Soil Mapping and Advisory Services

Botswana

SOIL TESTING PROCEDURES
FOR SOIL SURVEY

Part 3
Variability of Laboratory results

FOOD & AGRICULTURE
ORGANIZATION OF THE
UNITED NATIONS

UNITED NATIONS
DEVELOPMENT
PROGRAMME

REPUBLIC OF
BOTSWANA

GABORONE, 1988

AG: BOT/85/011

Field Document 3

Soil Mapping and Advisory Services

Botswana

SOIL TESTING PROCEDURES
FOR SOIL SURVEY

Part 3 : Variability of Laboratory results

by

Reinhard Breitbart
FAO Expert

Food and Agricultural Organization Of The United Nations
United Nations Development Programme

Gaborone, 1988

TABLE OF CONTENTS

INTRODUCTION

Classification and correlation of soils depends strongly on analytical data, as has been pointed out in the first part of this report. International soil correlation implies international exchange of analytical data and this requires international comparability of data.

A critical analysis of the reliability of laboratory data is important to give the user an idea about the error range all figures are associated with.

A chemical or physical analysis determines a numerical value of a parameter. This parameter has a 'true' value which is usually unknown and which the analyst tries to approximate as closely as possible applying certain procedures. In practice the results are scattered around this 'true' value.

1. DEFINITIONS:

ACCURACY and PRECISION

- 'Precise' results are scattered close together but not necessarily close to the 'true' value.

- 'Accurate' results are scattered around the true value but not necessarily close together.

REPEATABILITY and REPRODUCIBILITY

- 'Repeatability' is defined as: 'the value below which the absolute difference between two single test results obtained with the same method on identical test material under the same conditions (same operator, same laboratory, same equipment, short time interval) may be expected to lie within a specified probability'.

  'Reproducibility' is defined as: 'the value below which the absolute difference between two single test results obtained with the same method on identical test material under different conditions may be expected to lie within a specified probability.

2. SOURCES OF VARIABILITY:

Some sources for the variability of analytical results are:

> operator errors
> calibration and functioning of instruments
> imprecise execution of procedures
> contaminations of glassware and chemicals
> wrong or old standards
> calculation and writing errors
> random errors

For the variability of results produced at different laboratories at least one important source has to be added:

> non standardization of procedures

1

3. REPRODUCIBILITY OF DATA:

For the '7. Eastern African Soil Correlation Conference' held in Botswana 1987 twenty one profiles (124 soil samples) have been described and sampled. Analyses were carried out at the USDA Soil Survey laboratory in Lincoln, Nebraska, USA and at the Botswana Soil Survey laboratory. In the following the data produced in the two laboratories will be compared to obtain information about the reproducibility of analyses.

3.1. Linear regression analysis:

A conventional regression analysis assumes that all error is in the Y-variable. This is not the case here as both measurements are subjected to error. However, the conventional linear regression analysis still gives a useful indication of the relationship between the two measurements.

The method of least squares estimates the slope and intercept of the line to give the minimum sum of squares of the vertical distances between the line and the actual data points.

The analysis was carried out with an IBM PC compatible micro computer, using LOTUS 123 software for data manipulation, storage and graphics, and SYSTAT for the regression analysis.

Linear regressions were calculated for all determinations:

$$Y = a + b * X$$

X is the 'independent variable' representing the USDA Soil Survey laboratory results (usda).

Y is the 'dependent variable' representing the Botswana Soil Survey results (bot)

a is the constant or the intercept of the sample regression with the Y-axis.

Ideally it should have the value 0. Values other than 0 might indicate a systematic error at one of the laboratories using a wrong background correction (blank) or similar, leading to an additive factor.

b is the X-coefficient. It estimates the average change in Y associated with unit increase in X.

Ideally it should have the value 1. Other values might suggest systematic differences in the procedure for the particular determination yielding proportional higher results in one of the laboratories, respectively lower results in the other.

r is the correlation coefficient. It is a measure of the closeness to perfect linear relationship between two variables (the closer the value is to 1 the better the correlation.)

S is the square root of the residual mean square and is an estimate of the standard deviation about the regression line.

The residual mean square is the sum of the squared residuals of Y-values minus estimated regression values. It depends strongly on the slope and intercept of the regression curve.

Provided the regression model assumed is correct it gives an indication of the mean error of the determination. An independent observation will fall with a 50% probability within the band formed by the estimated regression values plus or minus the mean residual. The probability is 95% within the band of two times the mean residual.

2

Figures 1 to 15 are scatter plots of the data for each of the determinations and calculated soil parameters.

For most of the determinations the points are scattered closely around the regression line. For PBS and CEC clay data points are much wider scattered. This is reflected in the correlation and regression coefficients.

Table 1: Linear regression for evaluation of reproducibility of soil data analyzed at two different laboratories.
(Soil survey laboratory, Botswana and USDA soil survey laboratory, Lincoln, Nebraska)

r = correlation coefficient
b = regression slope
a = Y-axis intercept

S = Square root of the residual mean square or the estimate of the standard deviation about the regression line.

