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RWANDA SMALL MARAIS DEVELOPMENT STUDY

Investigations into the Agronomy of two Small Marais: Nyarutovu and Ilibunga

A WMS-II Study in Cooperation with the
MINISTERE DE L'AGRICULTURE, DE L'ELEVAGE ET DES FORETS
and
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Technical report outlining field research activities and results obtained in Rwanda during the period July 3 - November 17, 1987. The author is solely responsible for the opinions expressed herein.

WATER MANAGEMENT SYNTHESIS II

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PREFACE

The following report is a detailed technical outline of the agronomic research activities conducted in Rwanda as part of the USAID WMS-II Marais Development Study (MDS). The MDS had received the mandate to study existing hydrologic, agronomic and socio-economic structures of small marais and to formulate recommendations for their future development and use.

A final comprehensive report for the MDS is currently being compiled by Mr. Roelof Sikkens, coordinator of the study, and should be available in the beginning of '88. Reference to this document is suggested for any general information concerning Rwanda and small marais which may not have been covered in the following report. The purpose of this particular report was to provide details of the agronomic findings from a more scientific point of view than was displayed in the MDS final report and in the Agronomy mission report submitted by the author to USAID/Rwanda. Thus, only background information specifically related to the research activities will be supplied to avoid any redundancies.

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A. INTRODUCTION

The term 'marais' in Rwanda has been used to characterize any seasonally or permanently inundated valley or depression with alluvial soils, which may or may not be organic (Cambrezy, 1981). Small marais, as opposed to their larger counterparts in the flood plains, are found scattered throughout the country with a high concentration in the Central or High Plateau region of Rwanda (Jones and Egli, 1984).

The marais have long been considered a last resort for expanding cultivated acreage in landlocked Rwanda, which is facing problems of overpopulation and land shortage and fragmentation (Cambrezy, 1981). Most marais are now cropped, and access to plots is controlled at the communal level, since land is under state ownership.

Few development schemes in the past have been concerned with soil characterization and existing cropping systems in small marais. Most have dealt with hydrologic aspects such as drainage and irrigation, although with relative success. There was thus a need to gain some insight into the nature and importance of soil constraints in small marais and their effects on the efficiency of existing cropping systems.

The main objectives of the research activities conducted in Rwanda from July 3 through November 15, 1987, were to characterize the fertility of the soils of two small marais and to relate fertility and soil water parameters to the performance of the traditional cropping system, sweet potatoes (Ipomoea batatas) on raised beds. Secondary objectives were to evaluate fertilizer response and assess growth of alternative crops on marais soils. The main body of the report comprises three sections: the first contains background information on the two marais studied, the second describes in detail the crop-soil-water system study and the third outlines the fertilizer trials.

B. NYARUTOVU AND ILIBUNGA

B.1 Location and climate

The two marais studied were those of Nyarutovu and Ilibunga, both located in the Butare prefecture, part of the Central Plateau region of Rwanda. This region is characterized by altitudes varying between 1550 and1800 m (medium elevation zone) and by an annual precipitation of 1000 -1200 mm (Jones and Egli, 1984). Rainfall pattern is bimodal, with the long rainy season extending February-June and the short rains, October-December. The main dry season in the Central Plateau lasts 95-110 days, and occurs in June-October. The marais of Nyarutovu and Ilibunga were in close proximity of each other, being separated only by a hill. Part of the Nyarutovu marais was occupied by fish ponds constructed by the USAID National Fish Culture Project, which also cultivated some of the land.

B.2 Soils - parent materials

Soils of the Central Plateau, where the two marais were located, are derived from ancient metamorphic rocks, granites, schists and gneisses originating from the basic pre-Cambrian shield (Jones and Egli, 1984). These parent rocks are very important factors

contributing to the chemical properties of Rwandan soils (Van Wambeke, personal communication). Granite and quartzitic rocks generally weather to form acid, chemically inert soils. According to field observations and the soil map of Rwanda (Van Wambeke, 1963), the Central Plateau is covered by extensive areas of soils rich in oxides and kaolinite clays. A study conducted by Mutwewingabo et al. (1985) also found that the electrochemical behavior of a set of Butare soils was almost identical to that of the metallic oxides of iron and aluminum. These highly weathered soils, also known as Oxisols and Ultisols in the USDA system of classification, generally display favorable physical properties but have poor chemical fertility. Alluvial materials and organic soils are found in valley bottoms, but their characterization is not as complete.

Soils of the Nyarutovu and Ilibunga marais appear to have developed from colluvial material washed down from adjacent hill slopes, as well as from subsurface alluvium (Rutunga, personal communication). Soils were thus predominantly mineral, and presented surface characteristics similar to the adjacent hill slopes. The exception was a small pocket of well-decomposed peat at one extremity of the Nyarutovu marais. A typical profile would show a high chroma surface layer subtended by a gleyed, heavy subsoil, although much variability in texture is found to occur. The alluvial, often hydro-morphic subsurface horizon seems characteristic of small marais soils and distinguishes them from hill slope soils.

B.3 Cropping systems

The main cropping system encountered in both marais (and in small marais in general), was that of dry season sweet potato (Ipomoea batatas) cultivation. Under this system, sweet potato vines consisting of a mixture of local clones are densely planted on raised beds of varying dimensions, but generally 60 cm high x 10-15 m long x 3-8 m wide. Considerable labor goes into the preparation of the beds, which often involves removal of rhizomatous grasses (Digitaria) proliferating during the fallow period. But once vines are planted, little work is required since they quickly cover the soil and

weeding is eliminated.

After about 6 months of vegetative growth, tubers are harvested and vines collected for hill slope planting at the onset of the rains. During the long rains, the marais land is either left fallow and grazed, cropped to sorghum or replanted to sweet potatoes. This shows that small marais are not exclusively cropped during the dry season, as is often assumed (Jones and Egli, 1984; Cambrezy, 1981). It is not clear, however, what factors determine use or non-use of marais land during the rains, although the frequency of flooding is most likely important.

As opposed to the hill slope which often receives regular additions of manure and/or compost, marais soils are mostly unfertilized. The only consistent amendment seems to be the turning under of grass fallow (rhizomes removed), and the addition of sedges and other weeds from the bordering ditches. Thus, one of the hypothesized reasons for the predominance of the sweet potato/raised bed system is its ability to tolerate low fertility conditions (Rutunga, personal communication). Even on the hill slope, manure is saved for other crops (Alvarez and Ndamage, 1985). In particular, Sanchez (1976) has stressed the low phosphorus (P) requirement of this crop, stating that 75% of maximum yield can be obtained with levels as low as 0.003 ppm P. The drought tolerance of sweet potatoes, as described in Acland (1971) and Purseglove (1968) is also a desirable asset for dry season cropping. Therefore, the sweet potato system seems well adapted to the constraints operating in small marais.

Few indications of disease or pests could be observed on sweet potatoes in either marais, although it has been mentioned that they pose a threat to production in Rwanda (Alvarez and Ndamage, 1985). Symptoms associated with virus diseases (shortened internodes, chlorosis, stunting, excessive leaf proliferation) were found to occur to some extent. Viruses are the most serious disease problem of sweet potatoes in East Africa, and are apparently responsible for the early demise of clones (Acland, 1971). No methods of pest control seemed to be practiced on sweet potatoes in the marais.

Other crops are grown to a lesser extent in the two marais: beans, potatoes, cabbage and other annual vegetables. In Nyarutovu, the

pocket of organic soil was intensively cropped to vegetables by a farmer cooperative, and seemed to be the most productive portion of the marais.

It is difficult to affirm whether the marais of Nyarutovu and Ilibunga were representative of small marais of Rwanda in terms of climate, soils and cropping systems. At best they exemplified conditions existing in marais of the Central Plateau region. Marais across the country display a considerable amount of variability, and, as shall be seen in the following sections, variability is high between neighbouring marais and even within a single marais. Thus, caution should be exercised in extrapolating research findings to all small marais of Rwanda.

C. CROP-SOIL-WATER SYSTEM STUDY

This study was the most important component of the agronomic research activities conducted in the small marais of Nyarutovu and Ilibunga. Its objective was to relate sweet potato yields from farmers' plots to soil fertility and water parameters. As such, it was an observational study rather than a controlled experiment, so the limitations with respect to cause and effect should be kept in mind.

C.1 Methodology

The measurements and analyses conducted as part of the study were divided into 3 general categories: soil fertility (chemical and physical), soil water and crop yields. The methodology used for each will be described separately, but it should be stressed that points of sampling and measurement were made to coincide for all three categories, i.e. for each water table reading there was corresponding soil sample and yield measurement.

C.1.1 Soil water

The soil water and hydrology studies in the marais of Nyarutovu and Ilibunga were managed by Roelof Sikkens, Department of Agricultural Engineering, Cornell University. Data retained for the Agronomy analyses included water table depths and soil moisture contents at two depths, 25 and 50 cm. Water table measurements were taken from 2 m-long PVC piezometer tubes installed along transects in both marais in late June. The position of the piezometers, as displayed in fig. C.1 for both marais, determined the areas of soil sampling and yield measurement. Only positions covered by a sweet potato crop were considered for this study, which amounted to 50 in total.

