AGL/MISC/28/2000

SIMPLE SOIL, WATER AND PLANT TESTING TECHNIQUES FOR SOIL RESOURCE MANAGEMENT

Food and Agriculture Organization of the United Nations

International Institute of Tropical Agriculture

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Proceedings of a training course held in Ibadan, Nigeria, 16-27 September 1996

Edited by
J.A. Adepetu
H. Nabhan
A. Osinubi

INTERNATIONAL INSTITUTE OF TROPICAL AGRICULTURE

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Land and Water Development Division
Rome, 2000

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Preface

Many African countries have serious problems in providing effective advisory services on soil resource management to farmers, even after they have established soil and water testing laboratories (SWL). The main problems of SWL in these countries include inadequate funds to acquire modern, high precision equipment, poor equipment maintenance due to absence of trained instrumental engineers/technicians, lack of trained and experienced laboratory technicians to manage the laboratories, and poor capacity to interpret laboratory test data and make rational recommendations for soil resource management.

Over the years, the Food and Agriculture Organization of the United Nations (FAO) and other international agencies have assisted less developed countries in establishing and/or improving SWLs through project fund mobilization, supply of laboratory equipment, standardization of analytical procedures, exchange of information through expert advice, human resources training, and improvement of capacity for good data interpretation. Despite these efforts, many African countries are presently beset with inefficient soil testing and soil management advisory services mainly because of the problems enumerated above.

In 1996, FAO sponsored a training course on simple, cost-effective methods of soil, plant and water analysis and interpretation of analytical results for senior laboratory technicians responsible for managing National Agricultural Research laboratories (NARs) in English-speaking African countries. The course was organized by FAO in collaboration with the International Institute of Tropical Agriculture (IITA), Ibadan. The purpose of the course was to strengthen NARs' capabilities in conducting simple tests on soil, plants and water, and making sound recommendations for soil resource management. It was hoped that the course would upgrade the proficiency of the course participants in:

- using simple, cost effective methods of soil, water and plant testing;
- conducting proper soil, plant and water sampling, including sample preparation and preservation;
- assessing data quality, identifying sources of errors and eliminating them;
- interpreting test data, identifying soil-related production constraints, and formulating management recommendations.

The course was made up of lectures, field and laboratory practice, case studies, active participation, discussions and debate by participants, as well as field visits to observe soil degradation sites and sampling facilities. Resource persons were drawn from among experienced scientists from FAO, IITA and Nigerian universities.

This publication is a synthesis of the background materials from the training course. It is believed that future participants in courses of the same nature, as well as other readers, will benefit from the experiences presented in this publication.

Acknowledgements

FAO and IITA jointly initiated this training course. Senior soil specialists from Botswana, Ethiopia, Gambia, Ghana, Lesotho, Nigeria, Sierra Leone, Sudan, Tanzania and Zimbabwe participated in this training course. The organizers would like to express sincere thanks to the participants and IITA's resource scientists who have contributed to the success of the workshop and consequently materializing this document.

Special thanks are due to J.A. Adeputu from the Department of Soil Science, Obafemi Awolowo University, Ile-Ife, Nigeria, Hassan Nabhan of FAO Soil Resources Management and Conservation Service, Land and Water Development Division, and A. Osinubi from IITA for their contribution as resource persons and for compilation and editing of the Proceedings. The review of this document by A.R. Mermut is also acknowledged.

Contents

Soil and water laboratories: role, objectives and weaknesses

Soil, water and plant testing is an indispensable tool for research, advisory services and formulation of rational fertilizer recommendations, as well as designing appropriate soil management and agronomic practices. Soil testing in particular is also important in monitoring the various types of land degradation and the choice of measures for land improvement. Development of effective and efficient analytical services of soil, water, plant and fertilizers, therefore, is an important means for increasing and sustaining land productivity as well as crop and food production; a challenge for many developing countries. These analytical services should be closely linked to the extension and advisory services and should maintain functional and technical relationships with universities and research institutions.

FAO and other organizations have assisted developing countries in establishing and improving their soil and water laboratories (SWL) and analytical services, through mobilization of funds (projects), supply of laboratory equipment, standardization of analytical procedures, exchange of information and experience, training of human resources and enhancing the capacity for data interpretation.

FAO has played a key role in assisting member countries in the establishment and improvement of the functions and impact of soil and water laboratories for agricultural development and to boost food production. Among others, FAOs efforts in this field have been devoted to human resources development of the soil and water laboratories. The assistance of FAO, particularly for the establishment of laboratories, has mainly been given through specific projects (extra-budgetary resources) in many countries. Concept development, guidelines and standardization of analytical techniques and related research and development programmes have been disseminated on a global basis. In the recent past and at present, the Soil Resources Management and Conservation Service (AGLS) of the Land and Water Development Division (AGL) of FAO is supporting some eight countries in projects which include soil laboratory components.

While many developing countries have already established SWL, there are still considerable deficiencies in providing effective advisory services to farmers, interpretation of data which are essential to support improvement of soil management practices, reclamation schemes, refinement of fertilizer recommendations, fertilizer quality control, land-use planning, monitoring of land degradation and the establishment of land quality indicators for policy decisions. The basic role of SWL is to support research or advisory services with multiple objectives and functions, such as:

H. Nabhan
Soil Resources Management and Conservation Service
Land and Water Development Division, FAO, Rome, Italy

- ***Soil survey and classification:***
  - Analysis of chemical and physical properties of soils, identification of major soil groups and series.
  - Evaluation of land capability classes, limitations and hazards.
- ***Soil erosion and monitoring its impacts.***
- ***Monitoring changes in soil fertility status:*** Assessment and quantification of processes and changes in physical, chemical and biological properties governing soil fertility, under different farming and cropping systems.
- ***Assessment and monitoring of land degradation and improvement:*** Identification of processes and factors responsible for land degradation (deterioration); quantification of related soil parameters as well as the appropriate corrective and improvement measures. Examples:

  i. **Nutrient mining:** This would require an overall initial assessment, not only at country level (which implies a lot of approximation/aggregation) but also at regional, zonal and area levels. The quantification and establishment of "plant nutrient balance sheets" will be required for initial assessment and also for the subsequent periodic monitoring of the situation. The exercise would, in general, include the quantification and comparison (at each level) of nutrient accumulation and nutrient removal.

  Accumulation: through organic manure and crop residues, wastes (urban/human and industrial), mineral fertilizers, rainwater deposits, sedimentation, biological nitrogen fixation, and so on.

  Removal: through harvested crops, removed plant residues, leaching, gaseous losses and erosion.

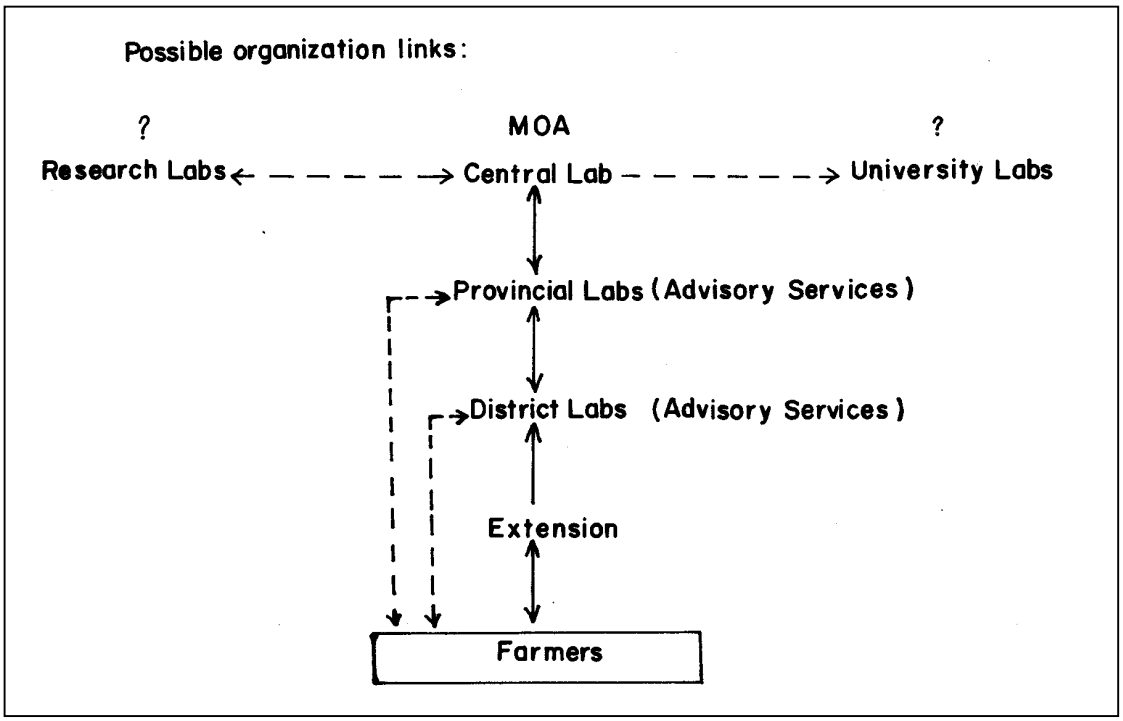
  ii. **Acidification**: Inherent and induced by inappropriate soil, crop and fertilizer management practices and other factors. Assessment and quantification of required soil amendments such as lime and dolomite.

  iii. **Salinization and sodication:** Assessment/quantification of degrees of severity, monitoring changes and guidelines for reclamation projects, use of soil amendments and improvement measures, irrigation water quality, leaching requirement, gypsum requirement, analysis of critical soil physical parameters, drainage requirement and improvement techniques, etc.

- ***Soil pollution and rehabilitation:*** Determination of the magnitude and type of pollution (contaminants), with particular reference to heavy metals and other toxic or hazardous products (for example, Cd, Zn, Cu, nitrate level in groundwater), monitoring changes and experimentation for minimizing the harmful effects on plants and human and animal health.
- C***rop response to fertilizers and other agricultural practices:***
  - For understanding and efficiently interpreting experimentation on fertilizer use (type, time and method of applications), nutrient dynamics in the soils, soil-test/crop response calibration studies, soil fertility mapping, etc.
  - Assessment of quality and impacts of the use of urban and agro-industrial wastes in agriculture. This would also require monitoring through long-term experiments.
  - Support for agronomy, horticulture and livestock research on related soil aspects (deficiency, physical properties, etc.).

- ***Quality control of fertilizer products:*** There is an increasing trend of deregulation in the marketing and distribution of fertilizer products in many developing countries. With the shift of responsibility in import and distribution of fertilizers from the public to the private sector, considerable adulteration is observed, particularly in the various distribution channels. In addition to fertilizer legislation and specifications, many countries are now setting up quality control mechanisms. Soil and water laboratories are essential to check the quality of fertilizer products. For cost effectiveness, generally, the SWLs either at central level or province/district level are assigned the tasks of fertilizer quality control.
- ***Soil, water and plant testing for advisory services to farmers:*** This is among the most important but usually inefficient functions of SWLs. In general, rather modest SWLs are established at provincial and/or district level for this purpose. These laboratories are technically and functionally linked to a more sophisticated and well-equipped central (national) laboratory.

  Farmers or the extension officers collect and dispatch farmers' soil, water or plant samples to these laboratories. After analysis of selected parameters, farmers are given the results of analysis (laboratory reports), with practical recommendations for soil improvement and management, and for fertilizers or amendments (for example, N, P, K, trace elements, lime, gypsum, etc.). This usually involves thousands of soil, water, and plant samples.



While the functions and efficiency of research and university laboratories are relatively satisfactory (in general), those assigned the tasks of advisory services to farmers are ineffective. Such a situation is generally observed in many developing countries, contrary to the situation in developed countries.

Despite heavy initial investment[1] in setting up soil testing laboratories for advisory services to farmers in developing countries, the following weakness or deficiencies are generally observed; although there are exceptions:

i. Lack of skilled and qualified staff: capable of carrying out analysis with precision (using appropriate and standard methods), interpreting the results and formulating practical/useful recommendations to farmers.

ii. Inadequate infrastructure and basic supplies (water, electricity, gas).

iii. Lack of adequate maintenance of equipment, supply of spare parts and chemicals: costly equipment may be lying idle because of minor defects or missing spare parts, with the result that such laboratories become only "showpieces".

iv. Considerable delays in forwarding the lab report/recommendations to farmers: in general small-scale farmers are not motivated for soil testing unless they see its benefit. At least for those who are willing or for large-scale farmers (and for commercial plantations), soil testing laboratories have to be credible, i.e. provide timely and accurate results. (In many countries, delays of up to six months in forwarding the lab reports and recommendations to farmers are common.)

v. Lack of effective linkage between the staff of SWLs and extension officers (institutional framework): quite often, there is no functional linkage between the two groups (they may belong to different departments); the number of extension officers (outreach/closer to farmers) is much higher than the number of lab technicians in a given country. Without close linkage (and adequate training) with extension workers and with farmers, the soil testing services are usually not satisfactory and the results are subject to considerable errors, for example, lab recommendations may not reach the farmer or could be misinterpreted by the extension worker due to lack of knowledge; Soil sampling errors, by an untrained extension worker or farmer, may far exceed analytical errors.

vi. Lack of operational funds: in many developing countries, the soil testing laboratories still belong to the public sector (government, MOA), where often there are no adequate funds to run these laboratories. On many occasions, farmers are not charged for the analysis of their soil samples; in some countries there are nominal charges. Such a system is not sustainable. Perhaps it is time for change.

POSSIBLE SOLUTIONS

a. If the lab is credible, interested farmers may have to pay the full charge of soil testing.
b. With increasing demand for soil testing services, the way could be opened for the private sector and specific agencies to establish soil testing facilities (privatization).
c. For problem identification, and broad-term, rough recommendations, simple analytical techniques (soil testing kits, etc.) could be envisaged.
d. Adequate and effective training, by lab staff, of extension workers and farmers for simple diagnosis.

CONCLUSION

These alternative possible solutions discussed above should not be considered as a substitute for the necessity of SWLs for other important functions. There is still a need for an efficient and

[1] Infrastructure (building and essential installations) is in the range of US$40 000 – 75 000 per laboratory; equipment supplies in the range of US$50 000 – 150 000, besides the cost of staff.

reliable SWL for specific functions in any given country; there are solutions for improving the advisory services to farmers in the field of soil and water management.

In view of the diversified experience of the participants in the workshop, these Proceedings include an appraisal of their country situations and suggestions for possible solutions to the problems.

Cost-effective laboratory techniques

The choice of cost-effective equipment and techniques depends on the samples analysed by the laboratory, and the cost of labour. Most laboratories in Africa handle under 5 000 samples annually. The methods and equipment discussed in this section have been selected based on this level of sample output. In most cases, however, the methods and much of the equipment are equally suited for higher output laboratories.

Labour costs in Africa are generally not high. Conversely, the cost to repair broken equipment can be considerable, because often spare parts must be obtained from overseas. As a general rule, equipment that employs high-tech options that reduce labour is not a good choice for small laboratories. Auto-samplers, auto-analysers, and computer connections may be justified in labs with very high sample outputs (over 20 000 per year). However, experience shows that such equipment has high maintenance requirements. The cost of additional labour to run simpler equipment is usually justified.

The material presented covers improved methods for soil and plant analysis, and a review of laboratory equipment that is deemed to be of excellent value for analyses performed routinely in soil and plant analytical laboratories. The sources of several pieces of equipment are given. A reference list of the methods discussed is included.

IMPROVED METHODS

Several improved laboratory methods for routine analysis are becoming available. This section discusses these methods, and the advantages and disadvantages.

Universal soil extractants: A "universal" soil extractant is one that extracts elements requiring two or more of the standard extractants. Jones (1990) gives a good review of several universal extractants. There are some errors in this paper regarding the make-up of the extractants. The original papers should be consulted when adapting any of these new methods. Two methods will be briefly discussed here.

The Mehlich-3 method (Mehlich, 1984) is used to extract Ca, Mg, K, Na, P, Mn, Fe, Zn and Cu simultaneously. This method can potentially replace the ammonium acetate, Bray-I, and DPTA extracts employed in many laboratories. Because the extractant solution is buffered at a low pH, it is not appropriate for soils with pH above 7 that may contain carbonates.

J.W. Wendt
IITA, Ibadan, Nigeria

The Mehlich-3 method is fast, requiring a shaking time of only five minutes. It has been compared to the more standard methods mentioned above in numerous studies. It is highly correlated with the ammonium acetate method for exchangeable cations. Correlation with the Bray-I method is dependent on soil type; however, there is no indication from reviews of literature that it is less correlated with P availability as measured by plant response than is the Bray-I method. It is also well correlated with the bicarbonate method on many soils. Likewise, there is a good relationship between Zn and Cu extracted by Mehlich-3 and DPTA, though the relationship is less certain for Mn and Fe. Wendt (1995) reviews several studies of the correlation of the Mehlich-3 with other methods.

The ammonium bicarbonate-DPTA (AB-DPTA) method effectively replaces the bicarbonate P and DPTA method (Zn, Cu, Mn and Fe). It also extracts K effectively, but is not thorough in extraction of Ca and Mg. This method is effective across the high pH range where the Mehlich-3 is not effective.

Universal extractants can save laboratories considerable amounts of time, while not compromising the quality of results. However, they may require that calibration studies be run for comparative purposes, particularly for metals and P. Field calibration studies are also recommended. Some researchers prefer the more standard methods to be used, particularly when fieldwork is being done to classify soils precisely. Soil classification systems specify certain procedures for some analyses.

Volume versus weight: The Mehlich-3 method employs a soil scoop to obtain a given volume of soil, rather than a given weight. Mehlich (1972) discusses the advantages of using a volume of soil versus a weight for an analysis. Fertilizer application is usually done on a volume basis (for example, kg per hectare, the hectare usually specified at a 15 to 20 cm depth). The amount of soil volume in a given weight can vary radically, depending on the bulk density of soil. It is much more rapid for an analytical laboratory to dispense a volume of soil with a scoop than having to analyse a precise weight. Volume dispensing of a soil is usually accurate within 2%. Some laboratories scoop the soil and weigh the amount scooped. This procedure is more rapid than weighing an exact volume, and permits the laboratory to calculate analyses on a weight basis, should the client desire.

Wet digestion and dry ashing: Most soil laboratories employ both a muffle furnace and a block digester. The block digester is used primarily to determine N, while the muffle furnace is used to determine a host of other elements. Dry ashing cannot be used for N determination, because N is volatilized. However, a host of elements can be determined from "wet" procedures.

"Wet" procedures are those which use an acid, usually sulphuric, as a medium for sample digestion. Many procedures specify the use of potassium sulphate in these procedures to raise the boiling point of sulphuric acid and hasten the digestion. However, many procedures do not require the use of this chemical, and can be used for multi-element determinations, including K. These procedures usually use hydrogen peroxide. Several of these procedures are reviewed in Jones (1991). A good wet procedure for multi-element analysis is presented by Lowther (1980).

The obvious advantage of these procedures is that they eliminate the need to dry ash a sample to analyse elements other than N. It is very easy to obtain P, K, Fe and Mn from a wet ash. However, there are some difficulties with other elements. Ca and Mg require the use of a

releasing agent in the dilution step if the digest uses sulphuric acid. The releasing agent is usually 3000 ppm La or Sr. It is extremely important that the quantity of sulphuric acid be the same in samples and standards. The digestion step consumes some acid and, if much is lost as vapour, the effect of the releasing agent will be different with samples and standards. In addition, the concentrations of Zn and Cu are very low in a wet ash after dilution to 50 ml. This can affect the sensitivity of read-out. These elements can be determined if the sample is diluted to only 10 ml or 20 ml. The wet ash method can be used without complication for N, P, K, Fe and Mn analysis. If other elements are desired, it may also be used, but dry ashing offers advantages of simplicity.

Filtration or centrifugation: Centrifugation, while generally more rapid than filtration, requires the purchase and maintenance of a centrifuge. It offers one key advantage, however: it eliminates contamination from filter paper. Many popular brands of filter paper contain unacceptable levels of contaminants. High levels of Zn, K and S have been found in many lab filter papers. Additional contamination of K and Na may be introduced from hands as the filter paper is folded. If using filter paper, check for contamination. Always run standard samples through filter paper in the same manner as samples. If the contamination is irregular or high, it will be apparent in deviations in the standard curve. Roots and other organic material are often not removed by centrifugation, because they float. However, they may be removed by placing a small piece of cotton or synthetic fluff in a filter funnel and pouring a sample through. These materials usually contain lower levels of contaminants than do lab filter paper, surprisingly, and can be washed and rinsed if they contain unacceptable levels.

Ammonium analysis: *Ammonium* determination is among the most common analyses performed in labs, both from soil and plant digests and from soil extracts. Most laboratories in Africa are analysing ammonium by the steam distillation method. This tried and true method, while very accurate, has two major drawbacks: it is time-consuming, and the equipment required is expensive. Most laboratories have spectrophotometers or colorimeters that can be used for ammonium determination. These offer considerable advantages in terms of speed. The indophenol method has many variations, one of which is presented by Kempers and Zweers (1986). The blue colour requires two hours to develop, and is stable for 12 hours.

The ammonia electrode is fast gaining popularity as a rapid and inexpensive method for N determination. The electrode is much like a pH electrode, but measures the concentration of ammonia in solution. The equipment required is the electrode itself, a pH/mV meter with a resolution of 1 mV (preferred resolution of 0.2 mV or better), and a stirplate. The electrodes cost less than US$ 500. The cost of the meters varies, but some of the finer resolution models are available for $300 to $500 - and these can be used as pH meters as well. Results are highly correlated with steam distillation methods. Special precautions need to be taken in meter calibration (Bremner and Tabatabai, 1972; Powers *et al.*, 1981).

Organic carbon: One of the more common analyses performed in soil laboratories, total carbon is commonly estimated using the Walkley-Black procedure. In this procedure, the organic C is partially oxidized by dichromate in the presence of sulphuric acid. The excess dichromate is titrated with ferrous ammonium sulphate. This method is convenient, and is fairly accurate for many soils. However, the titration step is time-consuming.

Several organic carbon procedures are compared by Soon and Abboud (1991). Of these, the spectrophotometric procedure of Heanes (1984) is particularly simple and very accurate. In this

procedure, the sample is oxidized with dichromate in the presence of sulphuric acid on a digestion block for 30 minutes at 1350C. The procedure completely oxidizes the organic C, so that an estimated conversion factor is not required. The digest is measured directly on a colorimeter or spectrophotometer, which is more rapid than titration.

Aluminium determination: Aluminium is usually determined by titration of the acidity in a KCl extract. Many colorimetric procedures have been developed for Al determination over the years, but perhaps the simplest and most reliable is the catechol violet procedure. Analysis of neutral salt extracts by this procedure is discussed by Mosquera and Mombiela (1986). Colorimetric procedures usually offer time savings over titrative methods. The catechol violet procedure can also be adapted for analysis of plant digests and soil solutions.

SELECTED LABORATORY EQUIPMENT

Laboratories can realize substantial savings by purchasing the right equipment. The "right" equipment is that which will handle the laboratory's sample load at minimal cost. Cost includes not only the price of the apparatus, but the funds required to operate and maintain it. The equipment discussed below is not meant to necessarily endorse any manufacturer or product. However, the information can serve as a guideline for helping laboratories to make decisions on purchasing.

Atomic absorption spectrophotometers: Buck scientific company makes AAS units that are characterized by low cost (starting at $12 000), simplicity and durability. The units are also very small, saving lab space. Buck also offers reconditioned AAS units.

UV-visible spectrophotometers: Turner spectrophotometers, available through Thomas Scientific, are low-cost, multi-voltage digital units that are simple to operate. Prices begin at $1400, and a UV-range attachment is available for an extra $1300. The UV range can be used for a very simple procedure for nitrate (Cawse, 1967). Special silica sample cells are required in the UV range. TlP, the 13 mm sample cell, can also accept inexpensive 13 mm x 100 mm test tubes. One can speed up sample reading and eliminate spills and cross-sample contamination by placing samples in individual test tubes.

Block digesters: EconoLab's rapiDigester-80 will digest 80 samples per batch. Its rapid heat-up time will permit two Kjeldahl batches per day. It can also be used for organic C samples, as per the method above. At only $2690 (including digest tubes), this unit digests twice the samples of standard 40-place digesters that cost twice as much. Uses very little space under the fume cupboard.

Ashing ovens (muffle furnaces): The Neytech model 3-550 has a large interior that can accept a shelf. It has low power consumption (1800 W) for an oven its size, and is fully programmable, so samples can be left in the oven in the afternoon to be ashed overnight. Currently priced at under $1500, these ovens are excellent value. Be sure to ask for the shelf when ordering.

Ammonia electrodes and pH-mV meters: If planning to use an ammonia electrode for ammonium determination, the Orion models 250A and 290A have mV precision to 0.1 mV, and

are priced at $475 and $650 through Cole-Parmer Instrument Co. Cole-Parmer also offers its own pH-mV meter, a portable unit with 0.2 mV resolution, for about $300. All of the above units can be run on batteries, and accept a mains-powered transformer. The Orion ammonia electrode is also available for $400. Be sure to order extra filling solution and electrode membrane tips.

Water purification: Most laboratories are using water stills, which have low water output and high power consumption, and require frequent cleaning. A much less expensive source of pure water is deionizers. USF-Permutit offers a series of dionizers for different laboratory requirements. The units use anion and cation exchange resins to purify the water. It is best to get units that allow regeneration of the resins by the user, such as the 12R or 24R. Regeneration is a simple step requiring only HCl and NaOH. These units do not require any power to operate, are priced competitively to stills, have a much higher water output, and are easier to maintain.

Centrifuges: The GP-8 centrifuge from IEC is good value at $4 500. It accepts a number of rotors and cups. It is recommended that this is purchased with a rotor, large buckets and inserts that hold multiple tubes. Rotors and inserts cost extra. Available through Thomas Scientific.

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Variabilities of soil properties

Soil is a dynamic and heterogeneous material that changes continuously both in time and space. This is due to the soil forming factors and processes that operate at different intensities and to soil management practices. The soil forming process is continuously modified by both environmental and geomorphological factors.

Quantitative evaluation of soil resources and their responses to management practices requires reliable information on the spatial and temporal variability of soil properties. The analytical precision of soil properties at a given location depends largely on the amount of variation within the sampling area. Generally, as soil heterogeneity increases, the precision to measure their properties decreases.

NATURE OF SOIL VARIABILITY

Spatial and temporal variation

Spatial variations of soil properties refer to the variation in soil over horizontal distance. Temporal variations in soil properties refer to variations occurring over a time scale.

Systematic and random variation

Systematic variability is gradual or distinct change (or trends) in soil properties that can be understood in terms of soil-forming factors or processes at a given scale of observation (Wilding and Drees, 1983). Systematic variation may range from differences in topography, lithology, climate, biological activity, age of soils in regional studies (Van Wambeke and Dudal, 1978) to differences in microfabric and physiological composition when soils are observed on a micro level (Blevins *et al.*, 1970; Miller *et al.*, 1971; Murphy and Banfield, 1978).

Random variations are differences in observed soil properties that cannot be related to observed or known cause. This unexplained heterogeneity often includes the spatial, temporal and measurement sources of variation that cannot be detected by the nature and the scale of the investigation (Ball and Williams, 1968).

SOURCES OF VARIABILITY IN SOIL PROPERTIES

Common sources of variabilities in soil properties include the following:

i. Bed/parent rock: The bed rock from which soil is derived varies in physical properties and mineralogical composition depending on the rate of cooling of molten magma from which they are formed. This variability in bed rock properties is eventually transferred to the soils.

D.J. Oyedele and A.A. Amusan
Department of Soil Science, Obafemi, Awolowo University, Ife-Ife, Nigeria

ii. Parent materials: These refer to materials from which soil is formed. They could vary from unconsolidated rocks to soil materials of eolian or alluvial origin. This factor often contributes to a large extent to observed vertical variabilities in soil properties. For instance, different horizons of distinguishing characteristics often occur when soil is formed from parent materials of more than one different origin.

iii. Climatic factors: These include rainfall, temperature and humidity, among others. This factor affects and modifies the rate of weathering and the process of soil formation. Fluctuations in the micro, regional and the global climate, therefore, cause variabilities in soil properties also at the local, regional and global scales.

iv. Vegetation: Vegetation influences the other biotic activities in the soil and also the micro-climate. Nutrients are recycled in soil through the process of organic matter decomposition and plant uptake. Variabilities in intensity of vegetation cover and the plant species often result in variabilities in soil properties.

v. Topography/relief: The position of soil on the topography usually determines its drainage ability. The soils in the middle to upper slope positions are often well drained, deep and well developed while lower slope soils are often shallow and poorly developed. The processes of erosion and deposition are also influenced by the topography.

vi. Crop/soil management practices: These include the cropping system, tillage practices, the direction of tillage, conservation measures, liming and fertilizer application. All these cause marked variabilities in soil physical and chemical properties.

MEASUREMENT OF SOIL VARIABILITY

It is desirable to evaluate soil properties at many points in the field. This will save cost and ensure an optimum use of soil resources. However, the dynamic nature of soil and variation in the properties makes this very difficult. An estimate of the soil property over a region on the field is made from representative samples that are usually obtained by bulking soil from several places.

There is no standard way of sampling to obtain information regarding soil variation in an area. However, a square grid is often used (as shown in Figure 1). The overall aim of any sampling scheme is to obtain representative samples to establish soil properties. It is assumed that by bulking several soil samples collected from several places, a representative sample is obtained. Grinding and sieving produce a homogenized sample from which a small subsample is taken for analysis, and it is assumed that this subsample is representative of a soil. Some sampling schemes that are commonly in use are described in another section of these Proceedings. Figure 1 shows an example of bulk density and organic matter content (in brackets) of samples collected on a 5 x 5 m grid from a field having different tillage practices.

EVALUATION OF SOIL VARIABILITY

Variabilities in soil properties are evaluated using the classical statistics involving the measurement of the sample mean and measuring the variance of the sample about the mean, or by trend analysis that identifies the presence of any trend in the variability of the properties.

FIGURE 1
Field layout showing the sampling points with values of soil bulk density and organic matter content (in parenthesis)

FIELD WIDTH (m)

FIELD LENGTH — 30 m

5 m

0.81 (1.64)	0.91 (1.61)	0.99 (1.41)	0.99 (1.48)	1.03 (1.54)	1.01 (1.68)
0.88 (1.48)	0.79 (1.74)	0.97 (1.61)	0.97 (1.61)	1.17 (1.61)	0.98 (1.54)
1.17 (1.01)	1.06 (1.01)	1.10 (0.94)	1.17 (0.94)	1.04 (1.01)	1.28 (0.94)
1.03 (0.94)	0.78 (0.74)	1.16 (0.94)	1.04 (1.14)	1.22 (0.87)	1.12 (1.07)
1.00 (1.34)	0.97 (1.41)	0.98 (1.01)	0.90 (1.14)	0.94 (1.14)	1.02 (1.27)
1.02 (1.27)	1.17 (1.14)	1.04 (1.21)	0.98 (1.14)	0.98 (1.21)	1.12 (1.14)
1.26 (0.87)	0.91 (0.94)	1.05 (0.80)	0.85 (0.94)	1.05 (0.94)	0.93 (0.40)
1.12 (1.01)	1.10 (1.14)	0.83 (0.87)	1.01 (1.07)	1.15 (0.87)	0.97 (0.87)
1.15 (1.07)	0.98 (2.15)	1.07 (0.94)	1.00 (1.14)	1.26 (1.21)	1.24 (1.21)
1.11 (0.94)	0.93 (1.88)	1.24 (0.87)	0.85 (0.87)	1.08 (1.07)	1.11 (1.01)
0.94 (0.74)	1.05 (0.41)	1.02 (0.87)	0.97 (0.40)	1.01 (0.74)	0.98 (0.47)
1.07 (0.87)	0.93 (0.88)	1.45 (1.07)	1.24 (0.80)	1.45 (0.54)	1.24 (0.74)

5 m

60 m

MEASURES OF DISPERSION

The classical statistical procedures assume that variations are randomly distributed within each class of observations and independent of sample location. The mean is therefore used for the estimation of properties for unsampled locations within each class. Statistics of dispersion (e.g. variance, standard deviation, coefficient of variability, confidence limits) are used to show the precision of the mean as an estimator. Variance is calculated using:

$$S^2 = (\quad X^2 - (\quad X \ )^2 / (n-1)) / (n-1)$$

where X is the observations and n is the number of observations in the population.

The standard deviation is computed as the square root of variance. The coefficient of variability (CV) is computed as follows: CV = S/X.

While the confidence limit

$$(L) = X \pm t_{\infty}(S^2/n)^{1/2}$$

where X is the mean, t_{∞} is the Student's t with (n-1) degrees of freedom).

Table 1 gives a summary of the statistics on the soil properties in Figure 1.

TABLE 1
Descriptive statistics of random samples of soil properties

Statistics	Bulk density	Organic matter
number of sample (n)	72	72
sum (ΣX)	75.39	78.57
mean (X)	1.05	1.09
variance (S^2)	0.0186	0.1207
standard deviation (S)	0.1363	0.3475
coefficient of variability (CV)	13.016	31.84
95% confidence limit (CL)	±0.03	±0.08

Assuming the samples were collected randomly from different locations in the field, the following conclusions can be drawn from these statistics:

(a) soil organic matter is more variable on the field than the bulk density;
(b) unless a 1 in 20 chance has occurred in sampling, the true population means lie within the range of 1.02 to 1.08 g/cm^3 for bulk density and 1.01 to 1.17% for organic matter.

MEASURE OF SPATIAL VARIABILITY

The basic assumption of the Fisherian (classical) statistical procedure is that the observed variations are random and independent of sample location. These assumptions however, make the classical model inadequate for the evaluation of spatially dependent variables. Soil properties have been found mostly not to vary randomly but to vary continuously in space (Webster, 1985) implying that they are spatially dependent.

Geostatistical techniques, which are based on the theory of regionalized variables (Matheron, 1971) provide a tool for the quantitative evaluation of the spatial dependent variables such as soil properties and can additionally be used to interpolate these spatially dependent variables. The variogram is the central tool of geostatistics and has variously been used (Webster, 1985; Uehara *et al.*, 1985) to quantify the scale, direction and intensity of spatial variation and to provide information for interpolation by kriging and optimization of sampling intensity. It is also helpful in explaining the underlying factors responsible for the observed variation in soil properties.

The variogram relates the similarity or difference, expressed as the semi-variance, between values at different places to their separation distance (lag) and direction. This theory is based on the assumption that the properties to be evaluated (soil properties) are locally stationary (Webster and Burgess, 1980).

Given this basic assumption of stationarity, semi-variances can be estimated using the formula:

$$y(h) = \frac{1}{2N(h)} \quad [Z(X_i)] - Z[(X_i + h)]^2$$

where Z(x) and Z(x + h) are the values of a random function representing the soil property of interest, Z, at places x, and (x + h) separated by the vector h, known as the lag. N(h) represents the number of pairs of observation.

FIGURE 2
Semi-variogram of soil bulk density and organic m

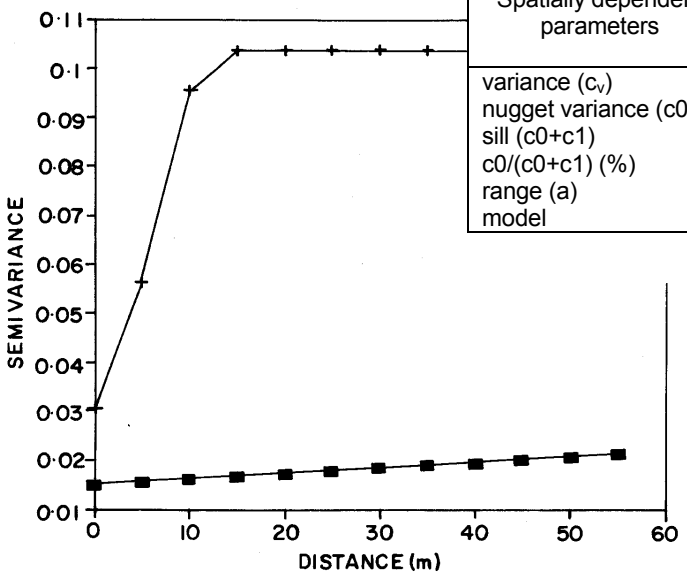
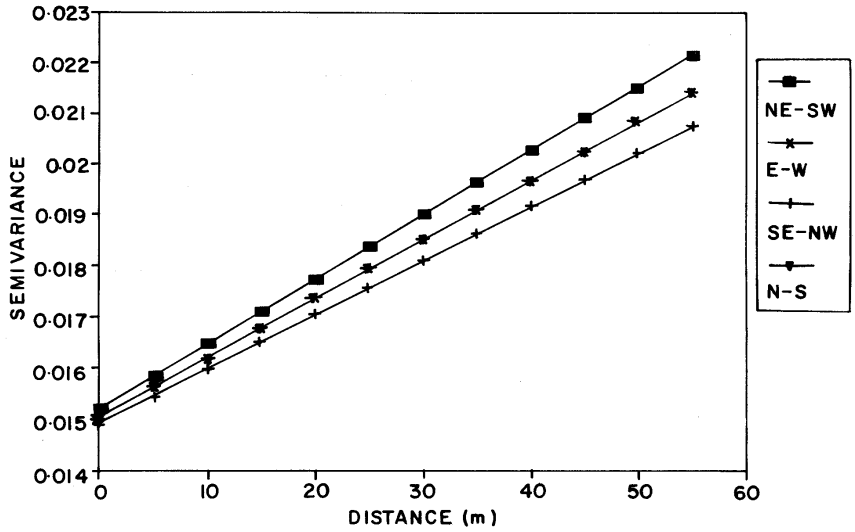


TABLE 2
Spatially dependent properties of soil bulk density and organic matter

Spatially dependent parameters	Bulk density (g/cm^3)	Organic matter (%)
variance (c_v)	0.018576	0.1207
nugget variance (c0)	0.015077	0.03824
sill (c0+c1)	-	0.1036
c0/(c0+c1) (%)	81.16	31.68
range (a)	-	13.24
model	linear	spherical

FIGURE 3
Semi-variogram of soil bulk density in different directions



A plot of the computed semi-variance and the sampling distance is called a variogram. The variogram generally provides information about the intensity, direction, the nature and trend of spatial variation. Table 2 presents the semi-variance properties of the data in Figure 1. The following can be concluded from the table: (i) the soil organic matter shows a higher variability than bulk density, (ii) about 82% of the observed variability in bulk density cannot be explained by its spatial dependence which showed that most of the observed variability was due to chance (or randomness) whereas about 32% of the variability in organic matter cannot be explained (i.e. is due to chance); often this proportion may be reduced by adopting a more efficient

sampling scheme or by sampling at a higher intensity, (iii) the soil bulk density fitted to the linear (unbounded) model indicates the spatial variability of bulk density to be continuous while the organic matter fitted to the spherical model implies that the spatial variability of organic matter is within a range of influence; (iv) the variability in organic matter has a range of about 13 metres implying that samples taken from within this distance are more related than samples from outside this distance. This information may be useful in deciding the size of plots during field layout for experiments. The variograms of the soil properties are presented in Figure 2. These show a gradual rise in semi-variance of soil organic matter reaching the sill (point of maximum semi-variance) and then flattening out.

The semi-variance of the soil bulk density show a slight rise with sampling distance indicating little spatial dependence. Additional information on the nature of the variability in bulk density is provided in Figure 3. This shows the slope of the semi-variance to be different along different directions on the field. This phenomenon is termed anisotropy. The direction of maximum variance is the north west (45 degrees) direction. This information is valuable in deciding the direction of blocks in laying out a field experiment. Blocks are often laid out across the direction of maximum variability to absorb most of the variations in soil properties.

