# Combination of soil classification and some selected soil properties to improve yield prediction: An experience from southwestern Nigeria

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ABSTRACT

The advantage in the combined use of soil classification and top soil analysis for explaining crop yield variation was examined. Soil properties and yields of maize (*Zea mays* L.) on different soil types were measured on farmers' fields for 2 years. Yield prediction improved from 2 per cent at the Order and Association levels to 31 per cent at the Series level in the 1st year. The following year, it improved from 5-6 per cent (at the Order and Association levels) to 39 per cent (at the Series level). Regression of yield on soil properties showed that, with one soil property in the regression, yield prediction improved from 30 per cent at the Order level to 37 per cent at the Association level and 38 per cent at the Series level. With five properties in the regression, yield prediction improved from 42 per cent at the Order level to 44 per cent at the Association level and 66 per cent at the Series level. With 10 properties in the regression, yield prediction improved from 50-51 per cent (Order and Association levels) to 84 per cent at the Series level.

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RÉSUMÉ

OLUWATOSIN, G. A. & OGUNKUNLE, A. O.: *Combinaison de la classification de sol et quelques propriétés de sol sélectionnées pour améliorer la prédiction de rendement: Une expérience de sud-ouest du Nigéria.* L'avantage d'utilisation de la combinaison de la classification de sol et d'analyse de la couche arable pour l'explication de la variation de rendement des cultures, était étudié. Les propriétés de sol et les rendements de maïs (*Zea mays* L.) sur les différents types de sol, étaient évalués sur les champs des cultivateurs pour 2 ans. La prédiction de rendement améliorait de 2 pour cent aux niveaux d'Ordre et d'Association à 31 pour cent au niveau de Séries dans la 1e année. L'année suivante l'amélioration était de 5-6 pour cent (aux niveaux d'Ordre et d'Association) à 39 pour cent (au niveau de Séries). La régression de rendement sur les propriétés de sol révélait que, avec une propriété de sol en régression, la prédiction de rendement améliorait de 30 pour cent au niveau d'Ordre à 37 pour cent au niveau d'Association et 38 pour cent au niveau de Séries. Avec cinq propriétés en régression la prédiction de rendement améliorait de 42 pour cent au niveau d'Ordre à 44 pour cent au niveau d'Association et 66 pour cent au niveau de Séries. Avec 10 propriétés en régression, la prédiction de rendement améliorait de 50-51 pour cent (aux niveaux d'Ordre et d'Association) à 84 pour cent au niveau de Séries.

## Introduction

One major purpose of soil classification is to ease the transfer of information about the use and management of soil-related technologies from one location to another. These technologies include agronomic practices, suitability assessment, crop yield prediction, and crop response to fertilizer (Beinroth *et al.*, 1980). It is commonly assumed that soil classification units represent a summary of the soil variation, and hence could also express variation in crop yield, crop suitability, and soil management requirement in a given location (Bartelli, 1978).

That assumption may not always hold because taxonomic class, as the representative of the modal profile, may not cover all the variations in soil conditions at all points in the landscape. Thus, it is possible for map units of similar pedons to respond differently to the same use or management. For instance, Costigan, Greenwood & Mc Burney (1983) reported significant crop yield differences between plots of the same soil series. The difference was due to inadequate native soil potassium in one of the plots. Webster *et al.* (1977), in a study with sugar beet, found that soil classification at any level in the existing general purpose classification accounted for no more than about 10 per cent of the variance in yield. It is, therefore, obvious that where the influence of soil fertility properties on crop performance overrides that of soil classification, soil classification alone cannot be reliably used as the sole basis for crop yield prediction or agrotechnology transfer. In such situations, crop performance would be better predicted by a combination of soil classification and the results of soil analysis.

Most of the studies in this area (e.g. Costigan *et al.*, 1983; Ogunkunle & Beckett, 1988) have been restricted to temperate regions. There is need to examine the practical relevance of soil classification and the complementary relationship it has with soil analysis for crop yield prediction in a tropical region.

The objective of this study, therefore, is to examine how the analysis of some selected soil properties could be combined with soil classification to improve yield prediction in the tropics.