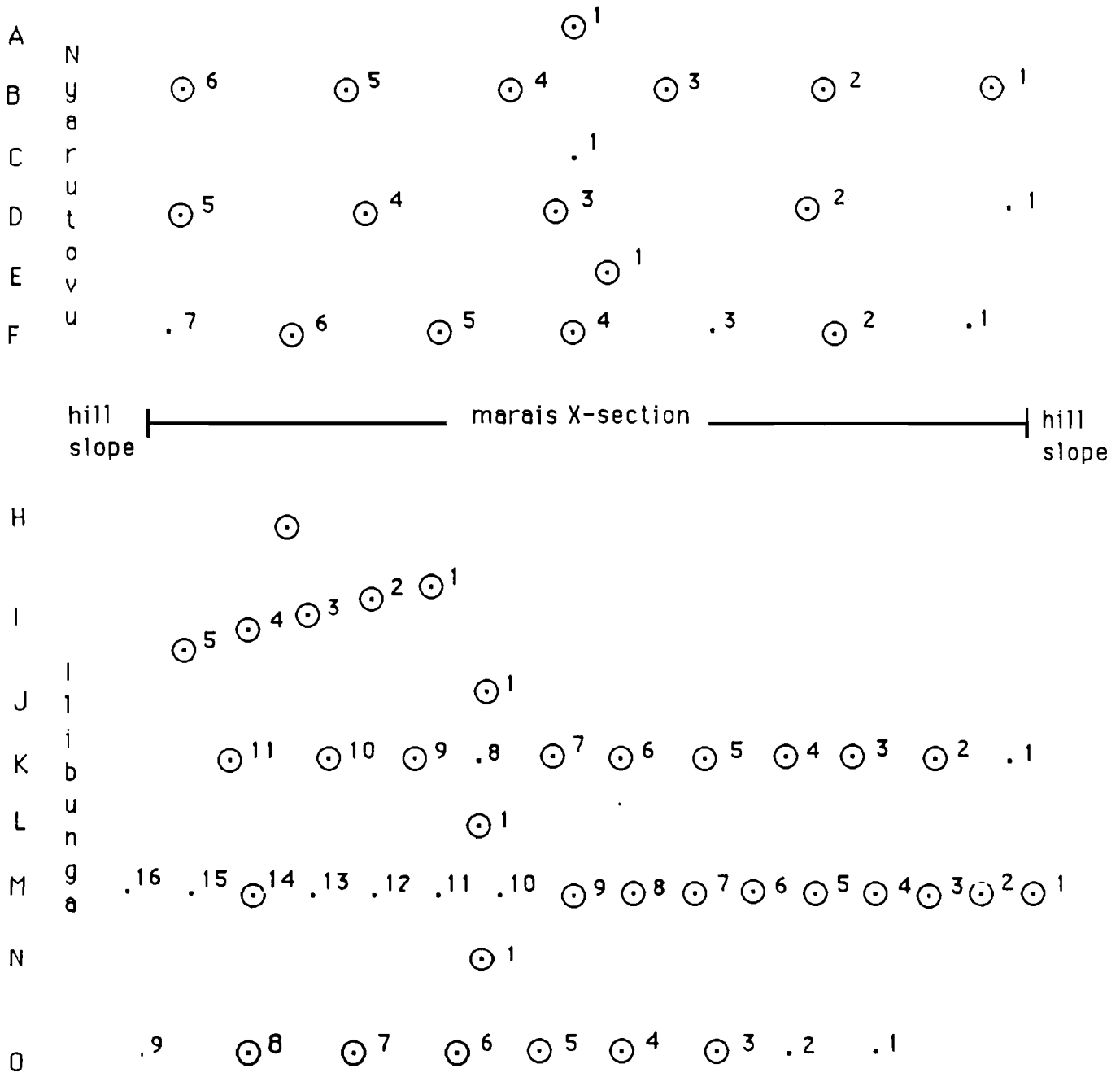
Data were recorded on a weekly basis for water table depth and samples collected every two weeks for soil moisture, starting July 1. Since readings tended to remain constant in time during the period of interest (dry season), an average value for water table depth and moisture content was computed and used in the final analysis.

C.1.2 Soil fertility

For the soil fertility analyses, two soil samplings were undertaken at all 50 considered positions in both marais. The first sampling involved collecting surface clods (aggregates) for estimation of bulk density, and in the second, soil for the chemical analysis was retrieved with an auger to a depth of 30 cm.

Bulk density of four different clods was measured for each point sampled and an average value computed therein. The method used was that of water displacement by wax-dipped clods which had previously been weighed. Although not very accurate, the method provided a good basis for comparison and a reasonable estimate of soil physical conditions.

The chemical analyses were conducted at the Soil Laboratory of the Faculté d'Agronomie, Universite Nationale du Rwanda, located in Butare. Air-dry samples (except for pH of moist soil) were submitted to the following analyses:



⊙ Positions with sweet potato crop = sampled points

figure C.1 Positions of piezometer tubes in marais of Nyarutovu and Ilibunga

1. pH (dry) - measured by pH-meter using 1:1 soil water solution
2. pH (moist) - same as for dry but using moist soil (field conditions)
3. Exch. Al and exch. acidity - extraction with 1 N KCl, complexation with NaF and titration
4. Exch. bases (Na, Ca, Mg, K) - extraction with 1 N NH_4OAc at pH7 and determination by atomic absorption
5. Organic matter - Walkley-Black oxidation
6. Effective cation exchange capacity (ECEC) - sum of exch. bases and exch. acidity

Soil tests for P were not conducted due to time constraints and reports of extremely low levels for Butare (Vander Zaag et al., 1984) which were confirmed by preliminary soil tests for Nyarutovu (levels at the limit of detection).

C.1.3 Crop yields

Sweet potato yields were measured from farmers' plots containing piezometer tubes. For this purpose, a 1 square meter area was delineated in close proximity to the tubes, and sweet potato vines and tubers growing within the quadrat were harvested and weighed separately in the field. Fresh weights were recorded and converted to t/ha.

Since date of planting of the crop varied from February to July, sweet potatoes were harvested at different dates to allow later crops more time to mature. Crops planted during February and March (about half the observations) were harvested September 12, those planted in April were harvested October 1, those in May, October 15, and those in June and early July, November 2. Although not ideal, this seemed the most practical way of controlling variability in planting date.

C.1.4 Statistical analysis

The data obtained from the soil water, soil fertility and yield measurements were compiled and summary statistics computed for

each marais separately. Regression analysis of sweet potato yields on selected variables was subsequently performed. The statistical analysis were conducted with the help of the StatWorks package on a MacIntosh microcomputer. Further details of the analyses are given in the results and discussion section.

C.2 Results and discussion

The soil test results, water measurements and yield data for each of the piezometer positions are presented in Appendix 1 of this report. Preliminary discussions on the soil test results and sweet potato yields are provided prior to regression of yields on soil variables.

C.2.1 Soil test results

Summary statistics for the soil test results were computed from the data in Annex 1. The mean, range of values and coefficient of variability (CV) for the different tests are displayed in table C.1.

To begin with, values for the CV's denoted a high spatial variability within both marais for most of the properties examined. This emphasized the difficulty of making precise statements concerning fertility conditions of the marais. In general, however, the numbers were indicative of a very low nutrient supply and high acidity for both marais, although the situation was more favorable in the Ilibunga marais. The reasons for the higher fertility of the Ilibunga marais were not quite clear, although the presence of higher activity clays closer to the surface (as indicated by plasticity and heavy texture) may have been responsible. In some areas, the heavy clays occurred as outcrops at the surface, and much higher pH values were recorded in these cases (e.g., piezometer I-1).

As a general rule, P, exch. bases and ECEC were low while acidity and exch. Al levels were high. Sanchez and Salinas (1981) state that the critical levels for K are in the 0.15-0.20 meq/100 g range; about 80 % of the points sampled in this study were below 0.15. Vander Zaag et al. (1984) reported for a transect of Butare soils higher

table C.1 Summary of soil test results for the Nyarutovu and Ilibunga marais

soil test	*Nyarutovu marais			Ilibunga marais		
	mean	range	**CV	mean	range	CV
pH - dry soil	3.8	3.2 - 4.5	9 %	4.1	3.5 - 5.1	9 %
pH - moist soil	4.3	3.7 - 5.1	9 %	4.8	4.2 - 6.5	8 %
Acidity (meq/100g)	2.72	0.83-6.23	51 %	1.71	0.25-4.18	59 %
Aluminum (meq/100g)	2.15	0.55-5.18	57 %	1.35	0.10-3.35	66 %
Organic matter (%)	2.7	1.5 - 6.2	57 %	2.0	0.7 - 3.8	41 %
Potassium (meq/100g)	0.11	0.08-0.18	28 %	0.12	0.05-0.21	35 %
Calcium (meq/100g)	0.81	0.16-1.68	59 %	1.23	0.12-3.52	65 %
Magnesium (meq/100g)	0.30	0.05-0.66	65 %	0.51	0.07-1.37	58 %
Exchange Capacity (meq/100 g)	3.96	2.45-6.76	32 %	3.56	1.43-7.10	41 %
Bulk Density (g/cm3)	1.38	1.07-1.60	10 %	1.46	1.29-1.67	8 %
Phosphorus	traces (limit of detection)					

* 16 samples for Nyarutovu; 34 for Ilibunga
** Coefficient of variability

values for fertility (pH: 5.8, Ca: 7.7, K: 0.54, Mg: 1.72 meq/100g) than was found in the marais of Nyarutovu and Ilibunga. Thus the common-held asumption that marais soils are much more fertile than their upland counterparts (Jones and Egli, 1984) did not hold here. In addition, the documented problem of Al toxicity in the soils of Rwanda (Jones and Egli, 1984) also could be present in the marais. Aluminum saturation (exch. Al/ECEC x 100) was found to reach 80 % in some points. This would suggest a high degree of fertility exhaustion in the marais soils around Butare, a reasonable proposition considering the soil parent materials the lack of fertility amendment by farmers.

Another point worthy of discussion was the difference exhibited between pH values of the moist and dry soil. The data in Appendix 1 and table C.1 show that pH of the soil measured directly after sampling (moist) was always higher than the pH for dry soil, a phenomenon not observed with upland soils. This difference in pH was possibly a result of the reduction potential characteristic of wetland soils in general. It is known that reduction reactions,

particularly iron reduction, consume H^+ ions and thus effect an increase in pH of acid soils (Sanchez, 1976; Ponnamperuma, 1972). This hypothesis was further supported in the marais by the presence of hydromorphic features (red mottles, gley) and by a near neutral pH of 6.5 of soil in close proximity to the water table. The lower pH of the dry soil was due to reversion to the oxidized state, which can occur within a few days (Sanchez, 1976). It should be noted that other chemical properties measured on air-dried soil may have been affected by this, e.g., exch. acidity and Al, ECEC.

The difference in pH may also have been caused by groundwater enrichment of basic cations from uplands (Van wambeke, personal communication). Chemical analyses of water are needed to verify this.

C.2.2 Sweet potato yields

Sweet potato vine and tuber yields are displayed in Appendix 1 for the individual piezometer positions. It should be noted that no yield data were available for piezometers K-4 and M-1 since they were harvested inadvertently by farmers. Summary statistics for yield data are presented in table C.2.

table C.2 Summary of sweet potato yield data - vines and tubers

marais	measure	vines (t/ha)	tubers (t/ha)
Nyarutovu	mean	14.4	6.6
	range	4 - 31	2 - 11
	CV	59 %	42 %
Ilibunga	mean	18.5	11.5
	range	3 - 54	0.2 - 22
	CV	75 %	58 %

Table C.2 shows a high variability in sweet potato yields for both marais, the range being very poor to good. As a basis for comparison, MINAGRI (1978) reports 7-8 t/ha tubers as the national average for

the country, although a more optimistic value of 12 t/ha has been cited (Alvarez and Ndamage, 1985). The average obtained at ISAR (national research center) is on the order of 20 t/ha, indicating the high yield potential of this crop with proper husbandry.

