agricultural development on a short term. In representing data at an early stage of the overall development program, the decision can be made whether to continue or to discontinue soil investigations in particular areas, in the latter case saving considerable time and cost. On the other hand soil investigations can be continued or concentrated in areas which show possibilities for successful agricultural development.

In predicting the latter studies of a more detailed nature have to be carried out in sample areas or project areas.

In some cases experimental data resulting from simple field trials and related to similar soils and soil conditions are available. This increases the accuracy of the prediction. Unfortunately, many field trials have been set up in the past without taking into account the existing soil variability; this in particular applies to tropical regions. Hereby important information for the soil/crop-response classification has been lost.

Nevertheless, from the soil/crop-response analysis it can be found out which of the various soil characteristics and soil properties are predominantly responsible for differences in crop behaviour such as crop production, disease susceptibility and so forth.

In setting up a soil-quality classification the various soil characteristics and soil properties which are important for a certain use of the soils and their influence on crop behaviour, should be tested if possible for their significance. This can be done for the crop in question, or for a crop which is similar in behaviour (*e.g.* reaction to hard-pans, poor drainage) and nature (root system, density and distribution in the soil profile).

If no data are available or can not be obtained in another way, the accuracy of the prediction becomes less accurate at its best. This may be the reason for the failure of some published soil-capability and soil-suitability maps when applied in practical agriculture.

If the soil-quality classification for a certain use of the soils has been established by statistical means, the sample area can be analyzed according to the classes set up for this purpose. It is then possible to correlate soil quality with certain terrain features which are also clearly visible in the three dimensional air-photo image.

The latter is important because, finally, the knowledge so obtained can be projected on adjoining areas of similar nature by means of systematic air-photo analysis. An assessment can then be made as to what extent the various soil-quality classes are represented in and distributed over the area of investigation.

In the following a brief discussion of the procedure followed by the author is presented. This investigation was carried out by him when in the service of the Cameroons Development Corporation.

2. Methods

2.1. Soil/crop-response analysis

In this kind of analysis the response of a crop on a certain soil type (or series or phase) is considered for a certain set of crop-management measures.
From investigations carried out by HASSELO (1961) in West Cameroons, it could be concluded that in areas with pronounced differences in seasons, the depth of the soil profile is a determinative factor in the selection of areas for plantation agriculture. HASSELO has given some excellent examples of the effect of soil-profile depth on vegetative growth, crop production and disease susceptibility of various perennial crops like bananas, rubber and oilpalms.
By the author several studies were carried out in connection with the root depth and root distribution of the latter crops, which confirmed the observations of HASSELO. It was found that in bananas and oilpalms which both form their greatest density of roots usually within two feet of the topsoil of a well-drained profile, a considerable amount of roots are still present up to three to four feet depth. In more shallow soils or imperfectly drained soils the depth of rooting was usually well related to these soil properties and soil characteristics.
In West Cameroons plantation agriculture, and also native agriculture, is based mainly on the growth of perennial crops with usually a moderately deep to deep rooting system. Therefore, series and phase distinction was considered to be an important criterion in differentiating mapping units in soil surveys and in the classification of the soils into soil-quality or soil-capability classes.

2.2. Soil-quality classification

Taking into account the prevailing climatic conditions, the variability of the soils and the information obtained from field trials and other investigations, the soil-quality classification classes were tentatively grouped as follows:

Class 1: (good)
- a. No occurance of root-impeding layers or horizons within 5 ft. of the soil profile;
- b. No stony layers (basalt) occurring within 3—4 ft. of the soil profile and only very few concretions present in the surface horizon.

Class 2: (reasonable)
- a. No occurance of root-impeding layers or horizons within 4 ft. of the soil profile;
- b. No stony layers (basalt) occurring within 2—3 ft. of the soil profile and only very few concretions present in the surface horizon.

Class 3: (mediocre)
- a. No occurance of root-impeding layers or horizons within 2—3 ft. of the soil profile;
- b. No stony layers (basalt) occurring within 1—2 ft. of the soil profile and only very few concretions present in the surface horizon.

Class 4: (poor)
- a. Occurance of root-impeding layers or horizons within 2 ft. of the soil profile or abundant laterite concretions present in the whole profile (60—90 %);
- b. Occurance of stony layers (basalt) within 1 ft. of the soil profile but only very few concretions in the surface horizon;
- c. Indication of ground water within 5 ft. of the soil profile.