## Materials and methods

### *Study area*

The study area is in the savanna zone of southwestern Nigeria. It lies between latitude 5° 15" and 7° 45" and longitude 2° 30" and 4° 39". The north and the central part of the area have periodically dry savanna ecology, while the southern part is the forest-savanna mosaic. The area covers about 29600 km$^2$ of southwestern Nigeria. The mean annual temperature is 27 °C with remarkably constant mean annual rainfall of about 1140 mm. The area is underlain by the precambrian crystalline basement complex rocks. The soils of the area include well-drained upper/middle slope soils (Alfisols) and internally poorly drained lower slope and valley bottom soils (Entisols) (Table 1). The soils have been classified to the Series level, with kaolinite dominating the clay mineralogy (Murdoch *et al.*, 1976).

TABLE 1

*Soil Classification and Parent Material of the Study Sites*

| *Order* | *Association* | *Series* | *Geological formation* |
|---|---|---|---|
| | | SI Egbeda | |
| | | S2 Shepeteri | |
| 01 Alfisol | Al Egbeda | S3 Igboho | Fine grained |
| | | S4 Titiale | biotite gnesis |
| | | S5 Owutu | |
| | | S6 Ibadan | |
| | A2 Iwo | S7 Woro | Coarse granite |
| | | S8 Temidire | and gnesis |
| 02 Entisol | A3 Shante | S9 Shante | Colluvial materials |
| | | S10 Fashola | of acidic granite |

### *Sampling and yield determination*

Ten farmlands were selected within three locations in the area for this study. Soil auger was used to identify the soils and profile pits were dug at points typical of the dominant class. The pits were then described and sampled for laboratory analysis. The choice of farm was based on the variety of maize (those with same varieties or varieties with similar yield). The varieties used here were TZRS-Y and TZRS-W. In addition, all the farms chosen did not apply inorganic fertilizers; the plots were previously under grass fallow (Table 2).

A plot of 30 m × 60 m was marked out on each farm at the site of the profile pit. Twenty blocks (1 m × 2 m) were randomly selected within each plot. Core soil samples (0-20 cm) were taken at the base of sampled maize stands at silking (Sopher & McCracken, 1973) and bulked into a composite

TABLE 2

*Agronomic Practices and Yield of the Site*

| *Farms* | *Soil series* | *Maize variety planted* | *Plant (per ha)* | *Weeding* | *Past land use* | *Land preparation* | *Planting date* | | *Farm yield* | |
|---|---|---|---|---|---|---|---|---|---|---|
| Ilora | Ibadan | TZRS-Y | 55.556 | One hand weeding at 4 weeks after planting | Grass fallow | 2 plough | 30/6/89 | 28/5/90 | 2.44 | 2.6 |
| | Egbeda | TZRS-Y | 55,556 | One hand weeding at 4 weeks after planting | Grass fallow | 2 plough | 9/7/89 | 26/6/90 | 2.81 | 2.6 |
| | Shante | TZRS-W | 55,556 | One hand weeding at 4 weeks after planting | Grass fallow | 2 plough | 21/5/89 | 27/5/90 | 2.72 | 2.6 |
| | Fashola | TZRS-W | 55,556 | One hand weeding at 4 weeks after planting | Grass fallow | 2 plough | 31/5/89 | 29/5/90 | 0.8 | 1.0 |
| Ilero | Shepeteri | TZRS-Y | 55,556 | One hand weeding at 4 weeks after planting | Grass fallow | 2 plough | 7/5/89 | 4/6/90 | 2.3 | 2.4 |
| | Woro | TZRS-W | 55,556 | One hand weeding at 4 weeks after planting | Grass fallow | 2 plough | 7/5/89 | 11/5/90 | 2.53 | 2.7 |
| | Igboho | TZRS-W | 55,556 | One hand weeding at 4 weeks after planting | Grass fallow | 2 plough | 7/6/89 | 8/6/90 | 2.3 | 2.7 |
| | Temidire | TZRS-W | 55,556 | One hand weeding at 4 weeks after planting | Grass fallow | 2 plough | 6/5/89 | 26/5/90 | 2.2 | 2.4 |
| Saki | Titiale | TZRS-Y | 55,556 | One hand weeding at 4 weeks after planting | Grass fallow | 2 plough | 4/5/89 | 5/8/90 | 1.3 | 1.5 |
| | Owutu | TZRS-W | 55,556 | One hand weeding at 4 weeks after planting | Grass fallow | 2 plough | 30/5/89 | 28/5/90 | 2.3 | 2.8 |

sample for laboratory analysis. Soil sampling was restricted to the upper 20 cm (Ap horizon) because studies have shown that soil properties in the upper 20 cm depth control the yield of maize (Lal *et al.*, 1977; Sopher & McCracken, 1973). Ten maize stands within each block were harvested at about 15 per cent moisture content and the grain yield was determined. These operations were repeated on the same plots in the 2nd year.