Determination	No. of observ.	r	b	a	S
pH-H$_2$O	124	0.953	0.976	0.411	0.520
pH-CaCl$_2$	124	0.964	1.010	-0.147	0.485
EC	124	0.991	0.774	-0.030	1.438
org. C	124	0.981	0.932	-0.038	0.202
CEC	124	0.992	0.866	1.603	2.187
Ca	101	0.983	0.860	1.135	2.401
Mg	124	0.992	0.921	0.041	0.704
K	124	0.955	0.750	0.195	0.228
Na	111	0.965	0.955	0.026	0.609
Sand	124	0.966	1.005	-0.015	6.299
Silt	124	0.650	0.465	1.219	3.734
Clay	124	0.945	1.068	3.226	7.096
PBS	95	0.858	0.94	3.481	14.161
CEC cl corr.	124	0.857	0.659	6.189	10.562
CEC clay	124	0.844	0.597	11.717	10.453

Note: exch. Ca regression was calculated only for non calcaric soils, exch. Na regression for non alkaline soils (pH < 9.5) and PBS for non calcaric, non alkaline soils.

3.2. Analysis of outliers:

Gross mistakes occasionally occur in measuring, recording or copying of data. The frequency of such outliers occurring in the different determinations affects strongly the reproducibility and reliability of data.

For all samples and all determinations the following were calculated:

- the leverage each observation has on the regression line

- the absolute difference of the Y-value (Botswana value) minus the estimated regression value (residual).

- the studentized residual of the actual Y-values and the estimated regression values.

- after elimination of outliers regression coefficients, residuals and studentized residuals were recalculated.

Leverage is an index of the influence of each observation on the size of the mean square error or in other words how strongly the regression curve is influenced by a particular observation.

As a rule of thumb leverage should have an average value of p/N where p is the number of estimated parameters (including the constant) and N is the number of observations. If leverage is larger than 2p/N an observation might have an undue influence on the regression estimates.

Studentized residual is the quotient of the residual (Y-value minus estimated regression value) and the standard error of the regression value at the respective 'X'-value.

Points with a studentized residual greater than +2 fall outside the 95% confidence interval about the line. For the purpose of this analysis these points are assumed to be outliers.

Often outlying observations also have an undue leverage. Observations having only a high leverage but with a studentized residual less than +2 are considered part of the data set. All points with a studentized residual of more than +2 were eliminated and the regressions recalculated (Table 2).

Table 2:   Linear regression analysis of data set after elimination of observations with a studentized residual of < -2 and > 2.

r = correlation coefficient
b = X-coefficient
a = Y-axis intercept

S = standard deviation about the line

Determination	No. of observ.	r	b	a	S
pH-H_2O	117	0.988	1.010	0.190	0.266
pH-$CaCl_2$	116	0.994	1.045	-0.361	0.200
EC	117	0.967	0.797	-0.018	0.584
org. C	119	0.972	0.925	-0.033	0.110
CEC	116	0.994	0.886	1.394	1.613
Ca	95	0.991	0.853	0.925	1.385
Mg	116	0.993	0.906	0.121	0.486
K	115	0.976	0.841	0.141	0.130
Na	107	0.991	0.903	0.038	0.21
Sand	121	0.981	1.023	-0.772	4.730
Silt	119	0.762	0.519	0.519	2.693
Clay	119	0.976	1.115	1.386	4.676
PBS	90	0.900	0.981	-0.481	11.758
CEC clay corr.	115	0.892	0.660	8.880	8.841
CEC clay n. corr	117	0.906	0.641	8.885	8.159

Figures 16 to 45 are histograms showing the frequency distribution of the residuals (including outliers) and of the studentized residuals. These histograms show that the distribution of the residuals is close enough to the normal distribution to satisfy the assumptions of the regression analysis.

Figures 46 to 60 show the residuals plotted against the corresponding estimated regression values. These plots show that the residuals are independent of the magnitude of the measurement.

3.3. Conclusions:

The correlation coefficients for the determinations are close to 1. This indicates high precision in both laboratories.

The regression slopes of the CEC and exchangeable cations determinations suggest that the USDA data are generally about 10 to 15 percent lower than the Botswana data. The clay values are about 10 percent higher.

Since the regression slopes of the exchangeable cations determinations and the CEC determination are both 10 to 15% lower for the Botswana data in the calculation of PBS (which is the ratio of exchangeable cations to CEC) this difference is cancelled out, which results in a slope very close to the ideal value of 1.0.

CEC clay is the ratio of CEC to the clay fraction (whether or not the contribution of organic matter to the CEC has been corrected).
The generally higher USDA values of the CEC determination (regression slope 0.89) and lower values of the clay determination (regression slope 1.12) explain the low regression slope of about 0.65 for CEC clay. If the regression model is correct then the Botswana laboratory CEC clay values are in average 35% lower than the USDA laboratory values.

Silt is determined indirectly as the difference between the sand and the clay determination. The silt values are usually low and contain the errors of sand and clay readings. This explains the poor correlation and wide scatter (figure 12) of this determination.

As already mentioned on page 3 the square root of the mean square error estimates the standard error of a determination provided the regression model is correct.

