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A NEW SYSTEM OF SOIL APPRAISAL IN TERMS OF ACTUAL AND POTENTIAL PRODUCTIVITY

(first approximation)

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Land and Water Development Division

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(First Approximation)

by

J. Riquier, D. Luis Bramao and J.P. Cornet *

I. Introduction

Because of the food shortages beseting mankind, it is urgent that an inventory be made of the world's soil resources to ascertain what uncultivated land can be brought into production and which cultivated soils could produce more than at present.

The task of compiling such an inventory has been entrusted to the FAO/Unesco Soil Map of the World project. The procedure adopted is to interpret soil maps since these provide an indication of the types of soils and their geographic distribution.

Soil maps are usually used not to find what genetic soil type exists at a certain place, but rather to determine the agricultural value of the soil and its susceptibility to improvement. It is necessary for this to interpret the soil map for the users, and to state the suitability of a given soil, in relation to its properties, for agricultural use. Only a soil specialist is capable of making such an interpretation, but since other considerations - geographic and socio-economic - have a place in determining both the possible and the most appropriate agricultural uses of a given piece of land, he must call in the agronomist, the botanist, the economist and the sociologist to assist him on such things as :

1. vegetation, rainfall, erosion and present land use;
2. response of soils to various management practices such as irrigation and fertilizer application;
3. crops already grown and yields obtained;
4. agricultural experiments conducted in the region.

The object of the interpretation and the use of the above data is to provide :

1. a classification of land in terms of its agricultural value, its specific capabilities and potential use;
2. land resource maps showing the geographical distribution of soils, their most appropriate use, their agricultural value, and their potentiality under specific management practices.

The maps may be small scale, sometimes covering an entire continent, or large scale, intended say, for a particular farm. Obviously, the classification will vary with the scale used.

II. Principal land classification systems

A classification system depends on :

a) the data available,

b) the scale of the map,

c) the purpose.

This explains the multiplicity of systems that have been evolved by individual researchers and government services.

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In his "Aspects de pédologie appliquée", Vink distinguishes seven main classification systems in use. These may be described as :

1. land classification in terms of inherent characteristics (soil classification in the strict sense);
2. land classification in terms of inherent qualities (soil quality, i.e. technical quality classification);
3. land classification in terms of present use (land use classification);
4. soil-crop response (or response to management);
5. land classification in terms of use capabilities (soil suitability classification);
6. land classification in terms of recommended use;
7. land classification in terms of programme realisation.

Classification systems 1, 2, 4 and 5 (in part) lie within the field of competence of a soil scientist without it being necessary for him to call in other experts.

Classification system 3, based on present land use, requires special soil surveys. The soil scientist may sometimes explain present use by reference to the nature of the soil and check his assumptions regarding soil fertility, but the system offers no way of determining ideal or future use.

The last three systems have socio-economic and even political implications, for which the soil scientist should not normally accept full responsibility. Classification under system 5 nevertheless can, and should, be guided by the soil scientist who will indicate the suitability of the soil in question for this, that or the other crop. The final decision, of course, rests with the economist, who will give due weight to such factors as distance from markets, dietary habits, and standard of living of the population.

What follows is an attempt to reconcile these different systems as far as possible.

III. The main classification systems currently employed

The principal classification systems currently in use and the reasons that we have discarded them are given below.

1. Storie's index for rating the agricultural value of soils. This was conceived especially for land appraisal for taxation purposes. It is highly appropriate to California and agricultural practices there, but does not allow assessment of improvements as a result of future management - the potential value of the soil.

In this report we have kept Storie's basic procedure of establishing a "productivity index" expressing soil conditions as ascertained, together with his ingenious method of calculation.

2. The land classification of the Bureau of Reclamation of the United States of America. This is not used here because it was conceived solely in terms of irrigability, and therefore also takes economic factors into account.

3. The land-capability classification of the Soil Conservation Service of the U.S.A. This is intended primarily as a means of determining the steps to take to control erosion. Its "capability classes" mainly reflect the extent and complexity of conservation problems; exaggerated importance is attached to slope, while other qualities indicative of soil fertility may be neglected. It is a classification in terms of the limitations of soils for agricultural use, and even according to the economic implications of such limitations. It is also an interpretive grouping according to capability. Moreover, the capabilities considered, such as suitability for cultivation, range or woodland, introduce economic factors the significance of which can only be judged by an agricultural expert who is thoroughly acquainted with the region.

In its latest versions this classification has gone somewhat beyond considerations of soil conservation to become, more precisely, a classification according to limitation. The capability subclasses are based on limitations due to climate, excess water, presence of salts, etc. The capability unit takes into account various criteria, among them "potential productivity", but without indicating the means used for appraising it. The limitations are, moreover, subjectively determined, the criteria utilized and the significance attributed to them by different soil scientists varying from one region to another. The resulting classification leads to rather vague definitions in such terms as : "Soil with few limitations that restrict their use". Class III, for instance, may include : a soil subject to erosion, a wet soil in need of drainage, a sandy soil limited by the low moisture-holding capacity, or a fertile soil in a region that is too arid. The authors themselves admit that their classification is not specifically intended for land-use planning and does not give sufficient information on land capability for growing individual plants, and that it does not classify the soils in terms of productivity. The potential value of a soil is neglected for a description of its limitations - a procedure that may be justified if the purpose is to determine the successive steps in conservation measures but not if it is to rate soil value. Moreover, it is inapplicable on a continent-wide scale where the primary purpose is to assess the value of virgin lands in terms of traditional agricultural practices.

4. The classification of Aubert and Fournier. Here soils are classified according to the type or magnitude of the conservation or development work required. The intrinsic value of the soil is excluded because, as the authors themselves recognise, the rating of agricultural soils as excellent, good, average and poor is a delicate problem. The appraisal of soil response to cultivation is highly subjective, the assignation to one class or another after management being decided upon in a very arbitrary fashion (e.g., irrespective of the difficulty involved in, or the cost of, management). The possibility of several types of management being employed simultaneously is not considered. This classification has one advantage, however, in that certain important soil characteristics are shown on the map, and management practices can be indicated with a greater degree of precision than in the American systems.

5. Christian's physiographic classification. Here land is classified from the standpoint of pedology, geology, relief and plant cover. Here again soil characteristics, the only true criteria of productivity, are almost entirely neglected. However, unlike the other systems which are intended for large scale maps on which climatic variations are irrelevant, this one is suitable for small scale maps.

<u>Limitations of the systems presently used</u>

Most of the classifications above discussed are concerned primarily with the extent, the difficulty, and the cost of management, or even solely with limitations affecting crop growing or requiring development work. However, a number of objections may be raised against the use of limitations as criteria for classification.

1. The concept of limitation is extremely complex. The term may indicate that soil conditions are such that :

(a) very difficult and costly work is required if a crop is to be obtained,

(b) only very poor crop yields are possible with ordinary farming practices,

(c) very few plant species can grow on the land in question, or

(d) combinations of these.

2. Limitation is merely a <u>negative aspect</u> of a given soil property. Why not consider the good property rather than the bad one ?

Again, the word suggests a gradation in the property under discussion, and within that gradation a cross-over point between good and bad. Now that point, or dividing line, from the standpoint of general land use, is not in fact clearly defined since it varies according to the crop and the requirements of the user.

For instance, a deep soil is looked on as good, a shallow soil as poor. Where does the dividing line between the two extremes lie ? No absolute limit is determinable in the classification phase. It is only under actual use, when minimum yield figures are set for a given crop, that it is possible to draw a line between adequate and inadequate depth.

3. A soil is classified either according to its most significant limitation or by the number of its limitations, but the seriousness of the limitation (e.g. greater or lesser degree of stoniness or shallowness) is rarely considered. Accordingly the classification systems reviewed lack flexibility. Again, if a soil has several limitations this may affect the total <u>cost</u> of development and management, but it is not the <u>number</u> of limitations that affects <u>yields</u> as even a single limitation is capable of reducing these.

4. From limitations, such as excess water or erosion, an attempt is made to predict plant growth behaviour. This is a mistaken procedure, however, because it is the soil as a whole, with all its complex of characteristics, taken together with factors of the environment that determines growth rate. The usefulness of certain soils, like the alluvial soils of the Nile, is limited by several factors - dryness, salinity, excess water - yet they are highly productive when properly managed.

5. In under-developed countries it is much more important to consider productivity, the positive factor, rather than limitations, the negative factor. The latter merely indicate required management measures, which are costly undertakings and therefore often feasible only over small areas.

IV. Evolving a new classification system

In our view what best expresses present and future land capability is productivity rather than limitations. This avoids economic and sociological considerations which lie outside the province of the soil scientist. Soil productivity, or known yields, moreover, provide the best grounds for understanding between the soil scientist and the economist.

It is a somewhat theoretical concept but it does provide a basis of comparison between soils which is our object. And yet it is reasonable, since in the same climate soils cultivated in a similar way produce more or produce less according to their inherent properties; it is the soil type that determine yields.

Despite the fact that the concept of productivity is somewhat abstract and relative, it is still the best basis of soil classification for the user who wishes to know before all else whether a piece of land is "good" or "bad" - in other words whether he can cultivate it to advantage. Vink suggests that a good system in land development planning would be to take soil mapping units and establish productivity norms or average yield estimates at various management levels, even if these be no more than rough approximations. Yields standards cannot in themselves be considered classifications, yet they constitute a big step in the direction of a quantitative classification of land capability.

The underlying principle in this study is that if favourable conditions extraneous to the soil are present (sound husbandry, good plant varieties adapted to the particular climate, freedom from pests, etc.), the productivity theoretically possible can be expressed by reference to the intrinsic soil characteristics (depth, base status, organic matter content, and the rest). We have thus been at pains to evolve a formula expressing soil productivity as a function of soil characteristics assuming an efficient farmer following normal practices is working the land. If, subsequently, soil management, land development, or intensive farming systems are introduced, these will improve soil properties, in which case, on the basis of the foreseeable improved characteristics, the same formula can be used to calculate "potentiality" or potential productivity. The indexes of productivity and of potentiality (see VI below) thus calculated are used to classify soils. The ratio of the two indexes gives a "coefficient of improvement" - either global, when every possible type of improvement has been introduced, or partial, if say only one of a number of possible improvements has been made.

Such a classification of soils in terms of productivity would necessitate compiling :

1. maps showing present productivity (under prevailing farming practices) and hence the agricultural value of land, and

2. maps showing potentiality or potential productivity resulting from new management practices.

V. Purpose and value of the system now proposed

When this study was begun the purpose was ultimately to compile a soil resources map on the basis of an interpretation of small scale soil maps. The system, however, lends itself to other purposes as well. Thus, now, on any map, each type of soil shown possesses specific characteristics - its distinguishing properties. Overlooking, for the time being, factors extrinsic to the soil itself, such as climate, slope and farming practices, those characteristics enable us to calculate average theoretical productivity and classify soil types on the basis of quality. Since soil improvement measures will enhance that productivity, the soil resources map will accordingly indicate not only actual but also potential productivity.

1. The calculation of a productivity index is of interest to the surveyor as well as to the farmer. By taking soil profile samplings and making a few routine chemical analyses, quite a clear idea of the soil value virtually mathematically accurate can be obtained, by amalgamating the

different soil properties into a productivity index. Nevertheless, the formula used is empirical and leaves a great deal of room for improvement. The system proposed in the Annexes has been evolved for interpreting the 1:5 000 000 scale map of Africa.

2. It facilitates land classification for purposes of taxation, consolidation of land holding, etc., and may be combined with other classifications, in particular that of Aubert and Fournier or that of the United States Soil Conservation Service, in which soil quality and potential productivity are expressed at land-capability unit or subclass levels.

3. It is possible to draw up large scale productivity or potentiality maps for a single holding, a large agricultural enterprise or a region where development is being planned.

It can, of course, also be used with small scale maps, since it was devised for that purpose. However, it should be emphasised that the formula suggested in the annexes may be adapted, depending on the purpose and on the data available. For instance, on a small scale map it is not possible to include the slope factor (which would be included on a large scale map) for the purposes of indicating the erosion (factor K) or degradation hazard.

The purpose here is not to put forward a formula of universal application but to state a principle and to suggest a methodology that can be improved upon. To summarize, with the system it is possible :

1. to determine the value or quality of a soil,
2. to set up a soil classification scale,
3. to compile large scale land use maps, and
4. to compile small scale maps

Maps

There is no need to enlarge upon the value of maps here. Maps answer the chief requirement of land users in that they show in such a region there is such and such a type of soil, which can be improved in such and such a manner and brought to a given potentiality.

Map usefulness depends greatly on scale. Small scale maps can help land-use planners and international organizations like FAO to estimate the area of arable land of a continent, while individual farmers, agricultural engineers and economists need large scale maps.