*Soil properties and classification*

Soil samples collected for the 2 years were air dried, crushed, and passed through a 2-mm sieve. The gravel content (materials > 2 mm) was determined and expressed as percentage of the total weight of the soil. Standard laboratory methods (Tell, 1984) were used to analyze the soil samples. Soil *p*H was determined potentiometrically in water. Exchangeable bases were extracted with neutral ammonium acetate solution;

Ca and Mg were determined by atomic absorption spectrophotometry, and K and Na by flame photometry. Exchangeable acidity was determined by the KCl extraction method (Chapman, 1965). Total nitrogen was determined by the macro-Kjeldahl method (Bremner, 1960), available phosphorus by the Bray & Kurtz (1945) method, and organic carbon by the method of Walkley & Black (1934). Bulk density was determined on core samples (Blake, 1965). Micronutrient was extracted by 1*M* HCl and determined by atomic absorption spectrophotometry (Udo & Ogunwale, 1982). The soils were classified into Orders (Soil Survey Staff, 1995), Associations (Smyth & Montgomery, 1962), and Series (Murdoch *et al.*, 1976).

*Data analysis*

The study aimed at showing the advantage of the combination of soil classification and soil analysis over either of them to predict crop yield. It was specifically designed to measure the fraction of the total variability in the 200 yield values (total variance) that was not described or predicted (i.e. error variance) by soil classification. This was done by using multiple linear regression on 21 soil properties within each classification unit (i.e. Order, Association and Series).

*Prediction by classification*

A one-way analysis of variance (ANOVA) of soil classification was used to predict yield. Table 3 is an example of the ANOVA for the Order level. There is, however, a complication as pointed out by Ogunkunle & Beckett (1988). For example, if all the sampling points were to be completely randomly distributed over the two soil Orders (Alfisol and Entisol) and the yield and values of soil properties were determined at each point, the regression SS (or MS) would be zero (i.e., no yield variation for regression to account for ). But the between-unit SS (MS) will not be zero; it will have a value higher than zero. Thus, the comparison of the predictive power of classification and regression in the error SS (i.e., undescribed variability) may favour classification over regression. Thus, an adjustment to the calculation of between-unit SS that makes the two more comparable will lead to a more valid result, even though complete randomization very rarely (if at all) operates in practice. So the between-unit SS was calculated, as follows, by using the ANOVA for soil Order (Table 3) as an example.

TABLE 3

*A One-Way Analysis of Variance of Yield on Classification (Soil Order)*

| *Source* | *Df* | *SS* | *MS* |
|---|---|---|---|
| Between classification unit | 1 | 32035.75 | 32035 |
| Within classification unit (error) | 198 | 1740875.17 | 8792.29 |
| Total | 199 | 1772910.92 | |

Corrected between-unit MS

$$=(32035.75-8792.29)$$

$$=23243.45 \text{ (i.e., } \frac{32035.75}{1}-\frac{1740875.17}{98}\text{)}$$

Corrected between-unit SS

$$=32035.75\times\frac{23243.45}{32035.75}$$

$$=23243.43$$

Thus,

$$\frac{1772910.92-23243.43}{1772910.92}=94.3\,\%$$

is the fraction of the total variability that the soil Order has failed to describe.

Instead of

$$\frac{174087.17}{1772910.92}=98.19\,\%$$

*Prediction by soil properties*

Multiple linear regression of yield on 21 soil properties was determined by a stepwise procedure. This procedure first determines the regression on all the 21 properties after which the least significant property is dropped. This process continues until the regression has been calculated on the last single property. The error sums of squares at each stage were determined from regression ANOVA.

*Prediction by the combination of classification and soil properties*

Similar stepwise regressions were calculated for each of the classification units. However, the regression was on the 10 most significant soil properties.

## Results and discussion

The results (Table 4) showed that crop yield prediction by classification alone is relatively poor, especially at the Order and Association levels.