Furthermore, the following soil characteristics were taken into account in placing the field observations in the soil-quality classes, *e.g.*:

a. *Soil texture* (series distinction: coarse-, medium- and fine-textured soil series);
b. *Cementation of concretional layers* (slightly compacted, rather compacted, cemented);
c. *Abundancy of concretions in surface horizons* (few, plentiful, abundant);
d. *Drainage* (contrast, abundance and colour of mottling) and *topographical position* (slope, relief).

Root-impeding layers consisted mainly of concretional layers and laterite hard-pans. Their position in the soil profile, as was noticed several times, had a distinct effect on the structure of the surface horizons and consequently on root growth.
Finally, the soil-quality classes were statistically tested for their significance. For this purpose an area of about 550 acres covered by similar soils and by one of the plantation crops was selected. A detailed soil survey was then carried out at a density of one observation per ha. During the soil survey a careful recording was made of the crop's appearance (*e.g.* fruit quality, disease symptoms, growth) surrounding each soil boring.
The crop's appearance was classified as "poor — rather poor" and "rather healthy — healthy".
The soil quality of each soil boring and the classified appearance of the crop surrounding each soil boring were statistically tested by means of the Chi-square method. Subsequently, the soil-quality classification classes were adjusted for use in the field.

2.3. Establishment of the relation between soil quality and terrain morphology

For this purpose a sample area of approximately 1500 acres covering similar soils was selected. After the detailed soil survey the soil borings were classified according to the final soil-quality classification classes and according to their position in the terrain in terms of macro relief.

2.4. Soil-survey procedure and air-photo analysis

Soil surveys in the sample areas were carried out according to a grid of 100 meters square, giving an average of one observation per ha or two observations per five acres. Air photos at a scale of 1/13000 were used as field and working maps. At a later stage the positions of the observations were transferred to topographical maps at a scale of 1/10000, which were used for the reproduction of the soil-quality map. The topographical maps were of reasonable accuracy and were made from air photos by means of photogrammetric methods. Plantation and field boundaries were shown in full detail on these maps.
Air-photo analysis was restricted to the extension of the knowledge into surrounding areas of similar nature and soils. Both 1/13000- and 1/44000-scale air photos were used for this purpose.
Since the sample area was partly covered by dense forest, the air-photo analysis in terms of micro relief proved to be extremely difficult. Only small pockets of swamp forest indicating concave relief were clearly visible in the photo image.
In those parts of the sample area traces were cut and set out by means of a compass. For other purposes this method would not have been the most accurate one but due

to a very careful recording of the topographical position of the soil borings, the latter could be re-allocated on the topographical maps without too much difficulty. Moreover, since the main aim was to find a relation between soil quality and topographical position, the above lack of accuracy was felt not to be a great disadvantage.
It was found that the time involved in the soil survey of the areas covered by forest was twice as much as compared with a similar soil survey in open lands. However, the detailed information obtained in this way could be utilized so effectively by a systematic air-photo analysis of the surrounding areas that the time spent normally in a soil-quality survey of the same standard and without the use of air photos, could be considerably reduced.

3. Results and discussion

3.1. Soil landscapes and soils

The main physiographic units of West Cameroons have been well described by HASSELO (1961), *e.g.*:

a. Landscapes with immature soils from volcanic parent material;
b. Landscapes with mature soils from volcanic parent material;
c. Landscapes with young soils from marine deposits;
d. Coastal-plain landscape;
e. River-Alluvium landscape.

The area under investigation covers mainly the landscapes with mature soils from basic volcanic parent material, situated beyond the 300 ft.-contour line and that with young soils from marine deposits below the 300 ft.-contour line. The former landscape is generally very broken-up by narrow valleys bordered by steep slopes.
The young soils derived from marine deposits were tentatively classified by BRZESOWSKY (1962) as zonal soils belonging to the Yellow Podsolic soil group and as intra-zonal soils belonging to the Hydromorphic soil group.
The soils covering the dissected landscapes derived from basic volcanic parent material are usually ferruginous in nature. Where they are eroded severely, rust and grey mottling and weathered basalt pebbles are usually present in the surface horizons. In many cases a very fine quartz-sand fraction is mixed throughout the soil profile.
Volcanism in West Africa was wide spread during the tertiary era and it is assumed that the presence of the basic parent rock is the result of these ante-quaternary eruptions through the pre-cambrium shield. Usually, one encounters great blocks of very coarse-grained basic rocks in the area under investigation which is likely to be the result of their exposure due to erosion of the more easily weathering effusives once covering the surface.
Evidence for a probable tertiary sea-shore level (Pliocene) was found by the author in the presence of a marine terrace (raised beach) situated between 800—900 ft. above M.S.L.. Small terrace scars of approximately 40—50 m^2 area covered by rather sandy to sandy clay deposits were also found in areas between the 300—800 ft.-contour line. The soils derived from the tertiary volcanic eruptions extend from 300 ft. to 1300 ft. above M.S.L. but are sometimes overlaid at lower altitudes by young quarternary lavas. The presence of laterite concretions increasing normally downwards in the soil profile and in other cases the presence of thick laterite hard-pans at various depth of the soil profile, together with the usually observed poor aeration of the soils, would place the