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Soil profile characterization

The way a person thinks of soil depends on how he/she uses it or is confronted with it. The two main concepts used by scientists today are:

- Soil consists of weathered rocks and minerals. This includes all the loose or unconsolidated rock and mineral material on the surface of the earth crust and even on other planets and celestial bodies. This definition of soil is held by engineers, geologists, space scientists and some oceanographers.
- Soil is the medium for plant growth.

These definitions, though containing elements of truth, do not describe soil significantly as it is known to exist today.

The Soil Survey Staff of USDA, Soil Conservation Service (1994) provided a comprehensive definition: "Soils are natural bodies, made up of mineral and organic materials, that cover much of the earth's surface, contain living matter and can support vegetation out of doors, and have in places been changed by human activity (Jenny, 1961). The upper limit of soil is air or shallow water. Its horizontal boundaries are where it grades to deep water or to barren areas of rock or ice. The lower boundary is normally the lower limit of biologic activity, which generally coincides with the common rooting depth of native perennial plants". Soil is thus an evolving entity (Figure 1), maintained in the midst of a stream of geologic, biologic, hydrologic and meteorologic material (Buol *et al*., 1980).

Soil is formed as a result of the interaction of some factors. The five groups of factors responsible for the kind, rate and extent of soil development are: climate, organisms, vegetation, parent material, topography and time (Figure 2). Collectively, they are called the soil forming factors. Differences in the factors of soil formation either within an ecosystem, zone or region form the basis of different soil types within an area, state or nation.

A soil profile is the vertical exposure of the horizons of an individual soil (Buol *et al.,* 1980). Hodgson (1978) explained it to mean a vertical column of soil, large enough in volume and lateral dimensions to evaluate and illustrate the soil properties at a particular place. It is a vertical exposure of a surficial portion of the earth's crust that includes all the layers that have been pedogenically altered during the period of soil formation and also deeper layers that influenced pedogenesis (Figure 3). As early as 1879 Dokuchaev and his colleagues were the first to establish the soil profile as a unit of systematic study.

The soil solum is considered as an incomplete soil profile (Figure 3). The soil solum is simply defined as the genetic soil developed by soil-building forces. It is that part of the soil profile which is influenced by plant roots. Since the primary difference between soil and geologic material is the presence of the living plant roots and deposits of organic and mineral materials originating in the rooting zone, the lower limit of the solum is taken as the lower limit of the perennial plant roots.

A.A. Amusan
Department of Soil Science, Obafemi, Awolowo University, Ife-Ife, Nigeria

CHARACTERIZING THE SOIL PROFILE

An assessment of the properties of soils and their response to management is required in agri-culture and forestry for informed decision making in rural and urban planning, for feasibility and design studies in land development projects, and for many engineering works (Dent and Young, 1981). A precise soil description using standard tech-niques and defined terminology is essential for lucid communication among soil scientists. As elsewhere in science, accurate characterization is the basis of taxonomy, and enables the transfer of ideas and concepts from one person to another (Hodgson, 1978). To classify and explain, it is necessary first to describe. Recently, there has been an increasing tendency for soil classifications to be based more firmly on detailed horizon and profile morphology. For instance, the FAO-UNESCO soil map of the World and USDA Soil Taxonomy Systems of Soil Classifications utilize differentiating characteristics that are essentially morphological: diagnostic surface horizons/epipedons, diagnostic subsur-face horizons, abrupt textural change, albic materials (L. *albus*, white), aquic conditions, redoximorphic features, lithic (Gr. *lithos*, stone) and paralithic contacts, plinthite (Gr. *plinthos*, brick), soil moisture regime and soil temperature regime among others.

FIGURE 1
Soil as a natural body

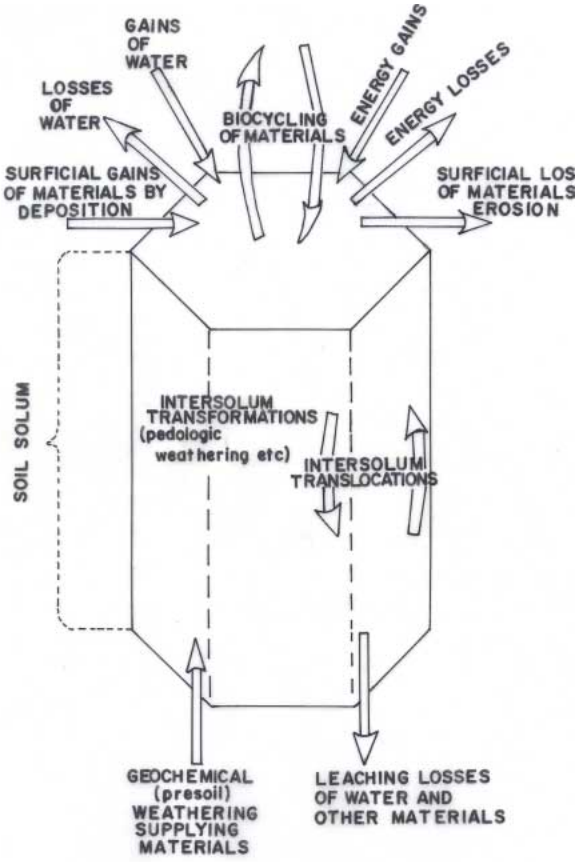
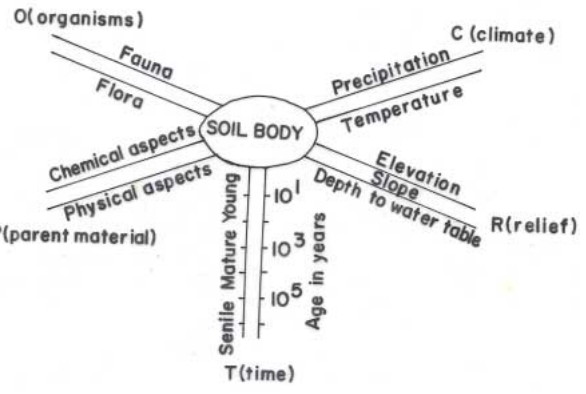


FIGURE 2
Factors of soil formation

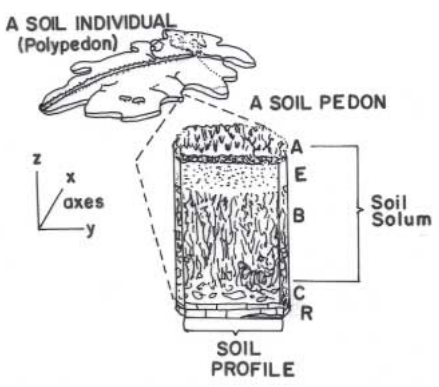


A sound description provides a basis for studies of soil formation or development. It is therefore useful, for example, in studies of the distribution of plant roots and soil fauna that may have important practical implications. For a meaningful land-use plan and manage-ment programme for sustainable use of a given soil resource, the soils and their sites need to be carefully described following the standard format, as in the guidelines for soil profile description (FAO, 1977; Soil Survey Staff, 1994)

SOIL PROFILE DESCRIPTION

As the science and art of soil description has developed, the complexity and length of descriptions has increased. Although there has been much improvement in the precision of terminology and some standardization in nomenclature, almost every national soil survey has its own system of soil description. Yet, comparison of soil description can only be greatly facilitated if, in each description, data are presented in the same order, so that the whole concept of uniformity is not lost. It is for this reason that standard outlines for soil description, which define even the order in which separate characteristics of individual horizons should be described, are given in the guidelines for soil profile description (FAO, 1977).

FIGURE 3
Soil profile showing most of the master horizons



DESCRIPTION OF INDIVIDUAL PROFILES

According to the FAO (1977) publication, the following order of presentation is proposed for description of individual soil profiles.

Information on the site:

A full soil description requires the description of the soil itself and of those environmental features of the site that have, or are likely to have, played a part in soil development. Furthermore, potential land capability and, to some extent current, land use are influenced by both site and soil factors. Site information required includes:

a. Profile number: valuable for coordination of data
b. Soil name (series, phase, or mapping index, etc.)
c. Higher category classification
d. Date of examination
e. Author(s) of description
f. Location: where possible indicate the longitude and latitude
g. Elevation (in metres)
h. Land-form:
    i. physiographic position of the site
    ii. land-form of surrounding country
    iii. microtopography (if any)
i. Slope on which profile is sited
j. Vegetation and land use
k. Climate: rainfall, temperature, evapotranspiration data, etc.

General information on the soil

a. Parent material: nature and origin of the parent material.

b. Drainage: refers to the frequency and duration of periods when the soil is free of saturation or partial saturation. For instance Class O means very poorly drained, i.e. water is removed from

the soil so slowly that the water table remains at or on the surface for a greater part of the time.

c. Moisture conditions in the soil: at the time of description.

d. Depth of groundwater table.

e. Presence of surface stones or rock outcrops: refers to large fragments or rock outcrops or near the soil surface that may limit the use of modern mechanized agricultural equipment. Gravels range from 0.2 - 7.5 cm in diameter; stones: fragments of 7.5 - 25 cm in diameter; and boulders are fragments larger than 25 cm diameter.

f. Evidence of erosion: distinguish between:

   i. Water erosion: sheet erosion, rill erosion and gully erosion
   ii. Water deposition
   iii. Wind erosion
   iv. Wind deposition.

g. Presence of salt or alkali: On the basis of conductivity measurements of saturation extracts, salinity classes are as follows:

Class 0 : Free	0-4 mmhos cm^{-2}
Class 1 : slightly affected	4-8 mmhos cm^{-2}
Class 2 : moderately affected	8-15 mmhos cm^{-2}
Class 3 : strongly affected	> 15 mmhos cm^{-2}

h. Human influence: evidence of management practices such as ploughing, irrigation, terracing, bunding, etc.

Brief general description of the profile

Two or three sentences outlining the essential characteristics.

Description of individual soil horizons

For each horizon:

a. Horizon symbol: designation of genetic horizons expresses a qualitative judgement about the kinds of changes that are believed to have taken place in a soil.

   i. For Master Horizons and Layers: the capital letters O, A, E, B, C and R are used as base symbols (see Figure 3).

   O horizons or layers: are dominated by organic material

   A horizons: mineral horizons which have formed at the surface or below an O horizon.

   E horizons: mineral horizons in which the main feature is loss of silicate clay, iron or aluminium or some combination of these, leaving a concentration of sand and silt particles (E - horizon of eluviation).

   B horizons: horizons formed below A, E or O horizon. They are characterized by (i) illuvial concentration of silicate clay, iron, aluminium, humus, carbonates, alone or in combination; (ii) residual concentration of sesquioxides.

C horizons: horizons or layers, excluding hard bedrock, which are little affected by pedogenic processes and lack the properties of O, A, E or B horizons. They are horizons of the parent material.

R layer: hard bedrock or parent rock.

ii. **Transitional horizons:**

These are horizons dominated by the properties of one master horizon but having subordinate properties of another: two capital letter symbols are used for such transitional horizons. e.g. AB, EB, BE or BC. The first of these symbols indicates that the properties of the horizon so designated dominate the transitional horizon. For instance, AB horizon has characteristics of both an overlying A horizon and an underlying B horizon, but it is more like the A than like the B.

iii. **Subordinate distinction within master horizons and layers:**

Lower-case letters are used as suffixes to designate specific kinds of master horizons and layers. Some of the suffix symbols and their meanings are as follows:

a - accumulation of highly decomposed organic material (Oa)
e - indicates organic material of intermediate decomposition
c - indicates significant accumulation of concretions or nodules
g - strong gleying, indicating either that iron has been reduced and removed during soil formation, or that saturation with stagnant water has preserved it in a reduced state
m - cementation or induration
p - tillage (plough) or other disturbance, e.g. Ap means ploughed layer
r - weathered or soft bedrock as in Cr
t - accumulation of silicate clay as in Bt horizon, i.e. argillic horizon.

For details see FAO (1977) and keys to soil taxonomy (Soil Survey Staff, 1994).

b. Depth of top and bottom of horizon (in centimetres)
c. Colour: (i) moist and (ii) dry
d. Colour mottling
e. Texture
f. Structure
g. Consistence: (i) wet; (ii) moist; and (iii) dry
h. Cutans (ped coatings)
i. Content of roots

Interpreted information on the soil

This refers to inferences the author may draw on the potential of the soil for agricultural development, which may include:

- suitability of the soil for mechanized agriculture;
- suitability of the soil for irrigation;
- susceptibility to erosion on account of slope and soil structure;
- suitability of the soil for specific crops, i.e. for specific forms of land use.

PREPARATION/EQUIPMENT FOR SITE AND SOIL PROFILE DESCRIPTION

Acquisition of basic knowledge

Before attempting soil and site description, it is important to carefully read and fully understand the appropriate manual and to know its layout well. Time taken to get familiar with the text saves time and trouble later in the field.

Use of appropriate equipment

An absent-minded, impractical or unsystematic approach never yields good descriptions and it pays to be systematically organized and to have a complete set of equipment. The equipment thought essential varies from worker to worker, depending on physical and organizational circumstances. The basic equipment which most pedologists would regard as essential for site and profile description is as follows:

- **Digging and excavating tools**: spade, shovel and digger.
- **Augers**: useful for preliminary investigations to choose the site for a profile pit, and also for borings in the bottom of the pit to investigate the substrata.
- **Knives and trowels**: These are used for marking out the horizons, picking out soil from the profile face, removing soil for inspection, and taking samples.
- **Geological hammer**: Useful when identifying rocks and stones, and can also be used to break cemented soil materials and concretions.
- **Munsell Soil Colour Book**: This is essential for recording soil colour.
- **Maps and air photographs**: These are useful for locating the profile site and for determining site features. A map case is useful for carrying and protecting them.
- **Recording equipment**: A field notebook, proformas, or cards or a portable tape recorder, for recording details of the sites and profiles, are essential. Appropriate pencils, pens and erasers are needed for note taking for marking air photographs and labelling samples particularly with a rapid drying, waterproof, felt-tipped marker.
- **Measuring tape**: The best kind of measuring tape is white, plastic-covered, rustproof, retractable, and marked in centimetres. This tape can act as a reference scale in profile photographs.
- **Magnifying lens**: A pocket lens (x10, x20) is desirable for the examination of small soil features such as clay coats, macroporosity, micro-structure and faunal remains.
- **Clinometer or Abney level:** to determine slope.
- **Sampling equipment**: This includes plastic sample bags, sample tins, labels and fasteners.

Other equipment

This is equipment which is essential in certain circumstances.

- **Acid**: Contained in tightly sealed dropper-bottle or squeezable plastic with a fine jet (wash bottle), of dilute (10%) hydrochloric acid (HCl) for testing for calcium carbonate.
- **Washbottle and water carrier:** Water is often required to moisten the soil profile surface if the soil is very dry.
- **Field compass**: Usually of the liquid, prismatic type, this is needed to locate the position of the site in heavily wooded, forested or wild terrain. Where frequent landmarks are present, a compass may not be required.

- **Altimeter**: An altimeter (aneroid barometer) is often necessary to determine altitude in hilly or mountainous terrain where maps are inadequate.
- **Photographic equipment**: A good camera is desirable for recording soil profiles, because good colour pictures complement the best and most detailed descriptions. Electronic flash equipment may be necessary for use along with the camera when working on dull days or when photographing soils in forests.
- **Axes and mattock or billhook:** These tools, such as a heavy cutting knife, may be required to clear vegetation when profiles are in dense woodland, forest or bush.
- **Colorimetric field pH test kit or portable pH meter:** for field determination of soil pH. Determinations to the nearest 0.1 of a unit are sufficiently accurate for most field purposes.

STEPS IN SOIL PROFILE SAMPLING

Most taxonomic systems suggest a complete sampling of pedons. The sampling is for detailed characterization analyses, hence the cost can be quite substantial. Therefore there is a need to be sure that the sampling is representative.

- Samples should be taken in freshly dug pits. Old pits and/or other excavations such as roadcuts should not be used.
- The soil profile pit should be 1 x 2 m across and at least 2 m deep, or to bedrock. Each sample should represent the entire cross-section of each soil horizon in the profile.
- When sampling the face of a pit, equal volumes of soil from the top to the bottom of the horizon being sampled should be taken. Do not take samples deep into the face. For instance, a sample area of 20 cm high x 10 cm wide and 20cm deep gives a volume of 4 000 cm^3. However, a sample of 20 cm high, 40 cm wide and only 5 cm deep will give a more representative sample of what had been seen and described in the face of the pit (Kimble, 1988).
- For representative surface soil sampling, a large area needs to be sampled, carefully homogenized and then subsampled for analysis.
- If there are special features of interest in a horizon, separate subsamples should be taken. For instance in a horizon with 50% red and 50% yellow, the first sample should be a mixture of both, and then two subsamples could be taken, one of each colour. As a general rule, always take samples that represent the dominant characteristic along with subsamples to characterize any major differences.
- Sampling needs to be done appropriately to resolve taxonomic questions such as in determining base saturation for Alfisols vs. Ultisols. This may require subsampling at a specific depth.
- Sampling generally starts at the bottom of the pit so as to avoid contamination of the lower samples with materials from above
- Sample handling is very important. Each sample needs to be placed in a separate bag. Plastic is preferred because samples are less easily contaminated in plastic bags. Often cloth bags are used, and this allows movement of moisture and dust between the different samples, which results in contaminated samples. Each sample bag should be identified with depth sampled, horizon number, pedon number and date sampled. Tags should be attached to the outside of the bag, made of material which will not break down when wet. Handling of samples is made much easier if there is a tag attached on the outside.

- Clods need to be taken from each horizon to determine the moisture retention at low suction levels (1/3 or 1/10 bar) and bulk density. Three clods should be taken from each horizon.

FIELD DETERMINATION OF SOIL TEXTURE, STRUCTURE AND CONSISTENCE

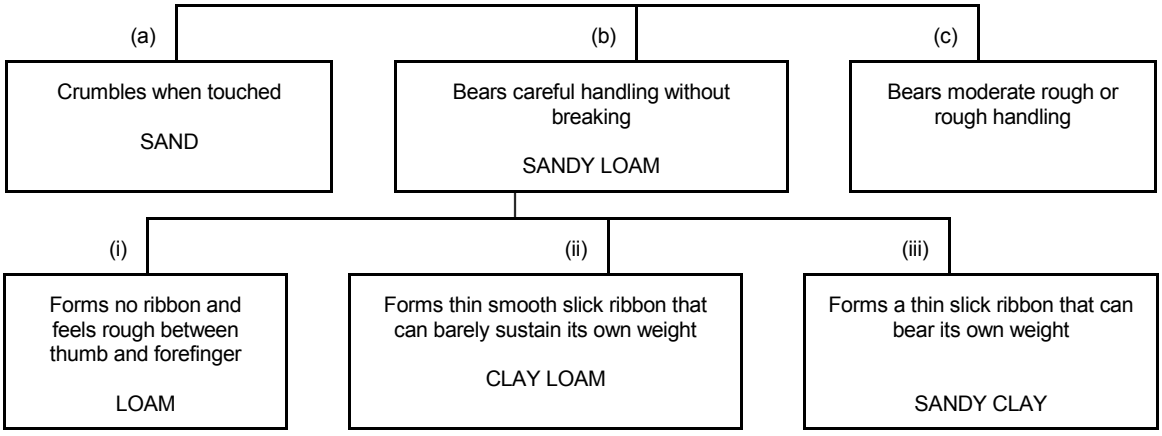
Determination of soil texture by the feel method

Principle

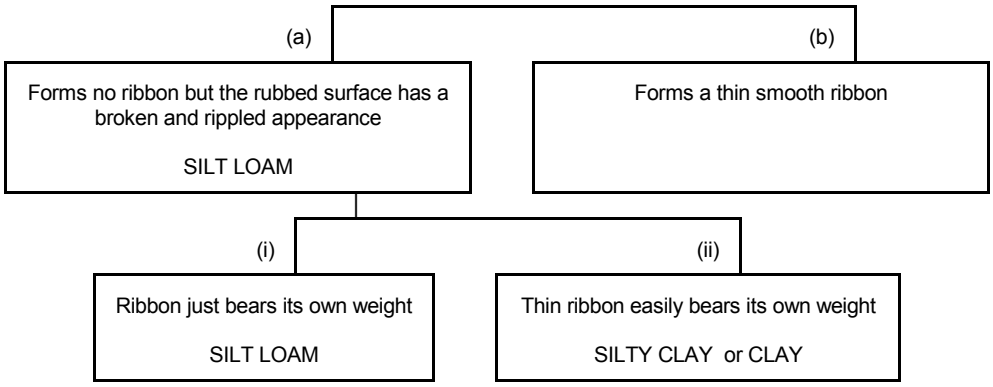
In a mineral soil, the "feel" of the soil when rubbed between the thumb and forefinger is dependent primarily on the relative amount of the soil separates. Since each separate contributes certain properties to the texture of a soil, it is important, in the feel method, to know the characteristic "feel" of each separate. Once this is done the feel method is then calibrated on soil of known particle size distribution until each required soil texture is mastered.

Procedure

1. Individual sand grain visible to eyes: Squeezed in the hand when moist, forms a cast that



2. Cannot see or feel individual sand grains. Moist soil forms a cast that bears handling when pinched



Soil structure

The relative proportion of sand, silt and clay particles in a soil constitutes soil *texture*; how the mode in which these particles are grouped together into aggregates is called soil *structure*. The primary natural soil aggregates are called peds. When no peds are observable, the soil is identified as structureless.

Soil structures are characterized into

(1) grade (according to the degree to which soils are aggregated);
(2) type (according to shape and arrangement of peds);
(3) class (according to the size of the peds).

1. *Grade*. The terms used to describe grades are structureless (single grain or massive), weak, moderate and strong.

   Structureless:

   (a) Single grain - incoherent
   (b) Massive - coherent

2. *Type*: There are six types of structure, each with its own distinctive shape and arrangement.

   Granular, approximately spherical with no accommodation of faces to surrounding peds.

   Platey, with vertical dimension smaller with regard to horizontal dimensions; faces accommodate with those of adjacent peds.

   Prismatic, without rounded caps, vertical faces well defined and with angular vertices, vertical length relatively long with respect to horizontal dimensions; faces accommodate with those of adjacent peds.

   Columnar, with rounded caps, otherwise similar to the primastic.

   Angular blocky, blocklike with all three dimensions of the same order of magnitudes, faces flattened, most vertices sharply angular; faces accommodate with those of adjacent peds.

   Subangular blocky, similar to angular blocky but both rounded and flattened faces occur with many rounded vertices.

3. *Class* of soil structure refers to the size (mm) of the aggregates or peds and is described as very fine, fine, medium, coarse and very coarse.

   Size: Size differs with kinds of structure as follows:

Size Class	Diameter of granular	Thickness of plates	Diameter of blocks	Diameter of prism
Very fine; very thin	<1	<1	<5	<10
fine or thin	1-2	1-2	5-10	10-20
medium	2-5	2-5	10-20	10-20
coarse or thick	5-10	5-10	20-50	20-50
very coarse or very thick	>10	>10	>50	>100

*Use for platey structure only. <= Less than. >= Greater than

Soil consistence

Consistence is a measure of the property of the soil to adhere or cohere or to resist deformation or rupture. This property varies with moisture content and is measured when dry, when wet, and about midway between, i.e. when moist.

Dry consistence: To evaluate, select an air-dry mass and break in hand.

0	loose,:	non-coherent.
1 -	soft:	easily crushes to powder or single grain
2 -	slightly hard:	easily broken between thumb and forefinger
3 -	hard:	can be broken in the hands without difficulty but difficult to break between thumb and forefinger
4 -	very hard:	can be broken in hands with difficulty, not breakable between thumb and forefinger
5 -	extremely hard:	cannot be broken in hands

Moist consistence: Select and attempt to crush in the hand a mass that is slightly moist (moisture content slightly midway between air-dry and field capacity).

0 -	loose:	non-coherent
1 -	very friable:	crushes under gentle pressure
2 -	friable	crushes easily under gentle to moderate pressure between thumb and forefinger
3 -	firm:	crushes under moderate pressure between thumb and forefinger but resistance is distinctly noticeable
4 -	very firm:	crushes under strong pressure, barely crushable between thumb and forefinger
5 -	extremely firm:	crushes under very strong pressure, cannot be crushed between thumb and forefinger

Wet consistence: Determined when the soil is at, or slightly above, field capacity.

(a) **Stickiness**

Stickiness is the quality of adhesion of the soil material to other objects. Stickiness is measured by pressing the wet soil between the thumb and forefinger and noting its adherence.

0 -	non-sticky:	practically no adherence when pressure is released
1 -	slightly sticky:	after pressure, soil adheres to both thumb and finger but comes off rather cleanly. Does not appreciably stretch
2 -	sticky:	after pressure, soil adheres to both thumb and finger and tends to stretch somewhat before pulling apart from either digit
3 -	very sticky:	after pressure, soil adheres strongly to both digits and is markedly stretched when they are separated

(b) **Plasticity**

Plasticity is the ability of soil to change shape continuously under the influence of applied stress and to retain the impressed shape on removal of the stress. Determination is by rolling the soil material between thumb and forefinger.

0 -	non-plastic:	no ribbon is formable

1 - slightly plastic: allows the formation of thick and medium thick ribbons
3 - very plastic: allows the formation of very thin ribbons.

Nature of boundary with horizon below

Describe the lower boundary of each horizon indicating: (a) width of boundary and (b) topography of boundary.

(a) Width of Boundary

Abrupt: boundary less than 2 cm wide
Clear: boundary 2-5 cm wide
Gradual: boundary 5 - 12 cm wide
Diffuse: boundary more than 12 cm wide

(b) Topography of Boundary

Smooth: boundary is nearly a plane surface
Wavy: pockets are wider than depths
Irregular: pockets are deeper than width
Broken: horizon is not continuous

DESCRIPTION OF SOIL PROFILE

l. **Information on the site:**

a. Profile Number:
b. Soil Name:
c. Higher Category Classification:

FAO: SOIL TAXONOMY

d. Date of Examination:
e. Describer:
f. Location:
g. Elevation:
h. Landform:
   i. Physiographic position:
   ii. Surrounding landform:
   iii. Microtopography:
i. Slope on which profile is situated:
j. Vegetation or land use:
k. Climate:

2. **General information on the soil**

a. Parent material:
b. Drainage:
c. Moisture conditions in profile:
d. Depth of groundwater:
e. Presence of surface stones and rock outcrops:
f. Evidence of erosion:
g. Presence of salt or alkali:

h. Human influence:

CONCLUSION

Until a subject of study is classified, knowledge of that subject is incomplete; so the first and fundamental duty of pedologists is the classification of soils. Though approaches may differ slightly in systematization and nomenclature, the necessity for the soil profile pit is widely recognized. For rational utilization, a soil-profile description is essential. Equipment required for soil profile pit preparation, description and sampling is briefly discussed. Profile pit sampling, sample handling and pretreatment were also highlighted. Since results are no better than the procedures used in profile description, sampling and sample pretreatments, the use of standardized procedures in all parts of the world is very important.

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Soil sampling and sample preparation

IMPORTANCE OF SOIL SAMPLING IN SOIL-TESTING PROGRAMME

Interpretation of soil-testing data for soil management recommendation is valid only if the test data are accurate. Otherwise the soil-test result and its interpretation are useless, misleading and costly to farmers who adopt recommendations based on such invalid data. A soil testing programme consists of four phases:

i. soil sampling;
ii. sample analysis (testing);
iii. soil-test data interpretation;
iv. soil management recommendation based on iii.

The care and accuracy of conducting each of the first three phases determine the validity of the fourth phase. Soil sampling is regarded as the most important step in a soil testing programme, because the error due to soil sampling confers error and invalidity on the soil analysis result even when the analysis is carefully and accurately conducted. Therefore, quality of the soil sample determines, to a great extent, whether or not the soil-test result is useful. A soil management recommendation based on soil analysis is good only if the soil sample analysed is representative of the field. The quality of the soil sample depends on the care taken in collecting, handling and preparing the sample for analysis.

WHY SAMPLE SOIL?

It is essential that a soil sample be truly representative of the field which it is supposed to represent, otherwise it will lead to erroneous conclusions and recommendations.

Soil properties vary not only from one location to another; the variability may arise from differences in parent materials, vegetation, erosion, drainage, topography management practices, etc. The magnitude of variability of a soil property determines the intensity with which the soil must be sampled to estimate to a high degree of accuracy the value of the soil property. The more heterogeneous the soils, the more intense the sampling must be in order to attain a given level of accuracy.

There are two major causes of obtaining non-representative samples: (i) contamination and (ii) inadequate sampling of a field with variable nutrient status. Contamination usually arises from carelessness, e.g. use of containers for sampling which were previously used for fertilizers, herbicides or detergent containing N, P or K; and which were not thoroughly cleaned before being used for soil sampling. Normal precautions will reduce the danger of contamination.

J.A. Adepetu
Department of Soil Science, Obafemi Awolowo University, Ile-Ife, Nigeria

The problem of non-representative samples arising from inadequate sampling is a more difficult problem. Overcoming this problem requires a thorough understanding of the nature and sources of variability in the field. This understanding allows the determination of the number of samples required to give a good representation of the total population.

SAMPLING METHODS: SAMPLING PLANS

Four different methods or plans are available for soil sampling:

i. judgement sampling,
ii. simple random sampling,
iii. stratified random sampling,
iv. systematic sampling.

A sampling plan designates which parts (specific locations) of the land are to be included in the sample. Some plans are more representative than others and some can be executed at lower cost than others. The best design is one that gives high precision (low error) at relatively low cost.

Judgement sampling

In this plan, the researcher or extension officer selects some part of the land which, in his/her judgement, is typical or representative of the field characteristics, and obtains the sample of the field from this typical part. For example the sampler may base his/her selection on differences in soil colour, and judge that some particular shades of colour are typical of soils of the site; he/she collects samples of such soils as representative of soils of the site. Also he/she may base it on plant growth pattern. The sampler or researcher has some knowledge about the soils of the field and uses this knowledge to obtain what he/she considers a representative sample. Any confidence in the results from the samples will have to rest on faith in his/her judgement, which may be good or poor.

Since sample unit selections have different (varying) but unknown probabilities, sample selections are biased. For example, in an attempt to include as many extremes as possible in the sample, the sampler may commit the error of over sampling. On the other hand, the sampler may exclude all extreme cases, thereby ending up with a non-representative sample.

Unless the researcher or extension officer is very skillful and experienced in selecting "typical" sites, this method has low precision; the selection of typical sites is difficult and time consuming; and the sampling method is inaccurate for large sample sites. However, if the sites are small and no estimate of accuracy is needed, this method is satisfactory. Generally, judgement sampling is used where soil or cropping differences are noticeable and where the focus of the survey is only a particular area of the field.

Simple random sampling

This sampling method is more precise and less subject to the bias of the sampler than the judgement sampling method. Sampling units are taken by selecting each sampling spot separately, randomly and independently of any spots previously taken. Thus each unit spot on the field has an equal chance of being selected as the sampling spot.

The detailed procedure for this sampling method is provided by Pleysier (1995) and Petersen and Calvin (1965). Although the method is very precise, it is relatively cumbersome and time consuming. For this reason the method is not used in routine soil testing programmes. It is more adaptable to research work, for sampling experimental plots.

Stratified random sampling

In this method, the field is divided into separate units (strata) based on observable differences in the field. The stratification may be based on soil types or series, land forms (slopes versus plain), soil drainage, crop growth pattern, differences in soil management history, erosion impact, etc. Each of the units is then sampled separately by random sampling. The details of the procedure for stratified random sampling are provided below.

This method has good precision as it is relatively faster and less cumbersome than the simple random sampling method. This is the method usually adopted in routine soil testing programmes. Researchers or scientists also prefer this method in experimental plots because it allows the worker to (i) make a statement about each sub-population, i.e. stratum or sampling unit, separately, and (ii) increase the accuracy of estimates over the entire field (population).

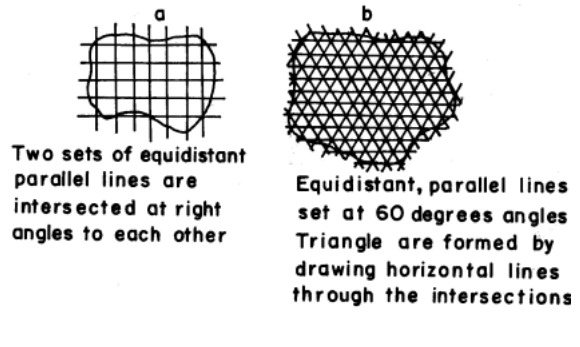
Stratified random sampling is selected for its accuracy (low error) in the sense that stratification itself is done to eliminate some of the variation from the sampling error. Since the strata are sampled separately, the differences among strata means are eliminated from the error, and only the within-stratum variation contributes to the sampling error. Although stratification increases precision (and the more the stratification the greater the increase in precision), excessive stratification for this purpose must be avoided, especially because of increased cost of sampling and analysis. Also it gets to a point where further stratification adds a very insignificant value to sampling precision. In any case, since at least two units (composites) must be sampled from each stratum to allow an estimation of the sampling error of a stratum, it becomes necessary to keep the number of strata as small as is just enough to allow satisfactory estimates of error.

Systematic sampling

This method is very simple to use, and it ensures better coverage of the population (field) than the three other methods. The basic characteristic of this method is that the selected sampling spots (units) are at regular intervals away from each other, either in one or in two dimensions, thereby forming a grid. The first sampling spot is selected at random, and the subsequent spots selected at uniform intervals.

Two examples of systematic sampling grids are shown in Figure 1.

FIGURE 1
Grid patterns for systematic sampling



Some workers have found the method to have about the same precision as simple random sampling and less precision than stratified random sampling. It is known, however, that under certain conditions, the system is inefficient; for example when there is fertility gradient on the yield or when there is a drainage or slope problem on the field. The main problem of systematic sampling is in the estimate of sampling error from the sample. Three main approaches for this purpose have been enumerated by Pleysier (1995).

PROCEDURE FOR SAMPLING FIELD SOILS FOR TESTING

Stratified random sampling is the preferred method in routine soil testing because:

i. it is simple, relatively fast, and cost-effective;
ii. it allows different parts of the field to be evaluated separately;
iii. it minimizes measurement error due to soil variability;
iv. it has relatively good precision.

The following procedure is to be adopted:

Preliminary planning

a. Sketch a map of the field to be sampled.

b. Outline on this map areas of the field which are observed to be different from other areas. These differences might be in soil types, degree of erosion, degree of slope, drainage, crop growth performance or past management. Each area (stratum) is a sampling unit (see Figure 2).

c. Obtain at **least two** composite samples from each sampling unit (stratum). Each composite sample should be from an area that is as uniform as possible. The number of composite samples depends on the size of each sampling unit (strata). The number as a fraction of the total number of samples is proportional to the size of the stratum as a fraction of the field size.

Sampling technique

a. Take a minimum of 25 and maximum of 40 cores per two-hectare field (depends on observed soil variability).

b. Take at least two composite samples per sampling unit (stratum).

c. Take a minimum of five cores per composite sample (the number depends on size of land represented by the composite sample, as well as the size of the sample container). Enough cores should be taken to represent the whole sampling area adequately.

d. If an area within a sampling unit (stratum) is quite obviously different from the rest of the stratum, but is too small to be of importance, do not sample it (i.e. ignore it). If it is large enough, take a composite sample from the area, but do not mix cores from this with cores from other areas in the stratum.

e. Avoid sampling a fertilizer band if the position of the band is apparent.

f. If possible sample when a crop, preferably a grain crop like maize, rice or wheat, is growing on the field. This enables variability in the field to be identified quite easily.

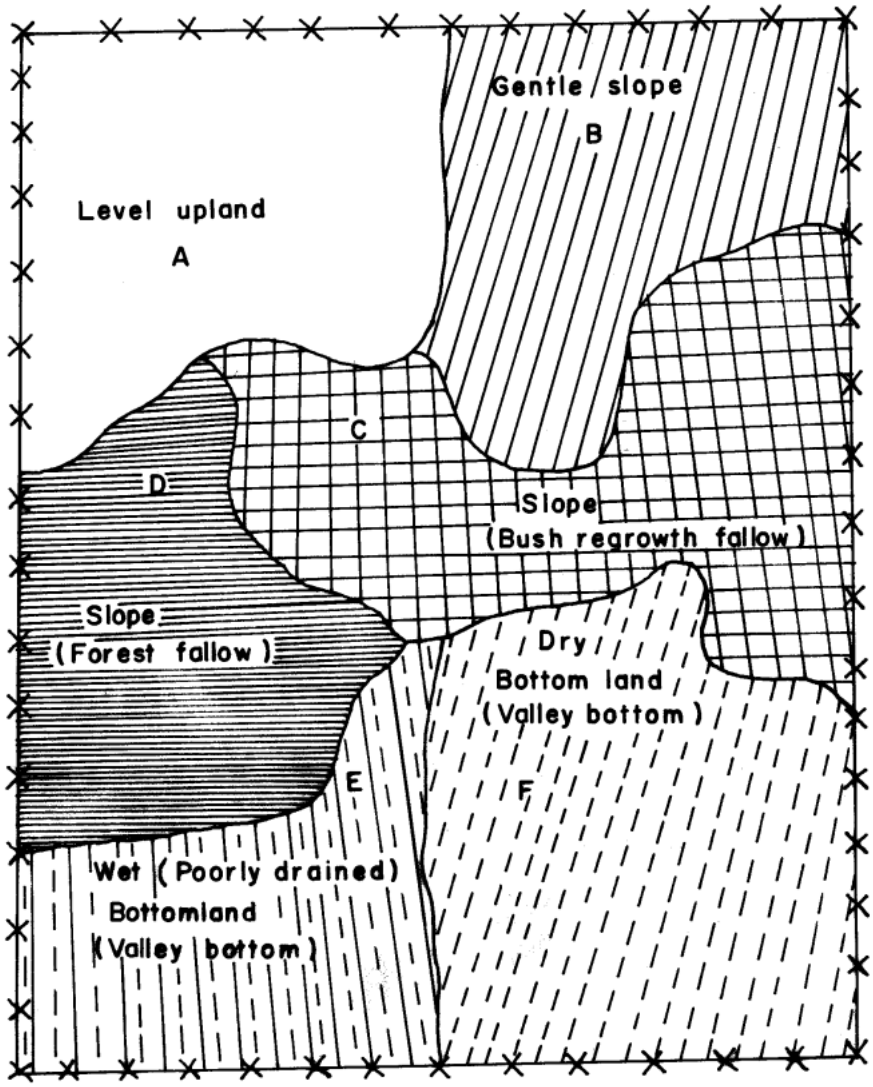
g. Record the position of each composite sample on the map.

h. Each core should be taken at the same soil depth so that core samples would be of the same soil volume. Select soil depth according to the purpose of sampling. For arable crops, sample at a depth of 0 to 15 cm. For perennial or tree crops, take deeper samples since tree crops often grow deep into the soil.

Sampling tools

Tools for soil sampling include: spade, shovel, soil-sampling tube, auger, cutlass or trowel (see Figure 3). It is preferable to use a soil sampling tube because of the ease of getting a uniform soil volume at each sampling point.

FIGURE 2
Stratification of field to sampling units



A sampling tube has a uniform dimension to the depth of sampling; hence it provides reproducible core-sample volume. An auger is less desirable than a sampling tube. A trowel, spade, cutlass or trowel can be used but it is difficult to get a small, uniform strip the size of a core taken with a tube. Tapered cores (auger) or slices (shovel, etc.) may bias the analysis results if systematic variations with depth are significant. Whichever of these tools is used, it should be rust-resistant and free of contamination at the time of use.