Tuber yields were on average nearly twice as high in the Ilibunga marais. This coincided with the higher level of fertility found in this marais. However, in both cases, vine production was much higher than tuber production, and the reasons for this occurrence were not quite clear. The most cited cause for vine production at the expense of tubers is excess N fertilization (Purseglove, 1968; IITA, 1977; IRRI, 1973), an unlikely occurence in the marais. Although vines have economic value as planting material, it should be emphasized that most farmers would welcome a higher proportion of tubers.

C.2.3 Sweet potato system analysis

C.2.3.1 Model selection

The summary statistics presented in the above sections indicated a large variability in sweet potato yields and soil properties. This provided a framework in which to test for relationships between yields and selected soil properties. The next step was to identify the most important variables affecting yield, a task complicated by the many interrelationships between soil variables and the lack of uniformity in extraneous factors such as planting date, quality of planting material and site microclimate. Despite these drawbacks, some interesting observations still resulted from the statistical analyses.

The data displayed in Appendix 1 was analyzed using multiple linear regression techniques (Snedecor and Cochran, 1982; Allen and Cady, 1982) with sweet potato tuber yields as the response variable and selected soil properties as the explanatory variables. The following regression model was used to describe the data:

$$Y = B_0 + B_1X_1 + B_2X_2 + \ldots + B_kX_k + e$$

where Y = response variable

$X_1 \ldots X_k$ = explanatory variables
B_0 = intercept
$B_1 \ldots B_k$ = partial slope between Y and X variables
e = residual

The first variable in the model was obtained by running one-variable regressions with all possible variables (Appendix 1) and selecting the one showing the smallest Residual Sum of Squares. The next variables were then chosen with respect to the reduction in the error term ensuing from their inclusion in the model, as well as their statistical significance. The procedure retained the following variables, in order of importance: pH (moist soil), bulk density and water table depth. Other variables, e.g. sum of bases, exch. Ca, acidity and Al were less related to yield or not related at all in the case of pH (dry), exch K, ECEC, organic matter and soil moisture. The analysis of variance outlining the sequence of variables and resulting prediction equation are depicted in table C.3.

The three-variable model was highly significant and had an R square of 0.38. Addition of the bulk density term increased the R square from 0.15 for pH only to 0.31, and this was highly significant ($p < 0.005$). It should be emphasized here that pH (moist) explained more variability than did bulk density when alone in the model, although this is not obvious from table C.3. The inclusion of water table depth further increased the R square to 0.38, although the significance level was not as high ($p = 0.057$). Although the resulting prediction equation offered little practical use, it was important in showing the effects of pH (moist), bulk density and water table depth on sweet potato tuber yields.

To account for the wide variability in planting date of the sweet potatoes (cf Appendix 1), a separate analysis was run for the Feb.-March period, which covered over half of the observations. The results are summarized in table C.4.

table C.3. ANOVA table and prediction equation for regression of tuber yields on selected variables

Source of variation	df	SS	F (model)
R (pH | Xo)	1	254.64	
R (BD | pH, Xo)	1	257.97	
R (WT | BD, pH, Xo)	1	109.04	8.88*
Residual	44	1056.02	
Total (Corrected)	47	1695.67	

Prediction equation:

$$Y(t) = -7.771 + 9.423\ pH\ (moist) - 20.883\ BD + 0.0424\ WT$$

where Y (t) = tuber yields (t/ha)
BD = bulk density (g/cm3)
WT = depth to water table (cm)

***Significance level < 0.001
R square = 0.38

table C.4. ANOVA table and prediction equation for Feb.-March regression analysis

Source of variation	df	SS	F (model)
R (pH | Xo)	1	12.29	
R (BD | pH, Xo)	1	165.02	
R (WT | BD, pH, Xo)	1	225.76	7.31**
Residual	1	385.97	
Total (corrected)	24	789.04	

Prediction equation:

$$Y(t) = -7.278 + 7.389\ pH\ (moist) - 16.730\ BD + 0.083\ WT$$

**Significance level = 0.002
R square = 0.51

This equation, which did not differ greatly in coefficients from the previous one, showed a much higher R square of 0.51. Thus the variability associated with planting date was reduced, and the effects of bulk density and water table depth became more distinct, as seen from the Sums of Squares. The effect of pH, however, was less important. These individual variables are further discussed in the following section.

C.2.3.2 Effects of individual variables

In the previous section, pH (moist), bulk density and water table depth were identified as the more influential variables and regressed on sweet potato tuber yields. A more in depth discussion of their individual effects and relationships to other variables will now be given.

pH (moist)
The soil variable which alone led to the smallest residual term and hence explained the largest portion of the yield variability (considering all 48 observations) was pH of moist soil. Its relationship to tuber yields is depicted in figure C.2.

A highly significant positive linear relationship was observed between tuber yields and pH of moist soil, although much of the variability still remained unexplained. The corresponding relationship with dry soil pH was non significant, perhaps because the moist soil more accurately reflected the field conditions. In a previous section (cf C.2.1), the higher pH of moist soil was related to the reduction potential of marais soils. These reduction reactions are apparently also associated with an increased availability of P, decreased levels of exch. Al and the displacement of cations from exchange sites (Sanchez, 1976; Ponnamperuma, 1972), processes which all could have affected yield response to pH in this study.

The pH of moist soil was also related to other soil variables, in order to better define the nature of the effects on yields. There was a weak but significant positive correlation of pH with sum of bases ($r = 0.332$, $p = 0.05$), and a strong and highly significant correlation with exch. Al ($r = -0.666$, $p < 0.01$). The regression of tuber yields on these variables, however, was more significant for sum of bases

(positive, p = 0.02) than for exch. Al (negative, p = 0.08). Thus, it is not obvious whether the response to pH was predominantly a response to base supply or reduction of exch. Al levels. The two factors were probably important in influencing yields. According to Sanchez (1976), toxicities of Al and Mn as well as cation deficiencies characterize acid soil infertility.

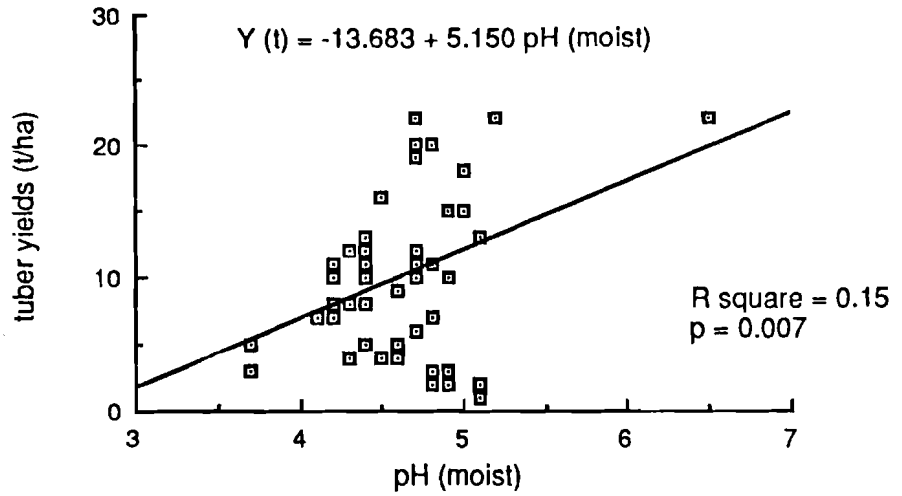


figure C.2. Relationship between pH of moist soil and tuber yields

It should be mentioned that the relationship between tuber yields and pH (moist) was not very clear when only the Feb.- March data were considered in the overall analysis (cf. table C.4). It is possible that pH values at the time of measurement (October) did not represent values occurring during the earlier months. During these months, in which long rains and high water tables prevailed, higher pH values would be expected.

Bulk density

With all 48 observations included in the analysis, the regression of tuber yields on bulk density alone was not significant. But when this variable was added to pH (moist) it significantly reduced the error term and explained a large portion of the variability. The individual effect of bulk density became more distinct and was highly significant when data from the Ilibunga marais (32 observations) were considered separately (fig. C.3). Tuber yields were negatively affected by high bulk density values. According to Acland (1971) and

Purseglove (1968), sweet potatoes prefer a friable soil to promote tuber expansion. It was also mentioned by farmers in the marais that the crop does not grow well on 'hard' soil.

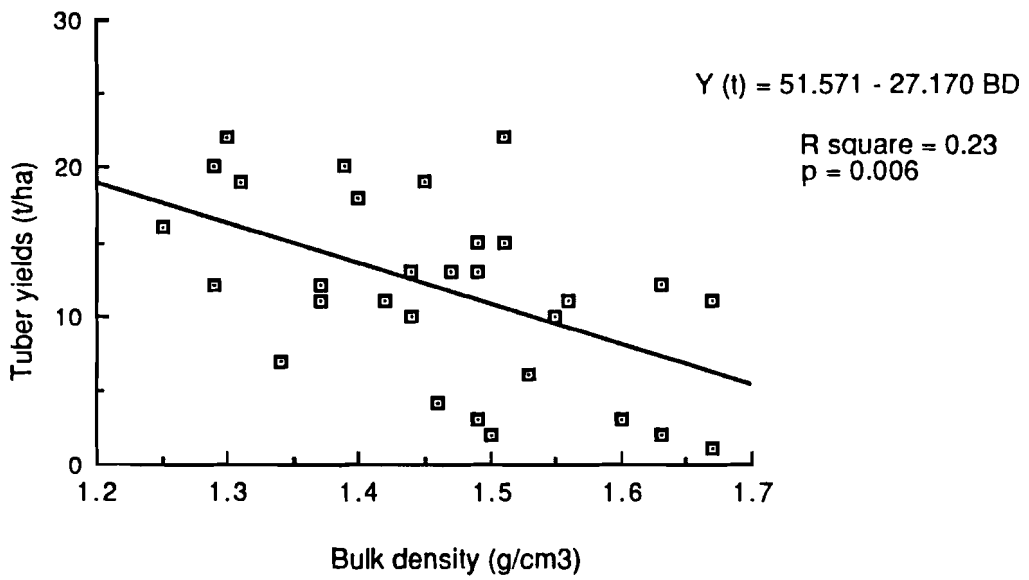


figure C.3 Effect of bulk density on tuber yields for the Ilibunga marais

The reason for the distinction between the two marais was most likely the greater constraint of chemical fertility at Nyarutovu preventing response to the favorable bulk densities. With the better fertility at Ilibunga, bulk density became more important, especially since 2:1 clays were often close to the surface horizons and had negative effects on soil structure.