Large scale maps rate land according to :

1. inherent characteristics,
2. technical properties,
3. response to cropping and management methods,
4. potential utilization.

But they do more than that, because :

(a) ecologists and agronomists can readily use them to compile maps indicating suitability of land for growing specific types of crop. If the soil requirements of individual plants are known, it suffices to refer to the tables attached to the map or to the map itself (if soil characteristics are indicated there) to determine which region offers soils with requisite properties (see Table VII which illustrates an imaginary case);

(b) economists knowing the selling price of a given commodity as well as the cost of land development or improvement can assess returns to be expected from farmland where management has been undertaken and from land where it has not been, and thus judge the advisability or otherwise of development in the case under review. Some idea of the type and magnitude of the necessary work may also be estimated from the number of letter-symbols (representing specific types of work) appearing on the map or in the table;

(c) the specific crop suitability of a soil is itself largely governed by the local economy and by such considerations as distance from markets. The soil capability distinctions of the classifications described earlier are subjective and very often amount to litte more than classifying land without further ado as suitable for crop growing, pasture or forest bearing, with no clear reasons given for the choice.

Land Capability

In the classification system proposed here a first approximation suggests :

(a) The lands of Classes 1 and 2 (see Table IV) are suitable for all agricultural crops.

(b) Class 3 is marginal, in particular where tree crops are concerned.

(c) Class 4 is land best for range, reforestation* or recreation, or planted to special crops such as rice.

(d) Class 5 is land which is not suitable at all for cultivation.

All these capabilities, however, are determined on considerations of economic returns.

By contrast, the calculation of each productivity index for crop growing, pasture or forest bearing (using the ratings as assigned to characteristics shown in Table II) allows a comparison between the various indexes of a soil; and it is from these that suitability may be deduced : the highest index means the greatest suitability considering not the likely financial returns from the operation but the productive capacity. Finally, as has been said, the specific crop-suitability of a piece of land will be decided by the user, who will ensure that soil characteristics and the requirements of the proposed crop are in harmony.

Tree Crops and Forest

A distinction should be made between the two concepts. Tree crops must be considered more exacting, especially as regards depth and often in aeration of soil, than forest.

This way of thinking is justified because :

(a) The term "tree crops" is intended as grouping all strictly cash crops, where the aim is to obtain (1) a partial product from the plant, (2) a seasonal harvest, and (3) a product whose quality must be constant and adapted to a narrow range of well-defined uses (orchard or plantation crops, Hevea latex or the like). In such cases account must be taken of the edaphic requirements of the plant;

(b) The term "forest" is more complex. The idea of returns in the economic sense is not the only reason for creating or maintaining a forest : the chief end in view may be the control of erosion or recreation, or purifying the atmosphere in industrial areas. Even where timber production is the main objective, it can only be on a long-term basis, and the various end-uses (joinery, pit props paper, fuel) will enable use to be made of wood of widely differing kinds.

Accordingly, as governed by the purpose of a forest, edaphic requirements may or may not be taken into account, and afforestation may be recommended on soils of widely differing productivity.

The value of this method lies in the fact that it largely avoids the arbitrary and subjective elements by its appeal to scientific data that are measurable (texture, contents of various chemical elements) or are readily definable in unambiguous terms (structure, nature of mineral reserves, etc.). The findings based on such data are accordingly reproducible, which allows for comparing the interpretations of various researchers. This possibility of comparison is of vital importance to FAO's World Soil Resources Office and similar agencies concerned in correlating soil data on a world wide scale because on this depends the further possibility of compiling productivity maps on a similar system and legend.

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* It may appear strange to read that with Class 3 one is already at marginal level, in particular for tree crops followed immediately by a statement to the effect that Class 4 refers primarily to land reserved for reforestation, etc., while tree crops and forest are lumped together.

VI. The method described

A. Definition of terms

The concept of "productivity" is a complex one and requires definition. Obviously, only theoretical productivity is envisaged - i.e. optimum soil yields, not taking into consideration damage caused by insects or other pests, or choice of seed, unsound husbandry, and the rest. The concept is very close to that of "soil quality". The term "productivity" is preferred, however, because a comparison of our index with production figures* (e.g., for peanuts on different soils in Madagascar, see fig. 2) indicates that the concept is far from being a mere fiction and that what it connotes can be calculated by the formula proposed here. It must be concluded then that this index is a true expression of productive capacity and not a mere comparative scale of the theoretical value of soils. But productivity varies also with the type of crop grown; some plants being able to withstand soil drainage or fertility conditions which others cannot and to give economically satisfactory yields where other plants cannot grow at all. Since it is impossible to review all cultivated plants (whose requirements differ widely) one must consider a level of productivity for the majority of farm crops or for specific crop sequences : grains/fodder legumes, or tree crops/forest. We have taken three cases : shallow-rooting plants (pasture), medium-depth rooting plants (field crops) and deep-routing plants (trees).

This difficulty of introducing considerations as to the type of crop into the notion of soil productivity is lessened, for instance, when a salt-tolerant plant like cotton will nevertheless give better yields in non-salty, good quality soils. By taking a large range of crops, therefore, it is possible to rate soils for productivity in full cognizance of the fact that productivity is a relative term. Each plant has its own soil-productivity scale, which does not coincide with that of the next plant. Accordingly, "productivity" (i.e. productivity here and now) is employed in the sense of initial soil capability to produce a certain amount of crop per hectare per annum, and is expressed as a percentage of the optimum yield per hectare of that same crop grown on the best soil. It is the natural fertility of virgin land in its first year of cultivation by simple farming practices (soil preparation, sowing, aftercare, harvesting). For soils already under cultivation it is the productivity of the year in which the soil was mapped, described and analysed - hence prior to its degradation, or improvement, as the case may be.

Assuming scientific development of virgin land or land brought under cultivation after surveying there should be no degradation. Thus, the slope factor (which governs erosion hazard and a soils suitability for machine cultivation) will not be taken into account in determining productivity except insofar as it renders erosion control measures necessary. If a sloping piece of land has already been cultivated, then erosion will have occurred and an equilibrium will have been attained, as may be seen in the soil conditions : low organic matter content, shallowness, more marked dryness, etc. Such characteristics that must be taken into consideration to obtain the actual productivity index.

In special cases where, for political or economic reasons, no conservation measures are taken, slope will be considered (see annexes).

In distinction to "productivity", the second term to be defined is "potentiality". This is that productivity of a soil, when all possible improvements have been made, even the most difficult and costly. It is thus the future productivity of that soil taking into account physical and chemical characteristics as modified by conservation practices or improvements, and also those characteristics which are not modifiable by present-day technology.

The theory has been propounded in certain quarters that a soil is of no value in itself because it can be completely changed by modern techniques. We are not of this opinion because there will always be land, particularly in underdeveloped countries which, for material or economic reasons, or even for simply natural reasons (lack of irrigation water for instance) cannot have the benefit of all that modern technology offers. What is more, there will always be certain fertility factors (i.e. texture) that are extremely difficult to modify by modern techniques even in wealthy countries. No matter what improvement measures are taken, there will always be limiting factors of one kind or another. Beyond soil inherent properties influences, the response to management : fertilizers, irrigation, and so on, cannot be neglected.

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* Figures communicated by Mr. Roche, Director, IRAM, Madagascar.

B. Principles underlying the method

1. Determination of the productivity index

Productivity is a function of the intrinsic properties of a soil, firstly as determined in the process of describing the soil profile in situ, and secondly by laboratory analysis. Soil moisture and temperature are included among such characteristics even though they are directly related to climate. Environmental factors - slope, vegetation and climate - will only be used to determine what set of management practices are necessary

A soil map and its accompanying report should supply the necessary data to establish the productivity of various mapping units.

From among the countless characteristics that influence soil productivity, the following have been selected :

(a) the most commonly accepted factors of productivity, since a great deal of study is still required to understand these factors, particularly their relative importance;

(b) those readily found in the literature on the subject or which figure in the definition of soil types;

(c) the most easily measurable;

(d) those with the fewest possible secondary characteristics in common, so that no minor characteristics will reoccur several times in the formula thus be exaggerated in significance.

We accordingly consider nine factors as determining soil productivity, viz : moisture (H), drainage (D), effective depth (P), texture/structure (T), base saturation (N), soluble salt concentration (S), organic matter content (O), mineral exchange capacity/nature of clay (A), and mineral reserves (M). Therefore :

$$\text{Productivity} = H \times D \times P \times T \times \begin{matrix} N \\ \text{or} \\ S \end{matrix} \times O \times A \times M$$

Attempt has thus been made to evolve a mathematical formula expressing productivity as a resultant of the various factors at play, following Storie's method of calculation. Each factor is rated on a scale from 0 to 100, the actual percentages being multiplied by each other. The resultant index of productivity, also lying between 0 and 100, is set against a scale placing the soil in one or other of five productivity classes (Table III).

The productivity index thus defined answers well enough to the definition of Storie's index as a "numerical expression of the degree to which a particular soil presents conditions favourable for plant growth and crop production under good environmental conditions", and is "based on soil characteristics which govern its potential utilization and productive capacity". Storie adds that his index is "independant of physical or economic factors, which might determine the desirability of growing certain plants in certain locations".

The main difference between this index and Storie's is in the actual choice of productivity factors. Here only intrinsic soil characteristics are used, all extrinsic, physiographic factors such as erosion, micro-relief or slope being disregarded, and the factors attributed by Storie by which soil types (only the soil types of California) are explicited.

The formula clearly is not perfect because the relationship between productivity and soil characteristics is more complex - possibly exponential or asymptotic in form. However, the mathematical approach advocated by Storie has four advantages :

1. the least favourable factor dominates, just as in nature the greatest limitation is often decisive in assessing the ultimate value of a soil;

2. interplay of the different factors is considered. For instance, a shallow but chemically rich soil may be just as productive as a deeper but less rich one;

3. by manipulating coefficients, it is possible :

   a) to avoid a linear impact of one factor on the final index (example : the first 30 cm of soil profile are much more important for plant growth than are the 30 cm between 90 and 120 cm depth);

b) to attribute to certain secondary or simply corrective factors less weight than the main factors (for example : the nature of the clay is rated between 90 and 100, while soil depth has a wider range (from 5 to 100);

4. it is permissible to disregard one of the factors assumed to be constant, for example soil moisture within a climatic region, and the soil classification according to productivity remains valid.

The coefficients are entirely empirical, but we have been at pains to incorporate in some way factors used by Storie, the Canadian Irrigation Service and Clarke, which have been tested in the field. The remaining coefficients are determined by successive approximations. The index proposed here has been used to forecast yields of peanuts in Madagascar (Graph No 2), maize, cotton in Swaziland, maize in Argentina (see Table XI), with accurate enough results even though other influences, namely pests, type of seed, weeds, etc., were not eliminated from the experiment.

Our formula, then, constitutes a first approximation. It is more scientific than preceding systems, yet is not wholly quantitative. It allows of a simpler, numerical classification, and can be applied almost automatically by agriculturists not specialized in soil science (the collaboration of all concerned in order to perfect the system would be welcomed). In the annexes, equivalences are suggested for characteristics that may be lacking (Table No I.a). Variants will be proposed in the future with factors more readily measurable if this becomes possible, for example : available water content (to replace moisture); Henin's structural stability index (to replace "structure"); conductivity of soil solutions (to replace "base saturation") and so on.

2. Factors used in calculating the productivity index

Factors to be used in calculating the productivity index have been selected with the above criteria in mind. An attempt has been made to group them in some sort of logical order, though it is recognised that there is a certain arbitrariness in including such dissimilar elements in the same formula. The reasoning behind the choice of factors is as follows :

A soil is the more fertile the more volume of it there is at the disposal of plants (depth : P), the richer it is in bases (base saturation : N), and the more water and the more nutrients it contains and the more readily penetrable it is to roots (texture and structure : T). Hence productivity = P x T x N. Certain corrective terms or additional factors are brought in, namely organic matter content (O), nature of the clay (A) and mineral reserves (M), since the more organic matter there is, the more the nutrients are available and the more stable is the structure. The greater the cation exchange capacity the more nutrients are retained by the soil, with less leaching of fertilizing elements. The greater the mineral reserves, the more nutrients will be replaced as they are used up by the plants. Consequently, A and M correct N and T and give a final productivity value equal to P x N x T x (O x A x M). Finally, the soil moisture factor (H) or excess water factor (D), also affect productivity.