TABLE 4

*Percentage Yield Variation Explained by Soil Analysis, Classifications and Combined Soil Analysis and Classification*

| | | | | | | |
|---|---|---|---|---|---|---|
| Soil properties alone | | | | | | |
| 1989 | 1990 | | | | | |
| 1990 | 57 | | | | | |
| Classification alone | | | | | | |
| | *Order* | | *Association* | | *Series* | |
| | *1989* | *1990* | *1989* | *1990* | *1989* | *1990* |
| | 2 | 5 | 1 | 6 | 31 | 39 |
| Combined soil properties and classification | | | | | | |
| | *Order* | | *Association* | | *Series* | |
| | *1989* | *1990* | *1989* | *1990* | *1989* | *1990* |
| (a) | 30 | 15 | 37 | 16 | 38 | 28 |
| (b) | 42 | 35 | 44 | 33 | 66 | 65 |
| (c) | 50 | 44 | 51 | 38 | 84 | 85 |

a = one property in regression
b = five properties in regression
c = 10 properties in regression

Nevertheless, classification at the soil Series level is a lot more appreciable, as 30-40 per cent of yield variation was explained in both years. In contrast, soil Order and soil Associations explained <5 % and <10 % of the yield variation, respectively. This is not surprising because soil taxonomic classes, even at the Series level, are defined mainly on subsoil properties whereas arable crop yield, especially cereals, depends on surface soil properties (Sopher & McCracken, 1973).

There is, however, an improvement in crop yield prediction when soil analyses alone were examined. The result of the regression also showed that the soil properties that contribute to yield variation vary from year to year (Table 4). Also, the percentage yield variation accounted for varied whether the number of properties in the regression varied or remained the same. These results indicate that, though yield prediction by soil analysis alone improved over soil classification, the inconsistency in the type of properties and the percentage accounted for make soil analysis alone not very reliable in crop yield prediction. A similar conclusion was reached by Boyd & Dermott (1964).

The results of regression of soil properties on yield within classification units follow the findings of Ogunkunle & Beckett (1988), in that the soil properties that determine yields within one classification unit are not the same as those that determine yields within another soil unit. As shown in Table 4, the percentage yield prediction by soil properties differed from one level of classification to another. For instance, with one best property in regression, <30 per cent yield variations were predicted irrespective of the level of classification. However, with five properties in regression, soil Series explained 66 per cent in the 1st year and 64 per cent in the 2nd year. The soil Order explained 42 per cent in the 1st year and 35 per cent in the 2nd year, while soil Association explained 44 per cent in the 1st year and 33 per cent in the 2nd year.

Similarly, yield prediction at soil Series level increased to 84 - 85 per cent in the 1st and 2nd years, respectively, when 10 properties were in the regression. However, at the Order level, yield prediction increased to 50 and 44 per cent depending on the year, while yield prediction by soil Association was 51 per cent in 1989 and 38 per cent in 1990. These results show that while it could be sufficient to analyze five "best" soil properties to improve the predictive power of classification at the Series level, it may be necessary to analyze 10 or more soil properties to appreciably predict crop yield at the Order and Association levels.

The results inTables 5 and 6 further show that the best soil property that determines yield within one soil unit is not the same as the one that determines yield within another unit. Similarly, the percentage yield variation explained by the properties varies from one soil unit to the other. Also, within the same soil unit, the percentage yield variation explained differs from year to year.

TABLE 5

*Relative Importance of the Five Best Soil Properties as Predicators of Maize Yield*

| *Classification* | | *Year 1 rank* | | | | | *Year 2 rank* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Unit | 1st | 2nd | 3rd | 4th | 5th | 1st | 2nd | 3rd | 4th | 5th |
| Order | 01 | Na | N | Si | P | fs | N | K | Fe | fs | P |
| - | 02 | Gravel | ECEC | Zn | Mn | P | Ca | Na | Zn | *p*H | ECEC |
| Association | A1 | Gravel | Mg | Zn | Mn | P | Na | Gravel | Ca | *p*H | Bd |
| | A2 | K | N | Cu | P | FS | N | K | Fe | fs | P |
| | A3 | *p*H | Ca | Si | Mg | Cu | Ca | Na | Zn | *p*H | ECEC |
| Series | S1 | Zn | Na | Cu | N | K | Mn | fs | K | P | Fe |
| | S2 | CS | *p*H | Si | Cu | Fe | Si | Mg | P | Fe | Exch. Acidity |
| | S3 | Zn | CS | Cu | *p*H | fs | Na | Cu | Si | Cs | P |
| | S4 | P | Zn | Gravel | fs | Na | Fe | Na | Zn | Mg | Ca |
| | S5 | Cu | CS | Cl | Na | P | Cs | Cu | Si | Mg | ECEC |
| | S6 | K | P | Si | Cu | N | Si | Base Sat. | pH | Na | Fe |
| | S7 | Mg | P | Bd | Mn | *p*H | Cu | Exch. Acidity | Zn | Ca | Si |
| | S8 | Bd | Cl | Mg | Base Sat. | ECEC | Zn | Mg | Na | Si | Cl |
| | S9 | P | Mn | ECEC | Fe | *p*H | Ca | SI | Cl | Cu | ECEC |
| | S10 | Org. Carbon | Mg | Ca | Zn | Cu | Si | Org. Carbon | Cl | Cu | *p*H |