soils in the group of the ground-water laterites or ferruginous lateritic soils. The formation of these soils is influenced by the solution of iron and manganese compounds under temporary water-logged and anaerobic conditions during the rainy season, and their precipitation on oxidation in the zone of intermittent saturation; in the drier periods dehydration and induration takes place (VAN DER MERWE, 1956).
From the descriptions given hereunder it may be noted that an A_2-horizon commonly present in a ground-water laterite soil is absent. It is assumed that the original A-horizon has been removed by erosion exposing hereby the B-horizon. The present A-horizon is formed in part of the exposed B-horizon.

TERRAIN MORPHOLOGY

Vegetation : Abandoned banana land, grasses, weeds.
Relief : Excessive.
Slope : Strongly sloping.
Altitude : 700 ft above M.S.L.
Rainfall : 75 inches per annum.

PROFILE DESCRIPTION

0—40 cm (A_1) : Brown-dark brown (10 YR 4/3) silty clay, medium angular-blocky, weak to moderate, friable. From 35 cm downwards some weathered basalt pebbles present. Plentiful roots present.

40—50 cm (A/B) : Boundary diffuse, smooth; Brown (7.5 YR 4.5/4) clay, medium angular-blocky, moderate, slightly friable.

50—60 cm (B_1) : Boundary diffuse, smooth; Brown (7.5 YR 4.5/4) clay, coarse angular-blocky, moderate, firm; distinct rust, reddish yellow (5 YR 6/8). A few roots present.

60—90 cm ($B_{2\,1}$) : Boundary diffuse, smooth; Brown (7.5 YR 4.5/4) clay, coarse angular-blocky, moderate, firm; distinct rust, reddish yellow (5 YR 6/8); plentiful laterite concretions. Few roots present.

90—150 cm ($B_{2\,2}$) : Boundary diffuse, wavy; Brown (7.5 YR 5/4) clay, very coarse angular-blocky, moderate strong, firm; distinct rust, reddish yellow (5 YR 6/8) and distinct. Light-grey to grey mottling (10 YR 6/1); abundant laterite concretions. No roots present.

CHEMICAL COMPOSITION

Horizon	pH		Percentage				ppm	
	H_2O	KCl	Org. matter (Walkey Black)	Base saturation	Ca	Mg	K	Na
0—40 cm (A_1)	5,9	5,4	1,816	52	0,198	0,064	110,0	12,0
60—90 cm ($B_{2\,1}$) ..	5,6	5,0	0,498	43	0,101	0,077	57,0	14,6

It is assumed that the dissection of the tertiary volcanic landscape is recent as is revealed by the terrain morphology and mainly occurred during and after the pleistocene era, *i.e.* during the gradual regression of the sea to its present level, exposing hereby the ferruginous-manganiferous subsoil layers. A certain uplift of the area due to renewed volcanic activity in the quaternary era is not unlikely.
The presence of laterite hard-pans immediately below the marine-deposited topsoil (in cases where the marine erosion had removed the solum of the ferruginous soil completely) and the presence of so called "buried" profiles (in cases where erosion has been less intense) in the area below the 300 ft.-contour line, suggest that the old volcanic landscape at present is underlying the landscape covered by marine-deposited soils.