Bulk density was also negatively correlated with soil organic matter levels (% O. M.), as shown in figure C.4. It is well documented that O. M. contributes to soil aggregation and improves soil physical properties, such as bulk density (Sanchez, 1976). Several authors have also reported the beneficial effects of farmyard manure on sweet potato yields in East Africa (Acland, 1971; Purseglove, 1968) and particularly in Rwanda (Ndamage and Rutunga, 1987; Nyabyenda and Rutunga, 1985). Since the responses to manure generally

surpassed those of chemical fertilizers, it is possible that the effects were also due to improved soil structure. It should be noted, however, that there was no direct relationship between yields and soil O. M. levels in this study.

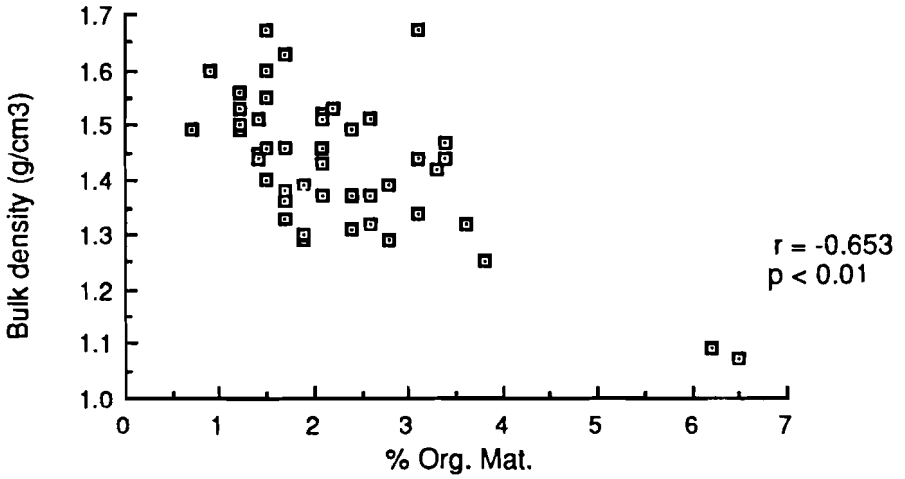


figure C.4 Relationship between soil bulk density and percent organic matter

Water table depth

As for bulk density, the regression of tuber yields on water table depth for the 48 observations was non significant, but the reduction in Sums of Squares for the full model was very close to significance at the 0.05 level, so the variable was included.

When the regression for the Feb.- March planting dates was taken separately, the effect of water table was highly significant (fig. C.5). Higher yields were associated with deeper water tables. This suggests that the Feb. - March plantings were adversely affected by higher water tables during the rainy season. As previously mentioned, depth to water table measurements began only in the beginning of July, so no data was available from Feb. to June. But it can reasonably be assumed that trends observed in July and thereafter existed during the earlier months.

The regression for the post-March plantings showed no relation between tuber yields and water table depth. This suggests that

water table depth had little effect on later plantings, probably due to a receding water table at the onset of the dry season. Regression analysis also showed that post-March yields were unaffected by average soil moisture content at 25 and 50 cm depths. Thus, lack of moisture during the dry season months was apparently not constraining yields. To further support the observations made, it has been found that sweet potatoes exhibit drought resistance as well as susceptibility to water logging (Acland, 1971; Purseglove, 1968). It should be mentioned, however, that correlations between water table depth and soil moisture contents were weak in the present study, probably as a result of the variations in texture and hence water holding capacity of the soils throughout the marais.

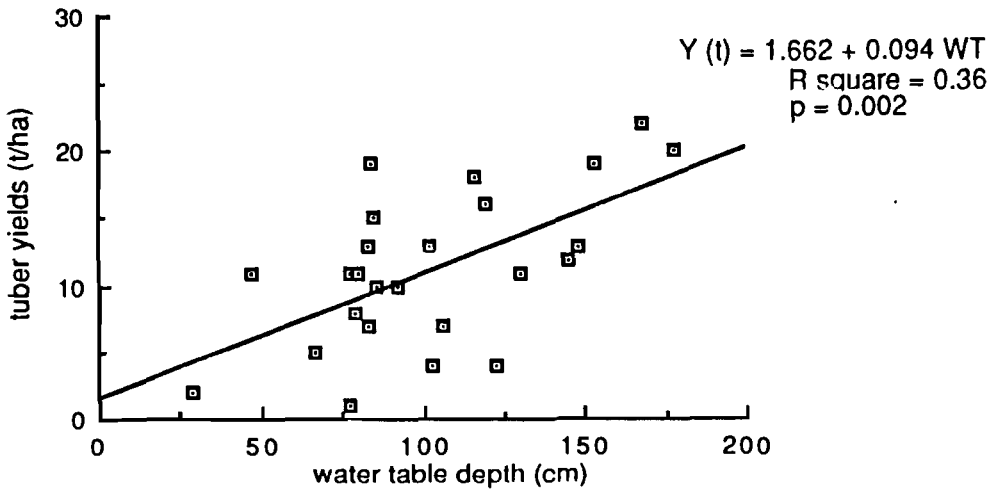


figure C.5 Regression of tuber yields on water table depth for February - March plantings

C.2.3.3 Effect of organic matter

Although O.M. content of the soils analyzed was not directly related to tuber yields in this study, a separate section on its effects was included for several reasons. First, organic matter addition has been a standard and highly recommended practice in Rwanda (MINAGRI, 1978; Jones and Egli, 1984; Nyabyenda and Rutunga, 1985) due in part to low supply of chemical fertilizers and low native fertility of

the soils. Second, sweet potato response to organic manuring, as previously mentioned, has generally been greater than response to chemical fertilizers. And third, organic matter was found to be closely related to several important soil properties in this study.

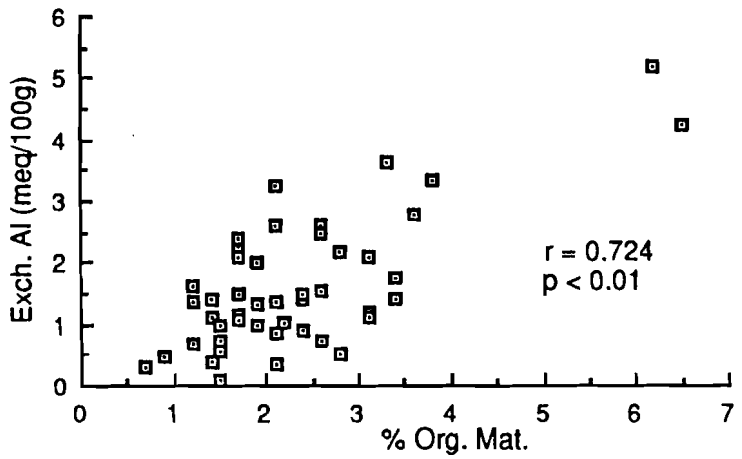
The O. M. levels in the marais of Nyarutovu and Ilibunga were quite variable, but generally high (Appendix 1). Sanchez (1976) reported that the organic carbon content of the surface layer of Oxisols was often not significantly different from that of temperate region Mollisols, and that interactions between oxides and organic materials were possibly responsible for the high levels found in the weathered soils. The wet conditions of the marais and regular incorporation of weeds into the soil may also have been responsible for the high O. M. levels in the marais.

As previously discussed, organic matter content was closely related to bulk density in this study. The Nyarutovu marais, for example, with its higher levels of O. M. also had lower bulk density values. Yields in this marais, however, were lower than at Ilibunga and more constrained by low chemical fertility than by bulk density. The nutrient supplying power of the organic matter did not seem to benefit yields in this study.

It was also observed that O. M. content was positively correlated with exch. Al levels for both marais (fig C.6 a). This effect was surprising, since O. M. is known to form strong complexes with Al, thus decreasing levels in solution (Lucas, 1982; Sanchez, 1976). Aluminum, however, is also more soluble at low pH (Bohn et al., 1979) and in view of the negative relationship observed between pH and O. M. in this study, higher levels of Al at high O. M. levels are justified.

Percent organic matter was also positively correlated with effective cation exchange capacity (ECEC), as shown in fig C.6 b). According to Sanchez (1976), O. M. supplies most of the CEC of acid highly weathered soils, due to the negative charge supplied by dissociated organic acids, and particularly the carboxyl ion R-COO- (Lucas, 1982). Mutwewingabo et al. (1985) have stressed the low permanent charge of Butare soils and the need for O. M. amendment to increase the negative charge and cation adsorption of these soils.

a)



b)

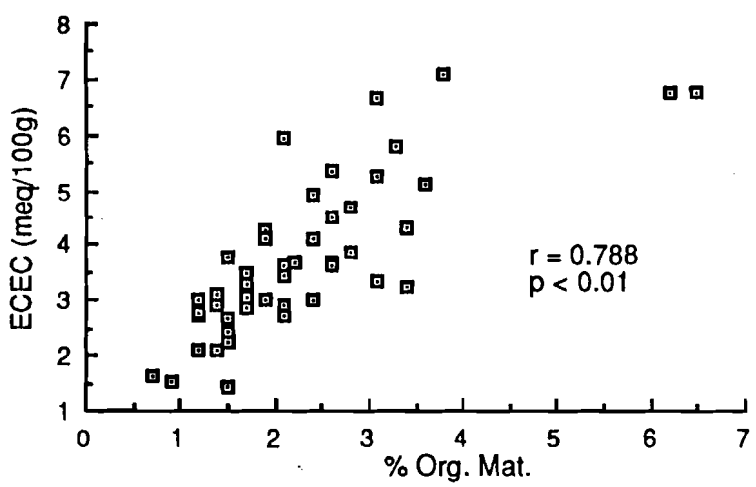


figure C.6 Relationship between % O. M. and a) exch. Al b) ECEC

Although it is difficult to imply cause and effect in this study, it seems that O. M. content was closely associated with bulk density, levels of exch. Al and ECEC.

D. FERTILIZER TRIALS

The second component of the research activities conducted involved small fertilizer trials on unused land in the Nyarutovu marais. The objectives of the trials were not to formulate recommendations for fertilizer use in the marais, but rather to identify possible limiting nutrients and assess growth of different crops on marais soils.

Four crops were selected for the trials: sweet potatoes, potatoes, cabbage and soybeans. The treatments consisted of different combinations of nitrogen (N), phosphorus (P) and potassium (K) fertilizers obtained from the FAO fertilizer project in Butare. The forms used were urea (46% N), triple superphosphate (46% P_2O_5) and potassium chloride, KCl (60% K_2O). In addition, farmyard manure was added to each crop except sweet potatoes to conform to farmers' practices. All seed used in the trials was obtained through local channels, and varietal information was not known. The arrangement of the trials in the marais is illustrated in figure D.1.