TABLE 6

*Percentage of Yield Variation Explained by Best 10 Soil Properties*

| *Number of properties* | *Order (O)* | | *Association (A)* | | *Series (S)* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *O1* | *O2* | *A1* | *A2* | *S1* | *S2* | *S3* | *S4* | *S5* | *S6* | *S7* | *S8* | *S9* | *S10* |
| 1 Year 1 | 16 | 43 | 26 | 43 | 13 | 41 | 26 | 42 | 29 | 17 | 16 | 20 | 32 | 22 |
| Year 2 | 16 | 15 | 17 | 14 | 16 | 20 | 66 | 34 | 38 | 25 | 16 | 31 | 16 | 20 |
| 3 Year 1 | 25 | 56 | 40 | 51 | 43 | 60 | 66 | 65 | 71 | 37 | 43 | 86 | 51 | 46 |
| Year 2 | 26 | 42 | 26 | 36 | 42 | 54 | 86 | 49 | 62 | 42 | 36 | 51 | 52 | 48 |
| 5 Year 1 | 28 | 56 | 46 | 58 | 54 | 70 | 83 | 75 | 80 | 75 | 56 | 48 | 56 | 63 |
| Year 2 | 27 | 42 | 30 | 42 | 52 | 55 | 91 | 62 | 72 | 49 | 53 | 62 | 73 | 70 |
| 7 Year 1 | 30 | 61 | 48 | 61 | 56 | 75 | 87 | 84 | 84 | 80 | 81 | 58 | 65 | 76 |
| Year 2 | 28 | 46 | 33 | 46 | 62 | - | 93 | 77 | 76 | 55 | 67 | 71 | 78 | 87 |
| 10 Year 1 | 31 | 68 | 49 | 68 | 72 | 84 | 90 | 92 | 88 | 94 | 93 | 67 | 72 | 87 |
| Year 2 | 29 | 58 | 34 | 59 | 77 | - | 94 | 83 | 86 | - | - | 80 | 82 | 96 |

For example, with five properties used in the regression in the Order Entisol (02), gravel content, ECEC, Zn, Mn and available P accounted for 56 per cent of yield variation in the 1st year. In the 2nd year, Ca, Na, Zn, *p*H and ECEC accounted for 42 per cent of yield variation. Similarly, in the Egbeda association (A2), K, N, Cu, P and fs accounted for 58 per cent yield variation in the 1st year. Also in the 2nd year, N, K, Fe, fs and P accounted for 42 per cent yield variation. At the Series level, however, Zn, Cs, Cu, *p*H, and fs accounted for 87 per cent yield variation in the 1st year, while Na, Cu, Si, Cs and P accounted for 93 per cent yield variation in the 2nd year.

The differences in the types of soil properties and percentage of yield variation accounted for might be related to the residual effect of past land use and management (being surface samples) as well as the basic difference in the effect the properties had on maize yield. Only Zn and ECEC are common to both years in Order O2, K, N, and P in association A2, and Cu and Cs in Series S3. The difference in climatic factors (e.g. rainfall and temperature) could have also contributed to the yield predictions for the two years. The result suggests that where soil mapping has taken place and the unit of mapping is at the Series level, analysis of a few relevant and easily determined surface soil properties would improve land use prediction substantially. However, where the unit of mapping is at higher categories, more soil properties need to be analyzed for a reliable land use prediction.