Sampling pattern

The sampling pattern for each composite sample should be random. The core samples are taken randomly in a zig-zag manner such that all points in the plot have an equal chance of being selected as a sampling point. One example for taking four composite samples of eight cores each from a field is shown in Figure 4. Cores should not be taken close to the field boundaries, because these areas are frequently disturbed and different from the main field.

Take soil samples at about the same time of the year, e.g. just before land preparation or before planting. This will allow for comparison of soil test data over periods of time, as there seems to be seasonal variation in soil tests for some nutrients such as P and K.

If a shovel, spade or cutlass is used instead of a sampling tube, proceed as follows:

a. dig a V-shaped hole, 15 cm deep;

b. take a 1.25 cm slice of soil sample from the smooth side of the V-shaped hole. This slice represents a core sample.

Put all core samples taken from one soil area together in a clean bucket, as a composite sample. Mix the sample thoroughly with your hand. Pour the soil sample into a clean plastic bag and tie it securely; label each bag properly for later identification.

FIGURE 3
Sampling tools include cutlass, sampling tube, shovel, hand trowel and auger

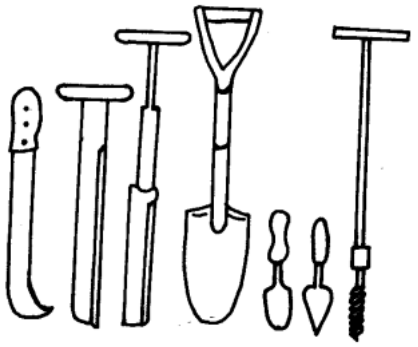
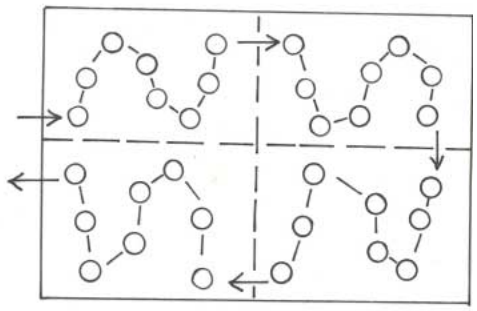


FIGURE 4
Random sampling pattern



Other related matters

a. Information should be obtained, if possible, from the farmer regarding:
   - crops to be grown in the succeeding 3-5 years (if it is a continuous cultivation system);
   - previous crops;
   - previous application of fertilizer and lime;
   - credit facilities or personal fund available to the farmer.

b. The field should be sampled for analysis again after 3-5 years.

Sample preparation

Samples collected in the field usually need to be processed ready for laboratory analysis. Processing of samples prior to analysis usually consists of drying, grinding, sieving, storage and subsampling. Mixing, sieving and subsampling a moist soil sample in the field are never satisfactory.

i. **Drying**: This is usually done so that the soil can be mixed uniformly for subsampling. The sample is usually air-dried for about four to five days in a well-ventilated room or shed. Avoid contamination from dust, gas, rain, etc. during air-drying. Do not air-dry sample in a chemical analysis laboratory where chemical fumes and salt can contaminated the sample.

ii. **Grinding**: Use a porcelain mortar and pestle to grind the sample. The grinding breaks down aggregates and mixes the sample.

iii. **Sieving**: This process removes large particles. To avoid micronutrient contamination of the sample from the sieve, do not use a sieve made of brass, copper or galvanized iron.

In gravely soils, the large particles (sieved out gravels) may make up a substantial fraction of the soil sample, even though they contribute little to the available plant nutrient content of the

sample. In this case, the fraction sieved out must be taken into consideration in interpreting the soil-test result.

iv. **Mixing and storage**: Mix sample thoroughly and then store it in a clean, closed container until ready to subsample and analyse the sample.

v. **Subsample**: Take a small, representative subsample of the sample for analysis. For research work, a weighed quantity is taken for analysis.

PRACTICAL EXERCISE

A field practical exercise will be conducted in two different fields of maize and cassava. The maize field is not ridged while the cassava field has ridges. The following will be carried out in each field:

i. Sketch a rough diagram of the farm.
ii. Divide the farm into separate sampling strata; outline this on the map.
iii. Separate each stratum into composite sampling units.
iv. Take composite samples of the farm with a sampling tube at 0-15 cm depth.
v. Collect and mix sample in plastic bucket, and store in a polythene bag.
vi. Practice sampling with:
    shovel or spade;
    auger and sampling tube.
vii. Air-dry samples in a preparation room.
viii. Prepare the samples for analysis.

QUESTIONS

i. What major factors did you consider in stratifying:
    a. the maize farm
    b. the cassava farm.
ii. How was the 0-15 cm soil layer obtained in the ridged farm.
iii. What difficulty had to be overcome in order to obtain a good, reliable sample with:
    a. shovel;
    b. cutlass.

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Plant sampling and sample preparation

Plant analysis is considered and primarily used as a diagnostic tool. There are two main applications of plant analysis:

- to confirm a suspected nutrient element deficiency when visual symptoms are present, before supplying a corrective treatment;
- to monitor the plant nutrient status in order to determine if the concentration of each tested nutrient is sufficient for optimum crop yield.

METHOD OF SAMPLING

The validity and usefulness of any chemical plant analysis are dependent on how representative the plant tissue sample is. A non-representative sample can result in incorrect diagnosis, leading to corrective treatments which are costly yet ineffective.

Obtaining a representative plant sample is essential for plant analysis; nevertheless, the researcher or scientist should be aware that this is a complex task requiring expert knowledge. Suggestions for gathering representative samples should be followed closely. They include:

Location: It is recommended that plant samples be taken from mature leaves located just below the growing tip of the main branches and stems. Their nutrient composition is stable compared to that of younger leaves which can undergo rapid change.

Maturity: The composition of a plant's nutrient elements can vary considerably, depending on plant maturity. Sampling should occur when the relationship between plant nutrient concentrations and yield, and the plant's physical appearance is at its best. The best time for sampling is just before the plant begins its reproductive growth. When plants begin setting and developing fruits or seeds, the nutrient concentration of the vegetative portions changes considerably. Particularly in the case of grain crops, sampling after pollination is not recommended.

Physical and chemical condition: Plants subjected to stress over a long period of time can develop nutrient concentrations that are often misleading. One way of avoiding this is to take samples when the plant has been initially affected. Sampling is not recommended if the plant is covered with soil or dust, damaged by insects, mechanically injured or diseased. Dead plant tissue should not be included in a sample either. In addition, sampling is not recommended if plants are under stress caused by moisture or temperature changes. Time of sampling can also be important when plants are under a nutrient stress.

J.I. Uponi
Analytical Services Laboratory, IITA, Ibadan, Nigeria

Table 1 shows recommended plant parts and growth stages at which to sample plants, as used in Nigeria.

SAMPLE PREPARATION

Once plant samples have been obtained, they must undergo four preparatory steps before any analysis can be carried out on them:

1. **Cleaning of Material:** It is not uncommon to find plant samples, which have been recently collected, covered with a thin film of dust. It is important that this be removed, since its presence can affect the samples' concentrations of Fe and Mg. Dust is difficult to remove by mechanical wiping or brushing only: therefore, washing the tissues in a 0.1 - 0.3% solution of detergent, followed by a rinse in pure water, is recommended. This washing should be done quickly in order to prevent any leaching of nutrients such as Na, K or Ca.
2. **Drying**: Following washing, plant tissue samples should be dried as rapidly as possible in order to minimize any chemical or biological changes. Drying at 65^{o}C is considered adequate to stop enzymatic action. The sample is placed in a hot air oven and dried until the weight is constant. This may require from 24 to 48 hours. After drying, the sample is ready to be ground.
3. **Grinding**: This is beneficial for two reasons: it allows the sample to be manipulated with greater ease and, even more important, it ensures greater uniformity in terms of composition. When selecting a mill, it is important to choose one that minimizes the possibility of contamination. This is especially critical when analysis is being performed to determine the presence of any micronutrients. Equipment having grinding surfaces of either steel or stainless steel is recommended. Grinding equipment available includes the hammer mill, wiley mill, jar mill with flint, porcelain with mullite balls, agate or glass mortar and pestle.
4. **Storage**: Under humid tropical conditions, samples that have been poorly dried are frequently in danger of becoming mouldy. Any samples that have to be stored for a prolonged period should be kept in a refrigerator, preferably at temperatures of -5^{o}C or lower.

TABLE 1
Recommended plant parts and growth stage at which to sample

Stage of Growth	Plant Part to Sample	Number of Plants to Sample
Maize (1) Seedling stage (less than 12 inches)	All the above ground portion	20 - 30
or (2) Prior to tasselling	The entire leaf fully developed below the whorl	15 - 25
or (3) From tasselling and shooting to silking	The entire leaf at the ear node (or immediately above or below it)	15 - 25
Soybean or Other Beans (1) Seeding stage (less than 12 inches)	All the above ground portion	20 - 30
or (2) Prior to or during initial flowering Sampling after pods begin to set is not recommended	Two or three fully developed leaves at the top of the plant	20 - 30
Small Grains (including Rice) (1) Seedlings stage (less than 12 inches) or	All the above ground portion	50 - 100
(2) Prior to heading Sampling after heading is not recommended	The 4 uppermost leaves	
Hay, Pasture, or Forage Grasses Prior to seed head emergence or at the optimum stage for best quality forage	The 4 uppermost leaf blades	40 - 50
Sorghum-millet Prior to or at heading	Second leaf from top of the plant	15 - 25
Sugar cane Up to 4 months old	Third or fourth fully developed leaf from the top	15 - 25
Groundnuts Prior to or at bloom stage	Mature leaves from both the main stem and either cotyledon lateral branch	40 - 50
Cotton Prior to or at first bloom or when first squares appear	Youngest fully mature leaves on main steam	30 - 40
Lemon, Lime Mid-season	Mature leaves from last flush of growth on non-fruiting terminals	20 - 30
Orange Mid-season	Spring cycle leaves, 4 to 7 months old from non-bearing terminals	20 - 30
Trees Current year's growth	Fully developed leaves	30 - 100
Shrubs Current year's growth	Fully developed leaves	30 - 100

Simple field test kits

PRINCIPLES OF OPERATION OF TEST KITS

Test kits are tools used for rapid, on-the-spot, rough (approximate) determination of chemical properties of water, soils and crops in the field. They are semi-quantitative devices in which the more elaborate laboratory analytical procedures of water soil and plant chemical analyses are simplified for rapid use in the field. Test kits are simple, quick and convenient to use, which make them very desirable as a means of diagnosing nutrient problems in certain circumstances.

The basis for rapid chemical testing is the quick calorimetric tests available for the levels of nitrate, phosphorus and potassium in water, soil extracts and in the sap of fresh plant tissue. The colour change is compared with calibrated reference colour charts or strips by observing with the naked eye. The colour hue on the colour chart that corresponds to or approximates the colour-change of the sample indicates the range of nutrient concentration in the sample, i.e. very low, low, medium or high nutrient levels in soil or plant tissue. In some brands of test kits, the ranges of nutrient concentrations designated as very low, low, medium and high are indicated numerically on the colour chart. Some brands, however, do not give such an indication. In any case very low, low, medium and high nutrient levels are interpreted as extremely deficient, deficient, fairly adequate and sufficient soil nutrient or plant nutritional status respectively.

To remove the subjectivity of test-kit visual colour readings and thereby improve reproducibility and accuracy, a reflectometer has recently been developed by MERCK Ltd. of the UK. This device replaces visual colour evaluation with quantitative assessment of colour change. The method combines the convenience of test-strip analysis with the precision of quantitative measurement. It is now available for pH, macronutrients, micronutrients and some heavy metals in soils and plants, and for various chemical properties of water.

Field test kits do not replace good laboratory analysis of water, soil and plant tissue since they are less accurate. However, their use becomes desirable under certain situations.

USES OF FIELD TEST KITS

i. *In lieu of a soil testing lab*: Although a test kit is not an alternative to a soil testing laboratory, it can fill this gap where such a laboratory is not available or not accessible to farmers. The kit can be used as a rough guide until a soil testing laboratory is available, functional and accessible in the area. A soil management recommendation arising from test kit results is superior to a blanket ("bind") recommendation.

ii. *To survey large areas quickly*: A very large area, e.g. a country or a region, can be surveyed for its soil nutrient status within a relatively short period.

J.A. Adepetu
Department of Soil Science, Obafemi Awolowo University, Ile-Ife, Nigeria

For example, selected maizefields across the area can be subjected to quick soil and maize plant tissue tests using several teams of surveyors. Through this exercise, valuable information will be obtained about individual maizefields; in addition the overall picture of the soil nutrient status of the entire area will emerge. This gives the agricultural worker or the farmer an idea of the fertility need of the area.

iii. *To verify suspected fertility symptoms*: When an apparent deficiency symptom appears on a plant in the field, a soil and/or plant-tissue test with a test kit can be made to ascertain quickly whether or not it is the suspected deficiency.

iv. *To call attention to the need for laboratory soil tests*: Test kits can be used quickly to determine whether a plant nutrient is deficient (very low to medium range), or adequate (medium to high range), in soil or plant tissue. If found deficient, the farmer is then advised to get the soil tested in a soil testing laboratory for accurate soil test values and soil management recommendations.

v. *To supplement routine soil testing*: A test kit can be used as a monitoring tool to check if a fertilizer recommendation is adequate and appropriate for a particular field. Extension officers can follow up on the recommendations with field tests. If the recommended level does not give the expected (desired) plant growth and plant-tissue nutrient status, it could be because the farmer did not follow the recommendation or that the recommendation was based on an inaccurate soil-test result from the soil testing laboratory. Another soil sampling and laboratory test may be suggested following the test-kit evaluation.

vi. *To follow nutrient uptake in research fields*: Treatment plots of field calibration studies can be checked to monitor if and when the crops are taking up nutrients. This information can enhance the understanding and balanced interpretation of results of the studies. For example it can indicate the most active nutrient-uptake stage of crop growth when it is important to ensure fertilizer nutrient availability at the root surface.

ADVANTAGES OF FIELD TESTING KITS

Some of the merits of a test kit are that:

i. It is simple, quick and convenient to use. A test for N, P and K can be completed in less than five minutes once the sample has been collected. It is convenient because the kit is contained in a small box (pocket laboratory) which can easily be carried to even the most remote rural field locations.

ii. It is much cheaper than laboratory testing facilities; therefore it is available for the use of poor farmers.

iii. The test can be carried out on the spot where the problem exists and the facts and conditions related to the problem are fresh in mind. In-the-field testing provides the kit user with immediate answers to nutrient problems.

iv. It cuts down on the cost of time, transportation and materials that may be needed to carry soil samples to the laboratory for analysis.

v. It provides a much better guide than blanket fertilizer recommendations that may be adopted in the absence of a functional and accessible soil testing laboratory. It can be used as a rough guide until soil testing laboratory facilities are available.

vi. It enables the literate and enlightened farmers to conduct their own on-the-spot analysis and interpretation of the test result without the assistance of an official extension agent. This is very important in most developing countries where the ratio of extension worker to farmer population is very low.

LIMITATIONS OF FIELD TEST KITS

The following limitations of field test kits must be borne in mind when using the kits and interpreting the test results.

i. The results obtained are less accurate than laboratory test results because they are deduced by visual colour observations. The results will therefore be influenced by the sharpness of the eye (visibility) of individuals conducting the test. The recent development of reflectometery (see above) for colour strip analysis has, however, removed the subjectivity of visual colour evaluation in the brands of test kits manufactured by MERCK Ltd. of UK. Other brands of kits produce only semi-quantitative results, and provide only a rough guide to solving nutritional problems.

ii. Trace and secondary elements are not considered in most brands of test kits, yet these can be very important to consider under certain condition. For example in Nigerian soils, Mg deficiency is a problem in acid forest soils, while S, B, and Zn are problems in some savannah soils.

iii. Guidelines for interpretation of test results in some brands do not state the nutrient quantities represented by qualitative (descriptive) statements of levels such as "low fertility" or "high fertility". Yet these nutrient status statements were based on field calibration of soils in temperate climatic regions. For example the BDH test kit derived its interpretation from calibration of British soils, and using British critical-soil-test standards. In comparison low levels of P and K for British soils, 10 ppm of P and 70-140 ppm of K, are adequate levels for grain crops and most other crops in Nigerian soils. Adjustment of the interpretative guideline can be effected if the quantitative nutrient ranges (numerical values) are indicated on the colour charts. Ultimately, new colour charts may have to be developed on the basis of field calibrations under local conditions.

iv. Crops that are considered on most kits are mainly temperate crops; most tropical grain and tuber crops are not considered. This will not be a problem in those Tropical countries where critical test-value standards and soil fertility-class values have been established for most crops, especially if the colour-charts indicate the nutrient concentration ranges of soil fertility classes.

v. Phosphate reagents of most test kits go bad a few months after preparation. Yet it takes quite some time for kits to arrive after ordering from foreign countries. Besides, most kits can do only 50 soil samples. Refills have to be continually ordered and this means that the user must depend on, and constantly be in contact with the manufacturer abroad.

vi. Mixing and subsampling moist soil in the field can hardly achieve satisfactory representative sampling. It is even more difficult with very clayey soils.

SOIL SAMPLING AND SAMPLE PREPARATION FOR FIELD TESTING

Soil sampling for field testing follows the same procedure as sampling for laboratory testing (see section on Soil sampling). Accurate, representative sampling is as essential here as sampling for a regular routine soil testing programme.

Sample preparation for field tests requires more patience and thoroughness on the field than is normally required in a regular routine soil testing programme. Since the soil sample will not undergo the process of drying, grinding and sieving, which engender further mixing of sample, thorough mixing of the freshly collected sample is imperative. A clean plastic bucket is used to collect the composite sample that is then thoroughly mixed by hand before subsampling for field testing. As stated earlier, satisfactory mixing of undried fresh soil samples is difficult; but it is possible if carefully done, especially when one realizes the implications of testing non-representative subsamples after careful representative sampling of the field. A part of the fresh

soil sample is taken to laboratory to determine water loss on drying i.e. moisture content on an air-dried basis. This may be used to correct the field-test results to make them comparable to both laboratory analysis and other field-test values.

PLANT SAMPLING AND PLANT SAMPLE PREPARATION

The process of obtaining representative plant samples for analysis is the same here as sampling for laboratory testing. In field testing however, a sample of each plant selected for sampling will be tested separately; interpretation of field test results is based on the frequency of test values. This is quite different from a routine plant tissue testing programme where a single "composite" plant sample is obtained for analysis from each field or sampling unit.

In general, two factors are important to consider in plant sampling: the stage of plant growth to sample must be specified and standardized for each crop type in the country; and plant part to sample must also be specific and standardized for the country.

The sampling procedure and plant growth stage at which sampling should be done in some tropical crops have been presented in the section on plant sampling.

For quick field tests, leaf petiole, leaf midrib, plant node or internode have been sampled for various crops. The required part is usually specified in the test-kit literature. Sample preparation may involve crushing or cutting the petiole end to obtain plant juice, e.g. in cotton, or slicing the plant stem between two nodes to expose the internal tissue of the plant, e.g. in maize. The sample preparation procedure is also often provided in the test-kit literature.

TEST KIT PRECAUTIONS

i. Tobacco ashes and smoke are extremely high in K, and will ruin any K test.
ii. Saliva and sweat are high in P, and must be prevented from getting into the sample or test-kit reagents.
iii. The potassium test reads too low if the reagents are very hot when used (e.g. if left in the sun for long), or if the soil sample is wet when run.
iv. Phosphorus reagents usually do not keep too long, as they go bad and become useless after some months. Thus new reagents must be ordered or prepared periodically.

PRACTICAL EXERCISE

Field exercises to practice in a maizefield:

i. Soil sampling and sample preparation for field testing.
ii. Maize plant sampling and preparation for field testing.
iii. Use of different brands of soil-test kits for soil and plant testing.
iv. Interpretation of test-kit analysis results.

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Field test for cation exchange capacity, total acidity, base saturation and pH

Cation exchange capacity (CEC) is a very important soil characteristic because it affects soil fertility and productivity. It is directly related to the amount and type of clay as well as the organic matter content of the soil. The CEC measures both basic cations (base saturation) and acidic cations (acidity) of the soil and it is usually affected by the soil pH.

This section will focus on the importance of these properties in soil management: measurement of CEC, acidity, base saturation, organic carbon and pH in the field as well as interpretation of results for management purposes.

CATION EXCHANGE CAPACITY

Cation exchange capacity is a measure of the quantity of readily exchangeable cations neutralizing the negative charge in the soil.

- The cation exchange sites hold Ca^{2+}, Mg^{2+}, K^{+}, Na^{+} and $NH4^{+}$ ions that are available to plant roots. As they are adsorbed, their losses by leaching are also reduced.
- Exchange sites adsorb many metals like Cd^{2+}, Pb^{2+} from percolating water, thereby cleansing the water that drains into groundwater or surface water.
- Cation exchange reaction is also important in causing and correcting soil acidity and basicity.

SOURCES OF NEGATIVE CHARGE

The following are the main sources of negative charge in soils:

- isomorphous substitution within the structures of layer silicate minerals;
- broken bonds at mineral edges and external surfaces;
- dissociation of acidic functional groups in organic compounds.

The first of these types of surface charge is a permanent charge, while others are variable. The variable charge varies in magnitude depending on the following:

* pH value; hence pH-dependent charge;
* valence of the counter ion;
* electrolyte composition;
* dielectric constant of the medium.

Funke Epebinu
Analytical Services Laboratory, IITA, Ibadan, Nigeria

Most soils have a mixture of permanent and variable charges. Since the cations are retained at the soil surface mainly through electrostatic attraction, their extraction from the soils will be dependent on the surface charge properties.

FACTORS AFFECTING EXTRACTION OF CATIONS

Many factors affect the extraction of cations from soils; these include: complexation, fixation (e.g. K), pH, ionic strength, valency (polyvalent versus monovalent cations), dielectric constant, effect of cation affinity/selectivity, charge density (function of surface charge and surface area).

The ideal extraction solution must have the following characteristics:

- unbuffered, i.e. it will extract cations at any soil pH. This is important particularly in soils with pH dependent charges;
- ionic strength or concentration of soil solution; generally low in ionic strength;
- can extract the plant available cations;
- extraction and measurement procedure should be fast, simple and cheap;
- universal (extract as many nutrients as possible simultaneously).

CONVENTIONAL METHODS FOR DETERMINING CEC

Most common methods for determining CEC may be categorized as one of the following:

- summation method;
- direct displacement method;
- displacement after washing method;
- radioactive tracer method

SOURCES OF ERROR IN CEC MEASUREMENT

- Exchange sites may not be completely saturated with the saturation cation because of competition for adsorption sites by other cations or because the saturating cations replacing power is insufficient to replace the more strongly adsorbed cations.
- *In the washing step;*
    - the adsorbed cation may be removed by hydrolysis and replaced by the hydrogen ion or other cations brought into solution by the dissolution of soluble salts;
    - cation exchangers may be lost during decanting;
    - some of the original saturating solution may be retained if the washing is incomplete.
- *In the replacement step;*
    - the adsorbed cation may be trapped between interlayers of clay particles;
    - non-exchangeable cations may be extracted from minerals by the replacing solution.

In general, the errors can be reduced by using a method of CEC determination that employs reagents of similar concentration and pH to those of the soil to be analysed. Also the error will be minimized if the displacing cation in the extracting solution has a much higher affinity for the soil exchange sites than the cations to be extracted; only then can there be complete extraction by a dilute extracting solution.

THE SILVER-THIOUREA COMPLEX METHOD OF CEC DETERMINATION

The silver-thiourea (AgTU) complex has been studied and used as an extractant for some time (Pleysier and Cremer, 1975; Pleysier and Juo, 1980; Searle, 1986) on different types of soils.

$$Ag(+) \text{----}[S = C - (NH_2)_2]n \qquad \text{where } n = 1, 2, 3, \text{ or } 4$$

The complex behaves as a large cation with one positive charge. The high polarizability of this complex partially explains its very high affinity to exchange cation from the negative surface charge. On the surface of clay minerals, this complex is much stronger (about 1000 times) than in solution and the free energy of exchange of Na and other cations in soil by the AgTU complex is about 5 KCal/equivalent at 25°C.

This exchange reaction can be written as:

$$\underset{\text{(extractant)}}{\text{(Ca, Mg, K, Na, Al) - Soil + AgTU(+)}} \text{ ----> } \underset{\text{(extract)}}{\text{AgTU - soil + Ca(2+), Mg(2+), K(+),Na(+),Al(3+)}}$$

The unbuffered solution has a pH value of around 6. All the exchangeable cations (basic and acidic) are displaced by a small amount of AgTU. Thus, a dilute solution of AgTU can be used to extract all the exchangeable cations and saturate the soil with AgTU(+).

The AgTU method is simple, rapid and convenient. It allows for a one-step extraction which ensures complete exchange because of the high affinity of the complex cation (AgTU) for negatively charged colloid surfaces, mineral and organic alike. This method measures the effective CEC, i.e. ECEC.

The AgTU CEC is determined by equilibrating the soil with a solution of AgTU, measuring the amount of Ag (as AgTU) in the equilibrium extract, and calculating the amount of Ag adsorbed by difference.

Preparation of AgTU complex

$AgNO_3$ solution 0.04M; Dissolved 3.4 g $AgNO_3$ in 500 ml of distilled water.

Thiourea 0.2M; Dissolve 15 g of thiourea in one litre of distilled water.

Silver-thiourea solution: 0.01 M AgTU, 0.1 MTU

- To 1 litre thiourea 0.2 M solution, add 500 ml of distilled water.
- Slowly add 500 ml of $AgNO_3$ 0.04 M under strong stirring.

The $AgNO_3$ is best poured to the TU with a funnel with a long stem so that the $AgNO_3$ does not pour along the wall of the flask.

NOTE: AgTU is not stable at pH >8

Measurement of Ag

Ag is usually measured by an atomic absorption spectrophotometer or with a radio isotope and scintillation counter in advanced laboratories. These require calibration and cannot be quickly carried out in the field. Also they are very expensive and most laboratories in developing countries cannot afford such instruments.

Another method for measuring Ag is by titration with chloride. However, this is not suitable for the AgTU complex as TU dissolves precipitates of AgCl. This led to the development of the clay suspension stability end point titration method (CSSET) for measuring equilibrium Ag in AgTU extract (Pleysier *et al*., 1986).

Silver measurement by CSSET

Silver has been found to be capable of flocculating clay suspension to some extent. Although other elements like Ca, Mg, Cu, Zn, etc. do the same, Ag gives large rapidly sedimenting flocs when AgTU is added to a stirred clay suspension. This flocculation with AgTU continues until all the clay is flocculated, leaving a clear supernatant when stirring is stopped. The critical amount of AgTU necessary for complete flocculation coincides almost exactly with the CEC of the clay.

The titration can be performed in two ways. The first is to titrate a given amount of a stable clay suspension with the unknown AgTU soil extract. The end point is reached when all the clay is flocculated and the supernatant has become clear.

In the second method of titration, a given volume of the unknown AgTU extract is titrated with the clay suspension. At the end point the supernatant changes from clear to turbid because all the AgTU has been adsorbed and any excess suspension added remains dispersed, causing a turbid supernatant. For both titrations, at the end point the same amount of clay will always have adsorbed the same amount of AgTU because the CEC of the clay is constant at a given pH. So when clay is titrated with known Ag concentration in AgTU extractant and then with unknown Ag concentration in AgTU soil extract, the unknown can easily be calculated.

The best flocculation by AgTU is obtained with smectite clays. These clays give large flocs which settle fast upon addition of AgTU and allow easy detection of the end point. Any smectite clay powder which disperses in distilled water and remains dispersed for a few hours can be used.

Interferences with the CSSET

As mentioned before, polyvalent cations such as Al^{3+}, Ca^{2+}, and Mg^{2+} also have a flocculating effect on a stable clay suspension. Since these cations are present in the soil extract used to titrate the clay suspension, they will interfere in the determination of the end point.

In the first instance, *addition-of-AgTU-to-clay* procedure will give an end point that is reached too soon because part of the clay particles will be flocculated by the polyvalent cations instead of by AgTU. As a result of this interference, the calculated CEC will be underestimated. On the other hand, the *clay suspension-to-soil-extract* titration procedure will give an end point that is reached too late because the polyvalent cations in the soil extract will delay the end point; this will produce an overestimation of the CEC.

The magnitude of this interference will be different for different soils. Highest interference is found with extracts from very acid soils (high content of Al^{3+} in soil extract) and from calcareous soils (high content of Ca^{2+} in extract).

Elimination of interference

The interference from polyvalent cations in the soil extract can be eliminated by adding excess di-Na-EDTA to the clay suspension. The EDTA will form a strong complex with Al, Ca, Mg. The overall charge of these complexes will be lower than the charge of the uncomplexed cations and will become zero or negative. These complexed cations will therefore no longer have a flocculating effect on the 'stable' clay suspension.

Flocculation of the stable clay suspension in the presence of an excess EDTA is therefore due only to the adsorption of the AgTU cation and the correct end point will be obtained. The Ag cation forms a much stronger complex with TU than with EDTA and it is not affected by

the presence of EDTA. The polyvalent cations in the soil extract (Al,Ca,Mg) on the other hand form a much stronger complex with EDTA than with TU and are only complexed by the EDTA ligand.

Preparation of the clay suspension

The clay suspension is prepared as follows:

i. To prepare a 0.5% clay suspension, weigh 5 g of the clay powder into a one litre volumetric flask.

ii. Add 11.2 g of di-Na-EDTA salt and make up to one litre with a magnetic stirrer until the clay is completely dispersed.

Procedure for measuring AgTU-CEC and exchangeable cations in the field

The procedure for measuring CEC, exchangeable cations and total acidity *in situ* using the AgTU method is as follows:

1. Sample a given volume of soil. Sampling can be effected by two methods:

(a) Use of rings of known volume to take the soil undisturbed. The disadvantage is that many samples have to be taken and analysed to have a representative result. Also, the depth of sampling at a time cannot represent the effective rooting depth of crops. However, since the soil is not disturbed, the result can easily be expressed on a weight basis if the bulk density is known.

(b) Use an auger or other sampling tools to sample from different points within the sampling unit. Mix the soil together and then use a calibrated scoop of known volume to take soil for analysis. This is more representative than the first method; the only disadvantage is that the soil is disturbed.

2. To this volume of soil, add 30 ml of the AgTU reagent in a centrifuge tube. Close the tube and shake the content by hand five times, for one minute each time, with five minute intervals.

3. Filter the suspension using Whatman No. 2 filter paper and collect between 5 and 10 ml of filtrate in a dropper bottle with one handed flip-top dispensing which allows reliable and repeatable dispersing of solutions in 50 microlitre drop size.

4. In a glass test tube, dispense a given number of drops (e.g. 40) from a dropper bottle of the clay suspension and titrate with the AgTU extract. Record the number of drops dispensed from the dropper bottle. The end point is reached when the supernatant has become clear.

Calculations

The volume of soil must be calculated from the diameter and length of the measuring ring. For example assume a ring of the following dimensions:

Diameter = 10 mm = 1 cm r = 0.5 cm
Height = 20 mm = 2 cm
Volume of the ring = $\pi r^2 h$
= 3.142 X $(0.5\ cm)^2$ X 2 cm
= 1.57 cm^3

The CEC is obtained as follows:

$$Ds \times 0.01 = De \times Me$$

where Ds = number of drops of extractant (0.01M Ag) used to reach the end point
De = number of drops of extract used to reach the end point
Me = unknown molarity of AgTU in the extract

Therefore: $Me = \frac{Ds \times 0.01}{De}$

The Ag adsorbed, which is a measure of CEC, is then obtained from: Ag added (30 ml x 0.01 M) - Ag in extract

i.e. CEC meq/ml = $\frac{0.3 - (30 \times Me)}{\text{wt or vol of soil}}$ (wt = weight; vol = volume)

By expressing the CEC per unit of volume instead of weight, the need for a weighing balance is avoided. If bulk density is known, results can be calculated on a weight basis.

It is worth mentioning that silver-thiourea also extracts Ca, Mg, K, Na and Al+H.

Note: At lower CEC values, so little Ag is withdrawn from solution that the procedure becomes too insensitive. At higher values, more than half of the Ag originally present is withdrawn whereby the non-proportionality adsorption range is entered. Therefore, the weight or volume of sample and volume of extractant used must be adjusted such that the amount adsorbed and the amount remaining in solution are almost proportional.

EXCHANGEABLE ACIDITY AND % BASE SATURATION (BS)

The exchange acidity may be defined as the acidity due to exchangeable hydrogen and aluminium ions.

Titrate H and Al ions in the extract as follows:

- Dispense 50 drops (2.5 ml) or more of AgTU extract into the glass test tube and add five drops of phenolphthalein
- Titrate with NaOH (0.01 M) from a dropper bottle till the solution turns pink

* Each drop from the dropper bottle is 50 µl.

Calculation

Total Acidity (meq/ml-soil) = $\frac{\text{(Vol of titrant for soil - vol of titrant for blank) x 0.01m x12}}{\text{Vol of soil}}$

Note: 12 is a factor from 30 ml extractant/2.5 ml extact used for titration.

$\%BS = \frac{(CEC - Acidity)}{CEC} \times 100$

ESTIMATION OF ORGANIC CARBON FROM CEC

It has been shown by several workers that there is an increase or decrease in CEC as the pH increases or decreases particularly when the pH is adjusted at the time of CEC measurement. The increase in CEC with pH starting from pH 5 has been attributed to the organic matter content. Previous experiments conducted by the author revealed that the slope of the CEC/pH curve is directly proportional to the organic carbon content of the soil. It is possible, therefore, to measure CEC at two pH levels, for example 4 and 7 with buffered AgTU in the field, and from the difference, estimate the organic carbon content. However, the relationship between organic carbon and slope of CEC/pH curve needs to be established for the particular location (soil) so as to obtain a factor for estimating organic carbon from CEC measurement. It must be noted that this relationship may not hold for soils with high 2:1 layer silicate minerals.

SOIL PH

Soil pH is the negative logarithm of the active hydrogen ion (H^+) concentration in solution.

The soil pH provides various clues about other soil properties. Whether a soil is acidic, neutral or basic has much to do with the solubility of various minerals and the relative bonding of ions to exchange sites. Most nutrient elements are available in the pH range 5.5 to 6.5. Other pH ranges that are particularly informative are :

pH <4.0 -- presence of free acids; toxicity of micronutrients
pH <5.5 -- likely occurence of exchangeable Al
pH 7.8 - 8.2 -- presence of $CaCO_3$.

Acidity can also influence plant growth by the effect on activity of soil microorganisms.

Measurement of pH in the field

This could be by colorimetric or electrometric method. Here the electrometric method is described. The principle is the use of a H^+ sensor attached to a suitable meter which displays the pH. A ***CAMLAB pH-Boy*** can be used for this purpose in the field. This uses a semi-conductor electrode. It has a digital display unit, is able to measure between pH 2.0 and pH 12.0 and has a wide range of operating temperatures of liquid samples (5 - 400C).

Procedure

- Make a 1:1 soil : water mixture and shake for some time.
- Wash the pH sensor well with tap water and blot off residual water.
- Place only one drop of the standard solution supplied in the sensor well.
- Push the CAL 1 SWITCH for at least 0.2 seconds to start automatic calibration. The "CAL" mark on the display will blink.
- When the "CAL" mark on the display disappears, calibration is complete.
- Wash the pH sensor well with tap water and blot off residual water.
- Place a drop of the sample to be measured in the sensor well or immerse the probe in the sample liquid (do not immerse the probe beyond the marked immersion level).
- Make the reading when the value has stabilized.
- After the measurement is complete, wash the pH sensor well with tap water and replace the sensor cap to turn OFF the unit.

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Field soil tests for NO_3, NH_4, PO_4, K, Ca and Na

Although there are about 16 essential nutrient elements, routine soil testing almost always involves the major nutrient elements (N, P and K) and some secondary nutrient elements (Ca, Mg and S) while micronutrients (Cu, Zn, Mn, Mo, Fe, B) are occasionally tested for in some soils. Sodium is not an essential nutrient element. However, when Na is present in the soil in significant quantities, particularly in proportion to the other cations present, it can have an adverse effect not only on many crops but also on the physical conditions of the soil.

TESTING SOILS FOR NITROGEN

Nitrogen occurs in soils in several forms: organic compounds, nitrate, nitrite and ammonium ions, which can occur as exchangeable cations; nitrates are the main forms of N used by plants. Apart from application of N fertilizers, the main source of N in soils is the breakdown and humification of organic matter; slow decomposition of humus releases NH_4 ions that are subsequently oxidized to nitrite and nitrate. This process is profoundly influenced by microbial activity.

Soil tests for nitrogen could be problematic due to interconversion from one form to the other. However, nitrogen fertilizer recommendations for several crops could be based on soil tests for inorganic nitrogen. Nitrate (NO_3^-) and ammonium (NH_4^+) in soil samples, taken before crops are planted or in early stages of growth, is useful in assessing the nitrogen needs of many crops. The nitrate soil test is becoming popular, perhaps because nitrate is the form of N that is most readily used by higher plants and also is the form of available N that usually accumulates in normal agricultural soils.

TESTING SOILS FOR PHOSPHORUS

Phosphorus occurs in soils in both organic and inorganic forms. Phosphorus is taken up by the plants in $H_2PO_4^-$ and HPO_4^{2-} forms depending on pH. Because of the complicated chemistry of P in the soil, available P has always been very difficult to define. Inorganic P can occur as various compounds of Ca, Fe, and A1, in solution, in surface films, in the solid state, or as exchangeable phosphate anions held by the positive charges on the edges of clay plates. Soil P can be represented thus: **Non-available-P Potentially available-P Available-P**. Available P is sometimes referred to as the 'intensity' of the nutrient in the soil, and potentially available P as the 'capacity'.

Many methods are available for the determination of available-P depending on soil conditions (mainly pH). The most widely used method of available-P determination is probably the Olsen method of bicarbonate extraction.

M.T. Adetunji
Department of Soil Science and Mechanisation, University of Abeokuta, Nigeria

However, for acid soils the Bray, Truog or Morgan methods are often used. The use of sorption parameters appears appropriate for high P-fixing soils although they may not be amenable to routine analysis.

TESTING SOIL FOR EXCHANGEABLE CATIONS: CA, MG, K AND NA

Testing soils for CEC has been discussed in another section. The levels of exchangeable cations in a soil are usually of more immediate value than CEC, because they do not only indicate existing nutrient status, but can also be used to assess balances among cations. This is of great importance because nutrient availability in soil could be influenced by the relative concentration of cations as well as by their total levels. Usually, exchangeable cation measurements are made using ammonium acetate at pH 7. In some situations, unbuffered solutions may be preferred.

Exchangeable potassium

Potassium exists in soils mainly in inorganic forms. These include solution K, exchangeable K, interlayer or non-exchangeable K and mineral K. The exchangeable K constitutes less than 1% of the soil K. Soil K tests involving the estimation of exchangeable K plus water soluble K appear to be the most reliable K tests to date; due to K fixation the use of quality/intensity relationships could be considered in certain circumstances.

Exchangeable K levels usually alter when the soils are dried. As a general rule, samples with large amounts of available K lose some by fixation during drying and those with low amounts have their exchangeable K augmented from sources that are non-available in the field.