The following soil series could be distinghuished during the detailed soil survey of the sample areas, *e.g.*:

a. Marine-deposited soils (MA series) : *i.e.* fine-textured soils (sandy clay or very sandy clay) with a sand fraction usually between 120—300 μ. Munsell Hue 10 YR.

b. Buried soils (MA/BF series) : *i.e.* soils with a marine-deposited topsoil and a very fine-textured subsoil (silty clay to clay) often mixed with a very fine quartz-sand fraction. Ferruginous-manganiferous subsoil, Munsell Hue 10–7.5 YR.

c. Brown ferruginous soils (BF/MA series) : *i.e.* soils with a very fine-textured topsoil and subsoil (silty clay to clay) and mixed with a very fine quartz-sand fraction (120 μ). Ferruginous-manganiferous. Munsell Hue 10–5 YR.

d. Brown ferruginous soils (BF series) : *i.e.* soils with a very fine-textured topsoil and subsoil (silty clay to clay). Ferruginous-manganiferous. Munsell Hue 10–5 YR.

3.2. Statistical test of soil-quality classes

In TABLE 1 the results are summarized according to the soil-quality class of each soil boring and according to the appearance of the crop surrounding each soil boring.

TABLE 1. Relation between tentatively defined soil-quality classes and appearance of Gros Michel bananas

Soil-quality class	Appearance of Gros Michel bananas (3–4 years after planting); No. of assessed cases			
	poor – rather poor (a)	rather healthy – healthy (b)	in %	
			(a)	(b)
1	5	11	33	70
2	6	12	30	67
3	15	11	58	42
4	51	22	70	30
Total	77	56		
	χ^2 = 13,78 **	P 0,01 = 11,341		

The test reveals that there is a highly significant departure from homogeneity. Moreover, the number of cases where a healthy to rather healthy crop is present, proved to be significantly higher on class 1 and 2 soils, and significantly lower on class 4 soils. Class 3 soils occupy an intermediate position (58 %—42 %) in this respect.

It was decided to group class 1 and 2 together, forming class I. Consequently, class 3 became class II and class 4 became class III. This seemed to be justified for a practical use of the classification in the field.

Based on observations obtained from soil-profile cum root-distribution studies carried out in oilpalms and bananas, and in view of their similar nutritional requirements (potash; HASSELO, 1961; BRZESOWSKY and VAN BIESEN, 1962) and their susceptibility to diseases (Fusarium; HASSELO, 1961), it was found justified to extend the information obtained in the Gros Michel bananas to oilpalms, but not to rubber which has a much stronger root system than the former two. In other words, more generous conclusions could be drawn for crops like rubber regarding the suitability of class I, II and III soils for cultivation.

3.3. The relation between soil quality and terrain morphology

In TABLES 2 and 3 the results are summarized according to the soil quality of each soil boring and according to their position in the landscape.

TABLE 2. Relation between soils, soil-quality classes and terrain morphology

Soil-quality class	Soil series				Total (actual observations)	Ratio class II + III/class I
	MA	MA/BF	BF/MA	BF		
On sub-normal relief						
Class I	114	5	4	2	125 (55 %)	0,8
Class II + III ..	80	8	12	3	103 (45 %)	
					228 (100 %)	
On normal to excessive relief						
Class I	27	4	2	13	46 (17,5 %)	4,7
Class II + III ..	61	34	24	98	217 (82,5 %)	
					263 (100 %)	

From TABLE 2 it can be seen that the physically better soils are predominantly situated on lands with sub-normal relief, that is on nearly flat to sloping lands.
TABLE 3 gives a more detailed break-down of the relationship.

TABLE 3. Relation between soils, percentage of observations as classified by soil-quality classes and terrain morphology

Soil series and relief	% of observations classified as			Ratio class II + III/class I (actual observations)
	Class I	Class II	Class III	
MA-series				
On sub-normal relief	59	14	27	80/114 = 0,7
On normal—excessive relief	30	30	40	61/27 = 2,25
MA/BF-series				
On sub-normal relief	40	20	40	8/5 = 1,6
On normal—excessive relief	10	25	65	34/4 = 8,5
BF/MA-series				
On sub-normal relief	25	10	65	12/4 = 3,0
On normal—excessive relief	10	25	65	24/2 = 12,0
BF-series				
On sub-normal relief	40	40	20	3/2 = 1,5
On normal—excessive relief	10	50	40	98/13 = 7,5

The differences in quality between soils on sub-normal relief and on normal to ex-

cessive relief is quite remarkable. It is interesting to note that the marine series (MA-series) situated below the 300 ft.-contour line show the lowest ratios both on subnormal relief and on normal to excessive relief. The highest ratios are shown by the BF/MA-, the MA/BF- and the BF-soil series respectively.
A part of the sample area is shown on the soil-quality map (FIGURE).