Since the experimental design was different for each crop, the methodology and results will be described separately for each experiment. It should be mentioned that design was much constrained by time, availability of land and planting material. Therefore the preliminary nature of the trials should be emphasized.

D.1 Sweet potatoes

Particular attention was given to this trial, as it was meant to complement the information on the sweet potato system studied in detail in section C. The experimental layout used was a completely randomized block design with 3 blocks and 5 treatments: (1) control (2) 80N-50P-50K (3) 50P-50K (4) 80N-50P (5) 80N-50K expressed as kg/ha of the nutrient. There were thus 15 plots in total, 5 plots per block, and each plot measured 12 m^2.

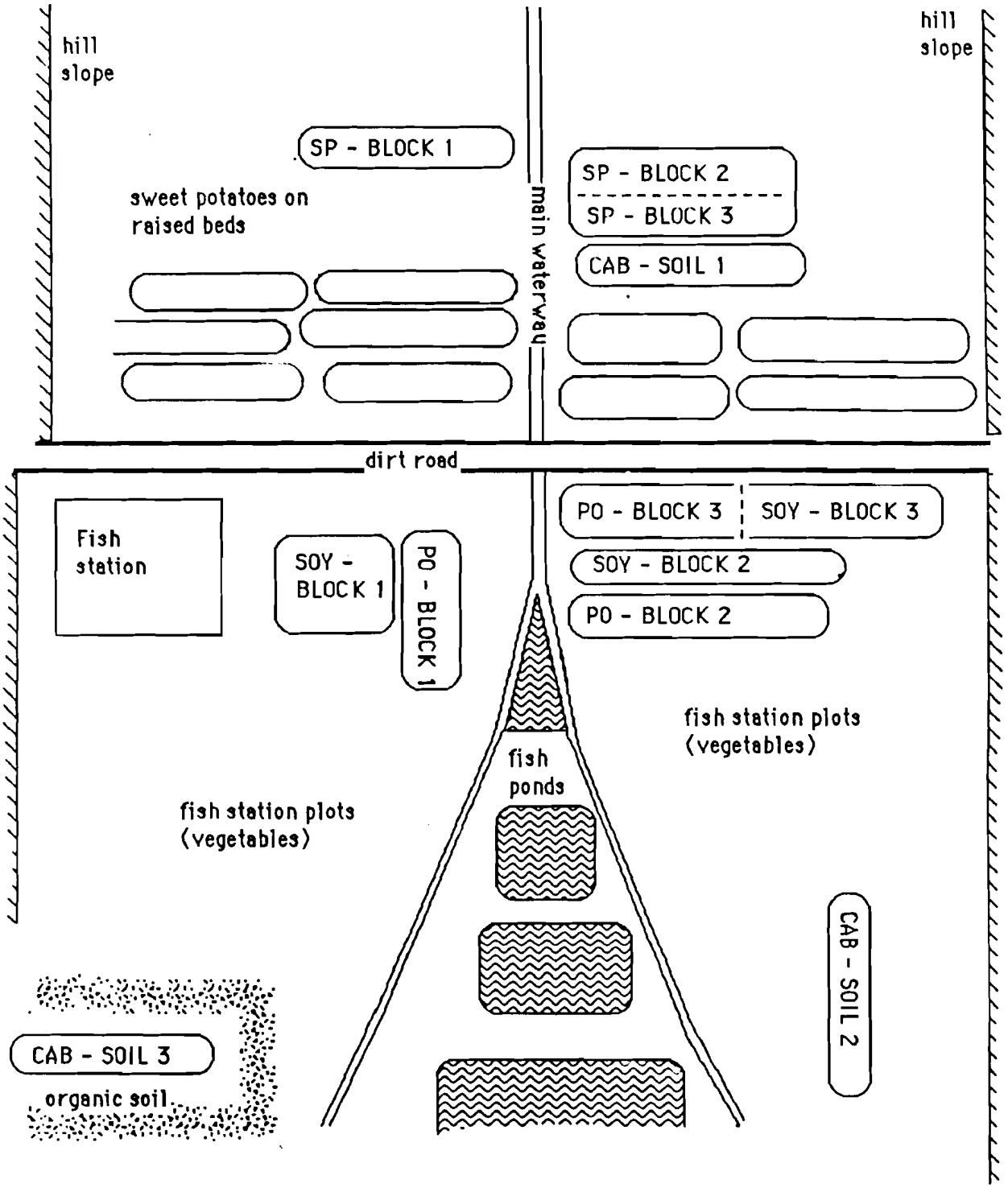


figure D.1 Disposition of fertilizer trials in Nyarutovu marais
(CAB = cabbage; SP = sweet potato; PO = potato; SOY = soybean)

The raised beds or blocks were worked and planted on July 15 in accordance with traditional cultural practices (cf B.3). After a two-week period to allow wilting and rooting of vines, the fertilizer treatments were broadcast by hand onto the designated plots. No further operations such as watering or weeding were carried out, and the trial was harvested after 4 months of vegetative growth. The harvest was premature as time constraints did not permit maintaining the crop for the standard 6 months. Vine and tuber fresh weights were recorded and converted to t/ha. Yields are summarized in table D.1.

table D.1 Sweet potato tuber and vine yields - mean of 3 blocks

treatment	yield of vines (t/ha)	yield of tubers (t/ha)
Control	16.6	4.8
80N-50P-50K	22.7	2.8
50P-50K	16.9	6.3
80N-50P	25.5	3.2
80N-50K	25.3	5.2

As shown in table D.1, tuber yields were very low, probably as a result of the early harvest. Vine yields, however, were quite high, more so than what had previously been reported for Nyarutovu (table C.2). This indicated an excessive proliferation of vine growth relative to tubers. Although it is difficult to speculate on the final vine/tuber ratio given a longer growth period, these values strongly suggest an inefficient translocation of photosynthate to roots which would most likely adversely affect final yields. The phenomenon of excessive vegetative growth in sweet potatoes is apparently complex, and affected by such factors as soil compaction, N and K fertilization and variety (Watanabe, 1979).

For both vines and tubers, the overall F-test for fertilizer effects was non significant (table D.2 for tubers; cf Appendix 2 for vines). The figures, however, showed higher vine yields for treatments containing N which also seemed to be associated with lower tuber yields. Since comparisons between means may show significant effects despite non significance of the initial F-test (Snedecor and Cochran, 1980), N treatments were compared to the others. This contrast proved to be non significant at the 0.05 level. Details of the

calculations are provided in Appendix 2.

table D.2 ANOVA table for sweet potato tuber yields

Source of variation	df	SS	MS	F-ratio
Between Fertilizers	4	25.491	6.373	1.205 NS
Beween Blocks	2	19.852	9.926	1.877 NS
Error	8	42.301	5.288	

NS = non significant at the 0.05 level

The lack of fertilizer response on these highly degraded soils was somewhat intriguing. Acland (1971) and Purseglove (1968) have mentioned the conflicting results obtained with N-P-K fertilizers on sweet potatoes, and the consistent effects of manuring. The FAO fertilizer project, however, reported yield increases of 33% from N-P-K fertilizer addition on Butare soils, with N and K being key nutrients (Eid and Van Droogenbroeck, 1985). Ndamage and Rutunga (1987) also observed a response to mineral fertilizers, but added that the effect of manure was greater. Nyabyenda and Rutunga (1985) recommended combining both mineral and organic fertilizers for optimal production of sweet potatoes, and stressed the importance of initial soil fertility in interpreting conflicting results. In a series of trials conducted throughout the country, they observed that the poorest yielding sites tended to give the lowest responses, because of the presence of more limiting factors. Explanations for the superior effects of manure were not provided in any of the papers, but it is thought that manure could be supplying additional nutrients not contained in the chemical fertilizers or could be reducing the toxicities of Al, Fe or Mn due to complexing reactions.

Several reasons can be given to explain the outcome of this particular trial. First are design problems (insufficient replication to detect differences) and early harvest. It is also possible that fertilizer rates were not high enough, but it seems more likely that response was hindered by more limiting factors. It was noticed, for example, that the highest yielding plots (9 t/ha) were the ones bordering the waterways, which suggests that the crop was otherwise constrained by water. This is a reasonable assumption,

considering that the crop had been planted in the middle of the dry season and that the water table surface was far beyond the rooting depth. In addition, the block showing the lowest yields (mean of 2.9 t/ha versus 5.2 and 5.4 for the others) had a more compact and dense soil, indicating possible physical limitations. Finally the high acidity and exch. Al levels reported for Nyarutovu (cf table C.1) may have also interfered with fertilizer response.

In summary, the experiment remains inconclusive with respect to the effects of N-P-K fertilizers on sweet potatoes in Nyarutovu, although there is a strong suggestion that more limiting factors were operating and the possibility remains that fertilizer responses would be observed if these were removed.

D.2 Potatoes

The potato is an important crop in Rwanda, especially in the higher altitudes above 1800 m and on the rich volcanic soils of the north. Potatoes have been grown with much success on peat in the Nyarutovu marais, which led to interest in the possibility of growing the crop on the mineral soils.

The design of the trial was the same as for sweet potatoes, with the exception that 150 kg/ha N was used instead of 80 and the treatment plots measured 20 m^2. Seed potatoes obtained from the local market were planted on July 18 in rows 60 cm apart, with 40 cm between seed tubers. Manure was added to each planting hole, and fertilizer treatments were applied broadcast directly after planting.

Plants were watered daily for the first few weeks after which the crop roots were presumed to absorb water from the capillary fringe of the water table. Water table depth was measured at different points for each block, and was found to vary between 30 and 70 cm, with much variation within one block. In this portion of the marais, water tables were much higher than in the sweet potato area (cf fig D.1) probably as a result of water management for the fish ponds.

On October 27, after 3 1/2 months vegetative growth, tubers were harvested by hand and each plot harvest weighed separately. Individual tubers were counted and an average weight per tuber recorded. Data are summarized in table D.3.

table D.3 Potato tuber yields and average weight per tuber - mean of 3 blocks

treatment	tuber yields (t/ha)	ave. wt./tuber (g)
Control	5.7	60
150N-50P-50K	10.5	83
50P-50K	5.7	66
150N-50P	9.7	75
150N-50K	9.1	78

Yields were low for this crop, considering that 20-25 t/ha tubers are easily obtained on volcanic soils in Rwanda without fertilizer inputs (Joseph, 1982). The highest yield recorded in this experiment was of 15 t/ha for one of the plots treated with 150N-50P-50K. The low yields were attributed to a high incidence of disease, most likely bacterial wilt (Pseudomonas solanacearum), the most serious disease problem on potatoes in Rwanda (Joseph, 1982). According to Sanchez and Salinas (1981), disease problems are often a greater limitation to potato production in warm climates than are acid soil constraints.