Exchangeable calcium

Normally Ca deficiency as a plant nutrient occurs only in soils of low CEC at pH values of 5.5 or less. Large inputs of K fertilizer or high natural K reserves may, however, inhibit plant uptake of Ca in soils having a more neutral reaction. Calcium may also be effectively deficient at high pH levels when there is an excessive Na content. As a rule of thumb, some response to Ca fertilizer may be expected from most crops when the exchangeable Ca levels in the soil are less than 0.2 $cmol.kg^{-1}$.

Exchangeable magnesium

The presence of Mg deficiency in a crop may not only be associated with low Mg content in the soil but also with the presence of large amounts of other cations, particularly K and Ca. Deficiency symptoms resulting from exchangeable Mg, rather than cation imbalance, could occur in acid coarse-textured soils having exchangeable Mg levels of less than 0.2 c mol kg^{-1}. Magnesium uptake may be inhibited if the K: Mg ratio exceeds 2:1 in soils low in Mg.

Exchangeable sodium

Although Na may, in particular circumstances, be utilized by some plants as a partial substitute for K, it is not considered an essential plant nutrient. When Na is present in the soil in significant quantities, particularly in proportion to the other cations present, it can have an adverse effect not only on crops, but also on the physical conditions of the soil.

A widely used measure of the effects of high sodium levels is the exchangeable sodium percentage (ESP) which is defined as:

$$ESP = \frac{\text{Exchangeable Na}}{\text{CEC}} \text{ X } 100$$

An ESP value of 15 is often regarded as the boundary between sodic and non-sodic soils. In general soils with exchangeable Na of 1 c mol kg^{-1} should be regarded as potentially sodic.

Field tests

Although certain physical and chemical tests require specialized facilities of a fully equipped laboratory, in some circumstances, there may not be access to normal laboratory facilities to obtain accurate information about the nutrient status of soil. Test kits provide simple and rapid on-the-field rough assessment of nutrient status of soils and plant samples.

A rapid soil test, as an estimate of plant-available nutrients, can provide a fair guide for making fertilizer recommendations. It should be emphasized, however, that reliable interpretation requires other information, in addition to the soil test results. Such things as soil type, soil rooting depth, drainage, irrigation practices, and previous crop are needed to make proper recommendations. The raw data must be related to the actual response of fertilizer additions of a given crop, for specific field conditions. This is equivalent to saying that rapid soil test results must be calibrated for local use.

There are many soil test kits in the market. Some are based on the use of liquid reagents, some use reagents compressed into stable tablet forms, some have battery operated photometers incorporated, while some use reflectometric principles. The procedures for use vary according to type. The OSK soil test kit is one of the popular test kits for N, P, K, Ca, Na, Mg in the market. The procedure for the use of the OSK soil test kit is given below to facilitate the understanding of the use of a test kit.

Field soil-test procedures of OSK soil test kit

1. ***Test for Nitrate - Nitrogen:***

i. Dilute one drop, equivalent to 0.05 ml, of NO_3-N Extract Agent A with distilled deionized water to give 5 ml in a measuring glass.
ii. Transfer this solution into a test tube that contains 2 ml of soil to be tested.
iii. Add a quarter spoonful, approximately 0.05 g, of NO_3-N Extract Agent B.
iv. Filter into a funnel-type test tube.
v. Transfer 1 ml of the filtrate into a medium test tube, to the lower mark.
vi. Add one quarter spoonful each of reagent No. 23-A (NO_3-N Test reagent A) and reagent No. 23-B (NO_3-N Test reagent B).
vii. Shake the tube vigorously for twenty seconds and let stand for another five minutes.
viii. Determine the amount of nitrate nitrogen by matching the colour produced with the colour chart.

2. ***Test for Available Phosphate:***

i. Fill soil sample up to the lower line of a medium test tube (1 ml).
ii. Add solution No. 2 (available phosphate extractor) to the upper line.
iii. Put a tin stick into the tube; stir vigorously for 30 seconds.
iv. Take out the stick, leave the tube until the supernatant fluid becomes transparent (3-10 minutes).
v. Then stir, again with a tin stick, the upper portion of supernatant fluid slowly for 30 seconds.

vi. Compare the colour of the fluid with the phosphate colour chart and measure the quantity of the available phosphate in the soil.

3. ***Test for Exchangeable Calcium*:**

i. Take 2 ml of the soil sample using the soil measure. Put the soil into a larger test tube.
ii. Take 5 ml of fluid No. 3 (calcium-exchangeable cation extractor) in a measuring glass.
iii. Add this to the larger test tube.
iv. Seal the tube with a rubber stopper and shake for 3 minutes.
v. Filter the content into a funnel-type test tube.
vi. Fill the filtrate up to the lower line of a smaller test tube.
vii. Add one drop of fluid No. 8 (Calcium Testing Fluid) and wait without mixing.
viii. Observe carefully the degree of white turbidity formed.

Interpretation:

a. White turbidity immediately present (highly turbid) - Very Rich.
b. White turbidity immediately at a lesser degree - Rich.
c. White turbidity present only after a while - Medium.
d. White turbidity does not form for a long time - Lacking.

4. ***Test for Exchangeable Magnesium:***

i. Take the filtrate prepared for testing the exchangeable calcium as explained above and add it into a medium test tube up to the lower line.
ii. Add one drop of fluid No. 10 (Magnesium Testing Fluid A) and shake for few seconds.
iii. Further add 5 drops of fluid No. 11 (Mg Testing Fluid B) and shake well.
iv. Compare the colour formed with the Mg colour chart.

5. ***Test for Exchangeable Potassium*:**

i. Take the filtrate prepared for testing the exchangeable calcium and put in a medium test tube up to the lower line.
ii. Add 3 drops of fluid No. 19 (K Testing Fluid A) and shake well.
iii. Wait for 3 minutes and add 10 drops of fluid No. 20 (K Testing Fluid B) shake well.
iv. Using measuring glass add 1 ml of fluid No. 21 (K Testing Fluid C) and shake well.
v. Wait for 3 minutes and compare the turbidity with the K turbidity chart.

6. ***Test for Ammonium-Nitrogen (NH_4-N)*:**

i. Use part of the filtrate prepared for testing exchangeable calcium and fill a medium test tube up to the lower line.
ii. Then add 3 drops of fluid No. 22 (NH_4-N Testing Fluid) and shake well.
iii. Wait for 3 minutes and then compare the colour with the colour chart for NH_4-N.

7. ***Test for Exchangeable Manganese*:**

i. Use part of the filtrate prepared for exchangeable Ca. Allow the tip of the filter paper to absorb a very small quantity of the filtrate.
ii. Add one drop of fluid No. 12 on the wet portion of the filter paper.
iii. Then add one drop of fluid No. 13.
iv. Finally add 2 drops of fluid No. 14.
v. Observe carefully the intensity and the period of appearance of the blue colour.

Interpretation:

a. Intense blue colour appears immediately - Very Rich.
b. Clear blue colour appears after a while - Rich.
c. Blue colour (very light) appears after long period - Low.
d. Blue colour does not appear at all - Lacking.

8. ***Test for Iron:***

i. Fill the soil sample up to the lower lines of 2 medium test tubes.
ii. Add fluid No. 2 up to the upper line.
iii. Seal them with rubber stoppers and shake vigorously for 30 seconds.
iv. Allow to stand for 3 minutes and then add 3 drops of fluid No. 17 to one tube; shake lightly to mix with supernatant part.
v. After 3 minutes add 3 drops of fluid No. 18 to the other tube; shake lightly to mix with supernatant part.
vi. Immediately compare the colour formed with the iron colour chart.

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Field tests for Zn, Fe, Mn, Cu, Mo, B and Pb in soil, plant and water

Six trace elements are considered essential for plant growth, even though they are needed in very small quantities. These are the micro nutrient elements B, Cu, Fe, Mn, Mo, and Zn. Lead (Pb) is important from an environmental pollution point of view. Both soil tests and plant analyses have been used to diagnose micronutrient deficiencies in crops.

Routine micronutrients tests are not common in most soil test laboratories due to the specialized facilities required for their analyses and also to the fact that micronutrient deficiencies are not as common as macronutrient deficiencies. Requests for micronutrient soil tests usually depend on which of the micronutrients constitute a crop production limitation in a particular environment; and it is usually based on the fact that a field assessment of the crops or previous experience with similar soils has indicated the likelihood of deficiency. Moreover, most soil tests for micronutrients have not been widely adapted and analytical results may be difficult to interpret. These difficulties have led to an increase in the use of plant analysis rather than soil analysis in the determination of the soil micronutrient levels. In many laboratories both soil tests and plant analyses are used to diagnose micronutrient deficiencies in crops.

These trace elements may be toxic to plants or contribute to pollution of surface and ground water. They are particularly important in water pollution. They are regularly monitored in both surface and groundwater in order to provide guidelines for the prevention of water pollution. Trace elements are linked to health because of the functions they perform in physiological processes.

However in soil, plant and water analyses, contamination of samples is always a problem. Concentrations of micronutrients in water, plant tissue and soil extracts are usually low. Consequently, small changes in micronutrient concentration could cause relatively large errors in analytical results. These errors frequently result in misinterpretation of the data. Therefore, sample handling constitutes an important process in micronutrient analyses. Proper care must be taken during sampling and post-sampling operation.

MICRONUTRIENT SOIL TESTS

The major objective of soil tests for micronutrients is to separate deficient from non-deficient fields. This information is important for determining whether a soil can supply adequate micronutrients for optimum crop production, as well as for adequate nutrition and safety of animals that may feed upon the products.

M.T. Adetunji
Department of Soil Science and Mechanisation, University of Abeokuta, Nigeria

Special precautions should be used to avoid contamination of the sample. Materials such as galvanized steel, brass, bronze and rubber should not be used in taking the sample or in the preparation or storage of the sample.

Testing soils for Zn: The active form of Zn in the soil is the divalent cation Zn^{2+}. Maize, citrus, legumes, and cotton are especially sensitive to Zn deficiencies. Several extractants have been used to estimate plant available Zn in the soil. These materials include complexing agents such as dithizone, chelating agents such as EDTA, DTPA; dilute acids such as 0.01N HCl and 0.05N HCl - 0.025N H_2SO_4; and neutral salts such as NH_4 NO_3, KCl and $MgCl_2$. The complexing agent dithizone is particularly useful in acid soils. The extracted Zn is usually determined using an atomic absorption spectrophotometer.

Testing soils for Fe: The major forms of iron in soils are very sparingly soluble ferric oxides, which occur as coatings of aggregates or as separate constituents of the clay fraction. Soil redox potential and pH profoundly affect the availability of Fe. The form of Fe that is predominantly taken up by plants is the Fe^{++}. Uptake of Fe is inhibited by phosphate levels, due to the formation of insoluble iron phosphate. Soil tests for available Fe include the use of extractants like chelating agents such as DTPA, EDTA and EDDHA; the test for exchangeable Fe involves the use of an extractant such as 1.0 M ammonium acetate.

Testing soils for Mn: The chemical behaviour of Mn in the soil is very similar to that of Fe. Soil Mn originates primarily from the decomposition of ferromagnesian rocks. Manganese is taken up by the plants predominantly as Mn^{++} ions, although it exists in many oxidation states. Manganese and P are mutually antagonistic.

The extractants used for soil Mn tests include reducing agents such as hydroquinone; phosphate solutions such as 3N NH_4 H_2PO_4 and 0.1N H_3P0_4; chelating agents such as EDTA; and water. Most of the methods seem to have merit. However, the use of hydroquinone appears to be most popular.

Testing soils for Cu: Copper like Zn exists in soils mainly as divalent ions Cu^{++}. It is usually absorbed by clay minerals or associated with organic matter, although they have little or no effect on its availability to crops. High phosphate fertilization can induce Cu deficiency**.**

Most plants are sensitive to Cu deficiency conditions; cereals and vegetables are particularly sensitive. Toxicity from Cu does not appear to be widespread and is of importance mainly in areas polluted by mining or excessive spraying activities.

Soil tests for available Cu include the use of biological assay such as the use of *Aspergillus niger*; the use of extractants like dilute acids such as HNO_3 and 0.1 N HCl and chelating agents such as EDTA. Other extractants used are NH_4 NO_3, acid ammonium acetate, dilute HCl and a citrate-EDTA mixture.

Testing soils for Mo: The principal reserves of molybdenum in soils are believed to be the oxides M_oO_3, Mo_2O_5 and MoO_2. These oxides are slowly transformed to soluble molybdates (MoO_4^{2-}) which is the form taken up by plants.

Molybdenum chemistry in the soil is pH dependent. The extractants used for Mo soil tests include ammonium oxalate, water, ammonium acetate and ammonium fluoride.

Testing soils for B**:** Deficiencies in B are commonly encountered when light textured acid soils are leached drastically by rain or irrigation or are limed. Many methods have been devised to

assess the level of available B in soil. Hot-water extractable B appears to be the most popular method and is often well correlated with plant available B.

***Testing soils for Pb*:** Lead reaches soil and plant cover as an aerial deposit and in precipitation, irrigation water, mine drainage, leaf litter or ground dust blown in from elsewhere. Lead is also sometimes added to soil as a pesticide, e.g. Pb arsenate, or as impurity in certain fertilizers. Contaminant Pb reaching the soil from various sources enters a new cycle of reactions following incorporation into the surface layer. This may alter its availability to plants. Thus Pb freshly precipitated from combusted gasoline and mostly associated with halides is relatively soluble. Lead enters humans by inhalation and ingestion. Absorbed and carried by the blood, it is accumulated in the liver, kidneys and bones. Lead poisoning, starting with convulsions and anaemia, may proceed to peripheral nerve disease, gout, chronic nephritis, encephalopathy and death.

PLANT TESTING FOR MICRONUTRIENTS

Plant analysis as a diagnostic technique involves several steps which include sampling, sample preparation, laboratory analysis and interpretation of the analytical data. The quality of plant analysis depends on the quality of the samples used for the analysis. It is important to give proper consideration to the time of sampling, the plant part to sample, the number of parts per plant, the number of plants to sample and the sample handling procedures.

Sampling is normally recommended just prior to or at the time the plant begins its productive stage of growth. The plant part that is usually sampled is the leaf. It is better to sample mature leaves just below the growing tip on the main branches and stems. The intensity of sampling varies widely. However, 15-30 plants may be adequate for most crops. It is advisable to take as many samples as practicable. Plant parts that are soil or dust covered, damaged by insect, mechanically injured, diseased or dead should be avoided. It is also a good practice to avoid plants that are under moisture or temperature stress.

Washing of plant samples may not be necessary except when the plant samples are excessively dusty or coated with spray residues especially when Fe and Mn are being analysed for. Soil contamination by dusts does not greatly affect the other micronutrients. When washing is necessary a mild solution (0.1 to 0.3%) of detergent is recommended followed by rinsing with deionized water.

Drying of the samples is necessary. Drying at temperatures of 60 to 80^{o}C for about 48 hours is recommended. Grinding of samples must be done with care to minimize contamination of the sample from grinding surfaces. An agate ball mill is usually recommended. The fineness of grinding is also important. Grinding through a 20 or 40 mesh screen may be adequate. It is important that the ground sample is mixed thoroughly after grinding.

The dissolution of the samples could be done by wet or dry ashing. Wet ashing could be accomplished by using various combinations of HNO_3, H_2SO_4, H_2O_2 and $HClO_4$. In dry ashing, the ashing temperature and length of ashing vary according to the properties of the elements to be determined and the particular methods of analysis. However, the recommended temperature is usually about 400-500^{o}C and the length of ashing is between two and eight hours.

Several analytical methods are available for micronutrient analysis. These include colorimetric, flame emission, atomic absorption, polarography, emission spectroscopy, mass spectroscopy, X-ray fluorescence and neutron activation analyses. By and large Atomic absorption spectroscopy is the most widely used analytical tool.

WATER ANALYSIS FOR TRACE ELEMENTS

All the trace elements are harmful when their concentrations are high in water, even though they are harmless or beneficial at low concentration, especially copper and zinc. Minerals containing heavy metals are of widespread occurrence in rocks and soils. When they are weathered, cations of the heavy metals are liberated and find their way into soil and surface waters. Other sources include deposition from the air, deliberate application for pest control and dumped industrial wastes. The relative importance of these sources will depend on the element and varies from area to area.

Lead is a pollutant of surface waters; $PbSO_4$ and certain other Pb salts formed by weathering of minerals dissolve in water to yield the toxic Pb^{2+} ion which is carried into rivers and streams with severe consequences. Lead has a number of well defined toxic effects upon humans including the production of anaemia, disturbances of haemoglobin synthesis, and damage to the nervous system and kidneys. Lead is also quite toxic to fish and it has been shown that concentrations as low as 0.33 ppm in water can be lethal to certain species.

Copper is toxic to most forms of life if present at certain concentrations; 0.5 ppm in water is lethal to many algae, whilst most fish succumb to a few ppm. In higher animals, brain damage is a characteristic feature of copper poisoning.

Zinc is a common pollutant of fresh water often in association with other heavy metals. Zinc toxicity is extremely variable among species. In water, a concentration of as little as 0.3 ppm is lethal to some snails and fish, whereas water boatman and stone flies can tolerate 500 ppm. Copper and Zn show synergistic effects in the poisoning of fish. The toxicity of the two ions supplied together is greater than the summation of their individual effects.

Routine chemical analysis of waters is important in monitoring and control of these pollutants. Many standard methods are available for the determination of these pollutants in water. These include polarographic techniques, atomic absorption spectrophotometric techniques, induced coupled plasma analyser, photometry, colorimetric and titrimetric techniques. Various rapid field test kits are also available; some are based on the use of soil test strips (microquant test kits) and some incorporate photometers (spectroquant test kits).

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Runoff, drainage and irrigation water sampling and testing

Water is an important resource, availability of which is a major factor in assessing the productivity of soil and ecological environment. Water is the main factor limiting plant growth in the semi-arid and arid regions, when irrigation is not available. It can be limiting even in the humid and sub-humid regions where dry periods with water deficit frequently occur. Terrestrial plants must rely on the soil as a mobile reserve for water in order to bridge the gap between plant requirements and the supply of water from rainfall, which can be infrequent and inadequate for plant requirements.

The soil reservoir of water, being relatively small at a given time, has to be replenished frequently by precipitation. Precipitation (rainfall or irrigation) which constitutes a major source of replenishing soil water reserve has several disposal routes at the soil surface. The field water balance equation itemizes accretions and depletions from the soil storage reservoir of rain or irrigation reaching the soil surface during a given period of time:

$$\Delta M = P - (S + \Delta D + \Delta U + Edt)$$

where ΔM is change in soil moisture storage, P is precipitation received, S is surface runoff, ΔD is increase in surface detention, ΔU is increase in groundwater storage and Edt is the total evaporation over a period of time. Runoff and drainage waters represent major disposal routes in field water balance.

RUNOFF, DRAINAGE AND IRRIGATION WATERS

Concepts

Surface rainwater runoff occurs when rainfall intensity exceeds the infiltration capacity of the soil, that is, the rate at which water penetrates the surface and is absorbed into the soil. The water which is lost without entering the soil is called *surface runoff* and that which enters the soil before reaching the stream is called *groundwater runoff or seepage flow* from groundwater.

Runoff is affected by numerous parameters including topography, surface roughness, vegetation cover, infiltrability of soil, soil water holding capacity and drainage. A simple method to quantify runoff is the use of the runoff coefficient, C, the ratio of the rate of runoff to the rate of rainfall. Sometimes it is also called rainfall efficiency. The catchment characteristic in terms of runoff can be approximated as the summed effect of parameters for *vegetation cover*, *soil type* and *slope.*

***P.O. Aina**, Department of Soil Science, Obafemi Awolowo University, Ile-Ife, Nigeria*
***G. Kirchhof**, International Institute of Tropical Agriculture, Ibadan, Nigeria*

Catchment characteristics

Cover		Soil type and drainage		Slope	
Heavy grass	10	deep, well drained soil	10	very flat to gentle	5
Scrub or medium grass	15	deep, moderately pervious soil	20	moderate	10
Cultivated land	20	soils of fair permeability and depth	25	rolling	15
Bare or eroded	25	shallow soils with impeded drainage	30	hilly or steep	20
		medium heavy clays or rocky surfaces	40	mountainous	25
		impervious surfaces and waterlogged soils	50		

Example: The catchment characteristic (CC) for a heavy grass (10) on deep, moderately pervious soil (20) in a rolling landscape (15) would be 10 + 20 + 15, CC = 45%. A weighted average can be calculated if the conditions in the catchment are not uniform.

Water that does not run off or evaporate from the surfaces of agricultural areas infiltrates the soil. Part of this water percolates into deeper layers as drainage water and becomes groundwater that may appear in drains or wells. Agricultural drainage waters are waters removed from agricultural lands by flow over (surface) or through the soil (subsurface) or, more commonly, a mixture of both. Drainage can be surface drainage by open ditches and lateral drains or subsurface drainage by open ditches and buried drains which are all connected to suitable drainage outlets. Drainage from mines, mine wastes, urban and industrial activity yields effluents quite unlike agricultural drainage in quality but which often get mixed together with agricultural drainage waters in streams. Similar to runoff, the ability of the soil to drain water into deeper horizons is affected by the water holding capacity and the soil permeability. Water holding capacity depends on the size and distribution of the soil's pore space and permeability depends on the continuity of the pore space.

Water holding capacity is normally defined as the water that can be held against gravity, i.e. the amount of water the soil contains after complete wetting (rainfall or irrigation) and when it was left to drain for two days. This water content is called *field capacity.* Definitions vary as to what matric potential field capacity refers to. A value of -100 cm (= 0.1 Bar = 10 kPa) is most commonly used, but potentials as low as -30 cm or as high as -300 cm are occasionally used. The water content at field capacity can be measured in the field after thorough wetting and two days drainage, or in the lab on undisturbed samples using a tension table or a pressure membrane apparatus.

Drainage capacity is the amount of water held above field capacity, i.e. pore volume less the water content at field capacity. Permeability, infiltration rates or hydraulic conductivity can be measured on undisturbed cores in the laboratory, *in situ* using a range of infiltration instruments (double ring infiltrometer, permeameters, borehole methods) or estimated from other soil properties (e.g. soil water release curve, texture). Irrigation is the practice of supplying water artificially to soil. In farming, the process of irrigation consists of introducing water into the part of the soil profile which serves as the root zone for the subsequent use of the crop. Irrigation systems include surface (in which water is conveyed to the point of infiltration directly on the soil surface by flooding, or partial flooding or furrow method), sprinkler or drip (trickle) irrigation systems. Saline or sodic irrigation water can lead to soil salinization or sodication. Irrigation water must thus be low in soluble salts and sodium cations. Over-irrigation can lead to water table rises which can bring salty or sodic groundwater to the soil surface.

The movement of water over the surface or percolating through the soil affords intimate contact with soil clays, organic matter and micro-organisms. Soluble nutrients and chemicals applied to or contained in the soil may be dissolved by soil water and leached from the soil profile

while on the other hand, some materials will be removed from solution by adsorption and precipitation. Such waters contain a variety of dissolved and suspended substances including salts, organic compounds and soil particles that determine their quality.

WHY TEST WATERS?

Runoff, drainage and irrigation waters are never pure. They sometimes contain nutrients and chemicals in sufficient concentrations to be of significance to subsequent users of the water, plants or to the aquatic environment. Soluble or particulate organic matter can come from surface runoff and from uncontrolled erosion of soils. Organic contamination of water may be involved in over-enrichment of surface waters to the extent that they become eutrophic and may produce algal blooms. Algae, the growth of which is promoted by N and P, deteriorate water quality for domestic and recreational uses and destroy fish by reducing the oxygen content of the water when the algae die. High nitrate water, when consumed by infants, may cause methemoglobinemia or blue "babies" and a number of disorders in livestock. Crop yield is reduced when excessive accumulations of solute salts exist in soils; this is as a result of osmotically produced water stresses that plants encounter under saline conditions, and also specific nutritional imbalances and toxicities created under certain salt constituents such as Cl, Na, and B. The major constituents of salinity of drainage waters, Ca, Mg, Na, HCO_3, Cl and SO_4 are of major concern in relation to water quality. In addition to the salts usually associated with salinity, agricultural drainage waters may contain nutrients (such as N, P) and other chemicals used in farming activities. Pesticides in drainage waters may be toxic to fish, wildlife and plants. The use of copper sulphate in tree-crop plantation sprays and mercury in fungicidal treatment of seeds are agricultural uses of heavy metals that have potential for causing undesirable side effects. Chlorinated hydrocarbon insecticides are potentialy injurious to aquatic organisms.

The primary sources of soluble salts in agriculture, among others, are irrigation and drainage waters (both surface and subsurface draining from upper-lying to lower-lying lands). For irrigation, other criteria to test for are the SAR and the B and Cl concentrations. The SAR value is used to estimate the extent to which soil irrigated with the water will accumulate or lose exchangeable Na.

$$SAR = Na/(Ca + Mg)^{1/2}$$

Adjusted Sodium Adsorption Ratio: The SAR of a water adjusted for the precipitation or dissolution of Ca^{2+} and Mg^{2+} that is expected to occur where water reacts with alkaline earth carbonates within the soil. Numerically, it is obtained by the equation:

$$SAR_{adjusted} = SAR\left(1 + 8.4 - pH_c^*\right)$$

pH*c: The calculated pH that a water would have if it were in equilibrium with calcium carbonate. It is used in conjunction with the measured pH of a water to determine if $CaCO_3$ will precipitate from the water, or if the water will dissolve $CaCO_3$ as it passes through a calcareous soil.

Boron at concentrations not much greater than that required for nutrition is toxic to all plants and Cl may be toxic to woody plants. Hardness, Ca+Mg concentrations of water usually expressed as mg/litre of $CaCO_3$ is an important criterion of water quality for domestic and industrial purposes. Excessive Na in an irrigation water may create a problem as a specific source of toxicity to certain sensitive crops and as a consequence of the deterioration of soil structure and permeability that it may cause. Residues of heavy metals such as Hg, Cu, Pb and Zn enter drain

water as waste from industry, or in runoff from agricultural use, and are capable of causing problems in aquatic ecosystems.

The flow of drainage water from irrigated land to bodies of surface and groundwater basins either naturally or through human-made conveyances such as tile lines, pipes or ditches, almost invariably decreases the quality of the latter because the quality of drainage water is poorer than that of the receiving body of water. The constituents of runoff, drainage and irrigation waters are of concern because of their potential to contaminate surface streams, lakes, rivers and reservoirs. The consequences are the impairment of the quality of receiving surface and underground waters and productivity of the land. These waters are therefore tested to ascertain their quality and potential impact on the receiving environment to enhance their proper management. Drainage waters collected by the tile lines and ditches or removed by pumping of wells can be disposed of, in some cases, in ways that do not reduce the quality of surface and groundwaters. Conveyance to sumps for evaporation or reclamation by desalination is another possibility. Drainage water does not become valueless for irrigation until its EC exceeds 7.5 mmhos/cm (concentration about 75 meq/litre).

WHAT TO TEST FOR

Soil resource impact-indicator properties of runoff, drainage and irrigation waters (e.g. total dissolved and suspended solids, pH, electrical conductivity, sodium adsorption ratio, nutrient and chemical loads: nitrate, phosphate, bases, trace metals, chloride, etc.) are analysed. Criteria of water quality vary with the intended use of the water and are measured against standards set by such regulatory bodies as WHO. Total salt concentration, expressed as chemical equivalents/litre, electrical conductivity or mg/litre is a criterion for most uses. Electrical conductivity (EC) of water is a reliable index of its total soluble salt concentration within practical limits. Salinity is of concern not only in arid and semi-arid regions where it occurs naturally but also in humid areas. As the soil solution is concentrated by evaporation and plant extraction, the salt species most likely to precipitate first are the alkaline earth carbonates such as calcite ($CaCO_3$) and dolomite (Ca, Mg)CO_3; their quantity depending on several properties of the soil chemical system. Carbonate precipitation and dissolution are therefore important considerations in irrigation and drainage design.

TABLE 1
Irrigation water quality: limiting values

Evaluation rating	EC S m^{-1}	Na^+ %	SAR	NA_2CO_3 meq l^{-1}	Cl^- meq l^{-1}	Boron ppm
1	0.05	40	3	0.5	3	0.5
2	0.1	60	6	1	6	1
3	0.2	70	9	2	10	2
4	0.3	80	12	3	15	3
5	0.4	90	15	4	20	4
6	>0.4	>90	>15	>4	>20	>4

The deleterious effects of excessive Na on crop growth are not as closely related to the absolute amount of soluble Na in the soil water as to the proportion of exchangeable cations that is Na, i.e. exchangeable sodium percentage (ESP). Sodium adsorption ratio (SAR) is a good estimate of the ESP of soils and may be used advantegeously in place of ESP.

The quality of water as it determines the suitability of water for irrigation has always been of primary concern; it is measured by the type and composition of the dissolved and suspended sediment. Although several schemes for the classification of irrigation waters have evolved, there

is reasonable agreement with respect to criteria and limits from the standpoint of plant nutrition and contamination of soil or environment

Approximate conversions

1. Total cation (or anion) concentration [meq l^{-1}] = 10 EC [dS m^{-1}
2. Salt concentration [mg l^{-1}] = 640 EC [dS m^{-1}]
3. Osmotic pressure [bars] at 25ºC = 0.39 EC [dS m^{-1}]
   (for comparison: seawater has 3.5% soluble salts = 5.5 S m^{-1}.)

The constituents usually determined in an irrigation water analysis include: EC, SAR, B, dissolved solids, pH, cations - Ca, Mg, Na, K, sum of cations, anions - CO_3, HCO_3, SO_4, Cl, NO_3, sum of anions. For many applications, EC is adequate as a measure of total concentration so the determination of dissolved solids can be omitted.

SAMPLING AND ANALYTICAL TECHNIQUES

Sampling techniques

Water samples are collected and analysed to obtain information about quality or potential pollution appraisal. Representative samples and accurate analytical work are therefore essential. The mechanics of a sampling programme will depend on the chemical characteristics of water and the nature of the water body.

i. **Groundwater**

- From auger or core holes deeper than the underground water surface (water table)
- From piezometer tubes. *Equipment required to collect samples*: stopper with two holes to fit piezometer tube, 1 short PVC tube, 1 PVC tube longer than piezometer tube, bicycle pump, sample container (see Figure 1).

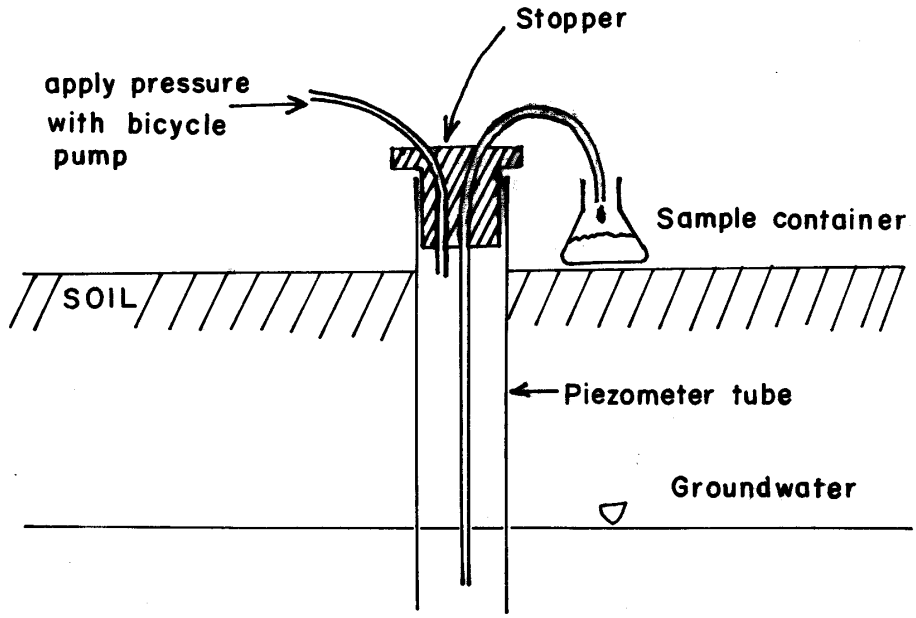
ii. **Unsaturated soil solution**

- *In situ* ceramic cups. *Equipment required to collect samples:* ceramic cup (1 Bar air entry), vacuum pump and tubing. **Limitation:** soil water can only be extracted when the water is held with a potential of less than atmospheric pressure (< 1 Bar).
- Collection of samples and extraction using high speed centrifuges. **Limitation:** samples should be wetter than field capacity, otherwise the extraction method becomes impractical.

iii. **Irrigation water** presents no particular sampling problem because, as long as the natural replenishment of the aquifer equals the withdrawal, there will be little change with time in the chemical characteristics of the water. Samples for irrigation water analysis should be collected in 1- or 2-litre clean glass or polyethylene bottles.

iv. **Runoff**: A runoff sample is collected from a defined area of land at the lowest part of the slope. Erosion flumes are normally used to trap the eroded soil and channel the runoff water into collection tanks. The upper part of these collection tanks must be below the flumes to allow water collection.

FIGURE 1
Equipment set-up for collecting water sample from groundwater



v. **Surface stream**: Samples are better collected from a gauging station so that the analytical data can be related to the discharge or to the runoff. The details of the sampling programme, including the frequency of sample collection, should be developed after a study of the stream's discharge characteristics. Daily or weekly samples are usually adequate for irrigation management or salt-balance studies for a controlled stream that is fed by the discharge from a reservoir. Samples from the outlet of small reserviors such as a runoff sediment tank are representative, as water in such reservoirs is usually homogeneous. However, water sampling in a large, deep reservoir is often not thoroughly mixed and it would be necessary to collect samples from several depths and locations in the reservoir. Samples from surface streams should be taken from running water, and a few centimetres below the surface. The samples should be analysed as soon as possible after collection because chemical changes can take place on standing. It is important that adequate descriptions accompany the samples and become a part of the records and reports.

METHODS OF WATER ANALYSIS

Spectrophotometry, flame photometry, gas chromatography, the Schwarzenbach reactions and other advances such as ion specific electrode meters for Cl, ammonia, Cu, nitrite, aluminium, phosphate and chromium have revolutionized water analysis in recent times.

Suspended solids

Suspended solids are determined in the runoff water to estimate the sediment load carried away during and after rainfall events. Under field conditions the total amount of runoff can be very large, depending on rainfall intensity and duration, and size of plot. For example, a plot size of 5 m x 20 m during a rainfall of 10 mm and a runoff coefficient of 20% could create 200 litres of runoff water. There are several methods of determining the amount of suspended solids:

1. The runoff in the collection tank is homogenized and a subsample, say 1.00 litre (exact) taken. A filter paper is oven dried and weighed, and the subsample from the runoff filtered. After oven drying, the filter + sediment mass is determined. Sediment load in the filter is proportional to sediment load from the plot. In areas of high humidity, oven-dry paper and soil will absorb water very quickly and will introduce errors. In such cases it will be necessary to let the filter paper and soil cool down in a desiccator and, when cooled, it must be weighed rapidly before substantial water absorption occurs.
2. As above, a runoff subsample is collected. It should also be about 1 litre but the exact volume is not needed. After shaking the container a subsample is taken using a volumetric pipette (20 or 50 ml). The content is emptied into a collection flask (e.g. beaker) and the pipette flushed with water to ensure that all sediment is transferred from the pipette into the collection flask. The collection flask is transferred into an oven at 105ºC and left until the sediment is dry. Due to the very small sample sediment mass it is necessary to use a balance with an accuracy of 0.1 mg and to let containers cool down in desiccators to avoid errors due to water absorption from the atmosphere.

   NOTE: Accuracy of weighing: The amount of sediment in the filter or in the beaker must be weighed accurately; as a rule of thumb the balance should register at least two significant digits. Thus, the smaller the volume of the subsample the greater the requirement for precise determination of volume and mass.
3. The turbidity of the suspension is proportional to the amount of suspended solids. A nephelometer can be used to determine turbidity and thus the amount of suspended solids very fast. However, the instrument needs to be calibrated and may be affected by the colour of the suspended solids.
4. The density of the runoff water can be measured using a hydrometer. The methodology is equivalent to that for particle size distribution analysis, except that density is determined immediately after homogenization of the suspension.

Electrical conductivity

For the measurement of salinity, a conductivity meter is required. Electric conductivity is affected by temperature. Unless a temperature compensation conductivity meter is used, the temperature should be held constant. Conductivity meters are either hand-held (battery operated) or mains powered. It is common that conductivity meters are combined with pH meters. In this case both measurements can be carried out simultaneously. Calibration of the conductivity meter is through two standard KCl solution, 0.010 and 0.100*N*:

at 25ºC; 0.7456 g KCl l^{-1} (0.010*N*) should read 1.412 dS m^{-1} and

7.456 g KCl l^{-1} (0.100*N*) should read 12.900 dS m^{-1}.

The amount of water sample required depends on the size of the probe; usually 10 ml is enough to submerge the probe fully into the water. The measurements are generally very stable and a constant reading is usually obtained quickly. The calibration of the instrument may drift; therefore calibration checks should be carried out frequently. The probe should be rinsed with deionized water between samples.

pH

Reaction, acidity or alkalinity of water samples can be determined accurately using electronic meters that employ the glass-calomel electrode. They are either mains-powered laboratory bench instruments or hand-held battery powered instruments. They are often combined with electric

conductivity probes, redox potential probes and temperature sensors. Less accurate, but suitable for field work are indicator methods, litmus paper or other colorimetric pH sensitive chemicals.

1. **Glass electrode-calomel electrode:** Prior to usage the electrode must be calibrated. The range of calibration depends on the expected pH regime of the sample but is normally done with two buffer solutions, one at pH 7 and the second at either pH 4 or pH 10. Measurements are temperature sensitive and should therefore be carried out under constant temperature conditions or using a temperature compensating probe. Measurements of water samples are carried out in the same way as described above. It may take longer to obtain a stable pH reading and the pH meters tend to drift. The latter need to be checked frequently using the standard solutions. Accuracy obtained is usually ± 0.02 pH.
2. Several 'quick test' indicators are available. The most commonly used ones are bromo thymol blue or bromo cresol purple. Strips of indicator are placed into the water sample or, although less common, a few drops of indicator added to the water sample. In either case the colour (strip or sample) gives an estimate of pH by comparing it with a chart. Accuracy is usually no better than ± 0.2 pH.

Anions and cations

Analysis of anions and cations requires rather sophisticated equipment. Anions are often determined colorimetrically, while cations are generally more suitable for analysis using flame spectrometers and resulting atomic absorption or emission. The newest and most sophisticated instruments are inductively coupled plasma furnaces (ICP). They can be used to determine a whole range of elements and compounds simultaneously. Field methods are available to test for a wide range of cations and anions. In most cases they are based on colorimetric assessment. Although such methods are excellent indicators for trends, their accuracy is often very limited.

Sodium adsorption ratio requires the determination of the major cations Na^{+}, Ca^{++} and Mg^{++} and is thus not easily possible without the appropriate equipment. However, sodium has a strong influence on soil structural stability and a range of simple tests exists to roughly determine soil structural stability.

Organic compounds

The determination of toxic organic compounds is important in high input agricultural production systems where pesticides, herbicides and other poisonous compounds may be used. Analysis for such chemicals requires very specialized equipment such as chromatographs or ICPs.

There are four principal hazards related to the chemical character of the water: total concentration, sodium, bicarbonate and boron or other phytotoxic substances. Criteria that measure these hazards are in general use. The quality of an irrigation water is determined by the composition and concentration of the dissolved substances or solutes that are present in the water. The principal solutes are the cations, Ca, Mg, and Na, and the anions bicarbonate, sulphate and chloride. Na and Cl predominate in more saline waters because of solubility limitations. B, F and nitrate are usually present in low but significant concentrations. Small amounts of carbonates are found in many waters as well as trace amounts of other less important constituents. Table 2 lists the more important constituents and suitable methods for their determination.