This means that each CEC and Ca determination has a standard deviation of about +1.5, which is quite reasonable, but each PBS value is subjected to a standard deviation of +12 and each CEC clay value to a standard deviation of +9.

The user of those data must bear in mind that especially PBS and CEC clay values are subjected to substantial error and that it might lead to wrong conclusions if this is not considered.

Sharp boundaries for these soil parameters as required in soil taxonomy and FAO soil classification cannot be justified from the laboratory point of view. A more flexible interpretation of those data should be allowed.

4. QUALITY CONTROL WITHIN THE LABORATORY:

Outliers, as discussed in the previous chapter are mostly operator or writing errors. To monitor the quality of the daily routine two controls have been introduced.

> 1. A standard sample is included in every batch. Technicians are instructed to check results of the standard sample and compare with allowed upper and lower limits.

> 2. A check routine has been programmed for the Hewlett Packart HP86B microcomputer, comparing soil parameters with each other and commenting if samples fall out of defined ranges. (The programm is incorporated into the print program.

The standard sample is meant to detect errors in preparation of the batch, like use of contaminated water or wrong standard curves. The test programm can detect outliers, but only after completing the whole standard analysis programm of the particular profile.

4.1. Repeatability of standard sample:

Means, standard deviations and medians were calculated from the standard samples. Table 10 shows also the number of replicas, the minimum and maximum values determined and upper/lower confidence limits for the median.

Table 3: Repeatability of CEC, exchangeable cations and pH determinations.

(CEC and exch. cations measured in meq/100 g soil)

	count	max	min	mean	stdev	median	upper	lower
CEC	97	6.8	4.5	5.7	0.5	5.6	5.8	5.5
Ca	97	3.2	1.3	2.1	0.5	2.0	2.2	1.9
Mg	97	1.3	0.4	0.7	0.2	0.7	0.7	0.6
K	97	0.5	0.3	0.4	0.1	0.4	0.4	0.3
Na	97	0.2	0.0	0.1	0.1	0.0	0.0	0.0
PBS	97	6.1	39.9	59.0	11.2	58.0	61.0	55.0
pH-H2O	80	5.6	4.7	5.3	0.2	5.3	5.5	5.3
pH-CaCl	80	4.6	4.2	4.4	0.1	4.4	4.5	4.3

Table 4: Repeatability of organic carbon and phosphorus determinations.

(Concentration of org. C in weight %, of P in ppm.)

org. C	conc	mean	stddv	spectrometer readings max	min
std 1	0.25	0.056	0.007	0.069	0.048
std 2	0.50	0.109	0.012	0.130	0.082
std 3	1.00	0.201	0.011	0.227	0.188
std 4	2.00	0.316	0.015	0.335	0.292
sample	0.27+0.04	0.058	0.008	0.069	0.048

Phosph.		mean	stddv	max	min
std 1	0.2	0.067	0.014	0.086	0.040
std 2	0.4	0.138	0.029	0.187	0.070
std 3	0.6	0.212	0.042	0.279	0.110
std 4	0.8	0.279	0.055	0.352	0.150
std 5	1.0	0.342	0.062	0.414	0.190
sample		0.586	0.064	0.696	0.425
sample*	12.8+0.9	0.063	0.004	0.069	0.056

* since the reading is over the highest standard the sample is diluted by factor 1 : 10.

The repeatability of CEC, exchangeable cations and pH determination is better than the inter laboratory comparison.

It is not expected that even with considerable improvement in equipment, laboratory facilities and training level of technicians these error ranges can be reduced much further under routine working conditions. However, improving especially the training level and laboratory facilities certainly will reduce the number of outliers and necessary repeats and will therefore improve the productivity and reliability of the laboratory.

4.2. LABEX programme:

Since end of 1985 the Botswana soil survey laboratory participates in the LABEX programme. LABEX stands for Laboratory Exchange and is organized from the International Soil Reference and Information Center (ISRIC) in Wageningen, The Netherlands.

Objectives of this programme are to cross check laboratory data produced in different soil laboratories world wide and to investigate the possibilities of standardization of determinations. Another aspect of the programme is the quality control for the participating laboratories.

Once or twice a year a set of 10 identical samples is mailed to the participants to be analyzed using recommended procedures and the procedures as adopted in the respective laboratories.

The results are compiled and statistically evaluated at ISRIC and distributed to the participants. In the report the laboratories are listed as numbers. Each laboratory knows its own number but not the others. This enables the individual participant to compare his own results with the results of the other laboratories.

In case the data fall out of the normal range the reason for this can be investigated and eventually corrected.

APPENDIX I

GRAPHICS REPRESENTATION OF STATISTICAL ANALYSIS

Figures 1-15:   Scatter plots of analytical data. USDA results as independent X-variable, Botswana results as dependent Y-variable.