As for sweet potatoes, the overall F-test for fertilizer effects was non-significant (table D.4 for yields; Appendix 2 for ave. wt./tuber). But figures indicate that yields and tuber weights were higher for the N treatments than for the others. When the means were contrasted, the difference was significant at the 0.05 level. Details are given in Appendix 2. The final interpretation was that the addition of 150 kg/ha N resulted in an average increase of 4.1 t/ha of tubers and 15.7 g/tuber. Therefore, N was limiting to the crop despite the addition of manure at planting.

table D.4 ANOVA table for potato tuber yields

Source of variation	df	SS	MS	F-ratio	Prob>F
Between fertilizers	4	62.789	15.697	2.02	0.355
Between blocks	2	57.621	28.811	3.71	0.072
Error	8	7.761			

There was no response to additions of P and K although their effects may have been masked by the following factors: (1) disease (2) insufficient replication (3) rates too low to effect response. It should also be mentioned that the height of the water table had no observable effect on yields or disease incidence in this experiment.

D.3 Cabbage

Cabbage is often grown as a dry season crop in small marais. High yields are achieved on peat in the Nyarutovu marais, but cabbage is also grown on mineral soils of the fish station with some success.

The cabbage fertilizer trial was different from the others in that it was designed to test the effect of one complete fertilizer treatment (150N-50P-50K) on three different soil types: two mineral and one organic. One of the mineral soils (soil 1) was located in the sweet potato portion of the marais, where soil samples for the main study had been taken (cf fig. D.1). The other (soil 2) was part of the fish station land, and displayed a heavier texture and lighter color than the first. The organic soil (soil 3) was in the localized peat pocket of Nyarutovu.

The experimental design involved 4 plots per soil type, i.e. two replications of the unfertilized check and two of the fertilized treatment.Therefore the trial was considered in the analysis as a combination of three experiments or a multi-site experiment. This allowed an assessment of soil x fertilizer interaction, the main emphasis of the trial.

To establish the crop, cabbage seed was sown July 9 in a nursery which consisted of a small heavily manured area shaded by reed laths. Seedlings were transplanted one month later onto the prepared trial plots, which measured 12 m^2 to accomodate about 25 cabbage heads. Manure was applied to each plantlet, and the mineral fertilizer broadcast onto designated plots. The crop was watered regularly for the first few weeks and weeded several times throughout the season. Applications of insecticide powder were necessary to control aphids and other insect pests, common dry season afflictions on cabbage.

After 3 1/2 months of vegetative growth, the trial was harvested. Twenty-five cabbage heads per plot were individually weighed, for a total of 50 heads per treatment per soil type (2 replications). The results are summarized in table D.5.

table D.5 Average weight of cabbage heads in grams - mean of 2 reps (50 heads)

	mineral soil (1)	mineral soil (2)	organic soil
Control	345	310	1410
150N-50P-50K	1050	670	1305

The numbers indicated a strong effect of fertilizer on the mineral soils and no effect on the organic soil, as well as higher yields on the organic soil. In the analysis of variance (table D.6), however, the soil x fertilizer interaction was not significant. It should be noted that due to the nested error structure (Snedecor and Cochran, 1980), fertilizer effects and interaction were tested against the error MS, and soil effects against the interaction MS.

A closer look at the individual 1 df interaction contrasts revealed that the mineral versus organic contrast was significant, but that the mineral (1) versus mineral (2) was not. This meant that the effect of fertilizer was different for the mineral soils as compared to the organic soil, but was the

table D.6 ANOVA table for average cabbage weights

Source of variation	df	SS	MS	F-ratio	Prob>F
Between fertilizer	1	0.4563	0.4563	11.837	0.074
Between soils	2	1.6416	0.8208	9.050	0.100
Interaction	2	0.1814	0.0907	2.352	0.176
Error	6	0.2313	0.0386		

same for both mineral soils. Interaction was thus considered significant, and simple effects of fertilizers were computed instead of the main effects given in the ANOVA table. Details of the

calculations are supplied in Annex 2, but the main result was that addition of N-P-K fertilizer significantly increased cabbage weights by an average 535 g/head on the mineral soils and did not affect yields on the organic soil.

Organic soils are known for their ability to supply nutrients through mineralization, especially with respect to N, P and S. According to Lucas (1982) the N content of peat varies between 0.3 and 4 % and the P content between 0.01 and 0.3%; crops growing on peats with over 0.2 % P are not likely to respond to P fertilizer. Estimates of N and P release from cultivated peats in the USA are in the range of 500-1000 kg N/ha/yr and 20-40 kg P/ha/yr (Guthrie and Duxbury, 1978), and it is likely that the lack of response to fertilizer and the high yields on the organic soil were due to the peat nutrient supply. It should be noted that the higher water tables may also have contributed to the higher yields on the organic soil.

D.4 Soybeans

Soybeans are considered the legume of the future for Rwanda. For over 15 years, the national research stations (ISAR) have been conducting variety trials on this crop and satisfactory yields have been obtained with several varieties on both the hill slope and marais. Soybeans have been rated as the most promising legume for drained marais, and reports show a tendency towards higher yields on the marais than on the hill slope (Nyabyenda, 1986). These considerations offered an incentive to include soybeans in the Nyarutovu fertilizer trials.

The soybean trial was designed to evaluate the effects of Rhizobium inoculation combined with P and K fertilizers. For this, a split-plot design was used, with inoculation as main factor and fertilizer as sub factor. Three fertilizer treaments were tested on the inoculated and uninoculated soybeans: control, 50P-50K and 50K (in kg/ha). With three blocks, this gave a total of 3 x 3 x 2 = 18 plots, each measuring 12 m^2.

Soybean seed of an unknown variety was densely planted with manure in rows 40 cm apart. Prior to sowing, half the seed within each block was inoculated with Rhizobium (soybean group) and the other half, uninoculated. The inoculum had been obtained through the FAO

fertilizer project in Butare, which was testing soybean Rhizobia strains in Rwanda. The fertilizer treatments were applied broadcast onto plots directly after planting.

The crop was watered by hand for the first few weeks of growth, and weeded on several occasions. The water table was also measured at several points, and was found to vary between 30 and 70 cm depth, the variation within a block being as great as between blocks. Crop emergence was complete within 10 days and a vigorous uniform stand resulted. The effects of inoculation and fertilization were not visibly apparent in the stand: only a slight yellowing showed up later in the season on uninoculated plots and plant heights were not affected. Nodulation, however, was evident on inoculated plots within the first two weeks, and plants were heavily nodulated by mid-September; uninoculated plots bore very few nodules. The trial was harvested after 4 1/2 months of vegetative growth and left to dry intermittedly for a few weeks due to the rains. Dry seed weights were recorded and converted to kg/ha. Results appear in table D.7.

table D.7 Soybean dry seed yields - mean of 3 blocks

Treatment	Seed yield (kg/ha)	
	Non-inoculated	Inoculated
control	1867	2363
50P-50K	1725	2384
50K	1672	2033

Yields were well in the range of those obtained by the research station trials which are in the order of 1000-3000 kg/ha (Nyabyenda, 1986). The figures also indicated an effect of inoculation on seed yields, which on average amounted to 505 kg/ha or 30 % increase over uninoculated plots. The increase, however, was non significant despite the high F-value of 5.86 for inoculation effects (table D.8). This result was a consequence of the experimental design, which gave greater precision (more degrees of freedom) to the evaluation of fertilizer effects and interaction, which were also non significant.

The lack of response to P and K fertilizer and the less than dramatic effect of inoculation were somewhat difficult to explain. It is possible that the manure had a greater influence than anticipated. To

table D.8 ANOVA table for soybean dry seed yields

Source of variation	df	SS	MS	F-ratio
Inoculation	1	1 151 655	1 151 655	5.86 NS
Fertilizer	2	227 141	113 570	2.35 NS
Fert. x Inoc.	2	66 790	33 396	0.69 NS
Blocks	2	1 991 466	995 733	
Error (main)	2	393 265	196 633	
Error (sub)	8	386 954	48 369	

support this, recent trials in Rwanda have indicated an increase in both nodulation and yields from the addition of organic matter to inoculated soybeans, and an increase in nodulation but no increase in yields from P and K additions (Nyabyenda, 1986). Reasons for the superior effects of the organic matter were not given.

Soil acidity did not prevent either nodulation or a vigorous growth of the crop. Apparently, there exists considerable tolerance to Al in certain soybean varieties and unlike other grain legumes, Rhizobia strains associated with soybeans tend to be more Al-tolerant than the crop itself (Sanchez and Salinas, 1981). The height of the water table also did not seem to influence yields to any extent, although an effect on root morphology was observed: a higher density of lateral, fibrous roots were found in the presence of a shallow water table and longer taproots were evidenced in the case of deeper water tables. These observations and the outcome of the trial would seem to indicate a suitability of the soybean to small marais conditions.

E. SUMMARY REMARKS

The agronomic studies conducted in the two small marais of Nyarutovu and Ilibunga provided preliminary information on the behavior of crops and soils in the marais ecosystem. Among the research activities were included the soil characterization of both marais, the study of the traditional cropping system, and the design of fertilizer trials with different crops.

The main findings of the research concerned the low chemical fertility of the marais: soils were deficient in basic cations and P,

had low CEC and high acidity and Al levels. The lack of fertility amendment by farmers further accentuated the problem in relation to the hill slope, which receives regular applications of manure. Despite their close proximity, Ilibunga and Nyarutovu had different soil properties, and variability was high even within a single marais. Ilibunga was the more fertile of the two.

Yields of sweet potatoes, the traditional crop in the marais, were affected by both soil fertility and water. Up to 50 % of the yield variability was explained by three soil parameters: pH (moist), bulk density and water table depth. Among these pH was the most limiting factor. The soil reactions and neutralizing processes associated with the wetness characteristic probably also led to higher yields than would have been expected from the dry soil pH values. Effects of water were not so defined as fertility, but suggested an optimal date for planting of sweet potatoes: early plantings suffered from a high water table, and the dry season fertilizer trial from lack of soil moisture.

The fertilizer trials gave different results depending on the test crop. Potato yields were increased by N but were more constrained by disease than fertility. Cabbage showed a high response to N-P-K on mineral soils but no response on the organic soil. Sweet potatoes did not respond, for reasons that remain unclear. Soybeans yielded well whether fertilizer was added or not, and the effect of inoculation was not as dramatic as anticipated. The trials demonstrated the possibility of growing alternative crops on marais soils, as well as a need to identify constraints specific to the production of each crop.