TABLE 2
Analytical methods and their analytical detection limits (ADL)

Parameter	Method and ADL (mg/l)
EC	Wheastone bridge measurement
pH	pH meter using glass electrode
Suspended sediment	Filtration, drying & weighing
Dissolved solids	Residue on evaporation to dryness
Nitrate	Colorimetric using phenol-disulphonic acid after removing NO_2 with treatment with sulphuric acid; ADL - 10
Chloride	Titration against AgNO3 with potassium chromate as the indicator after neutralizing with $CaCO_3$; ADL - 10
Sulphate	Gravimetric technique by precipitating barium sulphate in an acidified solution; ADL=10
Carbonate	Titration with 0.1M HCl and an indicator; ADL=10
Bicarbonate	Titration to pH 4.5 with 0.1M HCl and an indicator; ADL=10
Hardness	Calculated from Ca and Mg concentrations; ADL=50
Phosphate	Colorimetric using molybdenum blue as precipitating agent; ADL=0.1
Sodium, potassium	Using flame photometry; ADL=1
Calcium, magnesium	Using atomic absorption spectrophotometry; ADL=1
Boron	Emission spectrophotometry on sample residue evaporated to dryness; ADL=0.05
Lead, zinc, copper, nickel, cadmium	Atomic absorption spectrophotometry; ADL= 0.1 (Pb, Zn), 0.05 (Cu, Ni), 0.01 (Cd)

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Common sources of errors in soil and plant testing

The possibility of achieving good, efficient soil resource management with soil and plant testing results depends on the accuracy and reliability of all the various components of the soil testing programme. Specifically the usefulness of soil and plant testing efforts depends on the following:

i. How well the sample analysed represents the field in question.

ii. How well the soil test (extraction) method correlates with nutrient uptake by the crop.

iii. How accurately the testing was done.

iv. How sound the test data interpretation was, i.e how well the person making the interpretation understands the relationships between test values and crop response to soil amendments in the particular type of soil environment.

v. How well the person making the recommendation from soil test results understands the economic factors that may influence the usefulness of the recommendations.

ERRORS IN SOIL SAMPLING AND SAMPLE PREPARATION

A soil sample may not be representative of the field soil from which it was taken, due to inadequate sampling of fields with variable chemical/physical properties. Another contributing factor of a non-representative sample is contamination of the sample during sample collection. Sample contamination can be avoided by simple precautions because the problem usually arises from carelessness. Sampling adequacy can be achieved by following good sampling techniques, as enumerated in the sections on soil and plant sampling.

Errors may arise during any of the soil preparation processes: mixing, drying, grinding, sieving and subsampling. Usually the quantity of sample collected as a composite sample on the field is large; hence only a part of this is collected in a bag and taken to laboratory. It becomes very important that the composite sample is thoroughly mixed on the field before subsampling for bagging. Laziness or ignorance on the part of the sampler may result in bad mixing of sample and an unrepresentative subsampe. Efforts put into thorough mixing before subsampling are as important and critical as all the effort put into sampling on the field.

Soils are normally air-dried before laboratory analysis. Error can arise in drying process from two main sources. First, if the soil is not quite dry enough, the soil weight taken for analysis will be less than the air-dry weight since water constitutes part of the weighed out quantity of soil.

J.A. Adepetu
Department of Soil Science, Obafemi Awolowo University, Ile-Ife, Nigeria

The other possible source of error in drying will result if oven-drying rather than air-drying is adopted. Oven-drying tends to produce changes in the soil chemical constituents. Table 1 is a summary of effects of air drying on soil chemical properties.

TABLE 1
Summary of effects of air drying on soil

Soil constituent	Effect of air drying
Carbon	Total C: unaffected Organic C: Increasing oxidation with time and temperature
Manganese	Exchangeable Mn increases
Nitrogen	Total N: little effect Water-soluble N and water-soluble organic matter increase with time and temperature
pH	For sulphur-rich soils, levels can be drastically altered
Phosphorus	Low pH soils: P soluble in H_2O or dilute acid tends to increase. High pH soils (dry when samples): P levels tend to decrease. P fixing capacity of some soils changes with drying (may be linked to Fe and Al changes).
Potassium	Depends on clay minerals present, also on original level of exchangeable K: If < 1 me/100g soil, exchangeable K tends to increase If > 1 me/100g soil, more K tends to become fixed
Sulphur	With some soils more S is releasable to extracting solutions.

Grinding and sieving of samples may introduce bias (errors) if the grinder or the sieve is of the wrong material which can contaminate the sample. The types of materials that compose the sieve and mortar/pestle must be known to the laboratory so that wrong ones are not used. Grinding must only break down soil lumps/aggregates and not break stones and pebbles. Also, in sieving gravely soil samples, the sieved-out gravel fractional weight must be recorded and later taken into consideration while calculating the nutrient content of the soil determined by the analytical process. A sieve of the right aperture, as recommended, should always be used, otherwise change in size of particles analysed will introduce error during data interpretation; all the standard guidelines for interpretation, such as "critical soil-test values" and soil "fertility classification criteria" have been established on the basis of laboratory analysis of specified particle size (sieve size) of soil samples. One other major source of error in sample grinding and sieving is to perform these operations within the analytical laboratory. This introduces s large amount of dust which will contaminate laboratory reagents, contaminate soil and plant samples, and distort instrument reading. This is why a separate sample preparation room is essential in a soil and plant testing scheme.

ERRORS IN PLANT SAMPLING AND SAMPLE PREPARATION

Even after proper selection of representative plant stands to sample on the field, serious errors could still exist. The concentration of specific nutrient elements is different in different parts of the plant, and at different stages of growth. Therefore the test must be conducted on specific plant parts at specific stages of growth. The part and growth stage to sample depends on plant type and it is always specified in plant sampling guidelines. The guideline for plant part and growth stage for the crop of interest must always be followed. Otherwise plant-test data, though carefully acquired, will lead to erroneous assessment of the true nutrient status of the field. To prepare a plant sample for laboratory analysis, it is usually oven-dried at low temperature of about 75^{o}C. High oven-temperature may cause loss of some of the nutrients such as N, S or P. Plant samples should be ground in a special preparation room, and not in the analytical laboratory, to avoid introducing dust contamination into the analytical laboratory. A grinding machine can introduce

elemental particles to sample, especially micronutrient elements. To avoid contamination, stainless steel grinders are usually recommended for plant sample grinding.

ERRORS IN SOIL TESTING OPERATIONS

The first important step in a soil testing operation is to select an appropriate soil testing method. If the quantity of nutrient extracted by the soil testing method does not reflect (correlates with) the amount of the nutrient available to crop in the soil, that method is not suitable; and the soil-test data produced with this extraction method will lead to wrong conclusions about the conditions of the field. Any management recommendations made from such an endeavour will be misleading and costly.

The problem of maintaining accuracy of analytical determinations requires a lot of care on the part of laboratory workers. The main sources of possible errors are:

i. contamination of laboratory reagents, including substandard, low quality of chemicals;
ii. instrument error due to malfunction or poor calibration;
iii. errors in preparing the reagents;
iv. errors in subsampling (weight or volume) of soil and plant samples.

To check the first three potential sources of error listed above, the first two samples in each tray of samples for analysis will be a blank (no soil) and a standard soil for which the analytical values are pre-determined and known. The blank provides a check on reagent contamination, while the standard soil provides a check on instrument error, wrong subsampling or reagent composition. If either sample gives erroneous readings, no additional samples are analysed until the source of error is found and corrected.

Errors in analyses data may also arise from operator faults, such as incorrect preparation of standard solutions, misuse of instruments or incorrect calculations. Sample replication can help detect such errors. Errors due to sample contamination may arise from dust contamination, as explained above. A separate, well-aerated sample preparation room is needed to avoid such contamination. Use of brass sieves should be avoided while analysing for copper or zinc. The use of talcum powder can cause boron contamination. Handling coins while preparing samples can cause copper contamination.

ERRORS IN PLANT TESTING OPERATIONS

The first step in plant sample testing is the conversion of plant tissue (organic) material into solution form, thereby releasing the nutrient into solution for ease of analyses. Either of two methods is usually adopted for this purpose: wet oxidation and dry ashing. In wet oxidation, a strong oxidizing agent and strong acid is used, e.g. H_2O_2 -- H_2SO_4. The digestate may be cloudy if not digested long enough and this will interfere with colour development during later analysis.

Dry ashing requires care to avoid errors. The ashing temperature of the muffle furnace should not exceed 550-600^{oC}. Higher temperature will cause loss of P and K by volatilization. In fact, a significant amount of K could be lost even at 550-600^{o}C. To keep P from being lost, treat the sample with a solution of $Mg(NO_3)_2$ in alcohol; the sample will take a higher temperature without losing P because $MgPO_4$ is formed which is not very volatile. To keep K from loss, the sample can be partially ashed at 400^{o}C, then wet-digested with HNO_3, and then put in the furnace at 400^{o}C for about 10 more minutes; It is then dissolved in acid and ready for analysis.

All the other possible sources of errors listed above for soil testing operations are applicable to plant testing operations. The processes of preventing these errors are discussed under soil testing operations.

ERRORS IN INTERPRETATION OF SOIL TEST RESULTS

Soil test data must be interpreted in terms of soil requirement for good crop yield. The criteria for this interpretation are established through field calibration studies. Where such criteria for soil-test data interpretation have not been established for local conditions, guidelines established in other places or countries may be used initially until local criteria are developed. Sometimes, this causes a problem in that the interpretation criteria may not be appropriate for the local soil types, climate and crop cultivars. For example, the exchangeable soil-K levels classified as low in British soils are adequate for maize production on Nigerian soils, more especially because of the differences in soil characteristics, yield capacities of the maize cultivars commonly cultivated, as well as farmers' management levels. Moreover, even when local criteria have been established, these criteria are not usually universally applicable within the given country. Different criteria may have to be developed for different soil types. One of the commonest sources of error in data interpretation is to use the guidelines developed with a different soil-test method for the interpretation. The guideline developed for Bray-no-1 method of soil-P test in Nigeria will not apply to acid soils of Eastern Nigeria where the appropriate soil test method is Bray-no-2.

A source of error relates to interpreting plant analysis data in terms of soil nutrient deficiency and nutrient requirement. The value of plant-test data in soil requirement evaluation is limited; at best, it is to help determine if detailed soil testing is necessary. When a soil is deficient in two or more elements, the plant test will only reveal the deficiency of the element which is actually limiting plant growth (the most deficient element), while the concentration of the other elements appears normal and adequate. Therefore, when fertilizer is added to correct the indicated deficiency, deficiencies of other elements may show up.

ERRORS SPECIFIC TO N, P OR K TESTS

Possible sources of error in soil-N testing

Handling and analysis of soil samples for OM, NH_4^+, NO_3^- and NO_2^- determinations present some problems because these parameters change from one form to another through microbial actions. Hence the test values for each form may change from the time the sample was taken and during storage. The soil-test value for say NO_3^- may therefore not be the real, field condition soil-test value. Microbial activity could be stopped immediately after sampling by drying, freezing or adding toxic substances to the sample. Quick oven-drying at 55^{o}C has been recommended. Another source of error in sample handling is that soils may absorb atmospheric NH_3 if not air-tight during storage. This is especially possible if the sample is stored in the analytical laboratory. Other errors may arise during preparation of samples as follows:

Soil grinding - excessive grinding may lead to release of fixed NH_4^+; may cause increased accessibility of organic-N to micro-organisms and therefore increase inorganic-N tests.

Soil drying can lead to chemical and biological transformation of inorganic N forms. The best solution is no drying or storage before N analysis, otherwise the analysis is for total-N and/or organic matter as indicators of available N status of the soil.

In total-N determination, incomplete digestion of some complex-ring compounds of N during micro-kjeldahl digestion may introduce error into N-determinations. Also NO_3^- and NO_2^- are readily lost during digestion; this must be prevented.

Because of leaching losses on the field due to high solubility of NO_3^- -N, NO_3^- measured one day may be lost by leaching the next day or the next week if there is enough rain. Leaching could make soil-test data interpretation widely off. This is important especially in areas of very high rainfall or coarse textured soils, in which case NO_3^-N is not a good index of the available N-status of the soil.

In organic matter determination, errors may arise from the presence of high levels of MnO_2 and ferrous ions in soils. MnO_2 is very active in soil; it competes easily with $K_2Cr_2O_7$ when heated in acid medium containing oxidizable substances, thereby inducing a negative error on the analysis result. The magnitude of the error depends on the amount of MnO_2 in the soil. Generally, the amount in most soils is low and therefore there is no need to correct analysis data for this error. Ferrous (Fe^{2+}) ion, if present in soil samples, would be oxidized by $Cr_2O_7^{2-}$ and therefore give a positive error in the analysis data, i.e. high values of organic C are obtained. Only traces of Fe^{2+} are found in well-aerated soils, but appreciable amounts may be found in soils rich in organic matter such as in paddy soils. Errors that may arise from the presence of Fe^{2+} can be eliminated if the soil sample is air-dried one to two days before analysis. Also, addition of H_3PO_4 and NaF can complex the Fe out of solution during OM analysis.

Possible sources of error in soil-P testing

(a) New glassware, e.g. test-tubes, often contains arsenic; arsenic reacts just like phosphorus and produces similar colour reactions as P. This error inflates the magnitude of P in the sample. Soft glassware does not contain arsenic; it is safer to use.

(b) P levels of standard solutions are low and unstable. Also, some of the extracting solutions become flat after standing for some months. It is necessary to prepare new solutions of reagents from time to time.

(c) Wrong pH in colour development with $SnCl_2$ gives wrong readings.

(d) Cheap filter papers contain substantial ash, which is a source of P contamination of extracts.

(e) The use of the wrong wavelength and photomultiplier in the colorimeter will throw off the readings.

Possible sources of error in soil-K testing

(a) Na tends to interfere with K-determination by flame analysis.

(b) In dry ashing, heating the furnace above 550^{o}C may reduce the K content of the sample.

(c) Drying the soil sample before analysis may convert fixed, unavailable K, into surface-exchange K thereby increasing the determined level of exchangeable soil-K. In some soils the process goes in the opposite direction, thereby under-estimating the exchangeable soil K levels.

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Detecting and minimizing common sources of error for data quality

The following is a summary of factors that affect the quality of analytical data, and some suggested remedies.

i. *Sampling/subsampling*: Ensure that the sample adequately represents the population from which it is taken. Avoid outlayers. Follow properly laid out and statistically sound sampling techniques. In field conditions, use appropriate sampling tools.

ii. *Sample Preparation*: Avoid using materials that are capable of contaminating the samples. e.g. do not store digests containing fluoride in glass containers; the F ion would dissolve some of the glass into solution.

iii. *Weighin*g: Since final results are expressed in units that are quite large compared to the size of samples, small errors become very large errors in the final results. To minimize this, ensure that the weighing balance is calibrated regularly.

iv. *Moisture*: Ensure that samples are at the required moisture level; otherwise make adjustments for the moisture content by separately determining the moisture content of the sample. Under field test conditions, do not sample flooded or dry materials except if these are the predominant conditions of the field to be tested.

v. *Foreign Matter*: Always carefully examine samples for presence of materials like fertilizer/ pesticide residues, faecal deposits by insects or rodents, etc. These can produce unrealistic results.

vi. *Reagent Quality*: Ensure that only analytical grade reagents are used for the analysis.

vii. *Water Quality*: Only water of distilled water grade or better should be used. In the case of analysis for micronutrients, ultra-pure water (Resistivity > 19 mohms) should be used. Regularly test water, especially before using it to prepare reagents.

viii. *Instrumentation*: The precision and accuracy of instruments have to be checked regularly as recommended by the manufacturers. However, the instrument must be properly standardized and calibrated each time it is used. Results from soil-test kits need to be cross-checked with laboratory analysis from time to time.

ix. *Analyst*: The analyst can be a major source of errors. This could result from one or more of the following:

- improper preparation of reagents;
- careless recording or transcribing of results;
- calculation error;
- improper use of reference materials;
- inaccurate dilutions/concentration of sample, etc.

J.I. Uponi
Analytical Services Laboratory, IITA, Ibadan, Nigeria

To minimize the analyst error, the analyst has to attend refresher courses regularly; reducing the monotony of tasks performed by occasional change of assignment has been found to be helpful.

x. *Methodology*: Every analytical methodology has its limitations. For example, calcium may be determined using the AAS but one needs to take care of the interference from phosphorus by adding some lanthanum to the extract.

DETECTING ERRORS IN SOIL AND PLANT ANALYSIS DATA

i. **Standard reference materials:** The use of standard reference materials (SRM) can enable the detection of errors in the analytical data. SRMs are well-characterized materials which are produced in large quantity and independently certified for one or more properties. Appropriate SRMs should be analysed along with samples at regular intervals.

ii. **Internal (secondary) reference samples**: These are reference samples generated within the laboratory of the analyst. This is done by preparing a large amount of sample materials. This material is thoroughly mixed for homogeneity. It is then analysed repeatedly along with a SRM to establish its own properties. Once this is established, SRMs need not be used frequently except to crosscheck the internal reference sample.

iii. **Inter-laboratory sample exchange**: Exchanging samples and analytical results with other laboratories can be very useful in monitoring data quality. If other laboratories are succeeding and you are not, seek advice from the better laboratories. The International Plant Exchange (IPE) and the International Soil Exchange (ISE) programmes of the Wageningen Agriculture University, The Netherlands, are good examples.

iv. **Cross-checks of related analytical parameters**: This is also a useful tool for checking data quality. For example, one does not expect a soil with pH 7 to have exchangeable acidity. See notes below for some general guidelines for cross-checked soil test values.

v. **Control charts**: This involves the use of statistics for judging the acceptability of the results. The chart can only be used after accumulating data of repeated analysis of the check sample (SRM) of (IRM). Calculate the X and SD as follows:

$$X = \frac{\text{Sum of all analysis results for SRM}}{\text{No. of times analysed}} \qquad SD = \frac{\sqrt{(x - \bar{x})^2}}{n - 1}$$

Whenever the deviation of the test result from the mean (X) is not more than 2SD, accept the result as alright. When the deviation is greater than 2SD but less than 3SD, one may accept the result but investigate the cause of the wide deviation. When the deviation is 3SD or more, reject the result, identify the cause of the variation and repeat the analysis.

Some hints for checking soil analytical data

i. pH-KC1 should be lower than pH-H_2O
ii. Exchangeable acidity > 0 when pH-H_2O<5.4
iii. Exchangeable acidity = 0 when pH-H_2O>5.4
iv. $CaCO_3$ may be present when pH-H_2O > = 6.5
v. %Base sat. should be < 100 when pH-H_20 < 6.5
vi. C:N ratio should be between 7 and 20
vii. Total-N should be higher than NO_3-N
viii. Exchangeable Ca should be > exchangeable K in untreated soil.

Data collection, calculations and reporting

Various types of instruments are used in soil and plant testing for measuring the physical and chemical properties of samples. The results usually come in the form of analogue or digital electronic signals. For these signals to have any meaning, the instrument must have been calibrated using a known standard.

The result from the instrument could be recorded manually by the analyst or automatically using a personal computer (PC). Most of the more modern laboratory equipment now has provision for sending data directly to a PC via the RS232 port. Some field testing equipment, like the RQflex, has the capability of storing analyses results and downloading the results to a PC. Automatic data transfers minimize errors that could have arisen from transcribing data.

Where the data are collected manually, it is necessary to have a laboratory/field notebook. The notebook should contain the following information.

(1) Type of analysis, e.g. exchangeable acidity in soil.
(2) Date of analysis.
(3) Number of samples in the batch.
(4) Sample identity and results.
(5) Name of analyst.
(6) Others, e.g. reference samples used.

In the absence of a field notebook, worksheets containing all the information listed above may be used.

CALCULATIONS/REPORTING

The material to be tested usually undergoes various types of pre-treatment such as:

(1) sampling/sub-sampling;
(2) weighing;
(3) digestion/extraction;
(4) dilutions/concentration.

All these pre-treatments have to be taken into consideration when reporting the final result of the analysis.

The following example will help to illustrate this clearly:

J.I. Uponi
Analytical Services Laboratory, IITA, Ibadan, Nigeria

Exchangeable acidity by AgTU method

***Procedure*:**

1. Weigh 2.5 g of air dry soil (<2 mm) in extraction cup.
2. Add 30 ml of AgTU solution to the soil.
3. Stir for 25 minutes on a mechanical stirrer.
4. Filter through Whatman No. 5 or 6 filter paper.
5. Pipette 10 ml of the AgTU extract in a small glass vial and add a few drops of phenolphthalein indicator.
6. Titrate the extract with 0.01 N NaOH until a purple colour appears and remains stable.
7. Record the volume (V_{NaOH}) of NaOH used.

***Calculations*:**

1. Note that by extracting 2.5 g of soil with 30 ml of extractant, the exchangeable acidity of 2.5g soil has been taken into the solution.

   Exch acidity of 2.5 g soil = meq acidity in 30 ml extract

2. Since only 10 ml out of 30 ml of extract was used for the titration, the result has to be multiplied by 3 (i.e. 30 ml/10 ml) to give the acidity of the 30 ml of extract.

3. The milliequivalent of NaOH used for the titration = millieqvalent of acidity in titrated extract.

   Meq NaOH = Meq Acidity
   $= V_{NaOH}$ X N_{NaOH}

   where V_{NaOH} = Volume of NaOH used
   N_{NaOH} = Normality of NaOH used
   $= V_{NaOH}$ X 0.01 i.e., meq of 10 ml of extract.

4. Combining 1-3 above, meq acidity of 2.5 g soil = V_{NaOH} X 0.01 X 3

5. However, for reporting purposes, exchangeable acidity is usually expressed as meq/100 g soil. But in (4) above there is meq/2.5g soil. To report the result in standard form, therefore, multiply by 40, i.e. 100 g soil / 2.5 g soil

   Finally:

   Exch. acidity meq./100g = V_{NaOH} X 0.01 X 3 X 40
   = V_{NaOH} X 1.2

It is essential to have a good understanding of the units in which the final results are to be expressed. This is because often the results may need to be converted to other units.

Interpretation of soil survey data

The aims of a il survey report should be:

- to tell the potential user what information there is;
- to emphasize the practical importance of that information;
- to help each kind of users find the information they need, and enable them to understand it.

The people who are interested in the results of a survey vary in backgrounds and interests (Dent and Young, 1981). Therefore, the interests and technical knowledge of each must be identified and each must be able to locate relevant material in a comprehensive form.

SOIL SURVEY REPORT

Dent and Young (1981) gave an outline for a soil survey report. However, the general arrangement of a typical report is as follows:

i. *How to use the soil survey*: This is normally produced as a guide printed inside the front cover of the report.

ii. *General soil map for broad land-use planning*: This gives a brief description of soils and the landscapes.

iii. *Use and management of the soils*: This deals with the interpretation, land-use potential and management for crops, pasture, woodlands, engineering uses, recreation and wildlife, habitat, inclusive of interpretative tables.

iv. *Description of the soils*: Mostly pedological details but each ending with a paragraph on limitations, land capability and management.

v. *Formation and classification of the soils*: This is usually short and only semi-technical.

vi. *General nature of the area (physical setting of the area)*: This deals with the broad physical environment, printed first in some survey reports.

The above format applies both to general-purpose survey and special-purpose soil survey. The latter is directed at a specific object, or problems, while the former is often for a variety of uses.

INTERPRETATION OF SOIL SURVEY REPORTS

Soil survey reports usually include interpretations of their findings for land-use planning purposes in the form of land capability or suitability classifications. The aim of these classifications is to guide planning decisions in such a way that the resources of the environment are put to the most beneficial use, whilst at the same time conserving them for the future.

A.A. Amusan
Department of Soil Science, Obafemi Awolowo University, Ile-Ife, Nigeria

LAND CAPABILITY CLASSIFICATION

Capability is the potential of the land for use in specified ways or with specified management practices (Dent and Young, 1981). Land capability classification (LCC) is therefore a ranked system based on the severity of land limitations (for example, slope, flood or erosion risk) for general agricultural use.

In descending sequence of assumed desirability, LCC is as follows:

a. arable use for any crop and without soil conservation practices;
b. arable use with restrictions on choice of crops and/or with soil conservation practices;
c. grazing of improved pastures;
d. grazing of natural pastures or, at the same level, woodlands; and at the lowest level;
e. recreation, wildlife conservation, water catchment and aesthetic purposes.

Land which is allocated to any particular capability class has the potential for the use specified for that class and for all classes below it. The land-use alternatives of capability classes are given in Table 1. Limitations are land characteristics which have an adverse effect on capability. Permanent limitations are those which cannot easily be changed, at least by minor land improvements (for example, slope angle, soil depth, liability to flooding). Temporary limitations can be removed or ameliorated by land management (for example, soil nutrient content and minor degree of drainage impedence).

TABLE 1
Land-use alternatives of capability classes

		Management under cultivation				
Capability class	Limitations	Choice of crops		Conservation practices	Cultivation	Pasture (improved)
I	few	any		none	X	X
II	some	reduced	or	moderate	X	X
III	severe	reduced	and/or	special	X	X
IV	very severe	restricted	and/or	very careful management	X	X
V	other than erosion					X
VI	severe					X
VII	very severe					
VII	very severe					

From Table 2, three categories are recognized: capability classes, subclasses and units. A capability class is a group of capability sub-classes that have the same relative degree of limitation or hazard (Class I-VIII). Classes I-IV can be used for cultivation whilst classes V-VIII cannot. Classes I-IV can conveniently be thought of as 'very good', 'good', moderate and 'marginal' arable land respectively (Klingebiel and Montgomery, 1961).

A capability subclass is defined as a group of capability units that have the same major conservation problem/limitations. Four broad conservation problems or limitations are recognized: e- erosion hazards; w- excess water; s- soil root zone limitations (depth, stoniness) and c- climate limitations. A capability unit is a group of soil mapping units that have the same potential limitations and management responses.

LAND SUITABILITY CLASSIFICATION

This is the process of assessing the suitability of land for specified kinds of use. It deals with the fitness of the land for a given use, this being implied by the word 'suitability' rather than capability (see Table 3).

TABLE 2
Structure of land capability classification

	Capability Class	Capability Sub-class	Capability Unit	Mapping Unit
Arable	I	IIe, erosion	IIe - 1	P series
	II	IIw, wetness	IIe - 2	Q series
	III	IIs, soil	IIe - 3	R series
	IV	IIc, climate	etc.	
	VI	IIes,		
Non-arable	VII	etc.		
	VIII			

Source: Dent and Young, 1981.

TABLE 3
FAO recommended land class definition (for a system with three suitable classes)

Class	Designation	Definition
S1	Highly suitable	Land having no significant limitations to sustained application of a given use
S2	Moderately suitable	Land having limitations which are moderately severe for sustained application of a given use
S3	Marginally suitable	Land having limitations which, in aggregate, are severe for sustained application of a given use
N1	Currently not suitable	Land having limitations which may be surmounted in time, but which cannot be corrected with existing knowledge at currently acceptable cost
N2	Permanently not suitable	Limitations appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner

The FAO framework (FAO, 1976) for land evaluation is a standard set of principles and concepts on which national or regional land evaluation systems can be constructed.

TERMS USED IN FAO LAND SUITABILITY CLASSIFICATION

Some symbols are sometimes used for two or more land quantities/characteristics or deficiencies and may be particularly confusing; for example:

c - climate or soil composition or bush or tree cover;
d - soil depth or drainage;
e - erosion or soil structure;
s - general soil deficiency, or salinity, or stoniness or even slope.

REFERENCES

Dent, D. and Young, A. 1981. *Soil Survey and Land Evaluation*. George Allen and Unwin, London.

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Klingebiel, A.A. and Montgomery, P.H. 1961. Land capability classification. US Government Printing Office.

AN EXAMPLE OF MODIFIED US BUREAU OF RECLAMATION LAND SUITABILITY CLASS SPECIFICATIONS

Land characteristics	Class 1 Irrigable	Class 2 Irrigable	Class 3 Irrigable
SOIL		Fine sand to loamy	Fine sand to loamy
Topsoil Texture (0 to 30 cm)	Porous fine sandy loam to fine sand/ fine sandy clay loam	fine sand	fine sand
Subsoil texture (30 to 80 cm)	As top soil	Porous fine sandy loam to fine sandy clay loam	fine sand to fine sand
Depth (minimum)	150 cm	130 cm	110 cm
Available water capacity (minimum)	150 mm m^{-1} soil	120 mm m^{-1} soil	90 mm m^{-1} soil
Infiltration rate after 4h	0.7 - 5.0 cm h^{-1}	5.0 - 12.0 cm h^{-1}	12.0 - 15.0 cm h^{-1}
TOPOGRAPHY			
Slopes	$\leq 0.5^{o}$	$\leq 0.5^{o}$	$0.5 - 1.0^{o}$
Levelling requirements for surface irrigation	$\leq$ 350 m^3 ha-1	350 - 750 m^3 ha^{-1}	750 - 1000 m^3 ha^{-1}
Vegetation cover	moderate to low clearing costs	moderate clearing cost	moderate to high clearing costs
DRAINAGE Groundwater table	Normally > 10 m	7 - 10 m	5 - 7 m
Drainage	No immediate farm drainage required; profiles well drained	No immediate farm drainage required; profiles well drained	Minor farm drainage required in place. Good to moderate profile drainage

Class 4	Restricted irrigable or special use. Includes lands with coarse soils (fine and medium sand, loamy fine sands); high IR rates of greater than 15.0 cm h^{-1}; slopes between 1° to 3°; land levelling requirements greater than 1000 m^3 ha^{-1}; groundwater table levels within 5 m of the surface; poorly drained profiles. These soils are considered suitable only for overhead or drip irrigation systems, although small basin irrigation may be possible on a small scale.
Class 5	Provisionally non-irrigable. Includes lands underlain by laterite within 150 cm of the soil surface, additional economic and engineering studies are required to determine whether drainage is required or is practical.
Class 6	Non-irrigable: Includes lands with excessive topographic, flooding or drainage problems which are considered to be non-correctable at an economic rate.

Interpretation of soil test data

The purpose of soil testing is to provide a guide in soil fertility management. Soil test data are just numbers (quantities) which have no meaning unless they can be interpreted in terms of soil-nutrient level: crop-yield relationship. The process of determining this soil:crop relationship is referred to as **calibration** of soil test values; it is a field research study. Two main types of information, derived from calibration studies, form the basis for interpreting soil test data and making appropriate soil management recommendations:

- critical minimum soil test values;
- soil test rating (fertility classification criteria).

CRITICAL MINIMUM SOIL TEST VALUE

This is the level of a given nutrient in soil below which the nutrient is said to be deficient, and above which it is said to be sufficient for optimum crop growth and yield. Critical soil test value determines if the soil is deficient or sufficient in that nutrient. However it does not determine:

- the degree of deficiency;
- the magnitude (quantity) of amendment needed to correct the deficiency.

It indicates only if the application of this nutrient as fertilizer should or should not be recommended. With this index, soil test results can be evaluated but only two rate options can be considered: no application, and application of an amount deemed adequate, which is the same for all degrees of deficiency. Thus a uniform amount of fertilizer is added in all cases when the soil test is below the critical value and none is added when it is above the critical value. This is better than not conducting a soil test and fertilizing all cases just to ensure that deficiency does not occur, i.e. blanket recommendation.

The critical soil test value of a nutrient varies with soil type, crop species and the environment (ecology). It must be established for each crop and the different soil-climatic environment of each country. Also, critical values vary with the method of soil analysis employed. Therefore, soil test data must always state the method of analysis.

The critical soil test values established for the most deficient nutrients in Nigerian soils are given in Table 1. These values can be used as an approximate guide in other tropical countries where such values have not been established.

The critical nutrient concentration in plant tissue (internal critical minimum values) can serve a similarly limited purpose as the critical soil test values (external critical minimum values). Adepetu and Adebusuyi (1985) have summarized the most commonly reported critical crop nutrient concentrations; some of these are shown in Tables 2, 3 and 4 for maize, rice and sorghum respectively.

J.A. Adepetu
Department of Soil Science, Obafemi Awolowo University, Ile-Ife, Nigeria

Note that crop parts and stages of growth to sample plant for analysis are stated. The internal critical values stated may not be valid for parts and growth stages other than those stated in the tables.

SOIL TEST RATINGS: FERTILITY CLASSIFICATION CRITERIA

Soil chemical test values (fertility status) are grouped into categories reflecting the extent of deficiency or adequacy, in relation to crop nutrient needs. These soil test ratings are used as criteria for classifying soil-test values into fertility classes which can be translated into fertilization requirements. The classification criteria are described as low, medium and high soil test classes suggesting large, medium and little or no fertilizer requirements respectively.

The ratings could later be refined into very low, low, medium, high and very high soil test value categories, as soil testing programmes advance further in the country. The criteria established for soil fertility classification in Nigeria are shown in Table 5. This can be adopted in other tropical countries where such criteria have not been established. It will be noted that only nutrients that are most frequently deficient in Nigerian soils are included in the table; these nutrients are the present focus of soil testing in Nigeria because they are the most likely fertility problems that a farmer in Nigeria will encounter on the farm. It will also be noted that while Bray-No-1 extractant is used for P determination in most soils of Nigeria, Bray-No-2 is used on the acid soils of southeastern Nigeria.

The criteria in Table 5 and further information from field fertilizer-rate studies are used to adjust fertilization rates to soil test values. In this way, appropriate corresponding fertilization rates are established for the different fertility classes of the area. The fertilization rates at low and medium fertility classes established for different crops on Nigerian soils are presented in Table 6. This table shows that fertilization is unnecessary at high fertility.

TABLE 1
Critical soil-test values for Nigerian soils

Chemical Property	Critical values	Extraction Method
Total N	0.11%	Micro-kjeldahl.
NO_3-N	30 mg/kg	
Avail. P:	10 mg/kg 20 mg/kg	Bray - No -1 Bray - No 2.
Exch. K	0.2 me/100g (78 kg/ha)	1N Neutral NH_4OAc
O.M.	2.0%	Walkley and Black
Avail S	6 mg/kg	0.1M Ca $(H_2PO_4)_2$
Mg	0.28 me/100g	IN Neutral NH_4oAc
pH	5.0	0.01M $CaCl_2$
Zn	1.0 mg/kg	0.1N HCl
B	0.16* mg/kg	Hot water

*Clear response to B has been found only on cotton.
Source: Adepetu and Adebusuyi, 1985; Adepetu, 1990.

TABLE 2
Frequently reported critical plant-tissue values (internal critical) for maize

Nutrient	Critical levels	Plant part	Plant growth stage
N (%)	2.8, 2.9, 3.0	Ear leaf or sixth leaf from base	Tasselling; silk
P (%)	0.23, 0.25 0.30	Ear leaf	Tasselling
K (%)	1.7, 1.8, 2.1, 2.8	Ear leaf	Tasselling
Mg (%)	0.15,0.20, 0.25	Ear leaf	Tasselling
Zn (ppm)	12, 15	Ear leaf	Tasselling
B (ppm)	6	Ear leaf	Tasselling
Mn (ppm)	15, 20	Ear leaf	Tasselling
Fe (ppm)	11, 15	Ear leaf	Tasselling
S (%)	0.14	Ear leaf	Tasselling

Source: Adepetu and Adebusuyi, 1985.

TABLE 3
Frequently reported critical plant-tissue test (internal critical) for rice.

Nutrient	Critical levels	plant part tested	Plant growth stage
N (%)	3.0	Recently	Mid-tillering
	2.6	matured	
	2.4	leaf	Maximum tillering or panicle differentiation
P (%)	0.03	Most fully expanded leaf straw	Tillering or Panicle differentiation
	0.04		
K (%)	1.2	leaf	Mid - tillering
	1.0	leaf	Maximum tillering
	0.8	leaf	Panicle differentiation
Mg (%)	0.12	leaf	Mid-tillering
	0.16	leaf	Maximum tillering
Zn (ppm)	15	leaf	Mid-tillering
	22	leaf	Panicle differentiation
Mn (ppm)	20	leaf	Panicle differentiation
*Fe (ppm)	80,150,240	leaf	Panicle differentiation

* Wide variation due to variety differences.
Source: Adepetu and Adebusuyi, 1985.

However, experience in Nigeria shows that even at high fertility level, some amount of N is required at later stages of growth of most crops except legumes like cowpea and soybean. For example about a third of the fertilizer N rate for medium fertility soil is applied to high fertility soil at tasselling stage of maize.

TABLE 4
Frequently reported critical plant-tissue test (internal critical values) for sorghum

Nutrient	Critical levels	Plant part tested	Plant growth stage
N (%)	3.2-4.4	Youngest fully	37-56 days old
	2.5	developed leaf	
P(%)	0.2-0.6	Youngest fully developed leaf	37-56 days old
K(%)	1.5	leaf	flowering
	3.0-4.5	Youngest fully developed leaf	23-39 days old
Mg(%)	0.35-0.50	Youngest fully developed leaf	23-39 days old
Zn(ppm)	7, 10	third leaf below head	82 days old
	15	Young fully developed leaf	
Mn(ppm)	40-60	leaf	23-39 days old
Fe(ppm)	160-250	whole plant	23-39 days old
	55-20	whole plant	37-56 days old

Source: Adepetu and Adebusuyi, 1985.

OTHER FACTORS TO CONSIDER IN SOIL TEST INTERPRETATION

For balanced soil test interpretation and effectual soil management recommendations, the following factors, in addition to those listed in Table 1, should be considered:

Soil reaction (pH)

Soil pH can be rated according to classes shown in Table 7. Interpretation of pH values must take into consideration the method of measurement used. For most crops, the neutral pH range is the optimum i.e. pH 5.5-6.5. ($CaCl_2$). The following deductions can be made at low and high pH values of most tropical soils:

TABLE 5
Fertility classification criteria for Nigerian soils

Soil fertility classes	Soil-test ranges					
	OM (%)	Total-N (%)	Avail-P (mg/kg) Bray-1 Bray-2	Exch.K (me/100g)	Avail. S (mg/kg)	Zn (mg/kg)
Low	<1.5	<0.1	<8 <15	<0.15	<5	<1.0
Medium	1.5-2.5	0.1-0.2	8-20 15-25	0.15-0.30	5-7	1.0-3.0
High	>2.5	>0.2	>20 >25	>0.30	>7	>3.0

Sources: Sobulo and Adepetu, 1987; Adepetu, 1990.

TABLE 6
Nutrient requirement of crops at 'low' and 'medium' soil fertility levels.

Crops	Amount of nutrient element needed (kg/ha) at low and medium soil fertility							
	Low fertility				Medium fertility			
	N	P	K	S	N	P	K	S
Maize	100	20	40	20	50	10	20	10
Cowpea and Soybean	20	30	20	20	-	15	10	-
Tomato	120	50	100	20	30	25	50	10
Yam	50	10	70	20	25	-	45	10
Tall Upland Rice	30	30	50	20	20	15	25	10
Short Upland Rice	70	20	40	20	20	15	25	10
Sorghum/millet	80	25	40	20	50	15	25	10

Source: Sobulo and Adepetu, 1987.

a. ***Low pH values (less than 5.0)***

i. Micronutrient: all except Mo become more available with increasing acidity. May be present in toxic levels at low pH.

ii. Phosphorus: phosphate availability may be inhibited because of Fe and Al ions which combine with P to form insoluble compounds.