Figure 1:
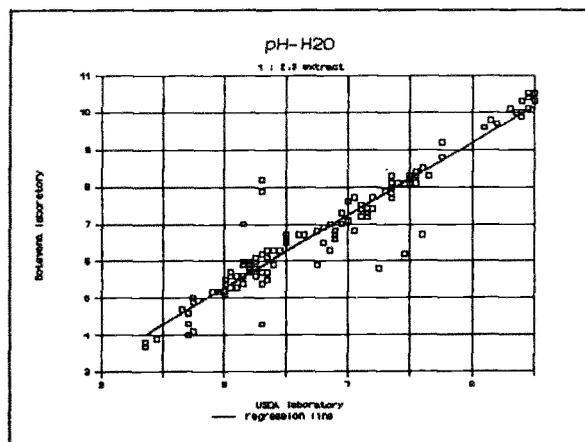
Figure 2:

Figure 3:

Figure 4:

ORGANIC CARBON

Figure 5:

CATION EXCHANGE CAPACITY
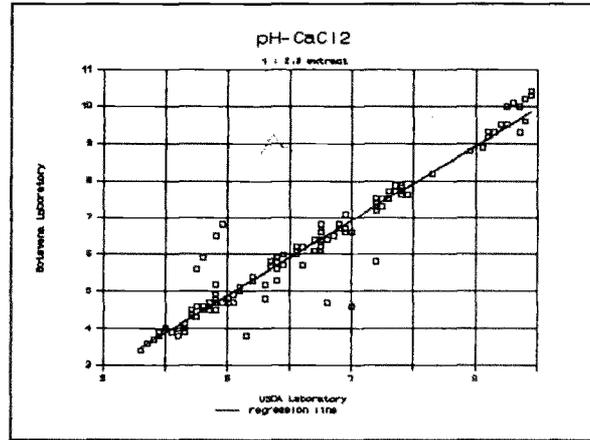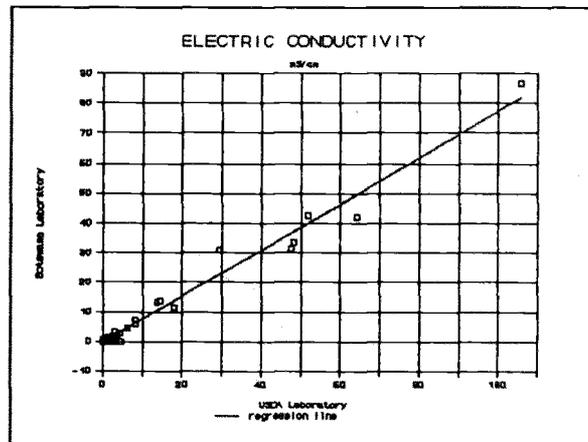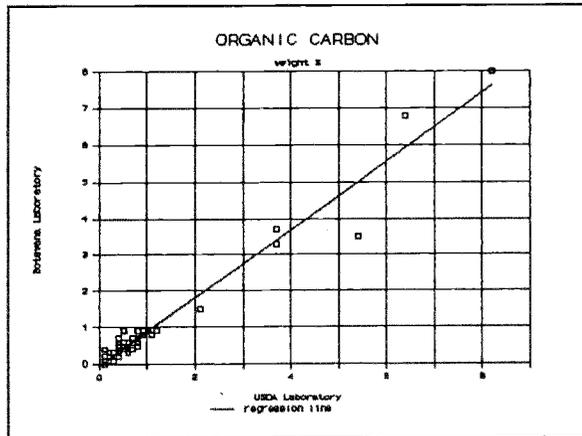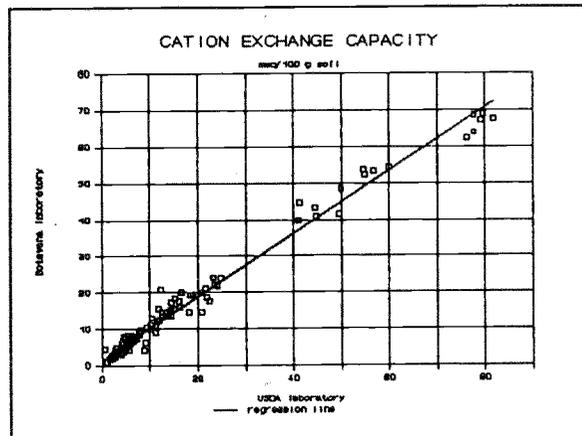
Figure 6:

Figure 7:

Figure 8:

EXCHANGEABLE POTASSIUM

Figure 9:

EXCHANGEABLE SODIUM

14

Figure 10:

Figure 11:

15

Figure 12:

SILT FRACTION

Figure 13:

CLAY FRACTION

Figure 14:

CEC clay (org. C corrected)

Figure 15:

CEC clay (not org. C corrected)