## Conclusion

Soil classification alone cannot be reliably used to predict crop yield in this environment. At the same time, the inconsistency in the types of soil properties in explaining yield variation from one year to another make soil properties alone unreliable for predicting yield. Very clearly, a combination of soil classification and soil properties has higher predictive value, especially when the unit of classification is the soil Series. Where soil mapping has taken place and the unit of mapping is at the Series level, analysis of a few relevant and easily determined surface soil properties would improve land used prediction substantially. However, where the unit of mapping is at higher categories, more soil properties need to be analyzed for a reliable land use prediction. Thus, a combination of soil classification and some selected soil properties of top soil provides reliable prediction of soil behaviour on which agrotechnology transfer can be based.

## REFERENCES


**Beinroth, F. H. G., Uehara, J. A., Silva, P. W., Arnold & Cady, F. B.** (1980) Agrotechnology transfer in the tropics based on soil taxonomy. *Advances in Agronomy* **33**, 303-339.

**Blake, G. R.** (1965) Bulk density. In *Methods of soil analysis* (*Agron. Monogr.* **9** (1), ed. C. A. Black), pp. 374-390. Madison: American Society of Agronomy.

**Boyd, D. A. & Dermott** (1964) Fertilizers experiment on maincrop potatoes. *J. agric Sci. Camb.* **63**, 249-259.

**Bray, R. H. & Kurtz, L. T.** (1945) Determination of total organic and available forms of phosphorus in soil. *Soil Sci.* **59**, 39-49.

**Bremner, J. M.** (1960) Determination of nitrogen in soil by Kjeldahl method. *J. agric. Sci.* **59**, 39-45.

**Chapman, H. D.** (1965) Foliar sampling for determining the nutrient status of crops. *Wld Crops* **16**, 36-45.

**Costigan, P. A., Greenwood, D. J. & McBurney, T.** (1983) Variation in yield between two similar sandy loam soils. I. Description of soils and measurement of yield differences. *J. Soil Sci.* **34**, 621-637.

**Day, P. R.** (1965) Particle fractionation and particle size analysis. In *Methods of soil analysis (Agron. Monogr.* **9** (1), ed. C. A. Black), pp. 543-550. Madison: American Society of Agronomy.

**Lal, R., Kang, B. T., Moorman, F. R., Juo, A. S. R. & Moowaw, J. C.** (1977) Soil management problem and possible solution in western Nigeria. In *Soil management in tropical America* (ed. E. Bornemisza and A. Alfredo), pp. 372-408. Raleigh: North Carolina State University.

**Murdoch, G., Ojo-Atere, J. O., Colborne, G., Olomu, E. & Odugbesan, E.** (1976) Soils of Western State Savanna. *Land Res. Study* **23**, I. Tolworth, England: Land Resources Research

Division.

**Ogunkunle, A. O. & Beckett, P. H. T.** (1988) Combining soil map and soil analysis for improved yield prediction. *Caterna* **5**, 529-538.

**Richards, L. A.** (1965) Physical conditions of water in the soil. In *Methods of soil analysis (Agron. Monogr.* **9** (1), ed. C. A. Black), pp. 128-151. Madison: American Society of Agronomy.

**Smyth, A. J. & Montgomery, R. F.** (1962) *Soils and land use of Central Western Nigeria.* Government Printer, Government of western Nigeria.

**Soil Survey Staff** (1995) *Keys to soil taxonomy (SMSS Tech. Monogr.* **19**, 6th edn).

**Sopher, C. D. & McCracken, R. J.** (1973) Relationship between soil properties, management practices and corn yield in South Atlantic coastal plain soils. *Agron. J.* **65**, 595-600.

**Tell, D. A.** (1984) *Soil and plant analysis: Study guide for Agricultural Laboratory Directors and Technologists working in tropical regions* (ed. D. A. Tell). Ibadan: International Institute for Tropical Agriculture (IITA) and Guelph: University of Guelph.

**Udo, E. J. & Ogunwale, O.** (1982) *Soil and plant analytical methods in Nigeria.* Special Publication of the Department of Agronomy, University of Ibadan, Ibadan, Nigeria.

**Walkley, A. & Black, I. A.** (1934) An examination of the Detjareff methods for determining soil organic matter and a proposed modification of chromic acid titration method. *Soil Sci.* **37**, 29-38.

**Webster, R., Hodge, C. A. H., Dray, A. P., Cott & Durrant, M. J.** (1977) The effect of soil types and related factors on sugar beet yield. *J. agric. Sci. Camb.* **88**, 455-469.