TABLE 7
Soil-test ratings for pH, CEC and base saturation

Classes	Soil-test ranges		
	pH ($CaCl_2$)	CEC (me/100g)	BS (%)
Very low	-	<15	<20
Low	<5.0	5-15	20-40
Medium	5.0-6.5	15-25	40-60
High	6.5-8.0	25-40	>60
Very high	>8.0	>40	-

iii. Al ions are released from clay lattices onto clay surfaces and soil solution at pH below 5.0. Therefore Al toxicity is a possibility at this pH range.

iv. Nitrification: may be reduced because of reduced microbial activities at pH of less than 5.0. This may cause N to become unavailable to crops.

b. ***High pH values (above 8.0)***

i. Micronutrients: availability is reduced with increasing pH except Mo.

ii. Phosphorus: solution P tends to be converted to insoluble calcium phosphate at high pH, thereby reducing P availability to crops.

iii. Boron toxicity is common in saline and sodic soils.

iv. Sodium: most soil pH values greater than 8.0 indicate ESP of above 15%; likelihood of soil structural and reclamation problems.

v. Nitrification: high pH decreases microbial activities, leading to poor rate of OM nitrification.

c. ***Lime requirement***

Since the availability of a lot of essential nutrients as well as activities of microbes are affected by soil pH, it becomes necessary to maintain pH at the optimum range. Soil test pH values will indicate when it becomes critical to amend soil with lime.

Cation exchange capacity

The results of the soil test for CEC can be used as an indication of the potential fertility of the soil, potential pattern of crop response to fertilizer application, a rough guide to types of clay minerals present, and a guide to method of fertilizer application for efficient utilization by crops. Table 7 shows that CEC values (by NH_4OAC leaching) that fall below 15 me/100g are low; such soils are probably dominated by low activity clays (LAC), are poor in organic matter, may have high leaching problems because of poor capacity to retain cations, and they may require careful management of the fertilization process. In fact, a CEC value of less than 10 me/100 g in the plough layer indicates a soil of low production potential under irrigation. Any CEC value of less than 5 me/100 g indicates a level of infertility normally unsuitable for irrigated agriculture; the soil has extremely poor capacity to retain applied nutrient in the root zone of soil.

Base saturation

This is the proportion of CEC accounted for by exchangeable bases (Ca, Mg, K and Na). It may be used as an index of soil fertility. It is used in the FAO/UNESCO system of soil classification as an indication of soil fertility status as follows:

- greater than 50% in 20-50cm depth = eutric or fertile soils
- less than 50% in 20-50cm depth = dystric or less fertile soils.

Cation ratio

Imbalance in the relative proportions of cations in soil can cause serious plant nutrition problems. In addition, imbalance may have adverse effects on soil physical conditions. Table 8 is a summary of critical ranges of cation ratios and the effects of these ratios on crops. The table shows that nutrient availability depends not just on the analytically determined available-nutrient status of that nutrient, but also on the interaction between the given element and other soil constituents.

Crop type

This determines the quantity of amendment material needed at each level of soil test. Different crop species need different quantities of amendment; the need is a genetic characteristic of each plant species. Also crops have a different capacity to tolerate adverse soil nutrient conditions; for example while some crops like cassava and pineapple are tolerant of Al toxicity, some other crops, e.g. tomato and maize, are very sensitive to it and will not perform well under this condition. Therefore soil content of exchangeable Al may dictate the choice of crop to cultivate.

Electrical conductivity

Electrical conductivity (EC) measures the total quantity of soluble salts in soil. It is usually determined in saturated soil pastes and in 1:1 to 1:5 soil: water mixture. In field tests, a 1:2.5 or saturated paste is used. Values of EC are quoted in dS m^{-1} (formerly mmhos cm^{-1}) at 25^oC.

TABLE 8
Critical-values and effects of some chemical ratios in soil

Ratio	Critical values	Effects
Ca:Mg	>5:1	Mg increasingly unavailable with increasing Ca. Also, at high pH, P available may be reduced.
	3:1-4:1	Optimum range for most crops
	<3:1	P uptake may be inhibited
	1:1	Lowest acceptable limit: Ca availability slightly reduced at lower values
	Ca:Mg	ratio commonly decrease with depth and often with cultivation
K:Mg	>2:1	Mg uptake may be inhibited
	>3:2	Recommended levels for field crops (available)
	<1:1	Recommended levels for vegetables
	<3:5	Recommended levels for fruit crops
K:CEC	2%	Suggested minimum level to avoid K-deficiency in tropics
	>25%	K-rich soils (very rare) with similar effects on soils as high Na; i.e. adverse effect on soil physical conditions
Na: CEC	>15%	Sodic soils. Effect usually gradual. 50% yield reduction in sensitive crops
(ESP)	15-25%	50% yield reduction in semi-tolerant crops
	35%	50% yield reduction for tolerant crops
Al:CEC	>30%	Al toxicity
	30-85%	Generally toxic
	<60%	Tolerated by sugar cane
	30-85%	Generally toxic
	< 60%	Tolerated by sugar cane
	85%	Tolerated by only a few crops.
B.S.	>60	Generally fertile soils
	20-60	Generally less fertile soils
	<20	Poor soil fertility
	>50	Eutric
	<50	Dystric

Source: Landon, 1984.

TABLE 9
USDA classification of salt-affected soils

Soil	EC (mmhos cm^{-1})	ESP	pH	Description
Saline	>4	<15	Usually <8.5	Non-sodic soil containing sufficient soluble salts to interfere with growth of most crops.
Saline-sodic soils	>4	>15	Usually <8.5	Soils with sufficient exchangeable sodium to interfere with growth of most plants, and containing appreciable quantities of soluble salts.
Sodic soils	<4	>15	Usually >8.5	Soils with sufficient exchangeable sodium to interfere with growth of most plants, but without appreciable quantities of soluble salts.

Source: Landon, 1984.

EC measurement is used as an indication of the degree of salinity and sodicity of soil (Table 9). These soil conditions occur more commonly in the arid regions where they may constitute very special problems in soil and water management for crop production. Soils with high sodium levels are referred to as sodic soils (formerly "alkali" soils); sodic soils may or may not be alkaline (i.e have high pH). Saline soils occur where the supply of salts, e.g. from weathering, rainfall, etc., exceeds their removal, e.g. by leaching or flooding. They tend to be prevalent where evapotranspiration exceeds precipitation and where there is no lengthy rainy season. Irrigation is needed for crop growth in such areas, although this may itself induce salinization unless salts are leached regularly and water tables are kept low by adequate drainage.

Toxic effects of excessive salts reduce crop growth because some ions, e.g. Na^+,Cl^-, $SO_4^=$ are specifically toxic to some crops; also water availability to the crop is reduced by excessive salts through the action of osmotic pressure: the high salt concentration in soil water reverses the flow of water into the plants by osmosis. In addition nutrient inbalance may result from excessive salts and adversely affect nutrient uptake and crop growth. The effects of high Na are also noticeable in deleterious effects on soil structure.

In interpreting EC values, Table 10 is useful when the values are determined on saturated extracts. Management recommendations made for the different values are influenced by other factors such as the quality of irrigation waters, soil texture, salt types present, crop varieties and species, soil drainability, stage of crop growth and climatic characteristics of the area.

TABLE 10
General interpretation of EC values

USDA soil class	Designation	EC (mmhos cm^{-1})	Total salt content (%)	Crop reaction
0	Salt free	0-2	<0.15	Salinity effects are negilible except for the most sensitive plants.
1	Slightly saline	4-8	0.15-0.35	Yields of many crops restricted
2	Moderately saline	8-15	0.35-0.65	Only tolerant crops yield satisfactorily
3	Strongly saline	>15	>0.65	Only very tolerant crops yield satisfactorily

Source: Landon, 1984.

Economic considerations

In making recommendations to farmers from soil test results, the financial situation of the farmer must be taken into consideration. This is to help determine if recommendations should give maximum returns per dollar invested, maximum returns per hectare of the farm, or something in between. A poor, small-scale farmer requires a recommendation that gives optimum gain per dollar invested, while a large-scale commercial farmer will benefit more from recommendations that give maximum return per hectare of land.

The guidelines given in Table 6 are intended for small-scale farmers. Recommendations for large-scale commercial farmers can be made on the basis of more finely partitioned, narrow-range classes than are shown in Table 6, in order to make recommendations more soil test specific. Table 11 shows ranges of P-fertilization rates for Nigerian soils corresponding to

different ranges of soil test values; and from which fertility rates for specific soil test values can be deduced. Similar ranges have been developed for N and K. The specific recommendation can, however, be more accurately made with the aid of a computer.

TABLE 11
Fertilizer-phosphorous (P or P_2O_5) requirements of crops at different soil test levels

Crop/Soil-Test Level Bray-1-P (ppm)	FERTILIZER - P RATE kg P/ha				FERTILIZER - P_2O_5 RATE kg P_2O_5/ha			
	0-8	8-15	15-20	>20	0-8	8-15	12-20	>20
Maize	50-30	30-20	20-10	Nil	120-70	70-45	45-25	Nil
Cowpea	40-25	25-15	15-10	Nil	100-60	60-35	35-25	Nil
Soyabean	40-25	25-15	15-10	Nil	100-60	60-35	35-25	Nil
Cassava	30-20	20-15	15-10	Nil	70-45	45-35	35-25	Nil
Yam	30-20	20-10	Nil	Nil	70-45	45-25	Nil	Nil
Tomato	70-50	50-25	25-10	Nil	160-120	120-60	60-25	Nil
Rice	45-30	30-20	20-10	Nil	100-70	70-45	45-25	Nil
Maize/Cassava	50-30	30-20	20-10	Nil	120-70	70-45	45-25	Nil
Sorghum/Millet	30-20	20-10	10-5	Nil				
Bray-2-P (ppm)	0-10	10-20	20-25	>25	0-10	10-20	20-25	>25

Source: Adepetu, 1986.

USE OF COMPUTERS IN SOIL TEST INTERPRETATION

Computer programmed recommendations have the advantage of:

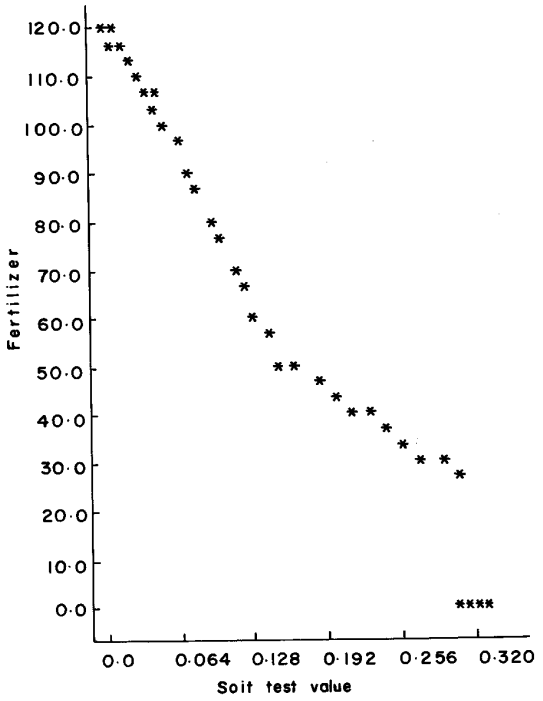
- accuracy;
- speed;
- possibility of including and taking into consideration many factors without significantly increasing the time needed to make the recommendation;
- possibility of using the results to make soil test summaries which help pinpoint problem areas and aid extension efforts in a given area.

TABLE 12
Nutrient fertilizer rates for cassava

**	The soil contains 45 soil - NO_3 - nitrogen (ppm). The amount of fertilizer to be added to the soil is 0 kg N/ha.
**	The soil contains 10.4 Bray no. 1 phosphorus (ppm). The amount of fertilizer to be added to the soil is 18.2857 kg N/ha.
**	The soil contains 0.13 potassium (me/100g). The amount of fertilizer to be added to the soil is 34 kg N/ha.
**	The soil contains 4 sulphur (ppm). The amount of fertilizer to be added to the soil is 20 kg S/ha.
**	The soil pH is 6.3. The amount of lime to be added to the soil is 0 kg dolomite-lime/ha.

Computer aided recommendation is not yet a common practice in developing tropical countries. However, with increasing availability and use of personal computers in these countries, it is now possible to develop computer programs using available soils research data in those countries. The first attempt at such development in Nigeria (Adepetu and Olufokunbi, 1987) gave recommendation outputs such as in Table 12. The program was also designed to give graphical output such as Figure 1, which could be used to determine fertilization rates whenever a computer facility is unavailable in the laboratory. This graphical output is particularly important for developing countries where only a few laboratories and extension personnel may have access to computer facilities.

FIGURE 1
Potassium (meq/100 g) by fertilizer rate (kg K/ha) for tomato (Adepetu and Olufokunbi, 1987)



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Soil tests in relation to fertilizer recommendations

Soils vary tremendously in their ability to supply nutrients to plants. When a soil has low ability to provide plants with one or more nutrients, it is usually the practice to apply these nutrients to the soil in the form of fertilizers in order to increase crop yields. When farmers invest money in costly fertilizers, it is logical that they are interested in using fertilizers on only those areas where yields will be increased. Applying chemical fertilizers without soil tests is like buying a box from a shop without knowing what it contains! This means that if fertilizers are to be applied in a rational manner, a soil test has to be carried out.

The major purpose of soil tests is to estimate the ability of a soil to supply the various nutrients under specific conditions.

With regard to soil tests, a clear distinction should be made between tests which can be interpreted easily in agricultural terms, such as gypsum requirements, pH and electrical conductivity measurements for salinity/sodicity purposes, and other tests for available plant nutrients in the soil. The latter tests are mainly centred on N, P and K. The values of these tests do not show fertilizer requirements directly. Classifying soil tests values as "high", "medium" and "low" does not indicate how much fertilizer to be applied to get the desired and economical yield increase. To make sound fertilizer recommendations or "site-specific recommendations", soil tests for available plant nutrients must be calibrated with crop response. Unfortunately, soil test interpretation worked out in one area is usually not valid for another different set of agro-ecological conditions. Soil test calibrations which are used or developed in one country (say a developed country) cannot be transferred to another country. New calibrations must be done under local conditions if soil tests are to be used to refine a generalized fertilizer recommendation.

Climatic conditions, weeds, plant diseases and other cultural practices will certainly affect the profitability from fertilizer investment on a particular soil and crop. So one must be concerned not only with which nutrients or fertilizer to apply, but also with which rate of application will provide the best return. Soil testing is a useful tool in determining the appropriate rate of fertilizer application.

ACCURACY AND RELIABILITY OF SOIL TESTS

A chemical soil test attempts to measure how much of a particular nutrient the soil will provide to a crop during its growth period. It is assumed that the amount of the given element extracted by the testing method indicates the amount the crop can remove, that is, the available fraction.

H. Nabhan
Soil Resources Management and Conservation Service
Land and Water Development Division, FAO, Rome, Italy

Because of the extreme complexity of soils, completely reliable predictions of the availability of soil nutrient cannot be expected. So, a soil test method should not be used until information is available on its reliability in the area. Extensive laboratory and field research work is required to determine how reliable a soil test is for a specific nutrient and for a certain crop. Fortunately, much progress has been made during the past 40 years in developing and improving the accuracy of soil testing.

GROWTH FACTORS

Before proceeding to the calibration work required for developing site specific fertilizer recommendations based on soil tests, it is of prime importance to review the growth factors and other relevant variables.

A plant grows under the influence of many environmental factors which together determine the response and final yield. Some of these factors are the amounts of plant nutrients (N, P, K) available in the soil which are determined by the soil test. Others are water supply, temperature, plant population, weeds, salinity status, planting time, and so on.

The plant production system can be expressed in a mathematical equation:

$$Y = b_1x_1 + b_2x_2 + b_3x_3 ....$$

where Y is the yield
x_1, x_2 - are the measured growth factors
b_1 b_2 - are the slopes or regression coefficients

Through graphical and mathematical methods, the influence of each growth factor on the soil test/yield correlation can be measured and corrected.

Growth factors (variables), relevant to calibration studies, can be summarized as follows:

i. **Soil factors:** Soil factors such as pH, salinity, gypsum application, CEC, texture, OM content, predominant clay minerals.

ii. **Climatic factors:** Climatic factors such as water supply/irrigation, temperature, light.

iii. **Farm management factors:** Farm management factors such as previous crops, previous applications of fertilizers, manure, soil amendments, plant density, and so on.

For planning the calibration experiments, it is advisable to keep these variables constant or to a minimum as far as possible, particularly those cited under farm management factors. For example, preliminary results of 62 field trials on calibration showed that variations in wheat response to applied phosphorus can be attributed to the following variables with different magnitudes (expressed as %):

P Olsen 21 %, OM content 12 %, clay 10 %, $CaCO_3$ 8 %, E.C. 6 %]

CALIBRATION OF SOIL TESTS

The aim of the soil test calibration is to obtain correlations between the soil test values (that is, available nutrients in the soil) and crop response to nutrient applications as found in the area where the field experiments are carried out. In other words, when a soil testing method is used, the laboratory tests must be related to crop responses to fertilizer rates under specific conditions. According to G.F. Hauser[1]:

[1] FAO. 1973. Guide to the calibration of soil tests for fertilizer recommendations. *Soils Bulletin 18*. Rome.

"The establishment of a soil testing service, including the preparatory field work and research involved in it, is not a matter of one or two years but longer and should be considered as the first period of a continuous and gradually improving service for the similarly improving farm operations in an area or country."

While relevant field experiments are not easy or cheap, there is no good alternative. Pot experiments, however, may be organized to provide useful information with regard to calibration work.

Pot experiments would serve in:

- comparing crop response and evaluation of soil test methods;
- correlation study;
- selection of soils and places where field experiments can be conducted with a maximum of chances for significant responses to a given nutrient.

Field trials are primarily for:

- calibration of the analytical system;
- verifying the effectiveness of fertilizer application and response on a given soil, for a given crop under real farming and ecological conditions.

For field calibration trials, the treatments are simply five rates of the tested element (say P) equally spaced, the lowest being zero and the highest so chosen to obtain maximum or highest yield. In addition to these increasing rates of P, all plots should be given a basal dressing of other main nutrients. If trace element deficiencies have been observed in the area, these elements should be applied in appropriate quantities.

[Example: rates for P calibration trials are: 0, 40, 80, 120, 160 and 200 kg P_20_5 / ha at 120 kg N and 90 kg K_20 / ha .]

STEPS OF CALIBRATION WORK AND HOW TO DERIVE FERTILIZER RECOMMENDATIONS (EXAMPLE PHOSPHORUS)

A. Calibration of soil P against P concentration in plant tissue

The first step in the whole procedure is the choice of the extractant which can measure the "available" fraction of the element (example P) in soil. One should not start from zero since information on the subject is quite rich. (for example Olsen's method using $NaHCO_3$ extractant). A good responsive crop such as maize or wheat should be used.

Calibrating soil P against P uptake (plant concentration of P) is usually done by pot experiments. Soils used should vary widely in soil P and other relevant factors such as pH, OM and $CaCO_3$.

Plotting plant concentration against soil P may yield a curve like that in Figure 1.

The deviations from the curve (due to relevant soil factors such as pH) may be corrected and this would provide a curve as shown in Figure 2, following the elimination of pH effect. The same procedure is adopted for eliminating other factors, that is, EC and so on.

FIGURE 1
Relationship between soil and plant nutrient concentration

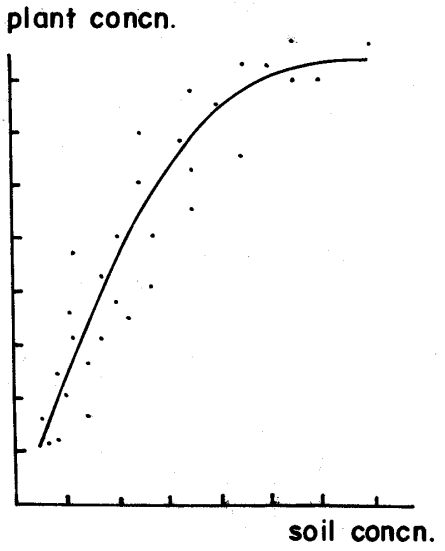
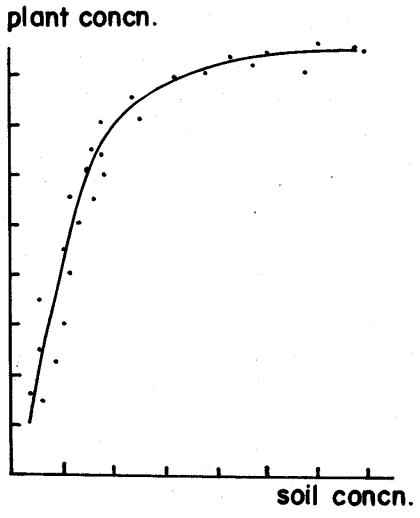


FIGURE 2
Relationship between soil and plant nutrient concentration as corrected for soil pH



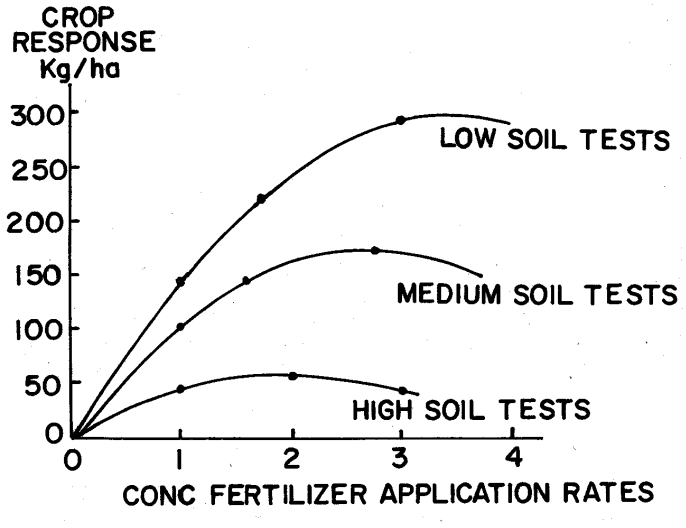
B. Calibration of soil test (P) against yield response to applied P

Once an effective soil extraction has been selected, on the basis of results from (A), the soil test value should be calibrated against yield response to applied P. This work is carried out by field trials as described earlier.

An example of expected response curves from applied P at three levels of soil P is illustrated in Figure 3.

Assuming that "Y_0" is the yield without, and "Y_x" is the yield with applied P, the results of field trials can be expressed as percentage of maximum yield "Y_m" as shown in Figure 4. The figure shows the nutrient requirements in relation to soil P. With increasing levels of soil P (that is, from a to d), the rates of applied P needed to prevent yield losses decrease (that is, from 3 to O). Beyond level "d" of soil P, the application of phosphorus is no longer needed to attain maximum yield.

FIGURE 3
Response curves

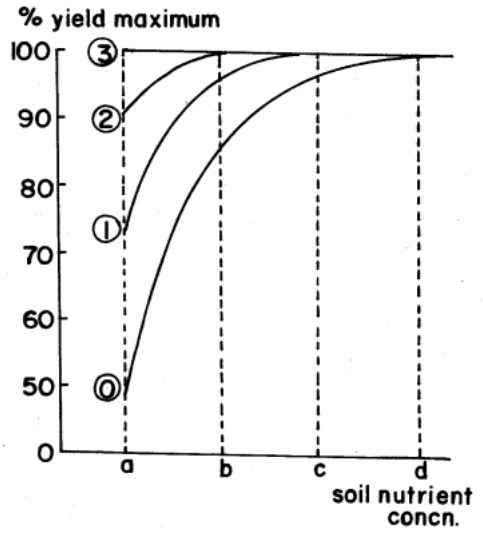


C. Calibration of soil test against optimum rate of applied P ; economic consideration

Definition:

- If increasing rates of applied nutrient (P) are plotted on the abscissa and the monetary values of yield increase (in Rs or US$ for example) on the ordinates, the resulting curve is a normal fertilizer response curve, (Figure 5).
- The straight line "FP_1" (fertilizer price) gives the price for increasing application rates.
- "C" is the point of maximum profit/ha from fertilizer application. "C" is the point where "marginal rate of return" equals zero.
- Point "C" is the point of tangency on the yield response curve for a line parallel to the fertilizer cost line (FP_1).
- The nutrient rate providing maximum profit is called "optimum nutrient rate", i.e. "A".

FIGURE 4
Percentages of maximum yield as affected by soil nutrient concentration and nutrient application



[MRR = $\frac{\text{Value of additional crop - Value of additional fertilizer}}{\text{Value of additional fertilizer}}$

Value/cost ratio "VCR" = $\frac{\text{Value of yield increment due to fertilizer}}{\text{Cost of fertilizer}}$]

It is generally accepted that farmers would not apply fertilizers if the VCR is less than 2 (economic indicator).

Figure 5 illustrates the following:

i. For cost line "FP_1" maximum net profit "C - B" (400 - 135 = 265 Rs) is attained at 100 kg of P (nutrient) per ha., and VCR is 3.

ii. With higher rates of applied P, net profit (distance between R and FP_1) decreases and also the VCR. With lower rates net profit also decreases but VCR increases (at 50 kg P/ha the VCR would be about 4.

iii. In the case of increase in fertilizer price, that is, line FP_2, the maximum profit point is at F. Only 60 kg P/ha (point D) is needed for lower maximum net profit "F - E" and also lower VCR.

With this price (that is, FP_2) the farmer may be reluctant to apply more than 30 kg P/ha (point G) where the VCR equals 2.

FIGURE 5
Determination of economic optimum fertilizer rates

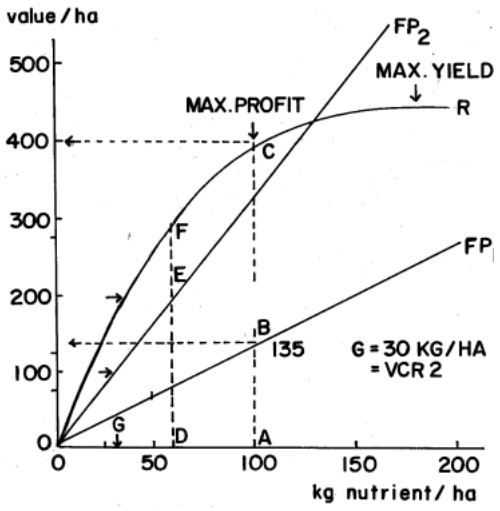


FIGURE 6
Economic optimum fertilizer (P) rates recommended for soils of various fertility classes

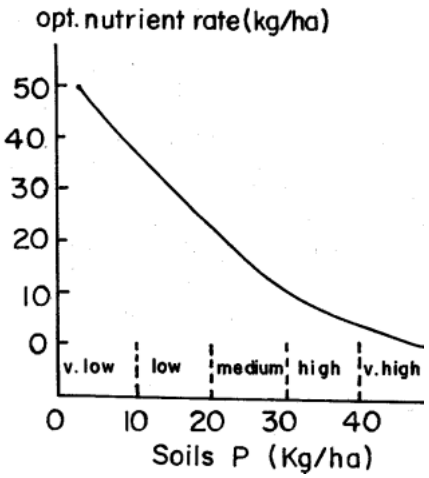
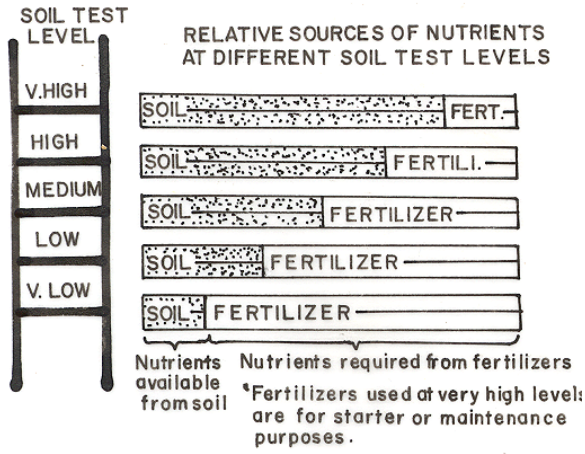


FIGURE 7
Fertilizer requirements in relation to soil test levels



Optimum nutrient rates (i.e., that at point A of Figure 5) obtained from various fertilizer trials are compared with the corresponding soil nutrient (P) content, grouped into fertility classes.

For various soil test classes, ranging from "very low" to "very high" decreasing nutrient rates (i.e. P fertilizers) can be established and recommended to farmers for a certain crop on a specific soil, that is, site specific recommendation (Figure 6). Fertilizer recommendations based on soil tests can be easily visualized in Figure 7. The final output (fertilizer recommendations) of the soil testing laboratory to the farmer would be as in Table 1.

TABLE 1
Standard phosphate (P_2O_5) recommendations

Phosphorus fertility level	P content in soil kg/ha in 0-15 cm depth (Olsen, NaHC03 extractable)	Kg P_2O_5 recommended / ha		
		Cereals	Sugarbeet	Beans
Very low	0 - 10	45	85	20
Low	10 - 20	45 - 35	85 - 75	15
Medium	20 - 30	35 - 25	75 - 65	10
High	30 - 40	25 - 10	65 - 50	0
Very high	40 - 100	10*	50	0

* For maintenance purpose

Overview of production constraints: physical, chemical and nutrient dynamics

The major production constraints in agriculture of sub-Saharan Africa result from the fact that the soils are highly weathered and, therefore, are low in nutrient reserves; they also have a low buffering capacity against acidification. This applies to the savannah as well as to the humid forest zone.

Nutrient depletion, soil acidification, erosion, structural fragility, low activity clay and low organic matter content have been identified as important constraints. Structural fragility is enhanced by the usually low content of silt which also leads to an unfavourable pore size distribution with respect to the capacity to store plant available water. These constraints become manifest with the transition from the traditional slash and burn/shifting cultivation system with long fallow periods, to systems with shorter fallow periods or permanent cropping, i.e. with the need to replace subsistence farming with more productive but sustainable systems. Some examples of constraints follow:

NUTRIENT DEPLETION

Causes	Effects	Solutions
• Leaching • Nutrient removal (export, nutrient mining) • Erosion (removal of fertile topsoil)	• Low yields • Poor ground cover • Low residue return (org. m. removal)	• Manure (stock keeping) • Mineral fertilizer • Residue management • Planted fallow (herbaceous legumes, alley farming)

SOIL ACIDIFICATION

Causes	Effects	Solutions
• Leaching • Org. matter decomposition • Nitrification	• Inhibition of root growth • Induced nutrient deficiency • Low yield	• Liming • Burning • Org. matter management

STRUCTURAL INSTABILITY

Causes	Effects	Solutions
• Org. matter input/output imbalance • Decrease of org. matter content • Improper soil tillage • Lack of soil cover	• Soil compaction • Surface crusting/sealing • Impeded infiltration • Inhibition of root growth • Runoff and erosion	• Cover crops • Org. matter management • Minimum/zero tillage • Fast ground cover

H. Grime
IITA, Ibadan. Nigeria

The question of nutrient supply, i.e. nutrient dynamics can only be adequately dealt with when the soil plant system is seen as a whole. The amount of plant nutrients in the immediate vicinity of roots is far less than the total requirement of plants. Hence nutrients have to move towards the roots through diffusion and mass flow. This movement depends largely on the concentration in the soil solution which is governed by the soil's sorption properties. Therefore, there is no simple relationship between soil test results and plant response. In addition, plants interact with the soil in such a way as to modify the soil environment by exuding organic components, H-ions and by withdrawing water and nutrients. Therefore, uptake properties of the plants, growth rate at different growth stage and specific nutrient demand are important factors.

Soil testing is thus a powerful monitoring tool but caution should be exercised in interpreting its results for assessing nutrient availability and fertilizer requirements. The soil/plant system is a dynamic system whereas soil testing gives only a static picture.

Fertilizer management: some principles

Management of fertilizer is dictated by the need to:

- avoid loss from the soil; and
- replace what is lost.

The main loss mechanisms of the major fertilizer elements (N, P and K) are examined here as guidance for how to manage fertilizer containing them.

POTASSIUM

Potassium is a relatively simple nutrient to understand and to manage. Loss of K occurs primarily by leaching and crop harvest. K is relatively soluble and leaching losses are common especially if cation exchange capacity of the soil is low. To avoid loss by leaching, K should be applied in the root zone during the cropping season. Split application of K is not often justified.

Estimates of nutrient removal through crop harvest (crop export) are given by Sanchez (1976). For example, a maize grain yield of one t/ha contains approx. 15 kg/ha K in the grain which should be replaced with fertilizer if the soil K supply is low. For the same grain yield there will be about 18 kg/ha K in the stover. If the stover is harvested then this additional K export should be taken into account in calculating the amount of fertilizer to apply.

PHOSPHORUS

Phosphorus is much less soluble than K and losses by leaching are minimal. The major loss of P from the soil is by ***crop export*****,** unless erosion occurs. Runoff can wash away P fertilizers if they remain on the soil surface. Soil erosion results in loss of P fertilizer which has been incorporated into the soil. The phenomenon called P fixation by soil can be thought of as temporary loss of P fertilizer to the crop. It is caused by strong adsorption of phosphate on certain soil particle surfaces. The most outstanding cases are volcanic soils high in allophane and Oxisols high in Fe and Al sesquioxides. Because P is relatively insoluble and not susceptible to leaching, it can be applied to the soil at any time during the year.

Because of its low solubility, placement of P very close to the root zone ('spot' or 'band' placement) is sometimes recommended. However, this may encourage rooting near the concentrated area of P application which may result in low rooting volume. A high rooting volume is good especially during drought periods so that the crop can get its water from more of the soil. Therefore, surface broadcast application and incorporation may be recommended in some cases.

R.J. Carsky
IITA, Ibadan. Nigeria

NITROGEN

Nitrogen is lost through many mechanisms, among which are volatilization, denitrification, ammonium fixation, leaching, runoff and erosion. The most common loss of N is by leaching and crop export. Volatilization is loss of gaseous ammonia which is favoured by high ammonium concentration and high pH as seen in the following equation:

$$NH_4^+ + OH^- \rightarrow NH_3\uparrow + H_2O$$

Ammonia volatilization has been found to occur when urea is placed in bands near the soil surface. Placement in a band means that concentrations are high. Urea is hydrolyzed to carbon dioxide and ammonia.

$$CO(NH_2)_2 + 2H_2O \rightarrow CO_2 + 2NH_3\uparrow$$

Therefore concentrated placement of high rates of urea (and also diammonium phosphate) should be avoided. There is also substantial gaseous loss of N from fresh animal manure applied to the soil surface.

Denitrification occurs when nitrate ion is present in waterlogged soil in the presence of labile organic matter. Bacteria which are adapted to anaerobic conditions can use nitrate as an electron acceptor in the respiratory pathway to generate their energy. In so doing, nitrate is reduced to a gaseous form and lost as N_2O, N_2 or NO. Denitrification is mainly a concern in flooded rice production.

Ammonium fixation is rarely an important source of loss of applied fertilizer. It occurs when the ammonium ion is strongly adsorbed to surfaces between 2:1 clay minerals. In Africa, it is most likely to occur in Vertisols.

Leaching is the major mechanism of loss of nitrogen from the soil. This is because most inorganic N, ammonium and nitrate are rapidly nitrified to nitrate by a large population of nitrifying bacteria. Nitrate is almost exclusively found in the soil solution (except in soils with high positive surface charges, which are rare) and therefore it moves wherever water goes. Compared to nitrate, potassium ion is held by soil surface negative charges which are relatively common compared to positive charges. To avoid leaching of nitrate, N fertilizer should be placed near the root zone when the root system is developed. In many areas, it is economically viable to split apply N fertilizer. A small amount should be applied at planting or soon after emergence and the larger part should be applied as the crop starts to develop rapidly. In most cereal crops, this is at four to six weeks after planting.

Natural processes which result in inputs of N to the soil are atmospheric deposition and biological N fixation (BNF). Atmospheric deposition results in a very low amount of N input, probably less than 5 kg/ha except near industrial areas. BNF is an important process which humankind has learned to manipulate to increase the input of N to the soil system and reduce the reliance on N fertilizer. N fertilizer should not be applied to leguminous crops in great amounts if BNF is to be encouraged. High nitrate levels in the soil act to suppress the development and function of the legume-Rhizobium symbiosis responsible for BNF. It may be appropriate to give legume crops a small amount of N at planting to encourage early growth and root development.

FERTILIZER APPLICATION RATES

Whether to apply fertilizer or not, and what amount, are questions whose answers require integration of many pieces of information. Among them are the price of fertilizer, the price of the agricultural product, the native soil supply and the yield potential of the target crop.

The observation of nutrient deficiency symptoms can help to decide whether or not fertilizer is needed. These symptoms are available in several textbooks for several crops. A response trial can confirm the need for a particular element and give an idea of the quantities needed. Soil testing can help if it is correlated to crop response studies.

Finally, a simple nutrient balance can help to predict future needs. The balance can be based on crop export as noted above using information such as that provided by Sanchez (1976). The balance requires knowledge of inputs of fertilizer and efficiency of uptake by the crop, as expressed in the following equation:

(soil nutrient supply*efficiency) + (other inputs*efficiency) + (fertilizer*efficiency) = internal requirement.

As an example, assume that the yield potential of sorghum is 8 t/h of grain. This value can be found in Table 1. (If the yield potential is not in the table then it will be necessary to interpolate.). For a yield of 8 t/ha of grain, there are 200 kg N/ha in the above ground crop. That is the internal N requirement of the sorghum crop for a yield of 8 t/ha. Assume that it is known from other crop response work or estimation of mineralization of soil organic matter that the soil supplied 80 kg N/ha. Also assume that the efficiency of uptake of N in your zone is 50% and that it is the same for soil N supply, other sources and fertilizer. (This assumption may not be accurate.) The equation can be re-written as:

Fertilizer = [internal requirement - (soil nutrient supply *efficiency) - (other inputs*efficiency)]/efficiency.

Fertilizer = [200 - (80*0.5) - (50*0.5)]/0.5,

So the fertilizer needed is 270 kg N/ha.

TABLE 1
Nutrient removal (kg/ha) by major crops according to their yield (t/ha)

CROP	PART	YIELD	N	P	K
Maize	Grain	1.0	25	6	15
	Stover	1.5	15	3	18
	TOTAL	2.5	40	9	33
	Grain	4.0	63	12	30
	Stover	4.0	37	6	38
	TOTAL	8.0	100	18	68
	Grain	7.0	128	20	37
	Stover	7.0	72	14	93
	TOTAL	14.0	200	34	130
Rice	Grain	1.5	35	7	10
	Straw	1.5	7	1	18
	TOTAL	3.0	42	8	28
	Grain	8.0	106	32	20
	Straw	8.0	35	5	70
	TOTAL	16.0	141	37	90
Sorghum	Grain	1.0	20	0.9	4
	Straw	1.2	6	0.4	2
	TOTAL	2.2	26	1.3	6
	Grain	8.0	135	10	27
	Straw	8.0	65	4	13
	TOTAL	16.0	200	14	40
Cassava	Roots	8.0	30	10	50
	Roots	16.0	64	21	100
	Roots	30.0	120	40	187
	Whole Plant	59.0	64	19	176
Sweet Potatoes	Roots	16.5	72	8	88
Soybeans	Beans	1.0	49	7.2	21

Land degradation and food security

Land degradation is the temporary or permanent lowering of the productive capacity of land. It covers the various forms of soil degradation, adverse human impacts on water resources, deforestation and lowering of rangeland productivity. Soil degradation processes may occur simultaneously or sequentially. The various types of soil degradation mainly encompass wind and water erosion, soil fertility decline, waterlogging and salinization (Tables 1 and 2).