17
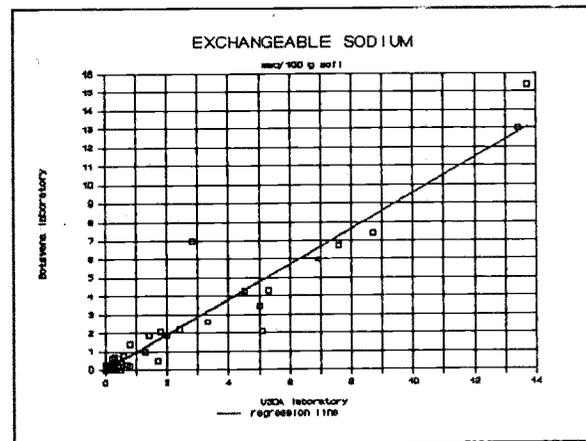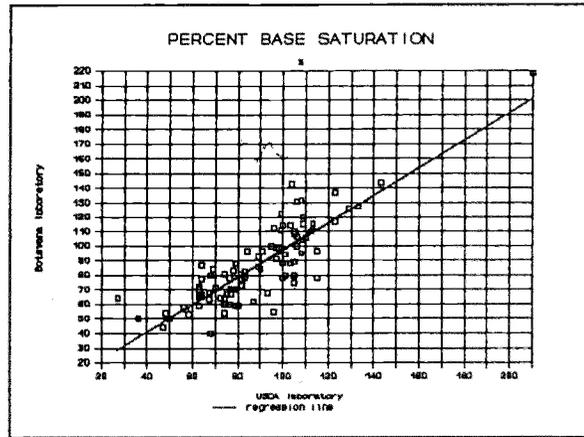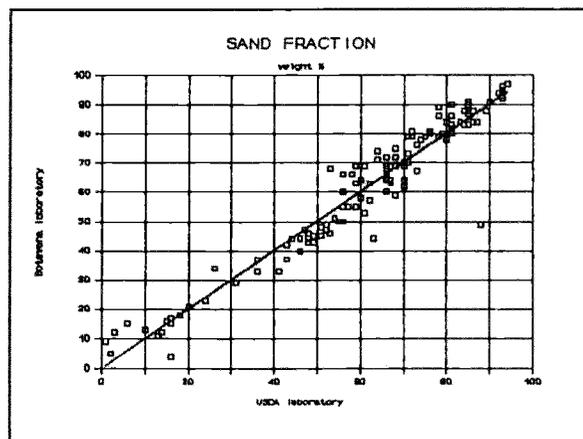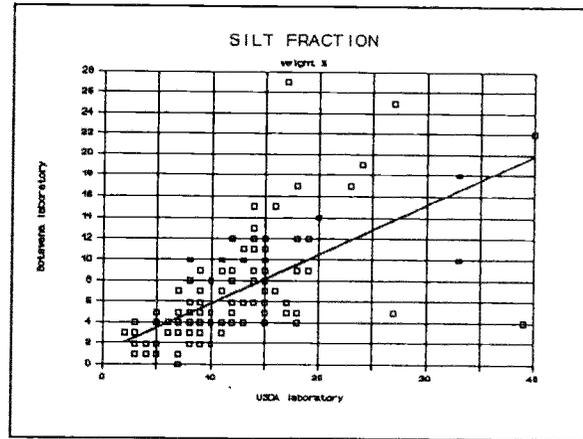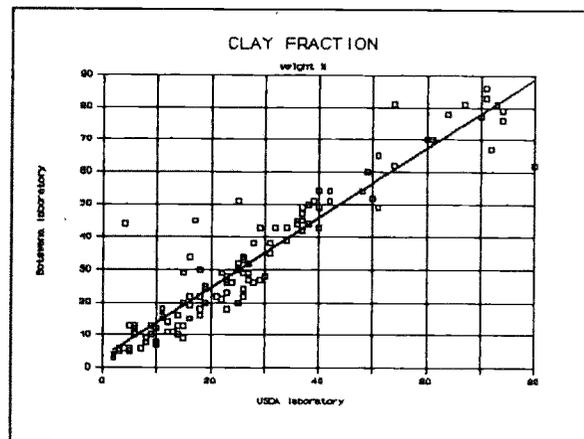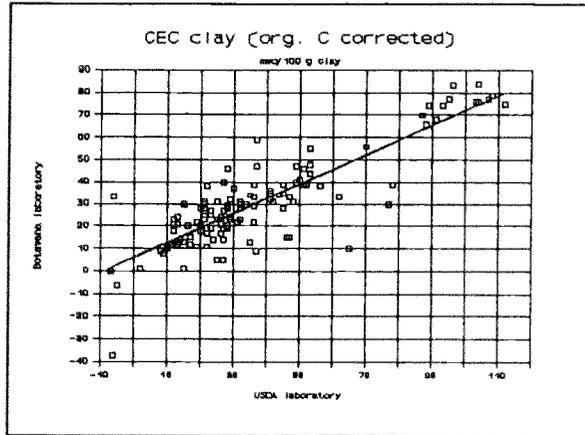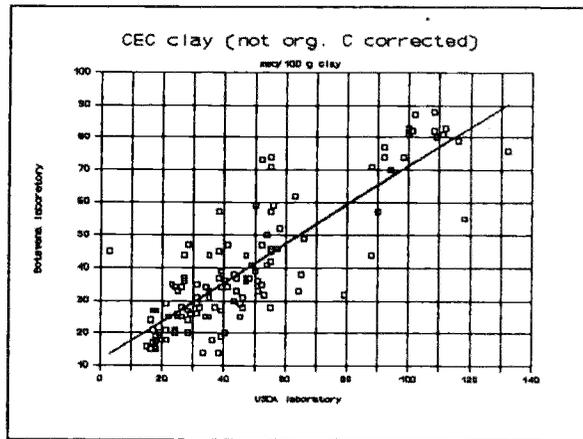
Figures 16-45:   Bar charts of frequency distributions of residuals and studentized residuals.