The definition of productivity has been worked out by comparing various soils with the same climate; but the productivity of otherwise identical soils changes from one climate to another. If we use a productivity index to compare soils of one continent or fairly large region (small scale map) to those of another then the climate factor, which may be ignored on a large scale map, must be introduced. Climate may, however, be disregarded on a small scale map in certain situations, say when considering irrigated soils in parts of Africa where temperature is not limiting. Again, climate may be overlooked if the index is considered not as an index of productivity but of soil quality or value. Without encroaching upon the domain of the ecologist, one readily notes that productivity increases as soil temperature and moisture content increases. These factors, therefore, cannot be considered as entirely extraneous to the soil, since they are features of the soil itself - which is precisely why they are introduced. However, in order to determine them, climatic data have to be taken into account because direct measurements of soil temperature and moisture content are very rarely available. We accordingly propose to take the number of dry months per year and the number of months during which the temperature falls below 10°. When the rooting zone is too dry, growth comes practically to a standstill, and the annual soil productivity per hectare diminishes. In arid zones, only one crop may be produced. If the soil is too cold the growing period is also shortened.

Hence the need for superimposing on a soil classification based on fertility under a given climate a second classification according to climate or microclimatic zones. The water factor is disregarded where irrigation is practiced - i.e., it does not appear on the soil potentiality map - and the temperature factor may be eliminated when for instance one is considering the case of the greenhouses of northern Europe.

3. Method of calculation

Calculation tables are given in the annexes. Here one soil type will be used for illustrative purposes, a vertisol in a region with 5 dry months a year; depth below the surface of the parent rock (basalt), 110 cm; high clay content; prismatic structure; 70 percent base saturation; no soluble salts in the rooting zone; 1.2 percent organic matter and a mineral exchange capacity of 42 mEq/100 g of clay; average reserves of minerals alterable by weathering and other processes, hence a fairly mature soil. Therefore, the formula for such a vertisol would be (using symbols explained in Table I) :

$$H_{4a} \times P_5 \times T_{5a} \times N_4 \times O_2 \times A_3 \times M_{20}$$

Referring to Table II, we read off H_4a carries a rating of 80 percent

P_5 = 100 percent, continuing to read of the value for each of the remaining symbols, we have therefore :

$$\text{productivity index} = \frac{80}{100} \times \frac{100}{100} \times \frac{50}{100} \times \frac{80}{100} \times \frac{100}{100} = 25.6$$

This figure is now referred to Table III, where the particular vertisol under consideration is found to belong in Class III, i.e. of average productivity.

4. Determination of the index of potentiality

The index of potentiality is required to express potential productivity after soil management. It is first necessary to determine which management practices are necessary, then what their repercussions are on potentiality. Two groups of management are to be considered :

1) Each limiting factor requires a soil management :

H (dryness) - requires irrigation (A and B)

D (poor drainage) - requires drainage (C)

P (shallowness) - requires deepening (D)

T (poor texture or structure) - requires stone removal (E_1) or mechanical working (E_2)

N (low nutrient content) - requires application of fertilizers (F)

S (salinity) - requires desalting (G_1 or G_2 if Na_2CO_3 present)

O (low organic matter content) - requires application of organic matter (H)

Table IV has a list of appropriate management measures and Table V the characteristics that can be improved and what happens to them following such treatments.

2) Other types of improvement are imposed by physiographic conditions and environment (situation, climate, vegetation, etc.), the control of wind erosion (J) and water erosion (K and L) and land clearance (M). The soil scientist must obtain information (in addition to that supplied by the soil map) regarding slope, climatic agressivity (e.g. distribution of rainfall, wind speed), etc. in order to decide what management measures are necessary. These data are essential in calculating the potential productivity of a soil and they have to be noted down in the field during soil surveys or must be taken from other maps (topographic map for slope, climate maps, vegetation maps, etc.) or from reports.

When the necessary management measures have been determined (those that are feasible under local circumstances, and those that are impossible due to certain soil characteristics - see Table VI), the next subject to be considered is which improvements will in fact be attempted. For example, by application of fertilizers in suitable quantities and proportions, the base saturation can be raised from N_3 to N_5. That done, one is in a position to calculate the potential productivity index with the same formula as that for actual productivity but according to improved soil characteristics shown in Table V.

For the management measures necessitated by conditions extraneous to the soil (which often affects several characteristics simultaneously) we have used a flat 10 percent or 20 percent rise in value of the index. For instance, erosion control may also increase soil moisture, organic matter content and depth.

The potentiality index is calculated from the improved characteristics and percentages of increased productivity resulting from management and is useful for classifying soils against a potentiality scale (the indices of which are identical with those of the productivity scale, see Table III).

The fact that a soil has been improved is shown by a change of class or, better, by the ratio of the two indices, i.e. the coefficient of improvement.

For instance, the vertisol taken as an illustration of the calculation for productivity (P = 25,6) is improvable :

- by supplementary irrigation (B) and H_4 becomes H_5
- by mechanical working of soil (E_2) in order to improve structure and T_{5a} becomes T_{5b}
- by amending the organic matter content (H) and the final index will gain 10 percent.

Then, the formula for potentiality becomes :

$$P_1 = H_5 \times P_5 \times T_{5b} \times N_4 \times O_2 \times A_3 \times M_{2c} + 10\%$$

$$= 100 \times 100 \times 80 \times 80 \times 80 \times 100 \times 100 + 10\%$$

$$= 51{,}2 \times 5{,}12 = 56{,}3$$

This index reported in Table III gives us the potentiality class II (good).

The coefficient of improvement of this soil is expressed by $\frac{P_1}{P} = \frac{56{,}3}{25{,}6} = 2{,}2$

It means that the productivity can be multiplied by more than 2 by the application of all suitable management techniques.

C. Productivity map and potentiality map

Several systems of representation can be used.

1. The productivity and potentiality maps for Nigeria can be taken as a first example. Each mapping unit on the productivity map is coloured according to soil productivity class, letters being used to express the soil characteristics considered in determining the productivity index and also specific crop suitabilities (see Table VIII). The potentiality map likewise has coloured portions showing potentiality classes and letters indicating the improvements necessary in order to attain the level of potentiality it is proposed to work for (i.e., the type of management recommended and used in calculating the potentiality index). (a) If the new management practice is difficult because of environmental conditions (for example, irrigation in desert regions) or for economic reasons, the letter is underlined, though this type of management is still considered in calculating potentiality; (b) Should the user of the map seem the particular type of management to be absolutely impractical due to external circumstances, he may recalculate the index without this item in order to obtain the true potentiality; (c) If, on the other hand, it is the intrinsic properties of the soil that make the improvement impossible, for example drainage of a sodium montmorillonite clay soil (see Table VI which shows incompatibilities) the letter is circled. The presence of a circled letter almost automatically places the soil in Class V.

Maps are drawn up in accordance with the procedure schematized in the diagram below :

PRODUCTIVITY MAP

Soil type from soil map → Soil characteristics (in letters) → formula → productivity index → productivity class (in colour)

POTENTIALITY MAP

Data from climate, vegetation & erosion maps, etc.	→	Management measures	→	Characteristics modified	→	Formula	→	Potentiality index	→	Potentiality class (in colour)

2. A second example is to be had in maps for Togo. The area occupied by a soil series is coloured according to its productivity class on the productivity map and its potentiality class on the potentiality map. A table is appended to these maps indicating for each soil series its characteristics, the appropriate management and the two indexes, together with the coefficient of improvement. This system is to be preferred to others when the areas occupied by certain soil series are so small that it is not possible to show characteristics and management measures on the map itself. It also allows the symbols referring to the soil map legend to be retained, making for greater ease of comparison of soil characteristics before and after management.

3. Both types of map can be combined into a single map, in which case it is to be recommended that actual productivity be indicated by a colour and potentiality, i.e. improved capability following upon management, by overprinting. An Arabic numeral might be used for the productivity class and a Roman numeral for the potentiality class.

VII. Soil resources appraisal : coefficient of improvement

A. Appraisal of value of soil units

In the equation $P = f\,(a,b,c\ ...)$, P represents the productivity of a given soil unit and a,b,c.. the soil characteristics. Some of these factors cannot be modified (for instance, texture, reserves of alterable materials) whereas others can be improved by agricultural practices (irrigation, drainage, amendments). Hence the potentiality P' of the same unit can be appraised by applying an identical formula $P' = f\,(a', b', c'\ ...)$ in which a', b', c' ... represent characteristics as corrected by the proposed management.

Some purpose will then be served if one can deduce from this what may be called latent improvement of the soil under study. For this coefficient of improvement we have used (see VI.B.4 above) the expression $C = \frac{P'}{P}$ in which C is the number by which the soil productivity index must be multiplied in order to obtain the potentiality index.

Theoretically this figure may be anywhere between unity and infinity but in practice it lies between 1 and 100 (the highest value calculated to date being 33). Generally value range between 1 and 5.

A low coefficient indicates little possibility of improvement either because actual productivity is already very high and it is therefore impossible to expect much better (example : Agni (An) series of Table IX) or because, whatever the actual productivity, it is subject to limiting factors which cannot be corrected even by modern technology (Atchasi (At) series, in which the limiting factor is the presence of a lateritic hardpan near the surface, or the Vokouteme (Vo) series, whose productivity is limited by the excessively light texture).

A high coefficient of improvement indicates a state of inadequate development or immaturity. It refers to soils whose productivity is low at the moment but which could be raised by a programme of land improvement (examples : Kezou (Kz) series after drainage, improvement of structure and application of organic matter). Obviously, for management to be economically worthwhile it should be introduced on soils having a high coefficient of improvement and a fair potentiality.

Such a coefficient is a non-dimensional number which can apply to any expression of soil productivity, e.g. crop yield in tons per hectare; forest yields in m3 of wood per hectare; or yield in kg of live-weight per hectare for livestock grazing on a given type of land (see Graph 2 "Productivity for peanuts as a function of soil characteristics"). It goes without saying that soil productivity and the yield of a crop are parallel where soil factors alone are considered in making the comparison. It is more appropriate to see present crop yields as dependent upon soil productivity, and increase in yield as a function of the coefficient of improvement. This can be expressed by the equation $R' = R.f(c)$, where R' is improved yield and R is yield before management.

Example : To apply the coefficient of improvement to productivity for peanuts in Graph 2, x represents the index of productivity P, and y = yields R in tons/ha with the equation

$$R' = R\ f(c), \text{ or } y'\ f(c)$$

We have in this particular example :

$$y' = c.y + (c - 1)\ 0.55$$

Let $x = 25$ and $x' = 50$, $c = P'/p$ or $x'/x = 2$

and for the equation of the straight line $y = 0.08$, $x = 0.55$

$$Y = (0.08 \times 25) - 0.55 = 1.45 \text{ T/ha}$$
$$Y' = (0.08 \times 50) - 0.55 = 3.45 \text{ T/ha}$$

One can also find y' as a function of y anc c applying formula (1) :

$$y' = 2 \times 1.45 + (2 - 1) \times 0.55 = 3.45 \text{ T/ha}$$

B. Evaluation of a heterogeneous area

The concepts "productivity", "potentiality" and "coefficient of improvement" can be extended to regions (subscript r) with soils of different values. A region with an area S_r having n soil series with respective productivities of P_1, P_2 ... P_n on areas S_1, S_2 ... S_n will have an average productivity shown by the formula :

$$P_r = \frac{(P_1 \times S_1) + (P_2 \times S_2) + \ldots + (P_n \times S_n)}{S_r}$$

Simplifying :

$$P_r = \frac{(P_n \times S_n)}{S_r}$$

Likewise :

$$P'_r = \frac{(P'_n \times S_n)}{S_r}$$

And $$C_r = \frac{P'_r}{P_r}$$

The average coefficient of improvement thus calculated has the same meaning, on a regional scale, as the exact coefficient for the soil category. High potentiality combined with high coefficients is indicative of regions yet to be developed and where the execution of a management plan has the best chances of producing satisfactory results.

VIII. Summary and the future of this method

It is the authors' view that the agricultural value of a soil depends primarily on its characteristics and properties which can be determined by soil surveys or by the interpretation of an existing soil map. A mathematical formula summing up its properties will provide an index of the value of a soil, expressed in terms of productivity. Limiting factors such as unfavourable physiographic conditions call for management, conservation and development work which, in turn, will modify the soil. Hence the need for an additional index which expresses the capability following upon management - i.e. "soil potentiality".

Three types of data : value of soil in the natural state, value of that soil when improved, and the magnitude of the management work needed to produce that improvement are indispensable for anyone considering land utilization. Up to now, soil classification efforts have been directed solely to determining what set of management practices were necessary, but here the emphasis is on the soil itself - the basis for any such work. Soil maps are all the more valuable to the extent that they can serve as the point of departures for the entire methodology.

A practical means of condensing a great quantity of data that can be useful for agronomists, engineers, economists and planners seems to be to present the findings on two separate maps, one showing productivity classes and the other potentiality classes, i.e. fertility factors and work to be carried out. Some persons, however, may prefer a single map with a table appended.