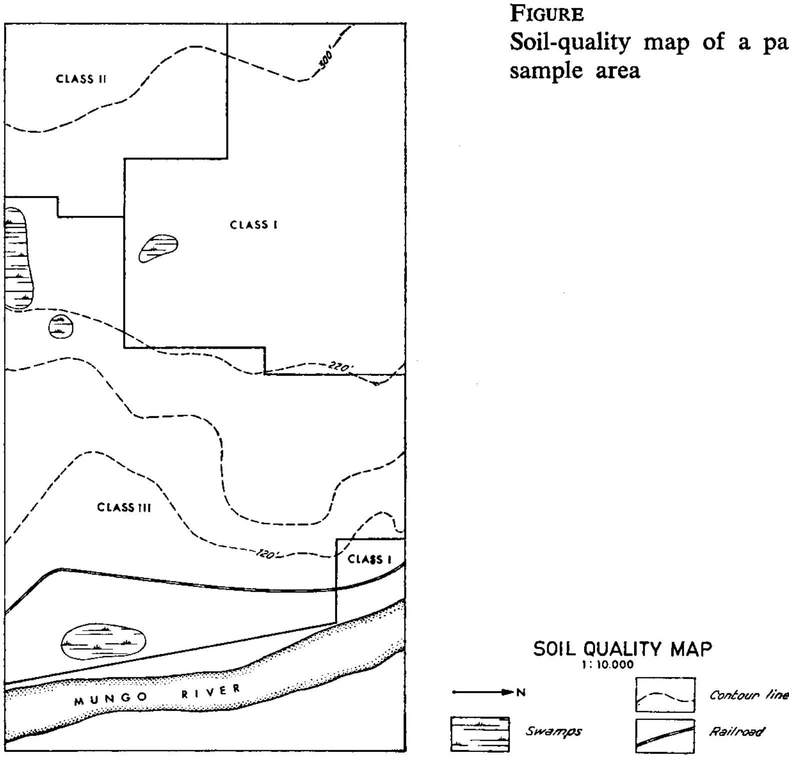

FIGURE
Soil-quality map of a part of the sample area

3.4. Extension of the information

The observed trend was used subsequently as an aid in assessing the quality of adjoining lands of the same geological origin.
Since most of these lands were still covered by forest (a most useful additional information in tropical countries), extension of the detailed information obtained in the sample area into adjoining areas proved to be quite effective by means of a systematic photo analysis of the lands, in that the latter considerably reduced the time of assessing the capability of the uncultivated lands.
In a final stage after the systematic photo analysis had been carried out in the office, some trips were made to the area and the results of the photo analysis were carefully checked for their validity.

ACKNOWLEDGEMENT

The assistance of Mr. Y. L. A. IJSSELMUIDEN in the recording of the field observations, sometimes under rather difficult conditions, is gratefully acknowledged.

REFERENCES

BRZESOWSKY, W. J. 1962 Podsolic and hydromorphic soils on a coastal plain in the Cameroon Republic. *Neth. J. agric. Sci. 10,* 145—153.

——, and J. VAN BIESEN 1962 Foliar analysis in experimentally grown Lacatan bananas in relation to leaf production and bunch weight. *Neth. J. agric. Sci. 10,* 118—126.

BURINGH, P. 1960 The application of aerial photographs in soil surveys. Manual of Photographic Interpretation. Handbook Amer. Soc. of Photogrammetry, Wash. D.C.

HASSELO, H. N. 1961 The soils of the lower eastern slopes of the Cameroon Mountain and their suitability for various perennial crops. Thesis, Wageningen.

KELLOGG, C. E. 1961 Soil Interpretation in the soil survey. USDA Coil Conservation Service, Wash. D.C.

MEESTER, T. DE 1961 The application of air photo analysis in a detailed soil survey in Tanganyiaka. *ITC-publication.* Series B, No. 10, Delft, Netherlands.

MERWE, C. R. VAN DER 1956 Clay minerals of the sub-tropical soil groups of the Union of South Africa. *African Soils. IV,* 2: 104—121.

VINK, A. P. A. 1962 Practical soil surveys and their interpretation for practical purposes. *ITC-publication.* Series B, No. 16, Delft, Netherlands.