Nearly one thousand million ha of vegetated land in developing countries are subjected to various forms of degradation, resulting in moderate or severe decline in productivity. Some nine million ha worldwide have had their original biotic function fully destroyed and have reached the point that rehabilitation is probably uneconomic. Poor and inappropriate soil management can result in physical and chemical degradation, such as compaction, surface crusting, poor drainage/ waterlogging, salinization and declining soil fertility, resulting in declining productivity.

Soil fertility/productivity decline: refers in general to deterioration in soil physical, chemical and biological properties and could be caused by:

- lowering of organic matter with associated decline in biological activities;
- deterioration in physical properties such as structure, aeration, infiltration and water holding capacity, brought about by reduced organic mater, erosion and loss of vegetation cover;
- adverse changes in soil nutrient resources, including reduction in availability of macro and micro nutrients (nutrient mining) and development of nutrient imbalance;
- build-up of toxicities due to acidification and pollution.

Increasing population pressure, particularly in fragile arid and semi-arid areas and also in the tropics, has caused serious soil fertility decline particularly under extensive farming practices. This is manifested in declining yields, decreasing vegetation cover and increasing erosion. As a result, farm labour productivity and revenues from agriculture are falling, migration to urban areas is increasing and household and country food security is declining.

If the vicious circle of land degradation cannot be stopped, the source of existence of large parts of the world population, particularly in the vulnerable regions, will be severely damaged. In order to address this dramatic development by restoring land quality, maintaining and improving productivity for sustainable agriculture, it is necessary to have appropriate land policies and to develop and implement appropriate management strategies in line with farmers' socio-economic environments.

Soil fertility decline proceeds in a gradual and slow way. Particularly in fragile zones with inherent poor fertility, farming practices that involve the continual removal of plant nutrients by crops, without concrete measures to replenish the soil system, result in negative nutrient balance (nutrient mining).

H. Nabhan
Soil Resources Management and Conservation Service
Land and Water Development Division, FAO, Rome, Italy

TABLE 1
Soil degradation by type (in million ha) and cause (classified as moderately to excessively affected)

Regions	Water Erosion	Wind Erosion	Chemical Degradation	Physical Degradation	Total
Africa	170	98	36	17	321
Asia	315	90	41	6	452
South America	77	16	44	1	138
North America	90	37	7	5	139
Europe	93	39	18	8	158
Australia	3	-	1	2	6
TOTAL	748	280	147	39	1214
Major Causes	..... percent				
Deforestation	43	8	26	2	
Overgrazing	29	60	4	16	
Mismanagement of arable land	24	16	58	80	
Other	4	16	12	2	
TOTAL	100	100	100	100	

TABLE 2
Main causes of soil degradation in Africa by region (millions of hectares)

	Region				
	North	Sahel	South	Others	Total
Overgrazing	27.7	118.8	44.0	3.9	194.4
Agricultural activity	8.6	34.8	12.8	4.2	60.4
Overpopulation	0.2	54.2	1.1	0.0	55.5
Deforestation	4.3	16.3	0.7	0.7	22.0
Total	40.8	224.1	58.8	8.8	332.3

Recent studies have attempted to evaluate the status of plant nutrient depletion in 38 African countries, through a comparison of nutrient ***accumulation*** (by organic manure, mineral fertilizers, rain/water deposits, sedimentation, biological nitrogen fixation) and nutrient ***removal*** (by harvested crops, removed plant residues, leaching, gaseous losses and erosion). On average, nutrient depletion in the magnitude of 45 kg nutrients per ha per year was estimated (that is, a loss equivalent to 100 kg fertilizer per ha per year). Other studies estimated that four million tonnes of nutrients are harvested annually in sub-Saharan Africa, while only 1/4 of it is returned to the soil in the form of fertilizers. For example, on the 6.6 million ha of land cultivated in Burkina Faso, an estimated 95 000 tonnes of N, 28 000 tonnes of P_2O_5 and 79 000 tonnes of K_2O are lost annually as a result of nutrient mining. In the Gambia, the estimated nutrient removal by the major crops amounted to 26 000 tonnes of nutrients per annum (roughly equivalent to 55 000 tonnes of fertilizer products) against nutrient inputs of only 2 850 tonnes (N, P_2O_5 and K_2O) from inorganic fertilizer and 5 640 tonnes from organic manure.

Besides declining yields due to nutrient mining, this type of degradation would also contribute to deterioration of soil structure due to reduction in biomass and organic matter, reduced water infiltration and increased erosion. With population pressure and low level of fertilizer use, farmers may be forced to cultivate marginal and low productive lands, and hence the continuation of the vicious circle of land degradation.

The serious problem of "s***oil fertility decline***" and its implication on crop production and food security has not previously received sufficient attention, though this form of degradation exists in both humid and dry zones. An inappropriate approach to address this type of degradation is the attempt to maintain crop yields through application of fertilizers without due consideration to corrective soil management practices, such as the maintenance of soil organic matter and improving both physical and chemical soil conditions with low-cost, low-risk packages. The latter

is very relevant to sub-Saharan Africa, where fertilizer use is very limited and has been almost stagnant for the last 15 years.

Desertification: refers to land degradation in arid, semi-arid and dry sub-humid areas, resulting from adverse human impact, besides climate variation (UNEP, 1992). Desertificaiton is mainly caused by:

- overcultivation, i.e., exhausting the soils;
- overgrazing due to livestock pressure, i.e. removing the vegetation cover that protects the soil from erosion;
- deforestation;
- salinization.

It is estimated that:

- one thousand million people worldwide are threatened by desertification;
- desertification affects one-third of the total land area of the world;
- about 73% of Africa's drylands are moderately or severely affected by desertification;
- desertification costs the world an estimated US$ 42 thousand million a year.

Salinity/sodicity: At global level, there are some 31 million ha of salt-affected soils (± 18% of irrigated land). In the Near East/North Africa region only, there are about 16 million ha of saline/sodic soils; the pace of salinization is some 750 000 ha/year, while that of reclamation is only 100 000 ha/year; the estimated cost of reclamation is US$ 3000-4000 / ha.

ECONOMIC IMPACTS OF LAND DEGRADATION

Various studies have attempted, with a lot of approximation, to assess the economic impacts[1] of land degradation. This assessment, however, is subjected to limitations and errors at all stages of assessment.

The different estimates of the extent and severity of degradation and the economic impacts vary widely, due to:

- failure to define what is meant by the *degrees of degradation* in quantitative terms which can be objectively determined and mapped;
- the absence of surveys and in-depth assessment, at country level, of the extent of degradation, and lack of monitoring of changes in land resources.

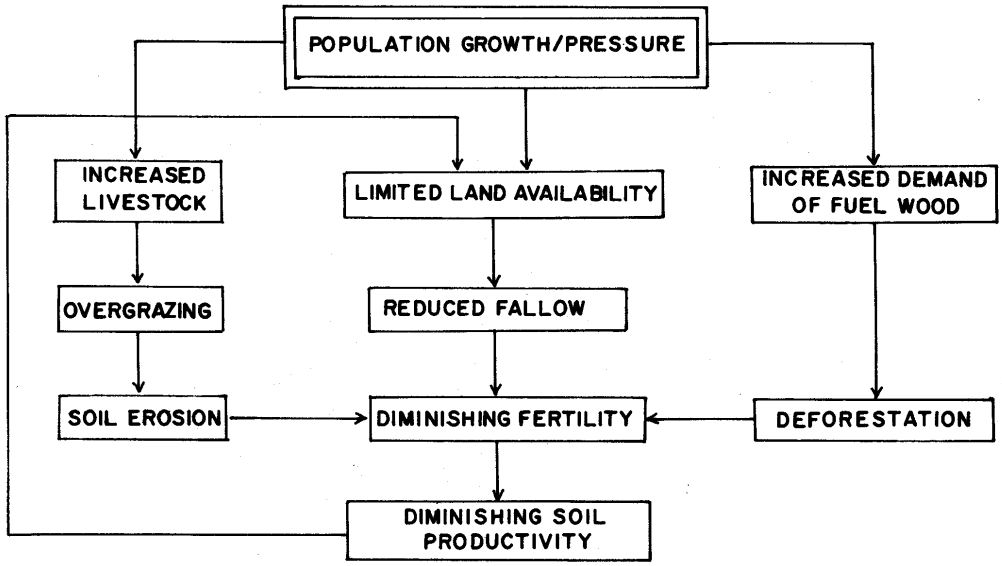
Although quantitative estimates differ, there is clear evidence that land degradation is widespread in many regions. Environmental "disaster areas" exist in many countries.

The direct causes of land degradation are inappropriate methods of land management. The underlying causes stem from the interaction of land resources with economic and social conditions: Population pressure → Land shortage → Diminishing productivity → Poverty → Degradation (Figures 1 and 2).

---

[1] FAO World Soil Resources Report. 1994; Global Assessment of the Status of Human-induced Soil Degradation; "GLASOD", UNEP/ISRIC/FAO, 1991. The methods used for the evaluation of soil resources and degradation include, loss in production, replacement costs, restoration or reclamation costs.

FIGURE 1
Relationship between population pressure and land productivity



As an indication of magnitude of the problem, although with broad approximation, examples of estimated economic cost of land degradation (mainly on production loss basis) are given below:

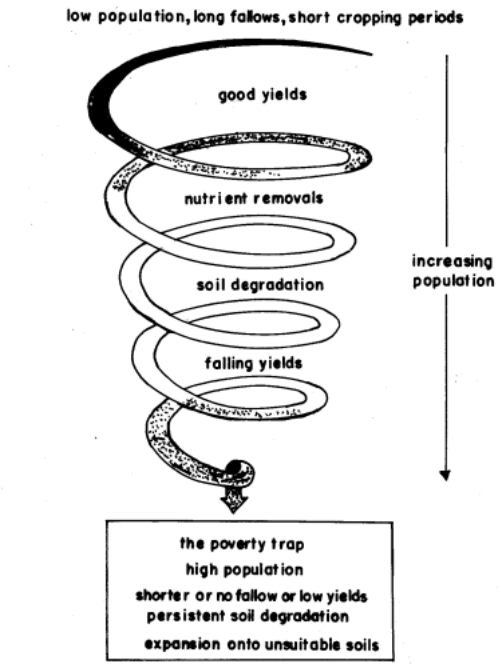
Southeast Asia: For the region as a whole, the cost of land degradation was estimated at US$ 10 thousand million per year (1994). The breakdown is as follows:

	$ 000 million / year
Water erosion	5.4
Wind erosion	1.8
Fertility decline	0.8
Waterlogging	0.5
Salinization	1.5

Australia: Annual loss of production was estimated at US$ 300 million due to salinity/ waterlogging, US$ 200 million due to soil structure deterioration, and US$ 80 million due to erosion.

Zimbabwe: Total financial cost, due to annual loss of nutrients by erosion, from arable lands (that is, equivalent cost of fertilizers) was estimated at US$ 150 million (1986).

FIGURE 2
The downward spiral to the poverty trap



Intensified land use in the areas of shifting cultivation leads to shorter rest times for fallow fields and, ultimately, to soil degradation and reduced crop yields. This will inevitably give rise to a non-sustainable system, incapable of supporting a growing community.

Burkina Faso: The estimated annual loss of nutrients (mining) amounted to US$ 159 million, in terms of N, P, K fertilizers (1983).

Intensified land use in the areas of shifting cultivation leads to shorter rest times for fallow fields and, ultimately, to soil degradation and reduced crop yields. This will inevitably give rise to a non-sustainable system, incapable of supporting a growing community.

CONCLUSION

The majority of developing countries are faced with great challenges to sustain and increase food production for their rapidly growing populations. Countries with limited land and water resources and particularly those which cannot easily finance increased food imports (the low-income, food-deficit countries) will be faced with serious hardship. The various forms of physical and chemical land degradation are seriously affecting the finite soil base and contributing to considerable yield decline and loss in food production, and hence food security at household and country level. It is evident that no food security could be expected without effective and adapted planning, and improved management of land, water and nutrient resources to ensure sustainable and increased food production.

Technical options and appropriate soil management and conservation practices, particularly those of low-cost, low-risk and farmer-driven packages, are available for correcting or minimizing the degradation of the soil base, for maintaining and enhancing land and labour productivity, and thus improving food production and security for a given country. However, despite the availability of cost-effective technical options to address land degradation, little would be achieved without policy-makers' awareness and determination to design conducive land and related economic policies, and to implement effective programmes to combat direct and underlying causes of land degradation.

In order to alert policy-makers, there is need for in-depth assessment of the extent and severity of land degradation, and the economic and social impacts. FAO/AGLS, with its lead technical, catalytic and coordinating role, has been and would continue to assist member countries in that direction, by strengthening country efforts to combat land degradation and to improve land productivity.

Soil conservation and water management

DEFINITION OF SOIL CONSERVATION

- Protection of the soil against physical loss by erosion or against chemical deterioration, that is, excessive loss of fertility by either natural or artificial means.
- A combination of all management and land-use methods that safeguard the soil against depletion or deterioration by natural or by human-induced factors.
- The branch of soil science that deals with the above.

Water and Soil Management plans must be closely linked - one without the other leads to disaster.

REASONS FOR SOIL CONSERVATION

Direct effects on agriculture: Maintenance of productivity.

I. *Short-term effects of soil conservation:*
   - increases input to implement soil conservation measures;
   - no immediate effects on yield unless disastrous soil loss occurs.

II. *Long-term effects of soil conservation:*
   - stable or improved yields;
   - possibly reduced labour requirement once soil conservation methods are implemented.

Indirect effects: Maintenance of environmental quality

I. *Short-term*: none.

II. *Long-term effects:* Minimizes the following:
   - flooding;
   - drought;
   - silting of rivers;
   - habitat destruction of wetlands/soil;
   - loss of soil resource base;
   - greenhouse effect;
   - famine.

G. Kirchhof
IITA, Ibadan, Nigeria

FORMS OF SOIL DEGRADATION

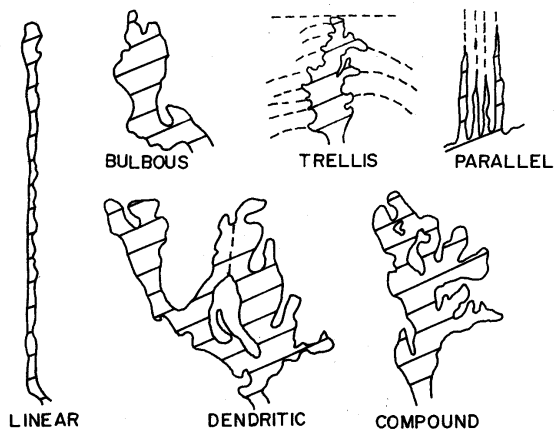
Erosion

Water erosion

Detachment of particles from the soil, their transport and subsequent deposition. Eroded soil is transported as sediment and sedimentation occurs when sediment is deposited. Rate of erosion depends on climate, soil, topography, plant cover and land use. Detachment is a function of the erosive forces of raindrop impact and flowing water, and the soil's resistance to erosion. Detached particles are transported by raindrop splash and flow. Deposition (sedimentation) occurs when transport capacity is exceeded.

- *Sheet erosion*: Removal of a fairly uniform layer of soil from the land surface by raindrop splash and/or runoff, most downslope movement of upland sediment is by flow in rills. Sheet erosion can be prevented by tillage.
- *Rill erosion: This type of erosion takes place* through small channels. It results primarily from soil detachment by concentrated runoff. This concentration may be due to topographic variation or tillage marks. Rill erosion will start when the flow shear forces exceed the resistance of the soil. Concentrated runoff therefore flows downslope before rills form. If the inter-rill sediment load is less than the flow capacity, rill erosion is likely to start; if the sediment load is greater, deposition occurs. A rill depth of 300 mm is usually used as the threshold between rills and gullies. Usually only a small portion of the field is affected, but it is much more visible than sheet erosion.
- *Gully* erosion: This is the removal of soil by running water that results in the formation of channels sufficiently large that they disrupt farming operations and are too large to be filled during normal cultivation. Once gullies have formed it is difficult to regain stability. Gully head erosion lengthens the gully, gully side erosion widens it. Subsoil erodibility is affected by water table height due to the low strength and coherence of saturated soil (see Figures 1-5).

FIGURE 1
Gully head forms developed due to the influence of the drainage pattern (after Ireland *et al*, 1939)



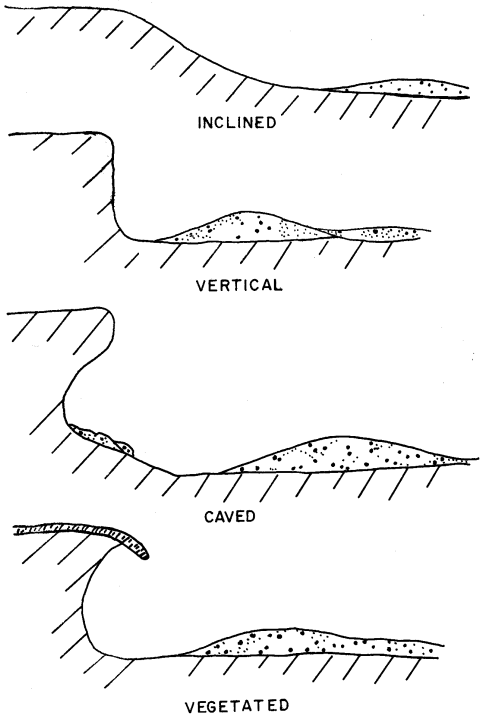
- *Tunnel erosion (piping)*: Removal of subsurface soil by water while the surface soils remains intact. The result is cavities which enlarge until the surface is no longer supported and caves in, forming circular holes (Figures 6 and 7).
- *Streambank erosion:* Removal of soil from streambank by the direct action of stream flow, wind and wave action.

Wind erosion

Wind erosion occurs when the lift forces of the wind exceed gravity and coherence forces of the soil grains at the surface. Movement is separated into three different size fractions: '**creep fraction**' where particles > 0.5 mm move at a low velocity and roll and bump their way across unstable surfaces as a result of other faster moving particles. The '**saltation fraction'** (0.1-0.5

mm) moves by jumping and bouncing across the surface. The maximum distance particles can move is about 50 cm. It is the largest proportion of soil moved by wind. The '**suspension fraction**' (<0.1mm) is carried by wind across the surface and is suspended in air (Figure 8).

FIGURE 2
Gully head types dominated by different processes (after Ireland *et al*, 1939)



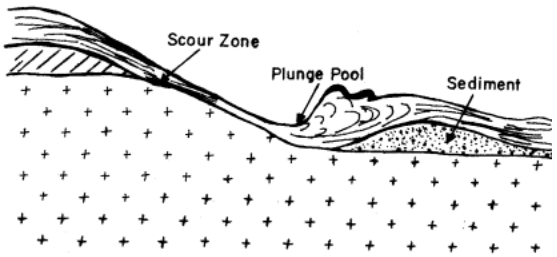
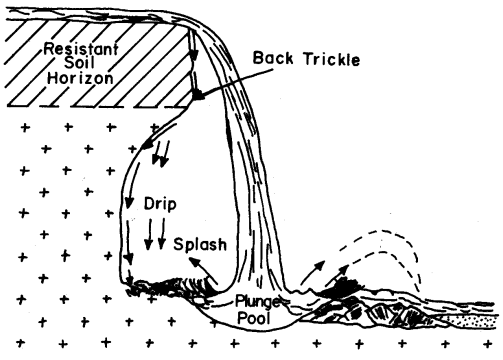


FIGURE 4
Major processes at a caved gully head



Landslides

Landslides occur after heavy rains on denuded steeplands when failure occurs because the weight of the slope exceeds its restraining capacity.

Soil fertility decline

Chemical fertility decline

Nutrients are removed from the soil each time a crop is harvested. While nitrogen and carbon can essentially be replenished from the air through soil microbiological activities (rhizobium), other nutrients cannot. Removal of P and K needs to be replenished sooner or later, where P is of immediate larger importance compared to K due to its relatively low availability and small total amounts present, particularly in most tropical soils.

Soil acidification

Causes of soil acidification are very complex, but generally associated with organic matter build-up and nitrate leaching resulting from pasture improve-ment involving legumes and ammonium sulphate application. It is more common on permeable soils and under high rainfall regimes.

Soil structure degradation

Soil structure and cultivation

Under most forms of cultivation the structural condition of the soil will deteriorate. This is caused by mechanical deformation of aggregates and decrease in soil organic matter content. Structurally degraded soils tend to set hard, crust and seal. Major effects are reduced crop establishment, and increased erosion risk. Cultivation of soils at inappropriate soil water contents increases the rate of

soil structure degradation. Soil compaction results in reduced rooting depth and lower yields, as well as reduced infiltration rates leading to both waterlogging and drought. It is often caused by the use of heavy agricultural machinery; it can however also occur when animal draught is used. Severe degradation can be caused by grazing animals on wetland.

Soil structure and irrigation

Soil structure can deteriorate under irrigation when soil aggregates slake or disperse. The extent of degradation depends on type of irrigation and structural stability of the soil. Flood irrigation on sodic soils with poor irrigation water quality results in fastest degradation, while trickle irrigation on sandy soil with good irrigation water quality causes little degradation.

FIGURE 5
Evolution of a continuous gully system from discontinuous gullies (after Leopold, Wolman and Miller, 1964)

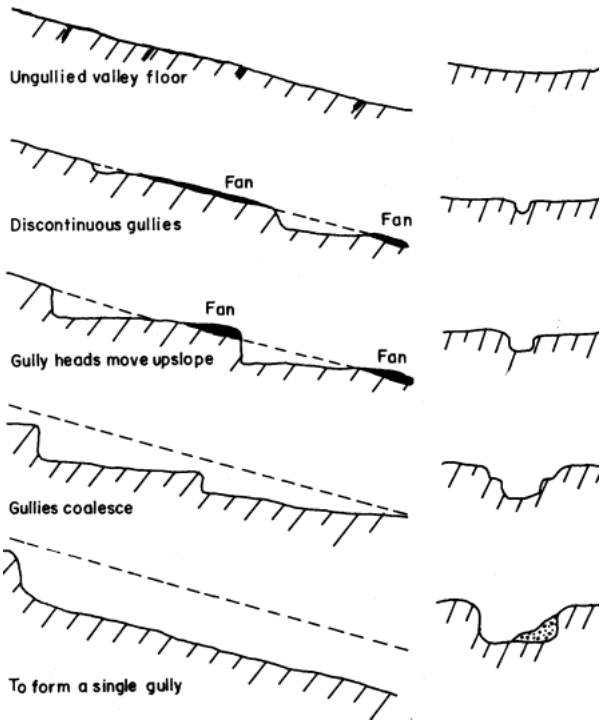


FIGURE 6
Three main mechanisms of tunnel formation – erosion tunnels may develop whenever there is enough water moving through soil to erode subsurface passages

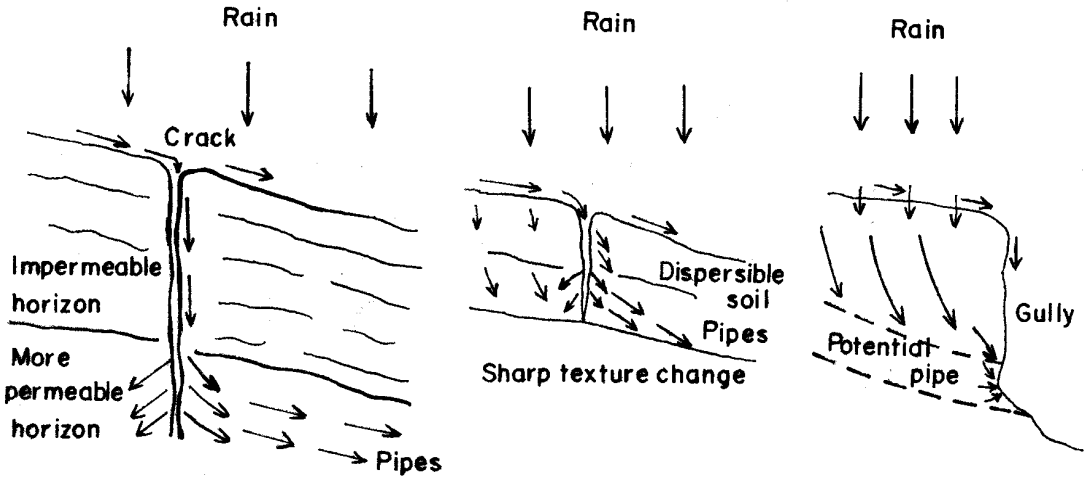


FIGURE 7
Hypothetical hydrograph of a stream following a storm event

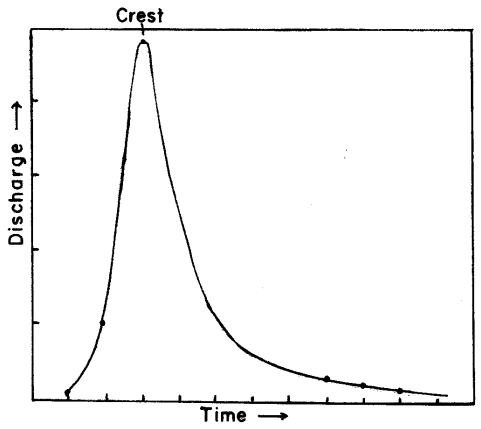
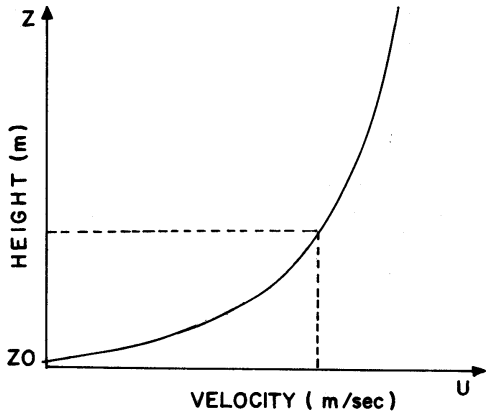


FIGURE 8
Wind velocity profile which is logarithmic with height



Salinization

Irrigation salinity

This is a result of increasing build-up of salts, mainly sodium chloride in soils used for irrigation due usually to a rise in water table when more irrigation water is applied than crops use. The problem of rising water tables and salinization of soils is endemic in all irrigation schemes worldwide.

Dryland salinity

Dryland salinity is usually the result of a human-induced change on the hydrology of a landscape. Deforestation of slopes reduces transpiration rates and more water drains through the soil following rainfall. This leads to increased subsurface seepage, dissolves salts and raises the water tables in depressions.

PREVENTION OF SOIL DEGRADATION

Water Conservation and Erosion Control

Universal soil loss equation:

$$A = R_{\text{rainfall erosivity}}\ K_{\text{soil erodibility}}\ L_{\text{length factor}}\ S_{\text{slope factor}}\ C_{\text{crop management}}\ P_{\text{conservation practice}}$$

Factors K, C and P can be altered by management practises but factors R, L and S cannot.

Soil erodibility

- *Mechanical properties:* Texture, structure, aggregation and size, crusts, bulk density, soil strength, cohesion and angle of internal friction, rheology (Atterberg limits).
- *Hydrological properties:* Soil water release curve, infiltration, permeability and hydraulic conductivity.

- *Physico-chemical properties:* Organic matter, clay minerals and cation exchange capacity (CEC), sodicity (exchangeable sodium percentage, ESP), dispersibility.

Crop management

The effect of crop management can only be evaluated by taking climate into account.

- Maintenance of crop cover (cover crops in inter row).
- Crop residue left on soil surface.
- No burning.
- *Strip cropping*: green manure crops in combination with food crops. Field strip cropping and contour strip cropping.
- Fallow management.
- Crop rotation (legumes/non legumes).
- Agroforestry systems.

Conservation practice

- Contouring, i.e. farming at right angles to the direction of slopes.
- Contour banks and grassed waterways.
- Wind breaks.
- Terracing: absorption and diversion.
- Gully erosion is most effectively stabilized by gully filling and water diversion.
- Conservation tillage (ASSS 1987 definition: Any tillage sequence, the objective of which is to minimize or reduce loss of soil and water; operationally, a tillage or tillage and planting system combination which leaves a 30% or greater cover of crop residue on the surface).
    i. Avoid clean tillage (i.e. clean tillage is the incorporation of all residue and prevention of growth of all vegetation except the desired crop).
    ii. Controlled traffic (all operations are performed in fixed paths so that compaction is restricted to permanent wheel tracks).
    iii. Minimum tillage (minimum soil manipulation necessary for crop production, usually seed bed preparation and weed control).
    iv. Mulch tillage (a tillage or planting combination that leaves > 30% of the surface covered with crop residue).
    v. No-tillage (maximum amount of crop residue maintained, weed control using chemicals).
    vi. Ridge tillage in combination with contour tillage.
    vii. Tie-ridges, ridge tillage where adjacent ridges are connected at certain intervals.

INDIGENOUS SOIL AND WATER CONSERVATION TECHNIQUES (SEE TABLE 1)

Some traditional or indigenous soil or water conservation techniques:

- *masakwa cultivation (Nigeria)* earth bunds
- *trus (tera) contour bunding (Sudan)* U- shaped bunds
- *wafipa mounds (Tanzania)* soil planting mounds
- *dambos (Malawi)* mulching and vegetation barriers
- *demi-lunes - half moons (Niger)* U- or V-shaped open contour bunds

- *dhagga (Ethiopia)* stone bunds or lines
- *dokki (Nigeria)* small basin irrigation using earth or stone ramps
- *gay cultivation (Ethiopia)* system using crop rotation, mulching and burning
- *ishi-mgboko (Nigeria)* stone wall terrace
- *migoka (Tanzania)* round ridges
- *kilimo cha vinyungu (Tanzania)* raised fadama beds
- *medoedoe (Cameroon)* terrace farming
- *zaï (Mali)* traditional planting pits
- *tassa (Niger)* improved traditional planting pits

TABLE 1
Indigenous soil and water conservation techniques

Technique	Rainfall, mm	Population Density, km^{-2}	Crops	Countries
Earth bunds	25-1100	1-410	sorghum, millet, cotton, rice, maize, wheat, sweet potatoes, coffee, chat	Sudan, Nigeria, Tanzania, Ethiopia
contour bunds	500-1300	220-292	maize sorghum	Malawi
bench terraces	45-2000	1-410	cereals, sorghum millet, coffee, chat, yam, coco yam, vegetables	Morocco, Cameroon, Ethiopia, Nigeria
(contour) stone bunds	350-1200	10-204	cereals, kif, millet, sorghum, groundnuts	Morocco, Mali, Burkina Faso, Ghana, Cameroon
contour banks	750-1400	84	maize	South Africa
step terraces	350-400	10-100	cereals, kif	Morocco
strips (vegetation, grass)	400-1500	30-292	maize, sorghum	Malawi, Swaziland
pits	900-1200	35-120	coffee, maize, beans	Tanzania
improved planting pits	350-700	20-130	millet, sorghum	Nigeria, Mali, Burkina Faso
micro-basin	500	25-80	millet, sorghum, vegetables	Mali
pitting	500	25-80	millet, sorghum, vegetables	Mali
modified contour ridges	400-600	45-60	maize, millet, sorghum	Zimbabwe
mulching	400-800	40-100	millet, maize	Burkina Faso
raised beds	650-1600	10-30	cassava, maize, beans, potatoes	Zambia, Tanzania
mounds	900-1000	30	maize, millet, beans	Tanzania
drainage ditches	1350	70-200	cereals, pulses	Ethiopia
basin irrigation	1000-1500	335	vegetables, wheat, maize	Nigeria
ridge cultivation, hedge barriers	>3600	50-272	maize, cassava, yams	Cameroon

Table summarized after Scoones *et. al.* (1996). Sustaining the soil: indigenous soil and water conservation in Africa. In: Chris Reij, I.Scoones and C. Toulmin (eds.). *Sustaining the Soil*.

Annex 1

Opening statement

I am extremely grateful to the Director General of IITA, Dr. Lukas Brader, for inviting me to be part of the opening session of this important training course. I am equally happy to stand before you today to present this goodwill statement. Please permit me to start by conveying to you the warm greetings and best regards of the FAO Director-General, Dr. Jacques Diouf.

I have been informed that the course has been organized for Senior Laboratory Officers who are responsible for their own national agricultural research and advisory laboratory services. I am therefore, confident that your work will play an important role in the attainment of food security at household and community levels of our respective nations. Please permit me to remind all here present today, that the FAO was established on 16 October 1945 with the sole objective of poverty alleviation and ensuring household food security. For this reason, the **World Food Day** is commemorated every year with a selected theme by the member nations. The theme for this year is "**Fight Hunger and Malnutrition**" within the context of the World Food Summit resolutions. The summit will be held on 13-17 November 1996 with the participation of Heads of State and governments worldwide.

I am not intending to touch on the technical aspects of simple soil, plant and water analysis and FAO's involvement in this very important endeavour. This is so because Dr. H. Nabhan, Senior Management Officer from FAO Headquarters, will participate as a resource person in the theoretical presentations and practical aspects of the training course.

To maintain current levels of food availability, there is an urgent need to ensure rapid and sustainable food production without destroying the natural resources for generations to come. This simply cannot happen without the development of proper of soil and water management techniques.

Distinguished participants, your role in this endeavour is very crucial. Agricultural activities that degrade the productive potential of land and water resources by causing soil erosion threaten biodiversity. The key to achieving sustainability is by involving farmers in developing the know-how of their farming systems and the availability of trained human resources in the field of soil and water management. Without the farmers' active participation, contribution and motivation, very little can be achieved.

Dr Hashim A-Shami, FAO Representative in Nigeria
FAO Office, Lagos, Nigeria

There is need to develop simple new approaches that can help to increase food production, without depleting the resources and relying heavily on mineral fertilizers by, for example, maintaining a diversity of crops that can protect farmers against failure. Recycling nutrients through intercropping and rotation of crops that fixes nitrogen and so reduces dependence on mineral fertilizers. The outputs of this important strategy will contribute immensely to world food security. I urge the participants to interact freely and share experience. In this way, we will all learn from each others mistakes and benefit from the different experiences and achievements in our countries, particularly in activities carried out in Centres of Excellence such as IITA, so that at the end we can use the outputs of this training course to move forward.

Finally, I must mention that, this being my first visit to the IITA since I assumed duties as the FAO Representative in Nigeria, I would like to assure the Director General of IITA, Dr. Lukas Brader, of my total support for collaborative work to improve household food security and sustainable agricultural development.

Distinguished participants, I wish you all successful deliberations.

Annex 2
Programme

16 September 1996

08.00-10.00 Opening session. Addresses by FAO Representative in Nigeria, IITA Training Unit Head and Course Coordinator

10.15-12.00 Cost effective laboratory techniques for physical, chemical soil and plant analysis *J. Wendt*

13.30-15.00 Discussions on laboratory and field methods/equipment currently used by NARS *J.A. Adepetu*

15.15-15.40 Evaluation procedures *S. Adebayo*

15.45-16.30 Recommended standard operating laboratory and field procedures *J. Uponi*

17 September 1996

08.00-10.00 Vertical and horizontal soil variability *A. Amusan*

10.15-12.00 Simple field test kits: principles, advantages and limitations *AJ.A. Adepetu*

13.30-14.00 Soil profile characterization: texture, structure, consistence, etc. *A. Amusan*

14.00-16.30 Field practicals: soil profile, sampling and description *A. Amusan*

18 September 1996

08.00-10.00 Soil sampling, sampling tools and sample preparation for field analysis *J.A. Adepetu*

10.15-12.00 Soil sampling, sampling tools and sample preparation for field analysis (field exercise) *J.A. Adepetu*

13.30-16.30 Plant sampling and sample preparation (practicals) *J. Uponi*

19 September 1996

08.00-10.00 Soil tests for pH, CEC, % OC, acidity and Al *O. Epebinu*

10.15-16.30 Soil tests for pH, CEC, % OC, acidity and Al (field practical; exercises) *O. Epebinu*

20 September 1996

08.00-12.00 Field soil tests for NO_3, PO_4, NH4, K, Ca, Na, Mg *M. Adetunji*

13.30-14.00 Tests for Zn, Fe, Mn, Cu, Mo and Pb in soil, plant and water *M. Adetunji*

14.00-16.30 Field exercises on the lectures *M. Adetunji*

21 September 1996

09.00-10.30 Mid-course evaluations/discussions *J.A. Adepetu*

23 September 1996

08.00-10.00 Plant tissue tests for NO_3, PO_4, K, Ca, Mg *J. Uponi*

10.15-12.00 Plant tissue tests for NO_3, PO_4, K, Ca, Mg (practical) *J. Uponi*

13.30-15.00 Runoff, drainage and irrigation water sampling and testing for pH, EC, NO_3, PO_4, Ca, Mg, K, Na and Cl *G. Kirchhof and P.O. Aina*

15.15-16.30 Runoff, drainage and irrigation water sampling and testing for pH, EC, NO_3, PO_4, Ca, Mg, K, Na and Cl (field exercise) *G. Kirchhof and P.O. Aina*

24 September 1996

08.00-10.00 Common sources of errors in soil and plant testing *J.A. Adepetu*

10.15-12.00 Data collection, calculations and reporting (case study) *J. Uponi*

13.30-16.30 Detecting and minimizing common sources of error for data quality (case study and laboratory demonstrations) *J. Uponi*

25 September 1996

08.00-10.00 Soil and water laboratories: role, objectives and weakness *H. Nabhan*

10.15-12.00 Group discussion on field/laboratory practicals *J.A. Adepetu*

13.30-14.30 Land degradation and food security *H. Nabhan*
Soil constraints and management options *H. Nabhan*

14.30-15.15 Evaluation of laboratory reports for data quality (case study) *J. Uponi*

15.20-16.30 Overview of production constraints: physical, chemical and nutrient dynamics *H. Grimme*

26 September 1996

08.00-09.00 Soil tests and fertilizer recommendations *H. Nabhan*

09.00-10.000 Interpretation of soil survey data *A. Amusan*

10.15-12.00 Interpretation of soil testing data (criteria and case study) *A. Amusan*

13.30-14.30 Interpretation of soil testing data (criteria and case study) *J.A. Adepetu*

14.30-15.00 Use of computer models for soil data interpretation and management recommendations (examples *H. Nabhan)*

15.15-16.30 Soil nutrient and fertilizer management *R.J. Carsky*

19.00-21.00 Closing ceremony, distribution of certificates

27 September 1996

08.00-10.00 Soil conservation and water management *G. Kirchhof*

10.15-12.00 Course review and final evaluation: closing *O.M. Ogunyinka and O.A. Osinubi*

Annex 3
List of trainees

Christopher MPOFU
Instructor
Bostwana College of Agriculture
P/Bag 0027,
Gaborone, Botswana
Tel: 328831, Fax: 328753

Daba Fufa SHIBRU
Lecturer
Alemaya University of Agriculture
P. O. Box 38,
Dire Dawa, Ethiopia
Fax: 251-05-151125/251-05-114008

Sheriff NJIE
Senior Technical Officer Soil Testing Laboratory,
National Agricultural Research Institute
Yundum, The Gambia,
Fax: (220) 47 28 75/6

James APASEKU
Chief Technical Officer
Savanna Agricultural Research Institute,
P. O. Box 52,
Tamale, Ghana
Tlx: 4036 BTH 23 GH

Fako Nathnael LENKOE
Laboratory Technician Asst.
Agricultural Research,
Box 829,
Maseru, Lesotho
Fax: 310362, Tlx: 4224,
Tel: 312395

Tajudeen Akinlawon BAKARE
Senior Technologist
Agronomy Department,
University of Ibadan,
Ibadan, Nigeria.