Much still has to be done by way of evolving a method of estimating yields from a piece of land as a function of its characteristics. Variants are allowable depending on the goal set - for example, adaptation of the formula for determining productivity for particular plant species to use for a large scale map, or employing a fuller and more comprehensive climatic coefficient - for comparing soils of one climate with those of another and so on. However, the main purposes of this new methodology are :

1) to make the chief line of approach that of identifying and combining productivity factors, without neglecting their interaction;

2) to draw up a balance sheet and synthetize findings of research;

3) to use the concept of productivity to compare soils, and

4) to evolve a quantitative approach to the assessment of soil value - the only basis for mutual understanding between soil scientists, engineers and economists; and finally

5) to arrive at a coefficient of improvement for appraising the development possibilities of a region.

By this method, a soil resources map can readily be compiled simply from interpretation of existing soil maps and the use of supplementary data such as climate, relief and vegetation. It will show the value of various soils, the conditions governing their utilization, and their future potentialities.

ANNEXES

TABLE I

Soil characteristics used to determine productivity

H Soil moisture content

H1 Rooting zone below wilting point all the year round

H_2 Rooting zone below wilting point for 9 to 11 months of the year

- H_{2a} 11 months
- H_{2b} 10 months
- H_{2c} 9 months

H_3 Rooting zone below wilting point for 6 to 8 months of the year

- H_{3a} 8 months
- H_{3b} 7 months
- H_{3c} 6 months

H_4 Rooting zone below wilting point for 3 to 5 months and wet below field capacity for over 6 months of the year

- H_{4a} 5 months
- H_{4b} 4 months
- H_{4c} 3 months

H_5 Rooting zone wet above wilting point and below field capacity for most of the year

Note : 1. If data on actual soil moisture is not available, it is possible to use instead the number of dry months per year calculated from weather intelligence (Gaussen's ombrothermic diagramme for instance) at least for small scale maps.

2. For cold countries, the months during which frost occurs as also the months of average temperature $< 10^{o}C$ (threshold of productivity) are considered as dry months.

D Drainage

D_{1a} Marked waterlogging, water table almost reached the surface all year round (Hydromorphic horizon at a depth of from 0 to 30 cm)

D_{1b} Soil flooded for 2 to 4 months of the year

D_{2a} Moderate waterlogging, the water table being sufficiently close to the surface to harm deep rooting plants (hydromorphic horizon at a depth of from 30 to 60 cm)

D_{2b} Total waterlogging of profile for from 8 days to 2 months

D_{3a} Good drainage, water table sufficiently low not to impede crop growing (hydromorphic horizon at a depth of 60 cm below the surface)

D_{3b} Waterlogging for brief periods (flooding), less than 8 days each time

D_4 Well drained soil, deep water table (hydromorphic horizon at over 120 cm depth); no waterlogging of soil profile.

In this case see H

Note : 1. If the hydromorphic horizon is not recognizable from morphological characteristics, the height of the water table is the only point to be considered. If, on the other hand, it is fossilized, it should be ignored altogether.

2. In some instances soils are both too dry in the summer and too wet in the winter, in which case the two functions H and D are combined.

P	<u>Effective depth of soil</u>
P_1	Rock outcrops with no soil cover or very shallow cover
P_2	Very shallow soil, less than 30 cm deep
P_3	Shallow soil, 30-60 cm deep
P_4	Fairly deep soil, 60-90 cm deep
P_5	Deep soil, over 90-120 cm deep
P_6	Very deep soil, over 120 cm deep

<u>Note</u> : By effective depth is meant the rooting zone. The latter extends to the horizon where the roots can no longer penetrate, whether it be parent rock, hardpan, claypan or gypseous layer ($>$10-25 percent gypsum).

T	<u>Texture and structure of root zone</u>
T_1	Pebbly, stony or gravelly soil
T_{1a}	Pebbly, stony or gravelly $>$ 60 percent by weight
T_{1b}	Pebbly, stony or gravelly from 40 to 60 percent
T_{1c}	Pebbly, stony from 20 to 40 percent
T_2	Extremely coarse-textured soil
T_{2a}	Pure sand, of particle structure
T_{2b}	Extremely coarse-textured soil ($>$ 45 percent coarse sand)
T_{2c}	Soil with non-decomposed raw humus ($>$ 30 percent organic matter), and fibrous structure
T_3	Dispersed clay of unstable structure (often $\frac{Na}{T} >$ 15 percent)
T_4	Light-textured soil, fine sand, loamy sand or light sandy loam, or coarse sand and silt
T_{4a}	Unstable structure
T_{4b}	Stable structure
T_5	Heavy-textured soil : clay or silty clay
T_{5a}	Massive to large prismatic structure
T_{5b}	Angular to crumb structure or massive but highly porous (e.g. soils with a high sesquioxide content)
T_6	Medium-heavy soil : heavy sandy loam, sandy clay, clay loam, silty clay loam or silt
T_{6a}	Massive to large prismatic structure
T_{6b}	Angular to crumb structure (or massive but porous)
T_7	Soil of average, balanced texture : loam, silt loam and sandy clay loam

<u>Note</u> : Texture should preferably be judged by touch in this way taking micro-aggregation into account. Otherwise reference to the texture triangle is necessary (see Graph 1). This chart is based on the U.S. Department of Agriculture's <u>Soil Survey Manual</u>, but the surface "sandy loam" has been further subdivided into T_4 ("light") and T_6 ("heavy").

N — Average nutrient content of A horizon

N_1 Soil with base saturation $V = \frac{S}{T}$ less than 15 percent
N_2 V from 15 to 35 percent
N_3 V from 35 to 50 percent
N_4 V from 50 to 75 percent
N_5 V over 75 percent
N_6 Soil excessively calcareous ($>$ 20 to 30 percent)

S — Soluble salts content

S_1 Total soluble salts less than 0.2 percent
S_2 Total soluble salts between 0.2 and 0.4 percent
S_3 Total soluble salts between 0.4 and 0.6 percent
S_4 Total soluble salts between 0.6 and 0.8 percent
S_5 Total soluble salts between 0.8 and 1.0 percent
S_6 Total soluble salts over 1 percent
If sodium carbonate is present in the soils (alkali soils) :
S_7 Total soluble salts (including sodium carbonate) 0.1 to 0.3 percent
S_8 Total soluble salts from 0.3 to 0.6 percent
S_9 Total soluble salts over 0.6 percent

O — Organic matter in A_1 horizon

O_1 Very little organic matter, less than 1 percent
O_2 Little organic matter, 1 to 2 percent
O_3 Average organic matter content, 2 to 5 percent
O_4 High organic matter content, over 5 percent
O_5 Very high content, but $\frac{C}{N}$ over 25

Note : Place in one category lower if the organic matter is raw, of mor or moder type

A — Mineral exchange capacity and nature of the clay in the B horizon

A_0 Exchange capacity of clay less than 5 mEq/100 g
A_1 Exchange capacity of clay less than 20 mEq/100 g (probably kaolinite and sesquioxides)
A_2 Exchange capacity of clay from 20 to 40 mEq/100 g (probably a mixture of clays or illite)
A_3 Exchange capacity of clay over 40 mEq/100 g (probably montmorillonite or amorphous clay)

M — Reserves of weatherable minerals in B horizon

M_1 Reserves very low to nil
M_2 Reserves fair
M_{2a} Minerals derived from sands, sandy materials or ironstone
M_{2b} Minerals derived from acid rocks
M_{2c} Minerals derived from basic or calcareous rocks
M_3 Reserves large
M_{3a} Sands, sandy materials or ironstone
M_{3b} Acid rocks
M_{3c} Basic or calcareous rocks

TABLE I bis

Table of equivalents to Table I

This table is to be used only where certain characteristics are missing and which can be replaced by close, though not entirely interchangeable, equivalents. These are listed below by way of guidance and have no rigid value :

T

T_{1a}	Stones and pebbles : 30 percent by volume
T_{1b}	Stones and pebbles : 20 to 30 percent
T_{1c}	Stones and pebbles : 10 to 20 percent
T_{2a}, T_{2b}	HE = equivalent moisture < 10 percent
T_3	$A + L > 40$ percent and pH 8.5 or $\frac{Na}{T} > 15$ percent (A = clay; L = silt)
T_4	HE : from 10 to 15 percent
T_5	HE $>$ 30 percent
T_6	HE : from 25 to 35 percent
T_7	HE : from 15 to 25 percent

N

N_1	pH (in water $\frac{1}{1}$)	from 3.5 to 4.5
N_2		from 4.5 to 5.0
N_3		from 5.0 to 6.0
N_4		from 6.0 to 7.0
N_5		from 7.0 to 8.5

Note : The use of pH instead of base saturation is advisable in cases of very sandy soils with a low cation exchange capacity. In such cases base saturation given by analysis is often unreliable.

S	Content of salts in % of soil	Conductivity in millimho of saturation extract	Conductivity in micromho of saline extract 1/5	Conductivity in micromho of saline extract 1/10
	0	0	0	0
S_1 ↕	0.2	2	1000	500
S_2 ↕	0.4	6	1750	875
S_3 ↕	0.6	8	2500	1250
S_4 ↕	0.8	12	3000	1625
S_5 ↕	1.0	16	3500	2000
S_6 ↓				

Note : These figures cannot be taken for an exact correspondence between the different conductivities, as they may vary according to the water capacity in the soil, and the degree of solubility of salts, thus according to their nature. However, these figures give an order of extent available in the proposed formula. In column 2 the American classification limits of Riverside have been chosen.

O Organic matter content = carbon x 1.7 = nitrogen x 20

O_1 Thickness of the humus-forming horizon : < 10 cm

O_2 Thickness of the humus-forming horizon : from 10 to 20

O_3 Thickness of the humus-forming horizon : from 20 to 30

O_4 Thickness of the humus-forming horizon : > 30

A Exchange capacity of clay

$$\frac{\text{TmEq/100 g of soil} - \text{K x \% organic matter) x 100}}{\text{\% clay}}$$

and K = 2,50 for very humic soils, peaty soils or soils of cold or high regions

K = 2,00 for soils of temperate regions

K = 1,50 for tropical soils with little humus

M

M_1 Sum of total bases determined by treating with hot nitric acid : Total bases < 10 mEq

M_2 Sum of total bases determined by treating with hot nitric acid : Total bases 10-50 mEq

M_3 Sum of total bases determined by treating with hot nitric acid : Total bases 50-300 mEq

TABLE II

Tentative ratings of different characteristics

		For crop growing			For pasture			For forest and non-forest tree crops		
H										
	H_1		5			5			5	
	H_2	H_{2a} 10	H_{2b} 20	H_{2c} 40	20	20	30		10	
	H_3	H_{3a} 50	H_{3b} 60	H_{3c} 70	30	40	60	10	20	40
	H_4	H_{4a} 80	H_{4b} 90	H_{4c} 100	70	80	90	70	90	100
	H_5		100			100			100	
D		H_4 H_5 H_2 H_3								
	D_1		10 – 40			60			5	
	D_2		40 – 80			100			10	
	D_3		80 – 90			90			40	
P	P_1		5			20			5	
	P_2		20			60			5	
	P_3		50			80			20	
	P_4		80			90			60	
	P_5		100			100			80	
	P_6		100			100			100	
T	T_{1a}		10			30			50	
	T_{1b}		30			50			80	
	T_{1c}		60			90			100	
		$H_4H_5H_6AB$	H_3	H_1 H_2						
	T_{2a}	10	10	10	(same ratings as for crop growing)			(same ratings as for crop growing)		
	T_{2b}	30	20	10						
	T_{2c}	30	30	30						
	T_3	30	20	10						
	T_{4a}	40	30	30						
	T_{4b}	50	50	60						
	T_{5a}	50	60	20						
	T_{5b}	80	80	60						
	T_{6a}	80	80	60						
	T_{6b}	90	90	90						
	T_7	100	100	100						

Table II (cont'd)

		For crop growing	For pasture	For forest and non-forest tree crops
N				
	N_1	40	60	80
	N_2	50	70	80
	N_3	60	80	90
	N_4	80	90	100
	N_5	100	100	100
	N_6	80	90	100

		T_1 T_2 T_4	T_5 T_6 T_7
S	S_1	100	100
	S_2	70	90
	S_3	50	80
	S_4	25	40
	S_5	15	25
	S_6	5	15
	S_7	60	90
	S_8	15	60
	S_9	5	15

		H_1 H_2 H_3 D_3 D_4	H_4 H_5 D_1 D_2 AB
O			
	O_1	85	70
	O_2	90	80
	O_3	100	90
	O_4	100	100
	O_5	70	70

A		
	A_0	85
	A_1	90
	A_2	95
	A_3	100

		H_1 H_2 H_3	H_4 H_5 AB
M			
	M_1	85	85
	M_{2a}	85	90
	M_{2b}	90	95
	M_{2c}	95	100
	M_{3a}	90	95
	M_{3b}	95	100
	M_{3c}	100	100

TABLE III

Classes of productivity (P) and potentiality (P')

P	classes	rating	P'
1	Excellent	65 - 100	I
2	Good	35 - 64	II
3	Average	20 - 34	III
4	Poor	8 - 19	IV
5	Extremely poor to nil	0 - 7	V

TABLE IV

List of land improvements necessary for development
(over and above prevailing agricultural practices)

A. Irrigation (essential) and drainage (usually required)

B. Supplementary irrigation : B_1 by sprinkling
B_2 by flood or furrow irrigation

C. Excess water removal : by reclamation, ridging, drainage or protection against floods

D. Deepening of top soil : by ridging, deep plowing or breaking up of soil crust

E. Improvement of texture and structure :

E_1 by stone or rock removal

E_2 by mechanical working of soil (difficult and costly - requiring heavy machinery)

E_3 by improvement of organic soils

F. Fertilizers, amendments, liming in large quantities (application of fertilizers - particularly those containing nitrogen - is considered indispensable for all soils)

G. Desalting :

G_1 by irrigation and drainage

G_2 by irrigation and drainage + application of gypsum ($CaSO_4$) to eliminate sodium salts (Na_2CO_3)

H. Enriching and maintenance of organic matter content, application of manure, green manure, mulching, crop rotation, forest fallow, etc.; also improvement of humic condition of peat and semi-peat soils.