The importance of organic matter was acknowledged both for its effects on soil properties in this study and its extensive use as a soil amendment in Rwanda. Notably, the peat area at Nyarutovu supported the most intensive agricultural production of both marais. Investigations into the potential use of peat as a source of organic matter and N fertilizer on adjacent mineral soils is suggested, especially considering the lack of manure available for marais production.

The above remarks concern mainly the marais of Nyarutovu and Ilibunga, and considering the spatial variability observed, can hardly be extrapolated to other small marais without verification. They do indicate, however, that water management is not necessarily the

most limiting factor to agricultural production in small marais, and that failure to recognize and correct soil fertility constraints could lead to disappointing results from hydrologic restructuring.

References

Acland, J. D. 1971. East African Crops. Longman Group Limited. London, England.

Allen, D. M. and Cady, F. B. 1982 Analyzing data by regression. Lifetime Learning publications, Wadsworth Inc. Belmont, California.

Alvarez, M. N. and G. Ndamage. 1985. La patate douce au Rwanda, situation actuelle. Bull. Agr. Rwanda. 18è année (4): 211-215.

Bohn, H. L., B. L. McNeal and G. A. O'Connor. 1979. Soil Chemistry. John Wiley and sons, New York.

Cambrezy, L. 1981. Conquète des marais au Rwanda et dynamique de population. Etudes rurales 83: 45-67.

Eid, A. and J. Van Droogenbroeck. 1985. Disponibilités et aspects économiques de l'utilisation des engrais au Rwanda - Programme Engrais FAO. p.271-282 In Premier Séminaire National sur la fertilisation des sols au Rwanda. Ministère de l'Agriculture, de l'Elevage et des Forêts. Kigali, Rwanda.

Guthrie, T. F. and J. M. Duxbury. 1978. Nitrogen mineralization and denitrification in organic soils. Soil Sci. Soc. Am. J. 42: 908-912.

International Institute for Tropical Agriculture (IITA). 1977. Annual report. Ibadan, Nigeria.

International Rice Research Institute (IRRI). 1973. Annual Report. Los Banos, Philippines.

Jones, W.I. and R. Egli. 1984. Farming systems in Africa. The great highlands of Zaire, Rwanda and Burundi. World Bank Technical Paper No. 27. Washington, D.C.

Joseph, W. 1982. La culture de la pomme de terre au Rwanda. Cours de

culture vivrière. UNR, Butare, Rwanda.

Lucas, R. E. 1982. Organic soils (Histosols). Formation, distribution, physical and chemical properties and management for crop production. Research report 435. Michigan State University. East Lansing, Michigan.

Ministère de l'Agriculture, de l'Elevage, et des Forêts (MINAGRI). 1978. Guide de l'Agronome.

Mutwewingabo, B., M.P. Cescas and C. R. de Kimpe. 1985. Les aspects de la fertilisation des sols acides de la région de haute et de moyenne altitude du Rwanda en relation avec leurs propriétes physico-chimiques. p 203-212. In Premier Séminaire National sur la fertilisation des sols au Rwanda. Ministère de l'Agriculture de l'Elevage et des Forêts. Kigali, Rwanda.

Ndamage, G. and V. Rutunga 1987. Effets de l'âge des boutures et de la fumure sur la production de la patate douce au Rwanda. Bull. Agr. Rwanda. 20e année (2): 115-119.

Nyabyenda, P. 1986. Le soja, la légumineuse d'avenir pour le Rwanda. Bull. Agr. Rwanda 19e année (3) : 131-142.

Nyabyenda, P. and V. Rutunga. 1985. Fertilisation à l'ISAR. p. 117-135. In Premier Séminaire National sur la fertilisation des sols au Rwanda. Ministère de l'Agriculture, de l'Elevage et des Forêts. Kigali, Rwanda.

Ponnamperuma, F. N. 1972. The chemistry of submerged soils. Adv. Agron. 24: 29-96.

Purseglove, J. D. 1968. Tropical crops. Dicotyledons. Longman Group Limited. Longman House. Essex, U.K.

Sanchez, P. A. 1976. Properties and management of soils of the tropics. John Wiley and Sons Inc., New York.

Sanchez, P. A. and J. G. Salinas. 1981. Low-input technology for managing Oxisols and Ultisols in Tropical America. Adv. Agron. 34: 279-406.

Snedecor, G. W. and W. G. Cochran. 1980. Statistical Methods. Seventh edition. Iowa State University Press. Ames, Iowa.

Van Wambeke, A. 1963. Carte des sols et de la végétation du Congo, du Rwanda et du Burundi. Rwanda et Burundi. A. - Sols. Publications de l'Institut National pour l'Etude Agronomique du Congo (I.N.E.A.C.). Bruxelles.

Vander Zaag, P., R. S. Yost, B. B. Trangmar, K. Hayashi and R. L. Fox. 1984. An assessment of chemical properties for soils of Rwanda with the use of geostatistical techniques. Geoderma 34: 293-314.

Watanabe, K. 1979. Agronomic studies on the excessive vegetative growth mechanism of sweet potatoes (Ipomoea batatas Lam.). J. Central Agric. Exp. Stn., Konosu, Japan. 29: 1-94.

APPENDIX 1: Soil test results, yield data and soil water measurements for the 50 piezometer points

	piezometer	planting date	tuber yields	vine yields	pH (dry)	pH (moist)
1	A-1	march -2	10	26	4.0	4.7
2	B-6	april-1	2	4	4.5	5.1
3	B-5	april-1	9	12	4.0	4.6
4	B-4	april-1	3	31	3.4	3.7
5	B-3	april-1	8	-	3.2	4.3
6	B-2	may-2	5	4	3.5	3.7
7	B-1	may-1	11	12	4.0	4.4
8	D-5	march-2	5	7	3.9	4.6
9	D-4	march-2	4	13	3.8	4.3
10	D-3	march-2	7	11	3.9	4.1
11	D-2	march-1	10	20	3.8	4.2
12	E-1	may-1	7	7	3.7	4.2
13	F-6	april-1	5	13	4.2	4.4
14	F-5	april-1	3	15	3.3	3.7
15	F-4	march-1	8	27	3.7	4.2
16	F-2	june-2	8	-	3.8	4.4
17	H-1	april-1	6	21	3.6	4.7
18	I-5	febr.-1	19	14	4.3	4.7
19	I-4	march-1	13	12	4.0	4.4
20	I-3	june-2	3	3	4.6	4.9
21	I-2	march-1	11	7	3.7	4.7
22	I-1	march-1	1	4	5.1	5.1
23	J-1	march-1	20	41	4.4	4.7
24	K-2	march-1	2	6	3.8	4.8
25	K-3	march-1	13	11	4.0	4.4
26	K-4	march-1	-	-	4.1	4.3
27	K-5	april-1	10	18	4.4	4.9
28	K-6	april-1	22	29	4.7	5.2
29	K-7	june-2	12	22	4.2	4.7
30	K-9	may-2	2	5	4.5	4.9
31	K-10	may-2	4	23	4.1	4.5
32	K-11	may-2	3	6	4.3	4.8
33	L-1	july-1	20	5	4.4	4.8
34	M-1	may-1	-	-	3.9	4.5
35	M-2	march-1	11	6	4.0	4.8
36	M-3	march-1	11	7	4.2	4.8
37	M-4	march-1	13	21	4.4	5.1
38	M-5	march-1	18	17	3.8	5.0
39	M-6	march-1	15	17	4.4	4.9
40	M-7	march-1	7	15	3.9	4.8
41	M-8	march-1	19	16	4.0	4.7
42	M-9	july-1	10	54	4.0	4.4
43	M-14	may-1	22	34	4.1	6.5
44	N-1	march-?	22	20	3.7	4.7
45	O-3	april-1	12	53	4.0	4.4
46	0-4	april-1	15	18	4.2	5.0
47	0-5	febr-1	16	14	3.5	4.5
48	0-6	febr-1	12	19	3.7	4.3
49	0-7	march-1	11	14	3.8	4.2
50	O-8	march-1	4	9	3.6	4.6
51						

	Exch Acidity	Exch. Al	% Org. mat.	Exch. K	Exch. Ca	Exch. Mg
1	2.20	1.75	3.4	0.09	1.46	0.53
2	0.83	0.73	1.5	0.08	1.06	0.46
3	1.98	1.48	1.7	0.15	0.74	0.30
4	5.30	4.23	6.5	0.18	0.96	0.30
5	2.60	2.28	1.7	0.08	0.26	0.10
6	3.25	2.63	2.6	0.09	0.16	0.16
7	2.70	2.10	1.7	0.11	0.32	0.15
8	1.23	1.05	2.2	0.09	1.68	0.66
9	2.93	2.38	1.7	0.09	0.36	0.07
10	1.85	1.38	2.1	0.11	0.68	0.08
11	1.83	1.53	2.6	0.13	1.14	0.49
12	3.03	2.60	2.1	0.08	0.30	0.21
13	2.38	2.00	1.9	0.16	1.24	0.44
14	6.23	5.18	6.2	0.10	0.34	0.05
15	3.48	2.78	3.6	0.10	1.10	0.38
16	1.65	0.35	2.1	0.09	1.12	0.53
17	0.93	0.68	1.2	0.09	1.24	0.43
18	1.83	1.43	1.4	0.10	0.68	0.28
19	1.40	1.13	1.4	0.06	0.46	0.18
20	2.33	1.38	1.2	0.10	0.40	0.18
21	1.68	1.43	2.4	0.05	1.18	0.31
22	0.25	0.10	1.5	0.20	1.62	0.72
23	1.88	1.33	1.9	0.16	1.50	0.56
24	1.73	1.63	1.2	0.08	0.62	0.30
25	1.80	1.43	3.4	0.11	0.84	0.46
26	0.90	0.63	0.9	0.11	0.52	0.21
27	0.78	0.55	1.5	0.07	0.12	0.44
28	0.55	0.38	1.4	0.07	1.80	0.66
29	1.50	1.15	1.7	0.11	0.92	0.31
30	1.40	1.08	1.7	0.17	0.96	0.43
31	0.95	0.73	1.5	0.12	0.88	0.28
32	0.78	0.48	0.9	0.05	0.46	0.23
33	0.73	0.50	2.8	0.21	2.58	1.09
34	3.18	2.80	1.2	0.09	0.18	0.07
35	1.73	1.35	1.2	0.09	0.82	0.33
36	1.53	1.20	3.1	0.13	1.10	0.56
37	1.18	0.88	2.4	0.14	2.04	0.76
38	1.25	0.98	1.5	0.10	1.68	0.72
39	0.95	0.73	2.6	0.09	3.08	1.20
40	1.63	1.13	3.1	0.12	3.52	1.37
41	1.78	1.50	2.4	0.18	2.16	0.81
42	2.63	2.10	3.1	0.12	1.92	0.61
43	1.10	0.85	2.1	0.18	1.00	0.59
44	1.48	0.98	1.9	0.13	1.04	0.36
45	2.73	2.20	2.8	0.08	0.32	0.69
46	0.45	0.30	0.7	0.13	0.72	0.28
47	4.18	3.35	3.8	0.16	2.04	0.69
48	3.03	2.48	2.6	0.12	0.98	0.35
49	4.18	3.63	3.3	0.12	1.18	0.30
50	3.68	3.25	2.1	0.17	1.44	0.63
51						