Peter Sunday Kolade ADETIFA
Principal Technologist
Agronomy Department,
University of Ibadan,
Ibadan, Nigeria

Godwin Ogbonnaya CHUKWU
Principal Agricultural Superintendent
National Root Crops Research Institute,
Umudike.
P. M. B. 7006,
Umuahia, Abia State, Nigeria,
Tel: 088/220188

Aruna F. DUMBUYA
Senior Laboratory Technician
Land and Water Development Division,
P. M. B. 187,
Tower Hill, Freetown, Sierra Leone,
Tel: 223481, Tlx: 3210 BOOTH SL.

Mohammed Elamin ABDELRAHMAN
Head Section
Soil Conservation and Land Use Administration,
P. O. Box 1942,
Khartoum, Sudan
Tel: 770172.

Richard Nguvumali MREMY
Senior Laboratory Technician
National Soil Service,
Agricultural Research Institute-Mlingano,
P. O. Box 5088,
Tanga, Tanzania.

Phineas MAMWA
Soil Chemist
Feed Laboratory Services,
No. 1 Coventry Road,
Workington,
Harare, Zimbabwe
Tel: 751097

Annex 4

Participants' assessment

Country	Functions of Lab				Constraints									
	1	2	3	4	1	2	3	4	5	6	7	8	9	10
1. Botswana	+	+	+	+		+	+			+			+	+
2. Ethiopia		+	+	+		+		+	+				+	
3. Gambia	+	+	+							+				
4. Ghana			+			+	+							
5. Lesotho		+				+		+	+	+			+	
6. Nigeria	+	+	+	+	+	+	+		+		+			
7. Sierra Leone		+	+			+				+	+			
8. Sudan		+			+	+			+	+	+			
9. Tanzania	+	+	+							+	+	+		
10. Zimbabwe		+	+											
Percentage	40	90	80	30	20	70	30	30	40	60	30	10	30	10

Country	Funding					Quality control				Suggestions/solutions						
	1	2	3	4	5	1	2	3	4	1	2	3	4	5	6	7
1. Botswana	+					+				+						
2. Ethiopia	+	+							+			+	+			+
3. Gambia	+	+			+					+		+				
4. Ghana	+	+			+	+		+		+	+	+		+		
5. Lesotho	+															
6. Nigeria	+				+	+		+		+	+	+	+			
7. Sierra Leone	+	+			+					+	+	+				+
8. Sudan	+								+		+	+				
9. Tanzania	+	+			+	+		+		+	+					+
10. Zimbabwe	+		+	+	+	+		+		+	+	+				
Percentage	100	50	10	10	60	50	0	40	20	70	60	60	20	10	0	30

Funding

1. Government
2. Foreign agency support
3. Non-government organization
4. Farmers' union
5. Nominal charged for advisory services

Constraints

1. Lack of equipment
2. Poor maintenance service for equipment
4. Delay in sending back test-results
4. Lack of good soil-test interpretation criteria.
5. Lack of coordination among labs
6. Inadequate qualified staff
7. Lack of money for day to day running of lab
8. Water or electricity shortage
9. Lack of interaction of lab and extension service
10. Too much work-load. Need more labs in the country.

Functions

1. Soil survey/classification
2. Soil testings and fertilizer recommendation service
3. Research
4. Training

Quality control

1. External reference laboratory
2. National reference laboratory
3. Internal control
4. None

Suggestions/Solutions

1. Charge for services i.e commercialize service
2. Locally organized short training courses
3. More FAO sponsored training courses
4. Organize sample exchange among laboratories - quality control
5. Need a central reference lab in the country
6. Need to set up service laboratories or expand research lab to cover service function

Annex 5

Soil constraints and soil management options

Soils have inherent and human-induced constraints which could be addressed through appropriate soil management. Poor management can result in physical and chemical degradation and, consequently, decreased productivity or total loss of soils for agricultural production.

EXAMPLES OF INHERENT SOIL CONSTRAINTS

Physical

- shallow soils;
- steep slopes;
- poor drainage;
- presence of gravel;
- vertic properties.

Chemical

- low nutrient reserves (N, P, K and others);
- low nutrient retention;
- aluminum toxicity;
- phosphorus fixation;
- acid soils;
- acid sulphate soils;
- free $CaC0_{3;}$
- soil salinity;
- excess sodium;
- amorphous materials.

PHYSICAL, CHEMICAL, BIOLOGICAL DEGRADATION AND CAUSES

Physical degradation: Physical degradation due to wind and water erosion, compaction, crusting, deterioration of drainage conditions causing waterlogging, salinization and sodication.

Biological degradation: Biological degradation associated with loss of organic matter and the adverse effects on biological life in the soil.

*Presentation by **H. Nabhan***
Soil Resources Management and Conservation Service
Land and Water Development Division, FAO, Rome, Italy

Chemical degradation: Chemical degradation associated with loss of nutrients (mining), loss of organic matter, increased leaching (when vegetative cover is removed), increased temperature and oxidation (due to soil exposure), salinization and sodication (due to inappropriate irrigation and inadequate drainage), pollution (from industrial, mining and urban wastes).

SOLUTIONS: EXAMPLES OF IMPROVED SOIL MANAGEMENT PRACTICES

Steep slopes / erosion

Soil erosion on steeplands is caused by surface runoff and may cause reduced infiltration and surface crusting. Erosion is accelerated by removal of or reducing vegetative cover.

Erosion control aims at:

- improving aggregation by raising organic matter content and encouraging biological activity and rooting in topsoil;
- reducing raindrop impact on the soil surface;
- reducing runoff by avoiding surface crusting and encouraging stable pores in the soil.

Soil conservation/soil management practices

a. **Mechanical:** construction of bench and step terraces, stone walls, contour bunds, tied ridges, hillside ditches and fanya juu terraces (labour intensive, costly and requiring regular maintenance).

b. **Agronomic or vegetation based measures:** rely upon cropping systems and crop residue management, are less costly and do not require heavy equipment, as:

   - perennial crops or intercropping systems;
   - alternate strip cropping (grass or legumes with cultivated row crops on the contour);
   - contour hedgerow (such as *Leucaena leucocephala*);
   - no-till and crop residue mulching;
   - contour alignment;
   - trees and agroforestry techniques;
   - pasture on steeper slopes and on sallow or gravely soils.

Poor drainage

Hydromorphy may be caused by flooding, high groundwater table and stagnation of water on the surface of the soil. Drainage intervention and flood protection are the most appropriate soil management practices. Artificial drainage may not be feasible in lowlying areas or basins without outlets. Waterlogging, except for rice, can cause total failure of crops, severe reduction in yields and restricted or reduced nutrient uptake. Drainage of wetlands for dry crop production often presents problems of potential acid or acid sulphate soil conditions.

- In humid tropical Africa: giant mounds (1.5 m x 30 m^2) are traditionally constructed with a range of crop plants located on the mound.
- Cambered beds, in the Caribbean, effectively lower the water table and provide rapid surface drainage and soil aeration - also Mican Chinampa system.
- Paddy rice cultivation with levelling, bunds and irrigation.

- Cultivation of other plants (besides rice) on undrained wetlands such as: sago palm in southeast Asia for commercial starch, taro as root crop, kang kong.

Vertic properties

Vertisols have a high content of clay with shrinking and swelling properties. Tillage is difficult when topsoils are either too dry or too moist - low infiltration when wet, however, they have higher water storage capacity, high CEC and rich in nutrients in general.

Management options

- Tillage practices that reduce bulk density and minimize compaction.
- Annual crops rather than perennial crops/trees (to avoid breaking and inclined stems due to crack development in dry season or the shrink-swell process).
- Growing crops on raised beds or improvement of surface drainage, broadbed and furrow plus grassed waterway system (example: techniques developed by ICRISAT and broad-bed animal traction implement devised by ILCA).
- Improved aggregation through no-till and retention of crop residues on the surface (example: Australia).
- Agroforestry (as *Acacia Senegal* and *A. albida*) - leguminous trees (example: Sudan, for improving physical properties, reducing erosion, supplying nitrogen and improving microclimate for both food and forage crops).
- Compaction through heavy agricultural machinery or livestock trampling could be addressed with appropriate ploughing techniques; such as manual (and not mechanized land preparation and harvesting methods, ploughing at different depths to break plough-pans).

Low nutrient retention

Soils that are constrained by low organic matter, dominance of unfavourable clay "Kalonite" and extremely low CEC and nutrient losses through leaching.

Management options

- Split applications of nutrients (from fertilizer), combined with liming.
- Incorporation of crop residues, manure application.
- Biological nitrogen fixation (Rhizobia, Azolla).
- Use of mycorrhizal plants combined with timely fungal inoculation.

Acid soils / aluminum toxicity

Common problems of acid soils particularly in the tropics: low fertility/low nutrient retention, high incidence of pests and diseases, high Al saturation, high phosphorus fixation by Fe and amorphous materials, frequent K and S deficiencies, etc.).

Management options

- Require special P management practices, including high quality rock phosphate and/or phosphate fertilizer applications.
- In soil with low pH (4.5 - 5.5), A1 toxicity combined with Mn toxicity and Ca deficiency will require lime or dolomite application.
- Plant cultivars which are resistant to high concentration of A1 and Mn.
- Intensive crop rotations (upland rice-maize-soybean or rice-groundnut-soybean), combined with sound fertilizer recommendations (example: Peru/Amazon Basin).

- Managed fallow of Kudzu (*Pueraria phaseolaides*) and return of crop residues.
- Legume-based pastures strategy has been successful on acid infertile soils in Latin America.
- Agroforestry systems, such as growing of *Gmelina arbore* (for poles and timber), having high level of bases in their tissues, have resulted in a net increase in soil pH and Ca return to soils (example: experience on Oxisols in Brazil).

Soil salinity/excess sodium

Soil degradation through salinization and sodication and the accompanying chemical and physical problems which are common in arid and semi-arid irrigated agriculture are threatening productive lands. The presence of excessive soluble salts, such as C1 and $S0_4$ of Na; Na carbonate and high ESP, results in severe decline in yields or even total loss of the soil for agricultural production.

Management options

- Drainage, leaching.
- Special management for salt-sensitive crops.
- Growing of salt-tolerant species and cultivars.
- Chemical amendments (such as gypsum, pyrite, sulphuric acid, sulphur, phosphogypsum).
- Reclamation (drainage, leaching combined with amendments).
- Sub-soil/deep ploughing.
- Crop residue incorporation.
- Rice-based cropping system.
- Use of special species such as *Albizia procera* trees, reducing the pH and electrical conductivity (India).
- Plantation into small postholes (with gypsum and manure on sodic soils) of *Acacia nilotica* and *Eucalyptus tereticornis*.
- Growing of Karnal grass on unamended alkali soils (in India), providing good forage yield. (the inorganic chemical composition of the shoots indicates a successful exploitation of the alkali soil and the lowering of soil pH due to biological activity and production of organic acids).

Organic matter

Water and nutrient retention, pore space and water movement are highly dependent on the content and degree of decomposition of organic matter in the soil.

The positive effects of OM on structural stability are more pronounced on sandy soils than on fine textured soils. Application of OM is useful in maintaining and improving topsoil physical properties and counteracting the adverse effects of excessive sodium on soil structure.

Soils with low organic matter content will require special management practices, such as fallowing, growing suitable legumes or grasses for sufficient period, application of organic manures, green manuring and incorporation of crop residues.

Annex 6

RQflex: the pocket laboratory

The small, very handy, high precision test-kit is a new product manufactured by Merck Limited. It consists of the Reflectoquant test strips, the reflectometer RQflex, and a barcode contained in each package for calibration and instrument control.

Colorimetric test strips are one of the fastest and least expensive analytical tools available today. Using these strips, a wide variety of elements can be detected in minutes. In most testkits, test-strip results are read with the naked eye by comparing the colour change to a reference colour chart. RQflex has changed all that. The hand-held reflectometer determines quantitatively the intensity of colour developed as a measure of the quantity of the element that reacted to form the colour. This removes the subjectivity of visual reading and comparison of colours, thereby improving the accuracy and reproducibility of the determination. Thus, this instrument combines the convenience of test strip analysis with the confidence of quantitative measurement that provide accurate, repeatable results. The barcode, the central feature of the Reflectoquant analytical system, is used to load all necessary information exactly. Lot-specific calibration of the barcode and correction of wavelength variation allow for an outstanding accuracy of measurement. During the training course, the kit was found to be as accurate as the atomic absorption spectrometer. The reflectometer RQflex is quick and simple to use. It can store up to 50 measurement results which can be displayed by pressing a key, and can be transferred to a PC for documentation.

RQflex is suitable for testing a wide range of aqueous samples, including water, wastewater, extracts from plants, fruits, foodstuffs, soils, fertilizers and beverages. Tests are currently available for the following parameters: N, P, K. Ca, Mg, Al, pH, Fe, Mn, Zn, Cu, Mo, Co, Ni, Pb, Sn, Cl, chromate, cyanide and total hardness.

One limitation of this textkit is that it can only do 50 samples for a given parameter before the strips are exhausted. Therefore new test-strips must be continually ordered and this means that the user must depend on, and constantly be in contact with, the manufacturer abroad. In using this test-kit for soil testing, a more serious limitation of the kit is that the soil extractants for some important soil nutrient elements have constituents that introduce interference which make the test kit inappropriate for such elements. For example NH_4+ ion in the NH_4OAC extracting solution for exchangeable K interferes with K determination by the reflectometer of this kit. This means that a new extracting solution that has no interference will have to be developed for local soil conditions, to allow the use of the test kit for determining plant available soil-K.

Annex 7

Use of computer models for soil data interpretation and management recommendations

*** OBJECTIVES OF TRIALS ***

1. DETERMINE REFINED ECONOMIC FERTILIZER RECOMMENDATIONS FOR RICE IN MADAGASCAR

2. EXAMINE RELATIONSHIP BETWEEN PLANT AND SOIL FACTORS AND CROP RESPONSE TO NITROGEN AND PHOSPHATE FERTILIZER

3. STRATIFY RECOMMENDATIONS ACCORDING TO ANY MEANINGFUL RELATIONSHIPS FOUND WITH SOIL AND PLANT MEASURES

These were carried out under adequate levels of inputs and management skills but can be related to lower levels

*Presentation by **H. Nabhan***
Soil Resources Management and Conservation Service
Land and Water Development Division, FAO, Rome, Italy

Nitrogen	Phosphate	Potash
0	0	0
0	0	60
0	40	60
0	80	60
0	120	60
40	0	60
40	40	60
40	80	60
40	120	60
80	0	60
80	40	60
80	80	60
80	120	60
120	0	60
120	40	60
120	80	60
120	120	60
80	80	60+20S

*** SOIL ANALYTICAL DATA ***
(Site key, laboratory number and block number on each file)

1	Clay %	Org Carbon	Mg exch	Fe DTPA
2	Clay + F Silt	Total N	K exch	Cu DTPA
3	Fine Silt	NH4 N	Na exch	Zn DTPA
4	Coarse Silt	NO3 N	Al exch	Mn DTPA
5	Fine Sand	P total	H exch	Fe free
6	Coarse Sand	P Olsen	Mn exch	pH Co
7	H2O pF3.0	P resin	S assim	pH aqueous
8	H2O pF4.2	P fix	Al satur	pH KCl
9	O M	Ca exch	CEC	

*** SOIL PARAMETER CORRELATIONS ***

PARAMETER	N RESPONSE	P RESPONSE	ORGANIC MATTER
O.M.	- ***	***	
P (resin)	n.s.	- *	
P (fix)	n.s.	- *	
Free Fe	*	**	*
Fe DTPA	- ***	*	***
Al exch.	- ***	***	
CEC	**	-**	**
Total N	n.s.	n.s.	*
NH4 N	n.s.	n.s.	n.s.
O.C.	- ***	***	***
K exch.	- *	n.s.	n.s.
Ca exch.	n.s.	**	n.s.
Mg exch.	n.s.	**	
Cu DTPA	**	*	
pH aq	n.s.	**	
S assim		*	- **
Silt F	**	**	
Silt C	n.s.	*	
Sand	**	n.s.	

Key : * = 90% ** = 95% *** = 99%

*** MAIN COMPUTER PROGRAMS USED IN ANALYSIS ***

1. DATA INPUT / CHECKING (MADIN MADSOLIN YCOMIN)

2. FACT2AM factorial analysis with 2 additionals

3. FACT orthogonal polynomial factorial (response surface)

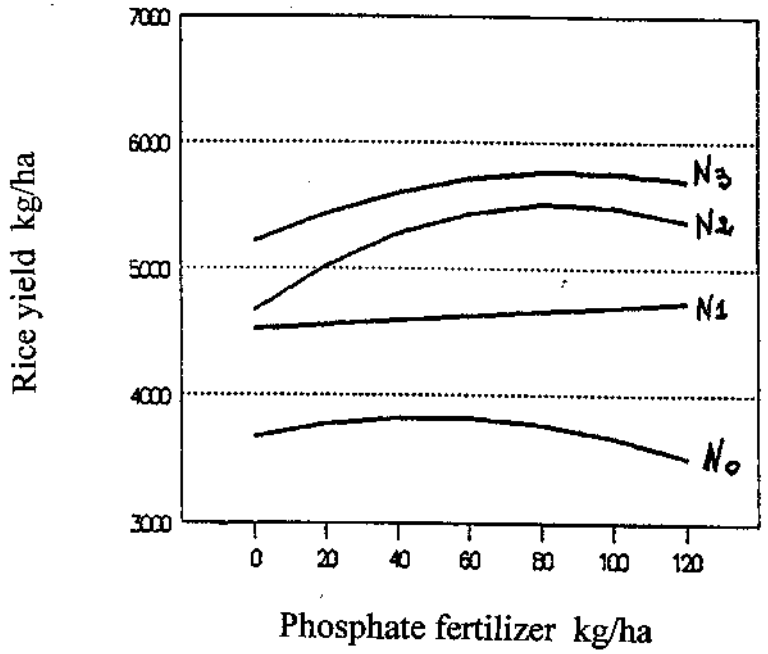
4. FP1TF linear and quadratic coefficients of response curve
   with EO, PI, VCR, Risk, Net and Gross Return, Yield % increase

5. GENFERT economics based on response surface calculated by FACT

6. FP1DF calculate economics for actual levels of N, P, K, S used

7. MULGF stepwise multiple regression

RESPONSE CURVES FOR PHOSPHATE AT AMBOLO



*** PREDICTED RESPONSES TO N FOR DIFFERENT O.M LEVELS ****

Organic matter %	Mean response to N at mean P level
<1	2087
>1 <5	1913
>5 <10	1695
>10 <20	1260
>20	825

FPIT - COMPUTE YIELD & PROFIT FOR DISPERSED TRIALS PROCESSING DATE : 26-11-88

COUNTRY : MADAGASCAR ZONE : *MULTIPLE* CROP : RICE CROP VALUE : 135 TRIAL DATE : ALL

CURRENCY : FMG NUTRIENT : N COST : 652 RATES : 0 40 80 120

MEAN OF 8 SITES MEAN YIELDS : 3720.263 4446.337 4683.163 5134.363

QUADRATIC EQUATION FITTED TO 4 POINTS : Y = 3755.4438 + 654.0687 * X -68.7188 * X * X

SSE = 24754.3203 RESIDUAL SE= 157.34 PAR.SE'S 3755.4 : 153.4 654.1 : 246.3 -68.7 : 78.7
F = 20.6431 R-SQUARED= 0.98 CORR. BETWEEN : A AND B -0.688 A AND C 0.513 B AND C -0.958

N curve at P level 0 K level 1

RATE	RATE kg/ha	T.YIELD kg/ha	YLD:CON kg/ha	YLDXCON	NET RTN FMG	GR RTN FMG	VCR	MRR	PI	RISK : % IN 4 VALUE/COST RANGES <1	1<2	2<4	4>
0.0	0.0	3755.4	0.0	0.0	0.0	0.0	0.0	0.0	0				
0.5	20.0	4065.3	309.9	7.6	28790.4	41829.8	3.2	2.0	15	0.0	0.0	33.3	50.0
1.0	40.0	4340.8	585.3	13.5	52942.3	79022.3	3.0	1.7	14	0.0	0.0	33.3	50.0
1.5	60.0	4581.9	826.5	18.0	72455.6	111576.2	2.9	1.3	13	0.0	16.7	33.3	33.3
2.0	80.0	4788.7	1033.3	21.6	87330.4	139490.1	2.7	1.0	12	16.7	0.0	50.0	16.7
2.5	100.0	4961.1	1205.7	24.3	97566.8	162766.8	2.5	0.6	12	16.7	0.0	50.0	16.7
3.0	120.0	5099.2	1343.7	26.4	103164.6	181404.9	2.3	0.3	11	16.7	16.7	33.3	16.7
AT ECONOMIC OPTIMUM RATE													
3.4	134.1	5176.0	1420.6	27.5	104323.2	191779.6	2.2	0.0	10	0.0	0.0	66.7	16.7
AT MAXIMUM YIELD													
4.8	190.4 *	5311.8	1556.4	29.3	85993.9	210110.0	1.7	-1.0	8	0.0	33.3	33.3	16.7

LEVEL EXTRAPOLATED MORE THAN 25% ABOVE ACTUAL MAXIMUM USED

*** NATIONAL AVERAGE FERTILIZER RECOMMENDATIONS FOR RICE ***

(Kg/ha rounded to nearest 2 % to convenient figures)

Conditions	O.M level	N	P2O5	K2O #
Favourable	< 5 %	140 - 160	85	40
	> 5 %	100	95	40
Less Favourable	< 5 %	100 - 115	60	30
	> 5 %	70	70	30

Potash estimated from earlier trials data

Recently Developed Sophisticated Model

for

Fertilizer and Soil Management Recommendations

- **Mainly based on Soil and Agronomy data**

- **Training requirement:**

Initial	**3 days**
Manipulation/Calibration	**10 days**

- **Estimated Cost:**

	US$
Computer	**3 000**
Model (2 Softwares)	**14 000**
	17 000

- **Technical Assistance (Consultancies):** **4-5 m/m**
  - **Data collection**
  - **Calibration, adaptation, installation of the Model**
  - **Cross-check, validation**

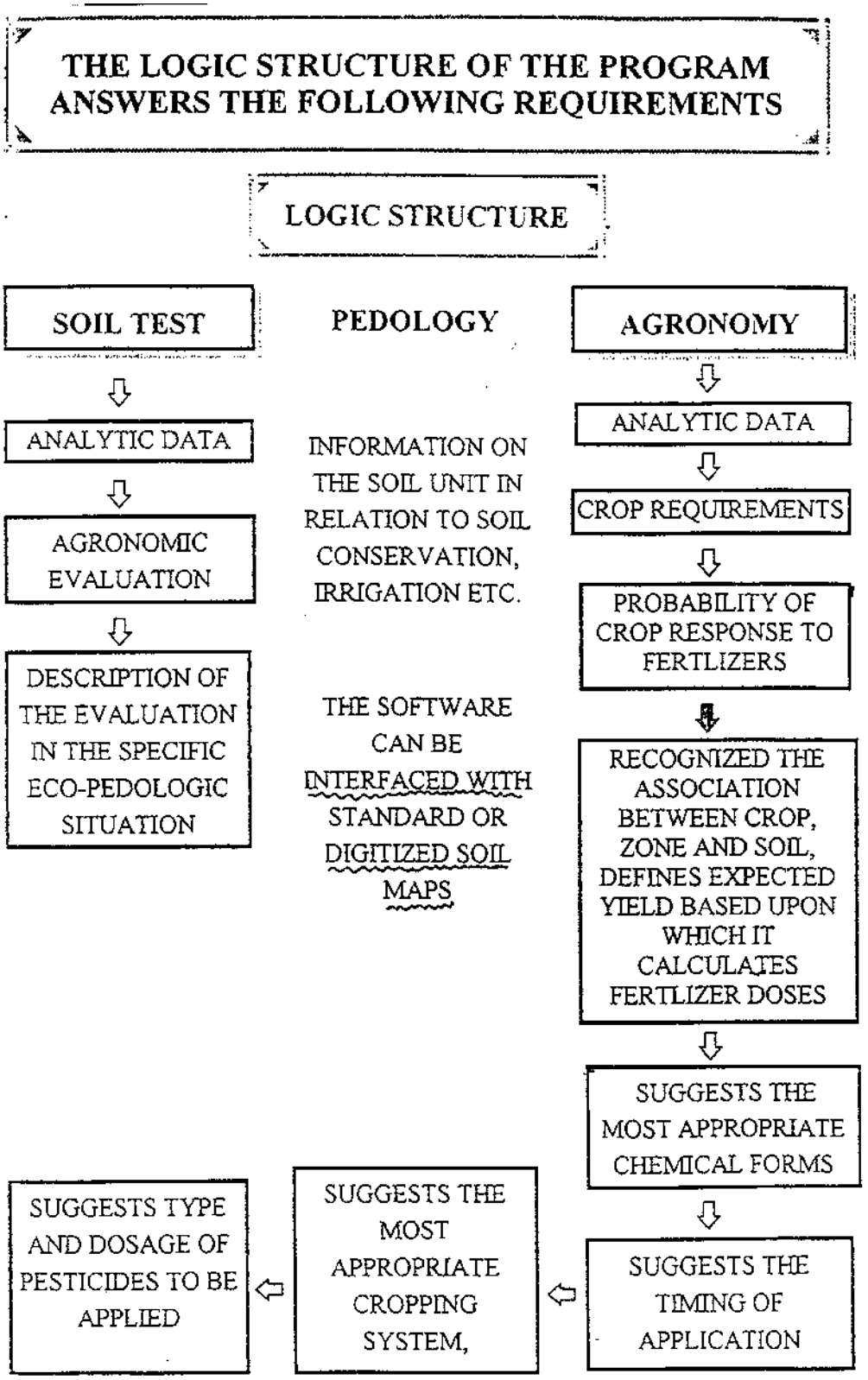
SOFTWARE CHARACTERISTICS

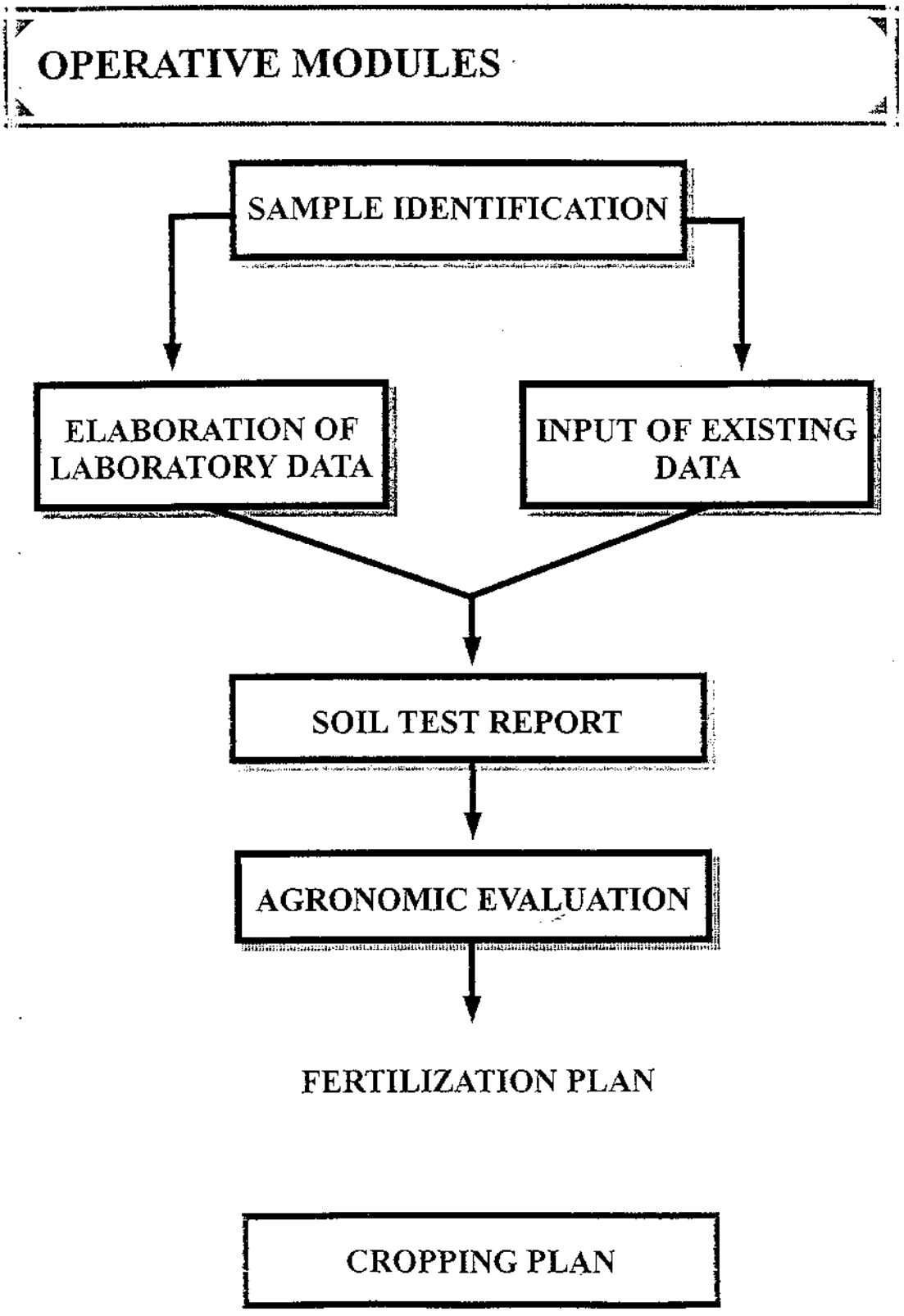
TOTAL FLEXIBILITY

THE SOFTWARE IS FULLY ADAPTABLE TO THE USER'S NEEDS. ALL AGRONOMIC INFORMATION, EVALUATION, DOSAGE AND APPLICATION SYSTEMS OF FERTILIZERS CAN BE ADAPTED TO LOCAL CONDITIONS, WITHOUT AFFECTING THE UNIVOCAL NATURE OF THE MODEL.

IN PRACTICE, IT IS POSSIBLE TO ERASE AND REPROGRAM ANY AGRONOMIC SITUATION ON WHICH COMPLETE DATA AND INFORMATION IS AVAILABLE.

THE STRUCTURE OF THE MODEL IS SUCH THAT IT MAY BE PROGRAMMED FOR ALL SOIL TYPES, FROM ACID TROPICAL SOILS TO SALINE AND SODIC SOIL OF ARID CLIMATES.


THE LOGIC STRUCTURE OF THE PROGRAM ANSWERS THE FOLLOWING REQUIREMENTS
LOGIC STRUCTURE
SOIL TEST
ANALYTIC DATA
AGRONOMIC EVALUATION
DESCRIPTION OF THE EVALUATION IN THE SPECIFIC ECO-PEDOLOGIC SITUATION
PEDOLOGY
INFORMATION ON THE SOIL UNIT IN RELATION TO SOIL CONSERVATION, IRRIGATION ETC.
THE SOFTWARE CAN BE INTERFACED WITH STANDARD OR DIGITIZED SOIL MAPS
AGRONOMY
ANALYTIC DATA
CROP REQUIREMENTS
PROBABILITY OF CROP RESPONSE TO FERTLIZERS
RECOGNIZED THE ASSOCIATION BETWEEN CROP, ZONE AND SOIL, DEFINES EXPECTED YIELD BASED UPON WHICH IT CALCULATES FERTLIZER DOSES
SUGGESTS THE MOST APPROPRIATE CHEMICAL FORMS
SUGGESTS THE TIMING OF APPLICATION
SUGGESTS THE MOST APPROPRIATE CROPPING SYSTEM,
SUGGESTS TYPE AND DOSAGE OF PESTICIDES TO BE APPLIED


OPERATIVE MODULES
SAMPLE IDENTIFICATION
ELABORATION OF LABORATORY DATA
INPUT OF EXISTING DATA
SOIL TEST REPORT
AGRONOMIC EVALUATION
FERTILIZATION PLAN
CROPPING PLAN

TYPE OF CROP: THE SOFTWARE RECOGNIZES THE TYPE OF CROP, THE VARIETY, THE CROPPING SYSTEM AND OTHER PARAMETERS. FOR EACH CROP, IT IS POSSIBLE TO DEFINE DIFFERENT AGRONOMIC MODELS THAT IMPLY DIFFERENT CULTIVATION TECHNIQUES AND FERTILIZATION. I.E. TOMATO: INDUSTRIAL TOMATO; GREENHOUSE TOMATO; OPEN FIELD TOMATO ETC.

AGRO-ECOLOGICAL ZONE: IF THE DIFFERENT AGRO-ECOLOGICAL ZONES HAVE BEEN CLASSIFIED ON A REGIONAL OR SUB REGIONAL BASIS, IT IS POSSIBLE TO DEFINE THE SUITABILITY OF THE AREA FOR A PARTICULAR CROP, ESPECIALLY WITH RESPECT TO THE BEST VARIETIES, THE CROPPING SYSTEM AND TO THE POTENTIAL AND EXPECTED PRODUCTION.

SOIL TYPES: IF THE SOFTWARE IS INTERFACED WITH SOIL MAPS THE SOIL TYPE CAN ALSO BE DEFINED AS:

- CLASS OF PRODUCTIVITY BASED UPON THE "LAND CLASSIFICATION";
- SOIL TYPE ACCORDING TO THE "FAO CLASSIFICATION" OR OTHER GENETIC CLASSIFICATIONS (AMERICAN, FRENCH);
- COMBINED SYSTEM "PRODUCTIVITY CLASS-SOIL TYPE".

THE "CROP-AGRO-ECOLOGICAL ZONE-SOIL TYPE" PARAMETERS MAKE IT POSSIBLE TO DEFINE HIGHLY SPECIFIC FILES WITH AN INDEFINITE POSSIBILITY FOR CODING.

THE LABORATORY VERSION AUTOMATICALLY EXECUTES ALL CALCULATIONS RELATED TO THE ANALYSES UNDERTAKEN. DATA IS ACQUIRED ON LABORATORY SHEETS AND MANUALLY CAN BE INSERTED IN THE COMPUTER.

ANALYTIC DATA CAN BE ACQUIRED AS CONCENTRATION; ABS; T%.

THE CALIBRATION CURVES OF THE INSTRUMENTS ARE MEMORIZED IN THE METHODS AND CAN BE ADJUSTED BY THE USER.

THE SOFTWARE CARRIES OUT ALL THE CALCULATION AND APPROXIMATIONS AND PRODUCES THE SOIL TEST REPORT.

ANALYSIS	*METHOD*
1. GRAVEL	
2. TEXTURE	ISSS; USDA; BY FEEL
3. SOIL REACTION pH	(1:2,5) IN WATER
4. ELECTRICAL CONDUCTIVITY	(1:2,5) IN WATER
5. TOTAL LIME	QUANTITATIVE; QUALITATIVE
6. ACTIVE LIME	AMMONIUM OSSALATE
7. ORGANIC MATTER	WALKEY & BLAKE; COLORIMETRIC
8. TOTAL NITROGEN	KJELDAHL; CALCULATED
9. NITRIC NITROGEN	
10. AVAILABLE PHOSPHORUS	OLSEN; BRAY & KURTZ
11. AVAILABLE SULPHUR	
12. AVAILABLE IRON	EDTA; DPTA
13. AVAILABLE MANGANESE	EDTA; DPTA
14. AVAILABLE COPPER	EDTA; DPTA
15. AVAILABLE ZINC	EDTA; DPTA
16. SOLUBLE BORON	TROUG
17. SOLUBLE CHLORIDE	
18. CATION EXCHANGE CAPACITY	BACL2 pH 8.2; ACNH4 pH 7; CECE
19. EXCHANGEABLE CALCIUM	
20. EXCHANGEABLE MAGNESIUM	
21. EXCHANGEABLE POTASSIUM	
22. EXCHANGEABLE SODIUM	
23. EXCHANGEABLE HYDROGEN	1N KCl
24. EXCHANGEABLE ALUMINIUM	1N KCl
25. EXCHANGEABLE ACIDITY	1N KCl; pH BUFFER; CALCULATED

THE AGRONOMIC EVALUATION OF A SINGLE DATUM, IS USUALLY EXPRESSED IN REFERENCE TO A THRESHOLD VALUE, FOR EXAMPLE:

K ppm 50 ⟶ LOW

K ppm 51-100 ⟶ MEDIUM

IN THE CASE OF MORE SOPHISTICATED SOFTWARES THE EVALUATION CAN DEPEND ON OTHER FACTORS, I.E. C.E.C., OR PERCENTAGE OF CLAY. IN THIS CASE, IT IS POSSIBLE TO MODIFY THE THRESHOLD VALUES BUT NOT THE TYPE OF PARAMETERS RELATED TO THE EVALUATION.

A "TOTALLY FLEXIBLE" SOFTWARES SHOULD OFFER THE USER THE POSSIBILITY OF MODIFYNG BOTH THE THRESHOLD VALUES AND THE CORRELATED PARAMETERS THAT CONTRIBUTE TO THE FINAL EVALUATION.

THE ENTIRE ANALYTICAL SPACE IS SUB-DIVIDED INTO ANALYTICAL SUB-SYSTEMS CHARACTERIZED BY A MAIN PARAMETER AND THREE CORRELATED ONES. THESE SUB-SYSTEM CORRESPOND TO AGRONOMIC REALITIES DEFINED BY: **RESPONSE PROBABILITY AND RERQUIREMENT OF FERTILIZERS, GYPSUM, LIME ETC.**

IN ORDER TO ELABORATE THE CROPPING PLAN IT IS NECESSARY TO PROVIDE SPECIFIC AGRONOMIC INFORMATION TO DEFINE THE SITUATION IN WHICH WE ARE OPERATING.
MAIN INFORMATION REQUIRED IS:

- CROP; AGRO-ECOLOGICAL ZONE; SOIL TYPE.
- PREVIOUS CROP; FALLOW PERIOD; YEARS OF CONTINUOUS CROPPING; BURNING OR BURIAL OF CROP RESIDUES; INTERCROPPING; IRRIGATION; BANDED OR BROADCAST FERTILIZATION; OTHER.

GYPSUM IS CALCULATED ON THE BASIS OF THE ESP (*EXCHANGEABLE SODIUM PERCENTAGE*) OR OF THE ES (*EXCHANGEABLE SODIUM*).
CROP TOLERANCE TO EXCHANGEABLE SODIUM IS CODIFIED AND TAKEN INTO ACCOUNT FOR CALCULATING GYPSUM.

LIME REQUIREMENT IS DEFINED ON THE BASIS OF SOIL pH. THE QUANTITIES TO BE APPLIED ARE BASED ON EXCHANGEABLE HYDROGEN (WOODRUFF OR SMP METHODS).
FOR ACID TROPICAL SOILS THE ACIDITY EXTRACTED IN 1N KCl IS USED. ALSO, CROP TOLERANCE TO ALUMINIUM EXPRESSED AS **H + Al/CEC** IS CONSIDERED TO EVALUATE THE NEED TO APPLY LIME AND ITS QUANTITY.

THE SOIL TEST REPORT AND THE CROPPING PLAN ARE FILED IN ARCHIVES. THROUGH SEARCH ROUTINES, IT IS POSSIBLE TO SEARCH, VIEW AND PRINT FILED REPORTS.

Outputs of the Model

- **Soil Analysis report (physical, chemical) and evaluation; i.e. low, medium, high, etc.**

- **Fertilizer/plant nutrient recommendations; macrro and micro elements; for a given crop and for specific yield target (on the anlaysed soil in specific agro-ecological zone).**

- **Timing, Frequency and Type of fertilizer products.**

- **Agronomic practices options/recommendations: seed rate, variety, sowing date, pesticides!**

- **Soil amendments: Lime, gypsum requirement and other management options!**