J. Measures to control wind erosion : windbreaks, mulching

K. Measures to control severe water erosion : construction of banquettes, terraces, etc.

L. Measures to control mild water erosion : digging of ditches, planting of hedgerows, etc.

M. Large scale land clearance

TABLE V

Improvement of soil characteristics or properties by management

Management practices	A	B_1B_2	C	D	E_1	E_2	E_3	F+H (with A_0)	F(with A_1 or A_2)	F(with A_3)*	G_1	G_2	H	J	KL	M
Initial soil properties	H_1H_2	H_3H_4	D_1D_2	$P_1P_2P_3$	T_{1bc}	$T_{5a}T_{6a}$	T_{2c}	N_1N_2	$N_1N_2N_3$	$N_1N_2N_3N_4$	S_3S_4	S_9	$O_1O_2O_5$	H_1H_2 + $T_1T_2T_4$		
Improved soil properties	H_5	H_5	D_3	$P_2P_3P_4$	T of fine soil materials	$T_{5b}T_{6b}$	T of sub-soil	N_3	N_4	N_5	S_1S_2 For T_6 and T_7 For T_2 improvement of 4 soil classes rated according to salinity. For T_5 improvement of a single soil class rated according to salinity	S_7	O_4 Add 10% to final index O_4 (T_{2c} T of subsoil)	Add 10% to final index	Add 20% to final index (10% if improvement of organic matter (H) has already been taken in consideration	0%

* Note : $A_0A_1A_2A_3$ refer to CEC data

TABLE VI

Incompatible management practices and characteristics

A and B_2 with P_{12}, $P_3 + T_{1247}$, $P_4 + T_{1a}$ T_2 T_3

B_1 with P_1 and T_3

C with T_3 (C and T_3 are compatible if G_2 is used)

S with T_1

E_1 with T_{1a} T_{1b}

E_2 with T_3

F with A_0; However F + H is compatible with A_0

L with P_{12}, T_3, T_{5a}

K with P_{123}, T_3, T_{5a}

TABLE VII

Illustration of soil suitability for different uses depending on its characteristics

Envisaged land use	Rice growing	Tree crops	Coconuts	Pasture
Soil characteristics permitting the proposed use	H_4 to H_5 or H_1 to H_3 and A or B	H_5 or H_1 to H_4 and A or B	N_4 to N_5 H_1 to H_3 and A or B	N_4 to N_5 H_1 to H_3 and A or B
Other characteristics preclude or considerably hamper the proposed use)	D_1 to D_2 D_3 to D_4 and/or B	D_3 to D_4 or D_1 to D_2 and C	D_3 to D_4	D_2 to D_3
	P_4 to P_6	P_5 to P_6	P_4 to P_6	P_2 to P_6
	T_5 T_6 T_7	T_{1c} T_4 T_6 T_7	T_{2ab} T_4 T_7	T_{1c} 5 6 7
	N_1 to N_5	N_3 to N_5	N_1 to N_5	N_1 to N_5
	S_1 to S_5 and G	S_1	S_1 to S_5 and G	S_1
	O_1 to O_5	O_3 to O_4	O_2 to O_4	O_2 to O_4
	A_1 to A_3	A_1 to A_3	A_1 to A_3	A_1 to A_3
	M_1 to M_3	M_1 to M_3	M_1 to M_3	M_1 to M_3

TABLE VIII

Special cases

1. Soils with several horizons of different texture

These are soils of heterogeneous texture (e.g. certain alluvial soils with alternate sandy and clay horizons) or simply highly developed soils with a horizon where there has been accumulation of different materials (soils leached into clay).

We arbitrarily divide the soil into two horizons :

1) the horizon from 0 to 50 cm in depth, which is the most significant as regards the supplying of plants with water and nutrients;

2) the horizon from 50 to 120 cm, supplementary to the first either because it is impermeable and holds water or because, on the contrary, it is too sandy and drains the profile; or because it hampers deeper rooting, or else allows a tree to survive when the uppermost horizon is too sandy. Only the dominant texture is considered in each of these two horizons.

Horizons from 0 to 50	Horizons from 50 to 120	Crops and pasture	Forest and non-forest tree crops
Clay dominant	clay dominant	T_{5a} or b	T_{5a} or b
	loam dominant	T_{5a} or b	T_{6a} or b
	sand dominant	T_{5a} or b	T_{4a} or b
Loam dominant	clay dominant	T_{6a} or b	T_{5a} or b
	loam dominant	T_7	T_7
	sand dominant	T_7	T_{4a} or b
Sand dominant	clay dominant	T_{6a} or b	T_{6a} or b
	loam dominant	T_{4a} or b	T_{6a} or b
	sand dominant	T_{4a} or b	T_{4a} or b
		or T_2 if there are 30 cm of coarse sand in the top horizon (0 to 50 cm in depth)	or T_2 if there is over 30 cm of coarse sand in the top horizon (from 0 to 50 cm in depth)

Generally speaking (1) a coarse-sand horizon of over 20 cm in the top horizon (from 0 to 50 cm in depth) places the soil in class T_2

(2) a compact clay horizon of over 10 cm in the top horizon (from 0 to 50 cm in depth) places the soil in class T_{5a}

Note : The following are excluded from this table : fragipan, hardpan, gypsum horizon, because where these exist the effective depth of the soil is that of the upper surface of these horizons.

2. Sloping soils, cultivated without special precautions, particularly without conservation practices. It is assumed that degradation occurs until a state of equilibrium proportional to the slope has been reached. In this case the usual productivity index is multiplied by a slope factor. The latter factor is to be applied whenever agricultural productivity after forest clearance, for instance, shifting cultivation in tropical countries, is being calculated.

Slope (%)	Factor
0 - 2	100
3 - 8	95 - 100
9 - 15	80 - 95
16 - 30	70 - 80
30 - 45	30 - 50
> 45	5 - 30

Depending on the "aggressivity" of the rainfall and soil erodibility, the upper, middle or lower figure is taken.

3. Toxicity or deficiency cases

Special cases of toxicity (excess of soluble and exchangeable aluminium, excess of manganese, presence of acid sulfate - catclays - etc.) or of deficiency in micro-elements (copper, zinc, boron, etc.) or deficiency in phosphorus have not been treated in the general formula. The excess or the deficiency being relative, and the curative treatments being very easy or very difficult, according to the cultivated plant and the type of soil, the consideration of these several special cases would singularly complicate the formula. Besides, the diversity of analytical methods and the still inadequately determined critical concentrations mean that the damages caused are not calculable as a function of the intensity of the toxicity or of the deficiency. The output of the culture may vary from 0 at the natural state to 100 percent after improvement of these soils.

The toxicity or the deficiency will be indicated by a particular sign on the map of productivity and the productivity index will be modified by a factor X that the interpreter of the map will fix himself according to his knowledge. On the potentiality map another particular indication will be noted for the legend, where the proposed improvement will be indicated (ex. liming to reduce an excess of aluminium). The potentiality index will be modified in the same way.

TABLE IX

Specimen presentation of data
(taken from Études pédohydrologiques au Togo FAO/SF: 13/TO –
Calculations made for crop growing)

Soil series & improve.	Productivity (P) Potentiality (P')			Coeff. of imp. P'/P	H	D	P	T	N	S	O	A	M	X*
Agble (Ab)	P	4	(11)		H5:100	D2b:60	P6:100	T4a:40	N4:80	–	O2:80	A1:90	M1:85	
C.H.	P'	IV	(19)	1.72	H5:100	D3:90	P6:100	T4a:40	N4:80	–	O2:80	A1:90	M1:85	+10%
Agni (An)	P	2	(58)		H5:100	–	P6:100	T6b:90	N4:80	–	O3:90	A2:95	M2b:95	
*	P'	II	(58)	1.	H5:100	–	P6:100	T6b:90	N4:80	–	O3:90	A2:95	M2b:95	
Agove (Ag)	P	4	(10)		H5:100	D3a:80	P6:100	T4a:40	N4:80	–	O2:80	A1:90	M2a:90	
*.H	P'	IV	(19)	1.90	H5:100	D3a:80	P6:100	T4a:40	N4:80	–	O2:80	A1:90	M2a:90	+10%
Atchasi (At)	P	4	(9)		H3:60	–	P3:30	T7:100	N4:80	–	O1:85	A1:90	M2a:85	
(B)	P'	IV	(9)	1.	H3:60	–	P3:30	T7:100	N4:80	–	O1:85	A1:90	M2a:85	
Awito (Aw)	P	5	(6)		–	D2a:40	P6:100	T4a:30	N4:80	–	O1:85	A1:90	M2c:95	
C.H.	P'	IV	(17)	2.83	–	D3:90	P6:100	T4a:30	N4:80	–	O1:85	A1:90	M2c:95	+10%
Canne (Cn)	P	4	(18)		H5:100	D2b:60	P6:100	T5b:80	N3:60	–	O2:80	A2:95	M2a:90	
C.F.H.	P'	II	(55)	3.05	H5:100	D3:90	P6:100	T5b:80	N4:80	–	O2:80	A2:95	M2a:90	+10%
Dasikpe (Dp)	P	5	(3)		H3:60	–	P4:80	T2b:20	N3:60	–	O1:85	A1:90	M1:85	
B.F.H.	P'	IV	(14)	4.66	H5:100	–	P4:80	T2b:30	N4:80	–	O1:85	A1:90	M1:85	+10%
Doukpo (Dk)	P	4	(12)		–	D2a:40	P6:100	T5a:50	N4:80	–	O3:100	A2:95	M2a:85	
C.E2	P'	II	(47)	3.91	–	D3:90	P6:100	T5b:80	N4:80	–	O3:100	A2:95	M2a:85	
Eko (Ek)	P	5	(6)		H3:60	–	P6:100	T4a:30	N3:60	–	O1:70	A1:90	M1:85	
B.H.	P'	4	(19)	3.16	H5:100	–	P6:100	T4a:40	N4:80	–	O1:70	A1:90	M1:85	+10%
Ese (Es)	P1	5	(3)		H5:100	D3a:90	P5:100	T2a:10	N3:60	–	O1:70	A1:90	M2a:90	
F.H.		V	(4)	1.33	H5:100	D3a:90	P5:100	T2a:10	N4:80	–	O1:70	A1:90	M2a:90	+10%
Ganove (Ga)	P1	4	(18)		H5:100	D2b:80	P6:100	T4a:50	N4:80	–	O1:70	A1:90	M2a:90	
C.H.		III	(22)	1.22	H5:100	D3:90	P6:100	T4a:50	N4:80	–	O1:70	A1:90	M2a:90	+10%
Hompou (Hp)	P1	4	(15)		H3:60	–	P4:50	T7:100	N4:80	–	O1:85	A1:90	M2a:85	
B.H.		III	(29)	1.93	H5:100	–	P4:50	T7:100	N4:80	–	O1:85	A1:90	M2a:85	+10%
Keklomé (Kk)	P	4	(8)		H3:70	–	P6:100	T4a:30	N3:60	–	O1:85	A1:90	M2a:85	
B.F.H.	P'	III	(22)	2.75	H5:100	–	P6:100	T4a:40	N4:80	–	O1:85	A1:90	M2a:85	+10%

* Column X : improvements affecting all factors taken together.