	Exch. Na	Sum of bases	ECEC	Bulk density	% mois-25cm	% mois-50cm
1	0.04	2.12	4.32	1.44	16.2	22.7
2	0.02	1.62	2.45	1.60	17.6	-
3	0.02	1.21	3.19	1.33	15.1	-
4	0.02	1.46	6.76	1.07	38.5	50.8
5	0.02	0.46	3.06	1.46	17.9	19.8
6	0.01	0.42	3.67	1.32	17.0	17.9
7	0.01	0.59	3.29	1.36	16.1	11.3
8	0.03	2.46	3.69	1.53	22.4	27.1
9	0.02	0.54	3.47	1.38	22.4	24.8
10	0.02	0.89	2.74	1.43	12.4	15.8
11	0.03	1.79	3.62	1.51	15.9	20.0
12	0.02	0.61	3.64	1.37	17.8	19.6
13	0.03	1.87	4.25	1.39	17.6	17.8
14	0.03	0.52	6.75	1.09	38.8	50.1
15	0.04	1.62	5.10	1.32	29.3	31.3
16	0.04	1.78	3.43	1.52	22.9	-
17	0.03	1.79	2.72	1.53	18.6	23.6
18	0.02	1.08	2.91	1.45	16.0	15.9
19	0.02	0.72	2.12	1.44	17.2	18.6
20	0.02	0.70	2.08	1.49	6.9	6.7
21	0.02	1.56	2.99	1.37	8.9	9.5
22	0.06	2.60	2.70	1.67	10.8	9.6
23	0.04	2.26	4.14	1.29	15.8	18.4
24	0.04	1.04	2.77	1.50	-	-
25	0.03	1.44	3.24	1.47	19.8	24.1
26	0.03	0.87	1.77	1.54	8.3	8.8
27	0.02	0.65	1.43	1.55	10.3	9.6
28	0.02	2.55	3.10	1.51	12.8	14.9
29	0.03	1.37	2.87	1.63	12.3	18.6
30	0.03	1.47	2.87	1.63	10.0	8.4
31	0.03	1.31	2.26	1.46	11.3	11.9
32	0.02	0.76	1.54	1.60	10.6	13.2
33	0.06	3.94	4.67	1.39	23.3	37.0
34	0.01	0.35	3.53	1.43	17.9	19.7
35	0.02	1.26	2.99	1.56	16.2	23.6
36	0.04	1.83	3.36	1.67	30.7	-
37	0.02	2.96	4.14	1.49	22.3	34.5
38	0.01	2.51	3.76	1.40	13.0	13.5
39	0.03	4.40	5.35	1.51	18.5	21.6
40	0.02	5.03	6.66	1.34	24.2	20.2
41	0.02	3.17	4.95	1.31	21.1	25.2
42	0.01	2.66	5.29	1.44	20.9	26.9
43	0.03	1.80	2.90	1.51	-	-
44	0.02	1.55	3.03	1.30	10.1	12.3
45	0.04	1.13	3.86	1.29	27.9	31.4
46	0.02	1.15	1.60	1.49	4.6	6.0
47	0.03	2.92	7.10	1.25	25.8	23.9
48	0.02	1.47	4.50	1.37	20.2	18.3
49	0.02	1.62	5.80	1.42	24.1	26.1
50	0.04	2.28	5.96	1.46	19.5	22.6
51						

	water table
1	86
2	62
3	161
4	92
5	72
6	127
7	140
8	67
9	103
10	106
11	92
12	109
13	99
14	95
15	79
16	40
17	87
18	153
19	148
20	117
21	80
22	77
23	178
24	29
25	102
26	136
27	171
28	125
29	100
30	147
31	156
32	68
33	86
34	130
35	77
36	47
37	83
38	116
39	85
40	83
41	84
42	126
43	4
44	168
45	75
46	104
47	119
48	145
49	130
50	123

UNITS:

Yields - t/ha
Exch. acidity, Al, K, Ca, Mg, Na meq/100 g
Sum of bases; ECEC - meq/100 g
Bulk density - g/cm^3
Water table depth - cm

APPENDIX 2: Details of calculations for fertilizer trials

A-2.1 Sweet potatoes

table A-2.1 ANOVA for sweet potato vine yields

Source of variation	df	SS	MS	F-ratio	Prob > F
Between fertilizer	4	230.751	57.688	1.180	0.495
Between blocks	2	35.364	17.682	0.362	0.711
Error	8	391.129	48.891		

Evaluation of contrast between N-treatments and others for vines:

Means:

u_1 = 16.6 t/ha vines
u_2 = 22.7
u_3 = 16.9
u_4 = 25.5
u_5 = 25.3

N-containing means : u_2, u_4, u_5
Other means: u_1, u_3

' N treatments versus others ' contrast (L_1) : Ho: $L_1 = 0$

$$L_1 = \left(\frac{u_2 + u_4 + u_5}{3}\right) - \left(\frac{u_1 + u_3}{2}\right)$$

$$= \left(\frac{22.7 + 25.5 + 25.3}{3}\right) - \left(\frac{16.6 + 16.9}{2}\right) = 7.75 \text{ t/ha}$$

$$SE(L_1) = \sqrt{\frac{s^2 \Sigma \lambda^2}{n}} = \sqrt{\frac{48.891 \times 5/6}{3}} = 3.685$$

where: L_1 = contrast estimate, $SE(L_1)$ = standard error of estimate, s^2 = error MS

$\Sigma \lambda^2$ = sum of squared coeff., n=number of reps.

$$t\,calc = \frac{L_1}{SE(L_1)} = \frac{7.75}{3.685} = 2.10 \quad t\,tab_{0.05,8} = 2.306$$

t calc < t tab Ho is not rejected

Vine yields for N treatments are not significantly different from vine yields without N.

A-2.2 Potatoes

table A-2.2 ANOVA for average weight per tuber

Source of variation	df	SS	MS	F-ratio	Prob > F
Between fertilizer	4	1037.60	259.40	2.43	0.310
Between blocks	2	386.53	193.27	1.81	0.224
Error	8	852.80	106.60		

Evaluation of effects of N fertilizer:

Same procedure as for sweet potatoes:

(1) tuber yields - u_1 = 5.7 t/ha
u_2 =10.5
u_3 = 5.7
u_4 = 9.7
u_5 = 9.1

$$L_1 = \frac{10.5 + 9.7 + 9.1}{3} - \frac{5.7 + 5.7}{2} = 4.067$$

$$SE(L_1) = \sqrt{\frac{7.761 \times 5/6}{3}} = 1.468$$

$$t\,calc = \frac{4.067}{1.468} = 2.77 \qquad t\,tab_{0.05,8} = 2.306$$

t calc > t tab Ho is rejected

There is significant difference in tuber yields between N and no-N treatments.

(2) Ave. wt./tuber - $u_1 = 60$ g
$u_2 = 83$
$u_3 = 66$
$u_4 = 75$
$u_5 = 78$

$$L_2 = \frac{83 + 75 + 78}{3} - \frac{60 + 66}{2} = 15.667$$

$$SE(L_2) = \sqrt{\frac{106.6 \times 5/6}{3}} = 5.442$$

$$t\,calc = \frac{15.667}{5.442} = 2.88 \qquad t\,tab_{0.05,8} = 2.306$$

t calc > t tab Ho is rejected

There is a significant difference between N treatments and no-N treatments for ave. wt. /tuber.

A-2.3 Cabbage

Given the following matrix of means (weights in kg):

		soil 1	soil 2	soil 3
fert.	1	$u_{11} = 0.345$	$u_{21} = 0.310$	$u_{31} = 1.410$
	2	$u_{12} = 1.050$	$u_{22} = 0.670$	$u_{32} = 1.305$

soil 1,2: mineral; soil 3: organic fert 1: control fert 2: 150N-50P-50K

<u>Evaluation of 1 df interaction contrasts:</u>

(1) mineral versus organic

$$L_1 = \left[\left(\frac{u_{12} + u_{32}}{2}\right) - \left(\frac{u_{11} + u_{21}}{2}\right)\right] - (u_{32} - u_{31})$$

$$= \left[\left(\frac{1.050 + 0.670}{2}\right) - \left(\frac{0.345 + 0.310}{2}\right)\right] - (1.305 - 1.410) = 0.638$$

$$SE(L_1) = \sqrt{\frac{s^2 \Sigma \lambda^2}{2}} = \sqrt{\frac{0.0386 \times 3}{2}} = 0.241$$

$$t\,calc = \frac{0.638}{0.241} = 2.65 \quad t\,tab_{0.05,6} = 2.45 \quad t\,calc > t\,tab$$

Ho is rejected, i.e. the effect of fertilizer is different between organic and mineral soils.

(2) mineral soil1 versus mineral soil 2

$$L_2 = (u_{12} - u_{11}) - (u_{22} - u_{21})$$
$$= (1.050 - 0.345) - (0.670 - 0.310) = 0.345$$

$$SE(L_2) = \sqrt{\frac{0.0386 \times 4}{2}} = 0.278$$

$$t\,calc = \frac{0.345}{0.278} = 1.24 \qquad t\,tab_{0.05,6} = 2.45 \qquad Ho\ is\ not\ rejected$$

There is no significant difference in the effects of fertilization between the two mineral soils

<u>Evaluation of simple effects for fertilizer - (mineral soil)</u>

$$L_3 = \left(\frac{1.050 + 0.670}{2}\right) - \left(\frac{0.345 + 0.310}{2}\right) = 0.533$$

$$SE(L_3) = \sqrt{\frac{0.0386 \times 2}{2}} = 0.196$$

$$t\,calc = \frac{0.533}{0.196} = 2.72 \quad t\,tab_{0.05,6} = 2.45 \quad t\,calc > t\,tab\ \ Ho\ is\ rejected$$

The effect of fertilization is significant on the mineral soils in general.