Soil series & improve.	Productivity (P) Potentiality (P')	Coeff. of imp. P'/P	H	D	P	T	N	S	O	A	M	X*
Kezon (Kz)	P 4 (12)		-	D2a:40	P6:100	T5a:50	N6:80	-	O1:85	A2:95	M2c:95	
C.E2.H.	P' II (49)	4.08	-	D3:90	P6:100	T5b:80	N6:80	-	O1:85	A2:95	M2c:95	+ 10%
Kodjin (Kj)	P 2 (40)		H4:90	-	P6:100	T7:100	N4:80	-	O1:70	A1:90	M2a:90	
A.H.	P' II (50)	1.25	H5:100	-	P6:100	T7:100	N4:80	-	O1:70	A1:90	M2a:90	+ 10%
Kodo (Ko)	P 5 (7)		H5:100	D2b:50	P5:100	T4a:40	N3:60	-	O2:80	A1:90	M2a:90	
C.F.H.	P' III (20)	2.85	H5:100	D3:90	P5:100	T4a:40	N4:80	-	O2:80	A1:90	M2a:90	+ 10%
Kouble (Kb)	P 4 (15)		-	D2b:70	P6:100	T4a:30	N5:100	S1:100	O1:85	A1:90	M2c:95	
C.H.	P' III (29)	1.93	-	D3:90	P6:100	T4a:40	N5:100	S1:100	O1:85	A1:90	M2c:95	+ 10%
Kponou (Kn)	P 2 (58)		H5:100	D3a:90	P6:100	T7:100	N5:100	-	O2:80	A1:90	M2a:90	
*H	P' II (62)	1.06	H5:100	D3a:90	P6:100	T7:100	N5:100	-	O2:80	A1:90	M2a:90	+ 10%
Legbako (Lg)	P 3 (24)		H4:90	-	P6:100	T4b:50	N4:80	-	O1:85	A1:90	M2a:90	
B.H.	P' III (30)	1.25	H5:100	-	P6:100	T4b:50	N4:80	-	O1:85	A1:90	M2a:90	+ 10%
Sémé (Sm)	P 5 (4)		-	D2a:40	P6:100	T4a:30	N3:60	-	O2:90	A1:90	M2a:85	
C.F.H.	P' IV (16)	4.	-	D3:90	P6:100	T4a:30	N4:80	-	O2:90	A1:90	M2a:85	+ 10%
Sio (Si)	P 4 (12)		-	D2a:40	P6:100	T5a:50	N4:80	-	O3:100	A2:95	M2a:85	
C.E2.	P' II (47)	3.91	-	D3:90	P6:100	T5b:80	N4:80	-	O4:100	A2:95	M2a:85	
Tankouti (Tk)	P 3 (20)		H4:90	-	P6:100	T4b:50	N4:80	-	O1:70	A1:90	M2a:90	
B.H.	P' III (25)	1.25	H5:100	-	P6:100	T4b:50	N4:80	-	O1:70	A1:90	M2a:90	+ 10%
Togble (Tb)	P 4 (13)		H5:100	D3a:90	P6:100	T4a:40	N3:60	-	O2:80	A1:90	M2a:90	
F.H.	P' IV (19)	1.46	H5:100	D3a:90	P6:100	T4a:40	N3:80	-	O2:80	A1:90	M2a:90	+ 10%
Togomé (Tg)	P 4 (18)		H4:80	-	P6:100	T4b:50	N4:80	-	O1:70	A1:90	M2a:90	
B.H.	P' III (25)	1.38	H5:100	-	P6:100	T4b:50	N4:80	-	O1:70	A1:90	M2a:85	+ 10%
Vokoutimé (Vo)	P 3 (22)		H4:100	-	P6:100	T4b:50	N4:80	-	O1:70	A1:90	M2a:90	
H	P' III (24)	1.09	H4:100	-	P6:100	T4b:50	N4:80	-	O1:70	A1:90	M2a:90	+ 10%
Voodou (Vd)	P 4 (08)		H5:100	D2b:60	P6:100	T4a:40	N3:60	-	O1:70	A1:90	M2a:90	
C.F.H.	P' IV (18)	2.25	H5:100	D3:90	P6:100	T4a:40	N4:80	-	O1:70	A1:90	M2a:90	+ 10%

TABLE X

Soil profile in the region covered by UNDP Project (Togo)*

Terminal continental soils	
Legbako (Lg) Vokoutimé (Vo) Kponou (Kn) Kodjin (Kj) Klékomé (Kk) Ganavé (Ga) Togomé (Tg) Eko (Ek) Agové (Ag) Agblé (Ab) Dasikpé (Dp) Atchasi (At) Tankouti (Tk) Hompou (Hp)	"…. little leached soils (Kodjin) eroded, with cuirass (Atchasi) and colluvium (Kéklomé). There are also leached soils without colluvium or serious erosion (Legbako, Vokoutimé, Kponou) and the entire gamut of sandy colluvium with various moisture regimes (Eko, Agové, Agblé, Yonor)."
Soils of the Pre-Cambrian Peneplain	
Kodo (Ko) Esé (Es)	"… sandy or loamy-sand soils, pebbly, probably formed from underlying rock (gneiss or migmatite). They have been subjected to surface upheavals, leaching, transportation (indicated by the presence of quartz and concretions). The Pre-Cambrian peneplain has the only tropical, leached, ferruginous profiles that were mapped in the southern part of Togo in the course of these surveys."
Alluvial plain soils	
Agni (An) Canne (Cn) Sio (Si) Doukpo (Dk) Togblé (Tb) Voodou (Vd) Sémé (Sm) Koublé (Kb) Awito (Aw) Keson (Kz)	"… Highly variable from the standpoint of texture, acidity, salinity and moisture regime, their only common character being their alluvial origin and the fact that they are subject to periodic flooding."

* Etudes Pédohydrologiques au Togo FAO/SF:13/TO

TABLE XI

Correlation and regression equations between crop' yields and productivity index

X productivity index

Y crop in t/ha

Maize's crop on 16 Swaziland soil series*

$Y = 0{,}058\ x + 0{,}73$ $F = 10{,}687$

Highly significant ($p = 0{,}01$) $F = 8{,}86$

Maize's crop on 26 Swaziland soil series

$Y = 0{,}042\ x + 0{,}99$ $F = 17{,}932$

Highly significant ($p = 0{,}01$) $F = 7{,}82$

Maize's crop on 9 Argentina soil series**

$Y = 0{,}047\ x - 0{,}43$ $F = 10{,}98$

Significant ($p = 0{,}05$) $F = 5{,}59$

Cotton's crop on 17 Swaziland soil series (mean yields of 1957/66)

$Y = 0{,}030\ x + 0{,}25$ $F = 5{,}50$

Significant ($p = 0{,}05$) $F = 4{,}54$

* Agricultural results and index calculation of G. Murdoch.

** Agricultural results of experimental stations of Pergamino and Runcinam (INTA) and index calculation of J.P. Cornet.

BIBLIOGRAPHY

AANDAHL - Soil Survey Interpretation, theory and purpose. Soil Sci. Soc. of Amer. Proc. 22, 160-163
1958

ABLEITER - Productivity ratings of Soil Type in "The Classification of Land", Missouri Agr. Exp. Sta.
1940 Bul. 421, p. 13-24

AUBERT - Observations on pedological factors that may limit the productivity of soils in the humid
1962 tropics. Trans. of Joint Meeting of Commissions IV and V, Massey University College of Manawatu, Palmerston, New Zealand, 13-22 November 1962

AUBERT et FOURNIER - Les cartes d'utilisation des terres. Projet de légende, Sols Africains, Vol. 3, No. 1

BALL, HEADY and BAUMANN - Economic evaluation of the use of soil conservation and improvement
1957 practices. USDA Tec. Bull. 1162

BECKEL - The application of soil classification in agriculture, forestry and other fields in the Federal Republic of Germany. Trans. of Joint Meeting of Commissions IV and V, International Soil Conference, New Zealand 1962

BLAGOVIDOV - Principles of soil and land evaluation, 7th Inter Congress of Soil Science, Vol. IV,
1960 p. 357-364, Madison, Wisc., USA

BLAGOVIDOV - Qualitative appraisal of soils, Moscow, U.S.S.R.
1960

BOWSER and MOSS - Soil rating and classification for irrigation lands in Western Canada. Can. Jour.
1950 of Agric. Science, 30, p. 165-171

CHARREAU et VIDAL - Facteurs pédologiques influant sur la croissance et la nutrition des doliques. Réunion sur la fertilité des sols et l'utilisation des engrais, Ibadan, 26 Nov.-1 Déc. 1962

BURINGH, STEUR and VINK - Some techniques and methods of soil survey made in the Netherlands. Neth.
1962 J. Agric. Science 10, p. 157-172

CLARKE - Productivity rating. Trans. IV Int. Congress of Soil Science 1950, Vol. 1, p. 345

CONKLIN - The Cornell System of Economic Land Classification. Cornell Univers., U.S.A.
1957

COOKE - Assessing the capabilities of soils for producing crops. Trans. of Intern. Soi. Conf. New Zealand 1962, p. 734

CUTLER - Soil Capability Classification based on the Genetic Soil Map. Trans. of Intern. Soil Conf., New Zealand, 1962, p. 743

DABIN - Agropédologie - l'utilisation des études pédologiques pour la détermination du potentiel
1962 de fertilité des sols tropicaux. Bull. techn. d'inf. des Ingénieurs des services agric. BTI No 172

DESAUNETTES - Classification binaire des sols en fonction de leur valeur. 7th Intern. Congr. Soil Sci., Madison, Wisc., U.S.A., 1960, p. 372-387

DURAND - Le choix des sols irrigables en Algérie. Trans. VI Intern. Congr. Soil Sci., 1956. Communication VI, 10.

EDELMAN - L'importance de la pédologie pour la production agricole. Trans. V Intern. Congr. Soil
1954 Sci., Léopoldville, Vol. I, p. 119-130

FERRARI - Growth factors and soil productivity. Trans. IV Congress of Soil Sci., Amsterdam, 1950, Vol, I, p. 348

FINK and OCHTMAN - Problems of soil evaluation in the Sudan. J. of Soil Sci., Vol. 12, No 1
1961

GIBBONS - J. Soil Sci., Vol. 12, p. 96-100
1961

HEDGE and KLINGEBIEL - The use of soil maps (Yearbook of Agr.), Washington, D.C., p. 400-411
1957

HOCKENSMITH - Classifying land according to its capabilities. Trans. IV Int. Congr. Soil Sci.,
1950 Vol. I, p. 342-345

JACKS - Land Classification. Imperial Bureau of Soil Science Technical Comminication No 43

KELLOGG - Potentialities and Problems of Arid Soils, Desert Research, Jerusalem
1953

KELLOGG - Soil Surveys for Use. Trans. of Intern. Soil Conf., New Zealand, p. 529-535
1962

KLINGEBIEL and MONTGOMERY - Land Capability Classification, USDA, Handbook 210
1961

LAG - Classification and Fertility of Norwegian Forest Soil. Trans. of Intern. Soil Conf.
1962 New Zealand, p. 462

LEAMY - The correlation of soil classification and soil capability in the upper Clutha Valley, Otago, Trans. Intern. Soil Conf., New Zealand, 1962, p. 749

LEENHEER et CAESTECKER - Les récoltes expérimentales comme indice de fertilité. Trans. IV Int.
1950 Congr. Soil Sci., Vol. 2, p. 252-256

LEWIS - Classification des terres aux fins du développement agricole. FAO progrès et mise en
1954 valeur, No 18

McLINTOCK - A descriptive atlas of New Zealand. Govt. print., Wellington, New Zealand
1959

LOVEDAY and BUTLER - The assessment of soil capabilities for irrigated pastures in the riverina, New South Wales. Trans. Intern. Soil Conf., New Zealand, 1962, p. 755

MARTIN - Problèmes d'utilisation des sols au nord Cameroun, IRCAM, Yaoundé, No 117,
1960

MARTIN et SEGALEN - Les sols de l'ouest Cameroun, feuille de Fossang au 1/50 000. IRCAM, Yaoundé
1958 No 95

MUCKENHAUSEN - Die wichtigsten Böden der Bundesrepublik Deutschland, All. Wiss. Schrift Heft 14,
1957 Bad-Godesberg

ODELL - Soil survey interpretation. Yield prediction, Soil Sci. Soc. America Proc. 22,
1958 p. 157-160

RIQUIER - Les cartes d'utilisation des sols à Madagascar. 2ème Conférence interafricaine des
1954 sols, Léopoldville, 1954, p. 1189

SCHICKELE - The role of land and water development in world food and agricultural progress.
1958 Rapport annuel Inst. intern. pour l'amélioration et la mise en valeur des terres, Wageningen, p. 7-22

SIMONSON and ENGLEHORN - Methods of estimating the productive capacities of soils. Soil Sci. Soc.
1938 Amer. Proc. 3, p. 247-252

SMITH and SMITH - A study of crop yield records by soil types and soil ratings. Soil Sci. Soc.
1939 Amer. Proc. 4, p. 375-377

STAMP - 1953 — Land for tomorrow. Indiana Univ. Press

STAMP - 1950 — The land of Britain, its use and misuse. London

STORIE - 1937 — An index for rating the agricultural value of soils. Berkeley, California, Bull. 556

STORIE - 1944, 1948 and 1955 — Revision of the soil rating chart. Univ. Calif. Agric. Exper. Sta., Berkeley, California

STORIE - 1952 — Land inventory form for summarizing soil and land characteristics and land use ratings. Land inventory chart legend. Associated students store, University of California, Berkeley

TAVERNIER et MARECHAL - The use of soil maps in Belgium. Trans. Intern. Soil Conf., New Zealand, 1962, p. 308

TOVBORG - Soil classification and soil mapping in Denmark. Trans. Intern. Soil Conf. New Zealand, 1962, p. 349

VERBOOM - 1961 — Planned rural development in Northern Rhodesia. ITC Publications No B 12/13, Delft

VINK - 1960 — Quantitative aspect of land classification. 7th Intern. Congr. Soil Science, Madison, Wisc., U.S.A., p. 371

VINK - 1963 — Aspects de pédologie appliquée. A la baconnière, Neuchâtel, Suisse

VINK and GIBBS - National and international soil resources maps. Trans. Intern. Soil Conf. New Zealand, 1962, p. 876

WHYTE - 1958 — A comprehensive approach to land classification. Intern. Seminar on development for agricultural uses. Wageningen

UNITED STATES DEPARTMENT OF AGRICULTURE - Climate and Man. The Yearbook of Agriculture, 1955. Soil 1941 Survey Manual Handbook No 18, 1951. Govt. Print. Office, Washington, D.C.

UNITED STATES DEPARTMENT OF THE INTERIOR, Bureau of Reclamation Manual, Vol. V, Part Land Classification Handbook. Govt. Print. Office, Washington, D.C.

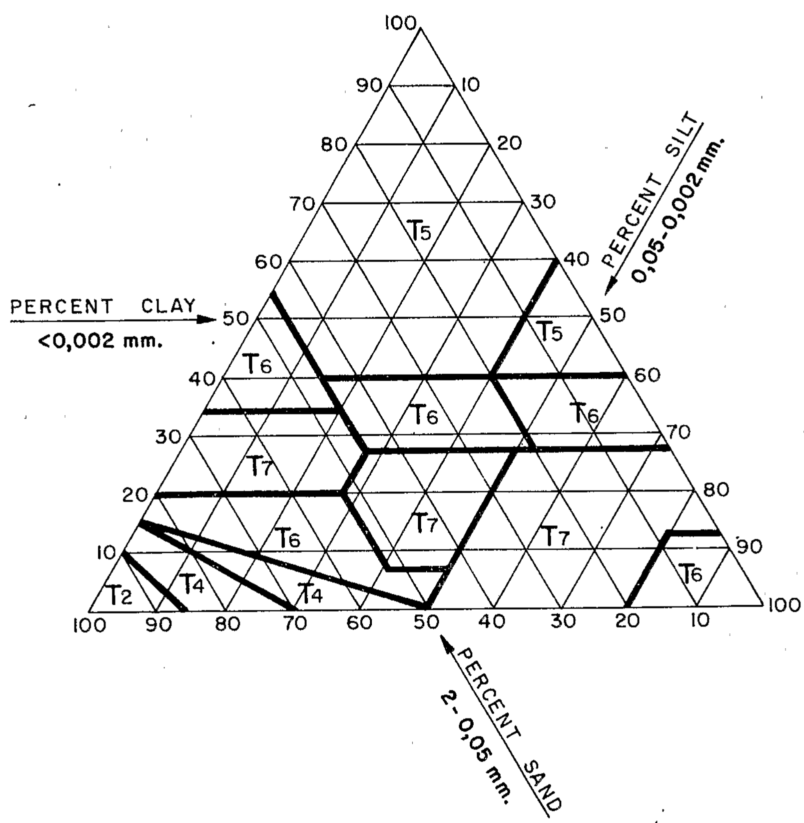
NATIONAL RESOURCES PLANNING BOARD, Land classification in the United States, Washington, D.C. 1951

MINISTRY OF FINANCE OF THE GERMAN DEMOCRATIC REPUBLIC - Soil Appraisal and Technical Instructions for its calculation, Berlin

CCTA - BIS - Sols africains, Vol. VII, No 1 et 2

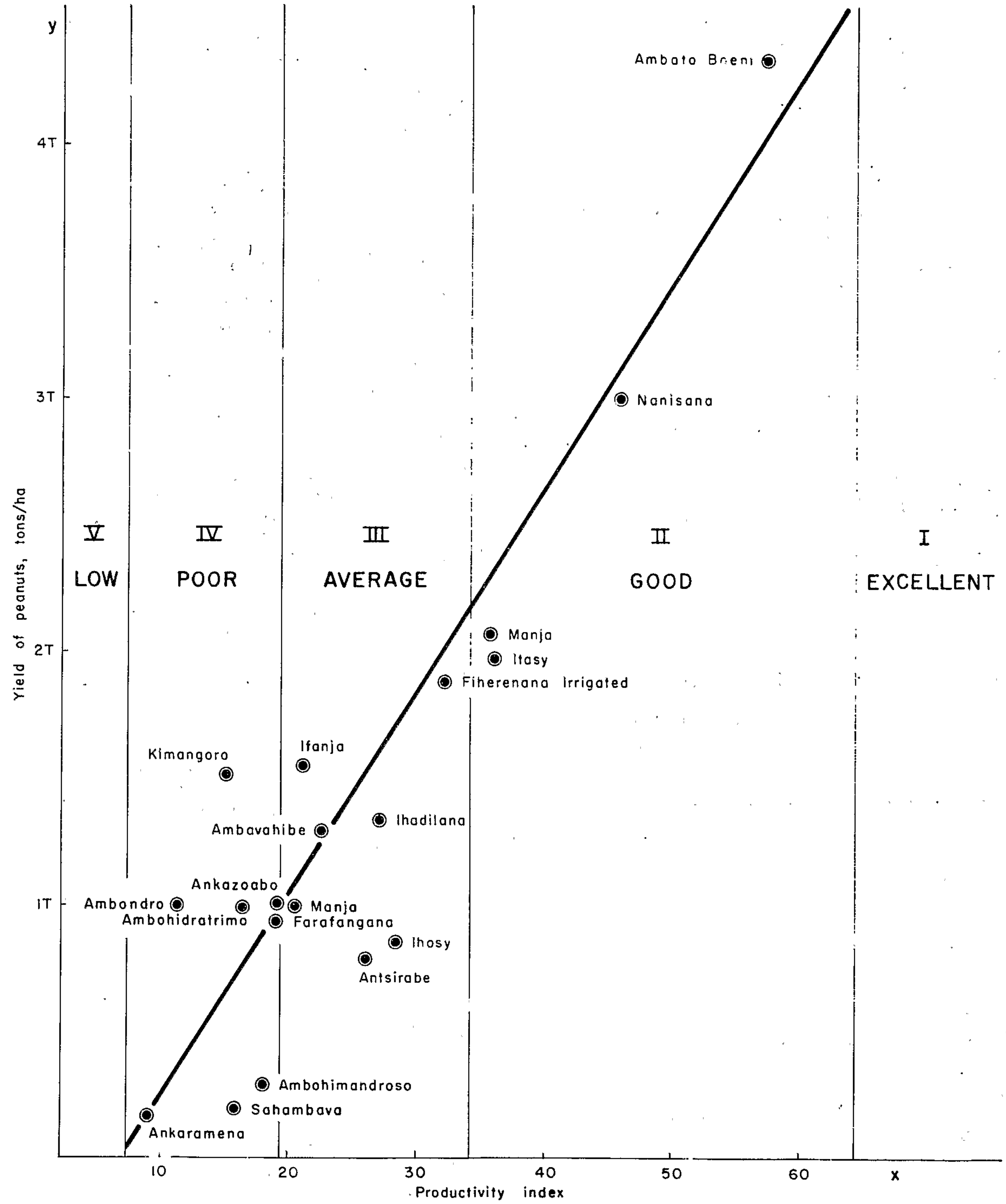
Graph. 1

TEXTURAL TRIANGLE



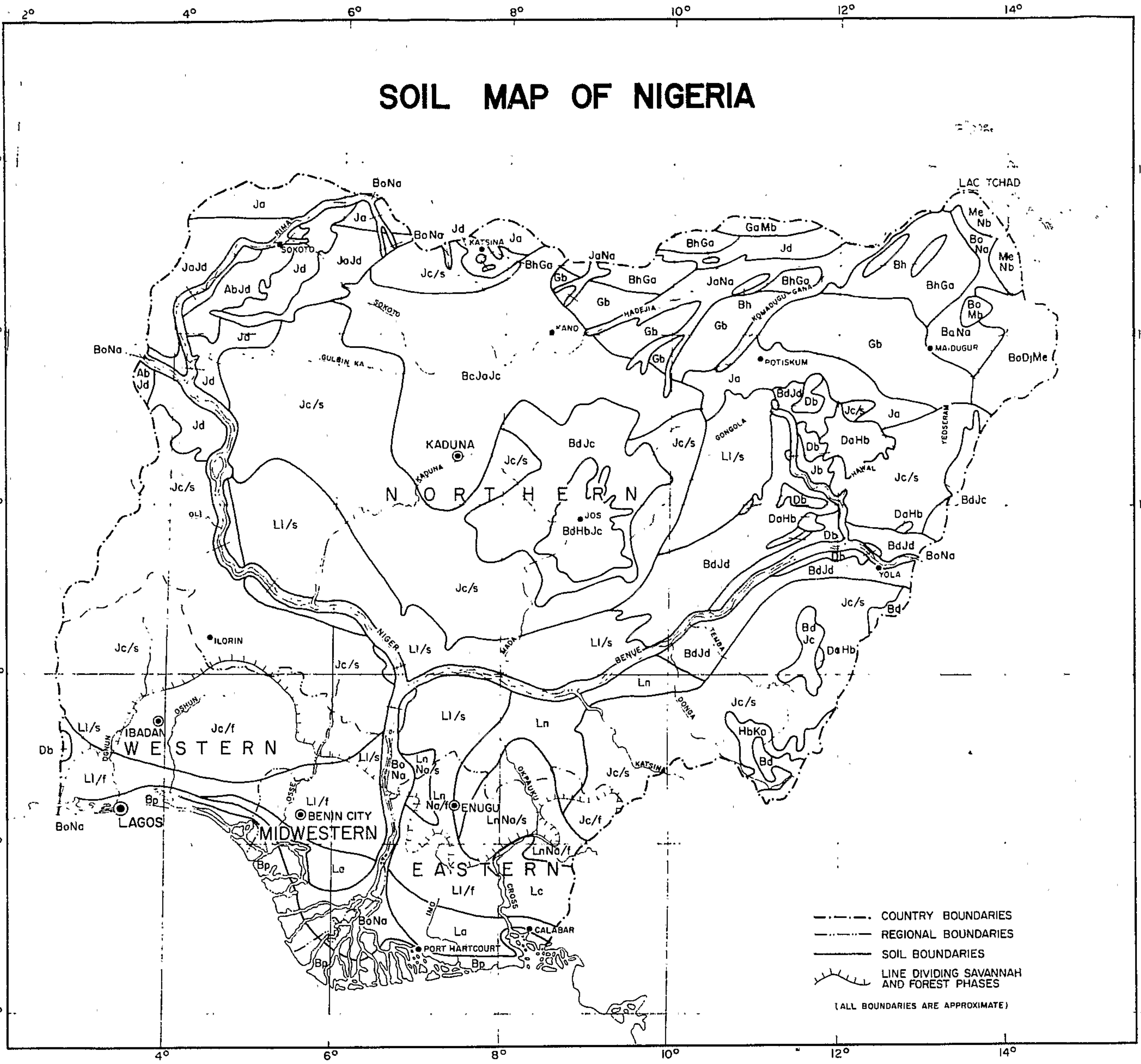
Graph. 2

PRODUCTIVITY OF PEANUTS IN RELATION WITH SOIL CHARACTERISTICS
(PRODUCTIVITY INDEX)



Equation for straight line: $y = 0.08x - 0.55$ / Coefficient of correlation: $r = 0.8292$, highly significant ($p < 0.001$)

SOIL MAP OF NIGERIA



L E G E N D

AbJd	LITHOSOLS ON FERRUGINOUS CRUSTS AND FERRUGINOUS TROPICAL SOILS (UNDIFFERENTIATED).
BcJaJc	LITHOSOLS ON FERRUGINOUS CRUSTS AND FERRUGINOUS TROPICAL SOILS ON SANDY MATERIAL AND ON CRYSTALLINE ACID ROCKS.
Bd	LITHOSOLS (UNDIFFERENTIATED).
BdHbJc	LITHOSOLS (UNDIFFERENTIATED), EUTROPHIC BROWN SOILS (UNDIFFERENTIATED) AND FERRUGINOUS TROPICAL SOILS ON CRYSTALLINE ACID ROCKS.
BdJc	LITHOSOLS (UNDIFFERENTIATED) ON CRYSTALLINE ACID ROCKS.
BdJd	LITHOSOLS (UNDIFFERENTIATED) AND FERRUGINOUS TROPICAL SOILS (UNDIFFERENTIATED).
Bh	REGOSOLS ON LOOSE SEDIMENTS (UNDIFFERENTIATED).
BhGa	REGOSOLS AND SEMI-ARID BROWN SOILS ON LOOSE SEDIMENTS.
BoDjMe	ALLUVIAL SOILS ON RIVERINE AND LACUSTRINE DEPOSITS, VERTISOLS (UNDIFFERENTIATED) AND SALINE SOILS (UNDIFFERENTIATED).
BoMb	ALLUVIAL, HYDROMORPHIC, SALINE AND ALKALI SOILS ON RIVERINE AND LACUSTRINE DEPOSITS.
BoNa	ALLUVIAL AND HYDROMORPHIC SOILS ON RIVERINE AND LACUSTRINE DEPOSITS.
Bp	ALLUVIAL SOILS ON MARINE DEPOSITS (MANGROVE).
DaHb	VERTISOLS ON ROCKS RICH IN FERROMAGNESIAN MINERALS AND EUTROPHIC BROWN SOILS (UNDIFFERENTIATED).
Db	VERTISOLS ON CALCAREOUS ROCKS.
GaMb	SEMI-ARID BROWN AND REDDISH BROWN SOILS AND EUTROPHIC BROWN SOILS.
Gb	SEMI-ARID BROWN AND REDDISH BROWN SOILS (UNDIFFERENTIATED).
HbKa	EUTROPHIC BROWN SOILS (UNDIFFERENTIATED) AND REDDISH BROWN LATERITIC SOILS.
Ja	FERRUGINOUS TROPICAL SOILS ON SANDY MATERIAL.
JaJd	FERRUGINOUS TROPICAL SOILS ON SANDY AND UNDIFFERENTIATED MATERIALS.
JaNa	FERRUGINOUS TROPICAL SOILS ON SANDY MATERIAL AND HYDROMORPHIC SOILS
Jb	FERRUGINOUS TROPICAL SOILS ON ROCKS RICH IN FERROMAGNESIAN MINERALS.
Jc	FERRUGINOUS TROPICAL SOILS ON CRYSTALLINE ACID ROCKS.
Jd	FERRUGINOUS TROPICAL SOILS (UNDIFFERENTIATED).
La	RED-YELLOW FERRALSOLS ON LOOSE SANDY SEDIMENTS.
Lc	YELLOW FERRALSOLS (UNDIFFERENTIATED).
Ll	RED FERRALSOLS ON LOOSE SANDY SEDIMENTS.
Ln	RED FERRALSOLS (UNDIFFERENTIATED).
LnNa	RED FERRALSOLS AND HYDROMORPHIC SOILS.
MeNb	SALINE SOILS (UNDIFFERENTIATED) AND ORGANIC SOILS.

PHASES: S = SAVANNAH
f = FOREST

BASED ON THE SOIL MAP OF AFRICA BY C.C.T.A.

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0 100 200 Km

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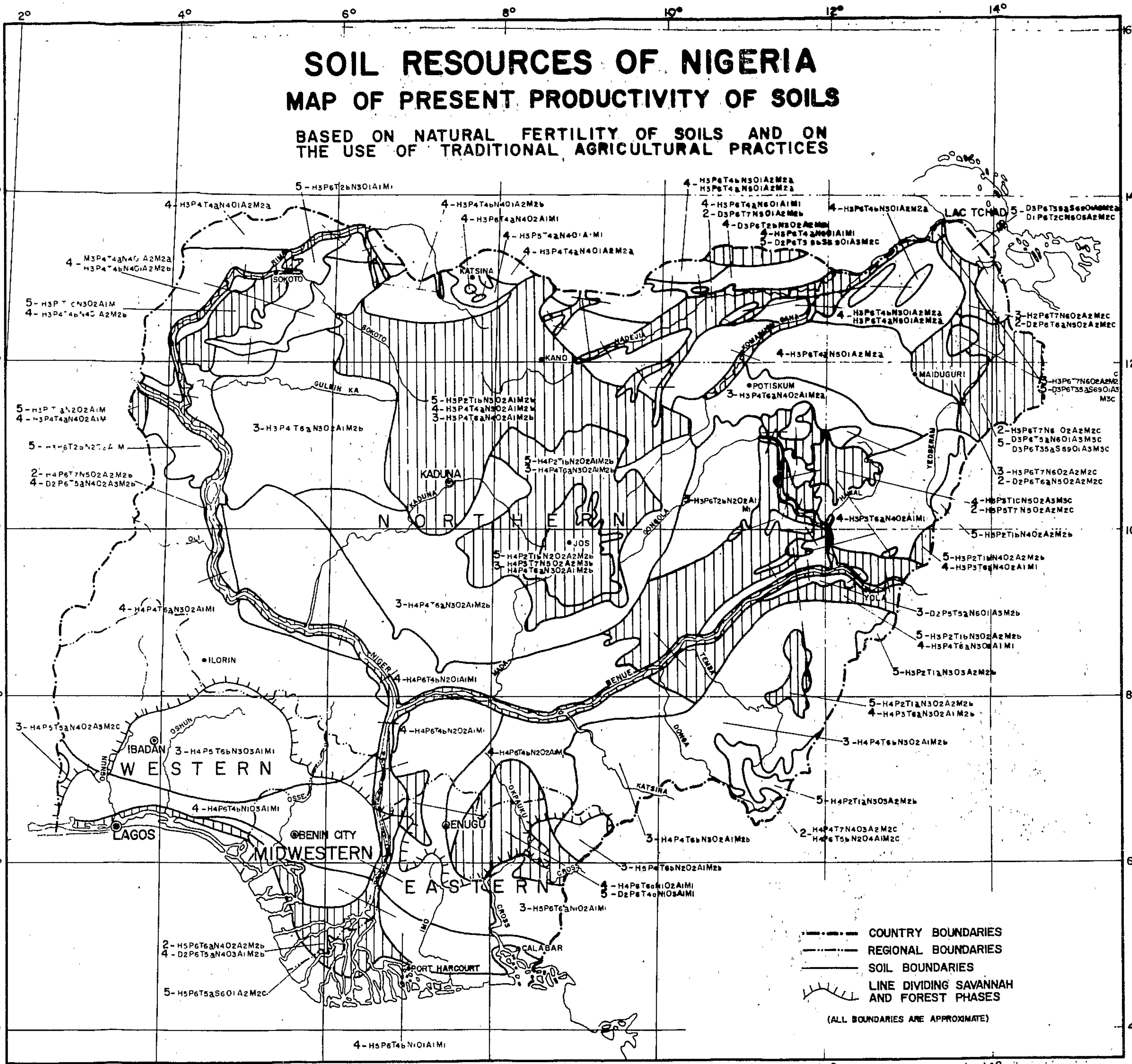
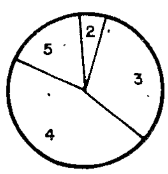


PRODUCTIVITY CLASSES

1	SOIL OF VERY HIGH PRODUCTIVITY
2	SOIL OF HIGH PRODUCTIVITY
3	SOIL OF MEDIUM PRODUCTIVITY
4	SOIL OF LOW PRODUCTIVITY
5	SOIL OF VERY LOW OR NO PRODUCTIVITY



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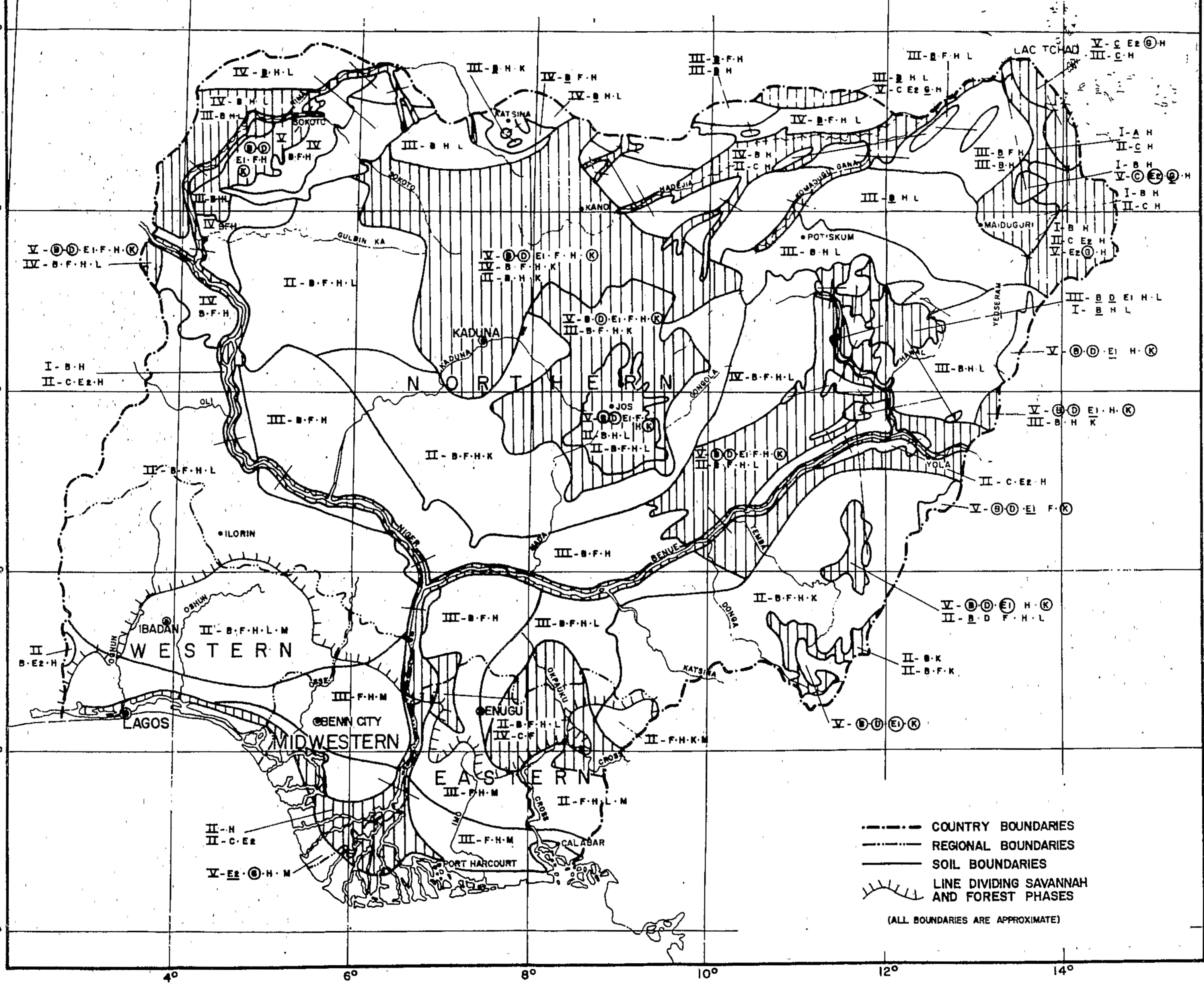
SOIL RESOURCES OF NIGERIA

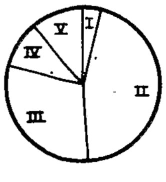
MAP OF SOIL POTENTIALITIES

BASED ON PREDICTED RESULTS FROM
ADEQUATE SOIL MANAGEMENT PRACTICES



SOIL POTENTIALITY CLASSES

I	STRONG POTENTIALITIES
II	GOOD POTENTIALITIES
III	MEDIUM POTENTIALITIES
IV	SLIGHT POTENTIALITIES
V	VERY SLIGHT OR NO POTENTIALITIES



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