Figure 16:
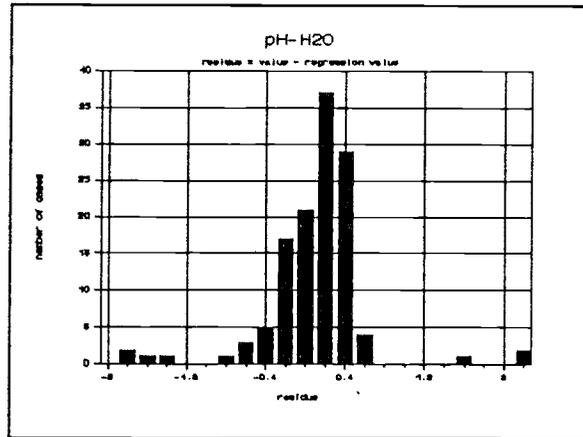
Figure 17:
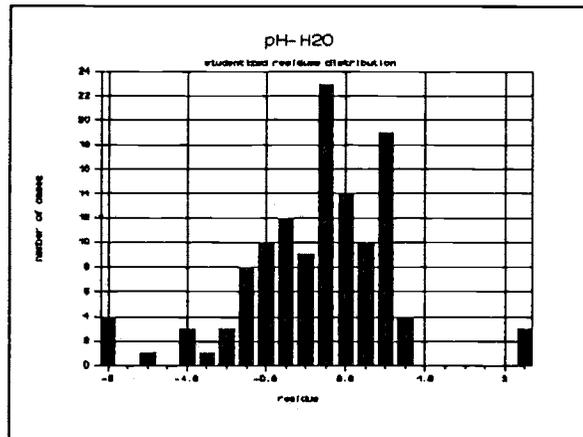
Figure 18:
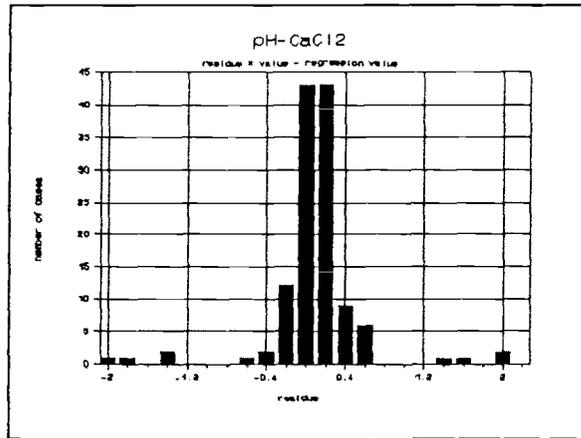
Figure 19:
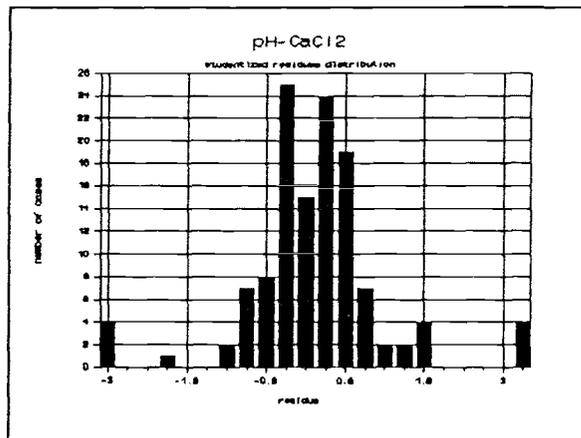
Figure 20:
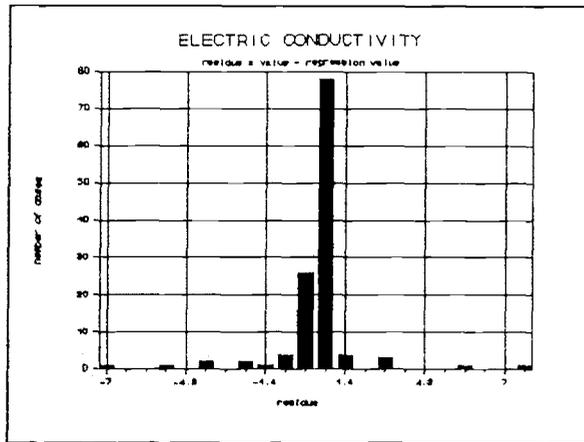
Figure 21:
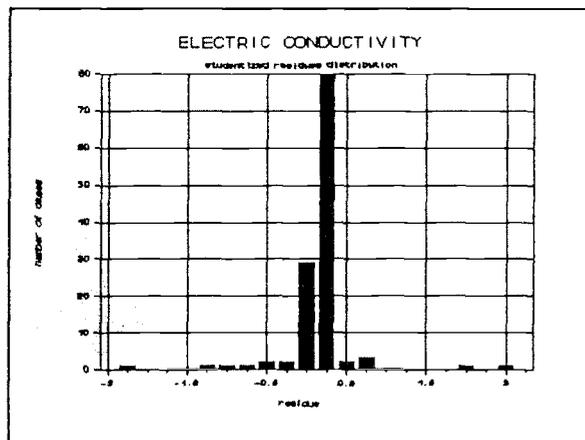
Figure 22:
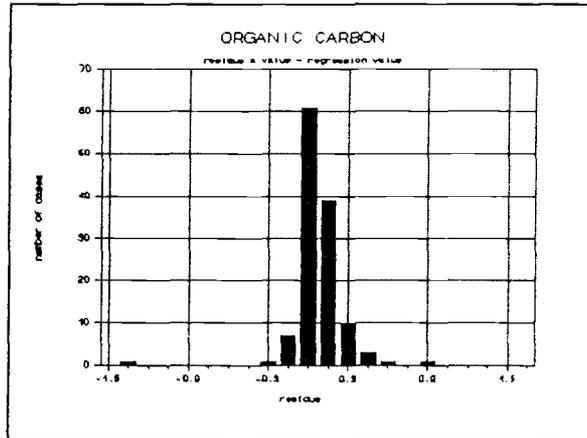
Figure 23:
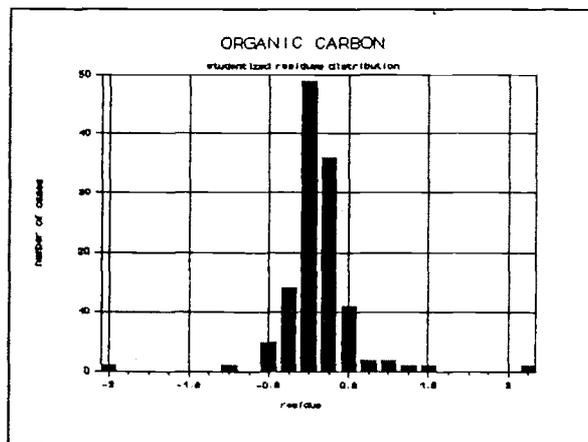
Figure 24:
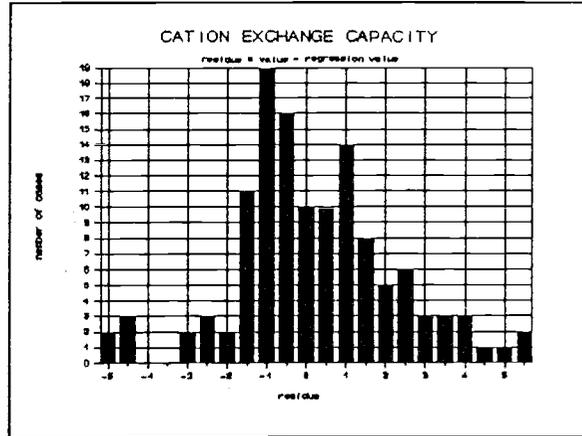
Figure 25:
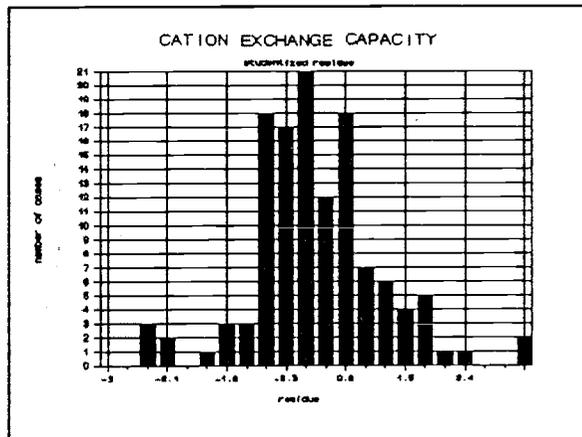
Figure 26:
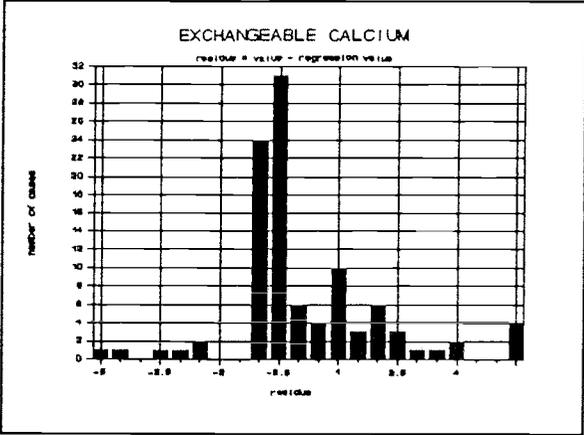
Figure 27:
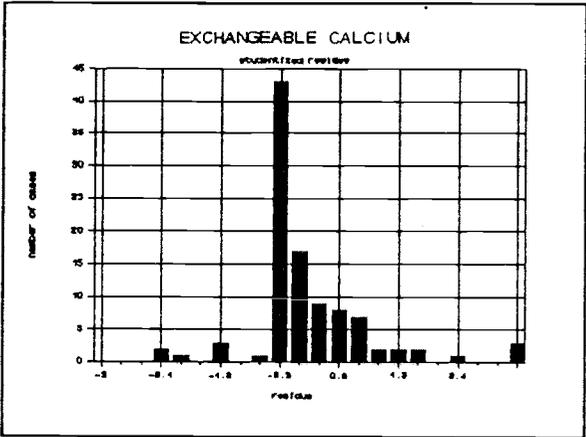
Figure 28:
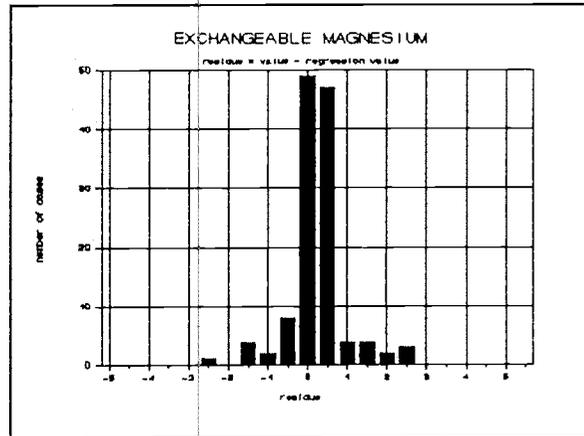
Figure 29:
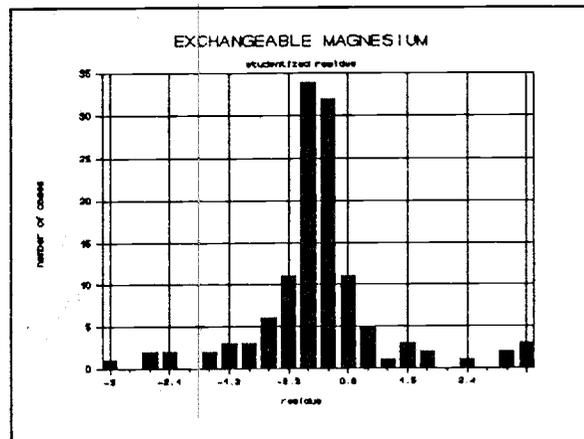
Figure 30:
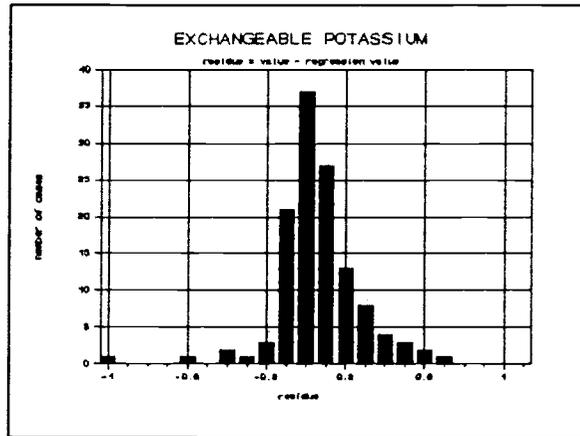
Figure 31:
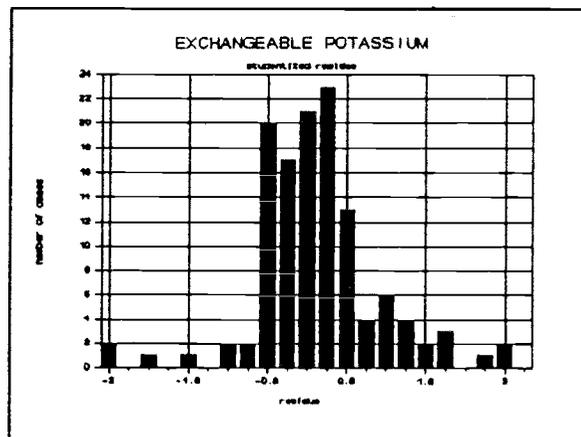
Figure 32:

Figure 33:

Figure 34:

PERCENT BASE SATURATION

Figure 35:

PERCENT BASE SATURATION
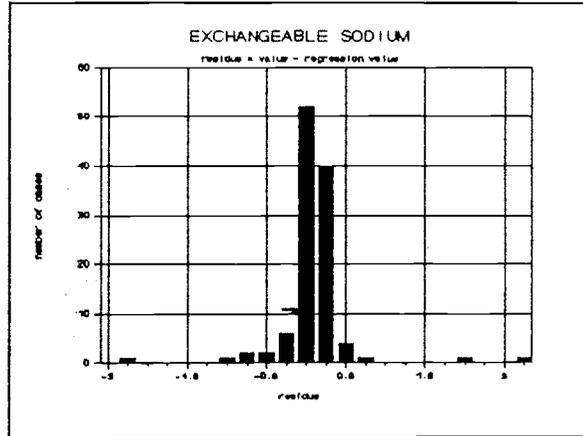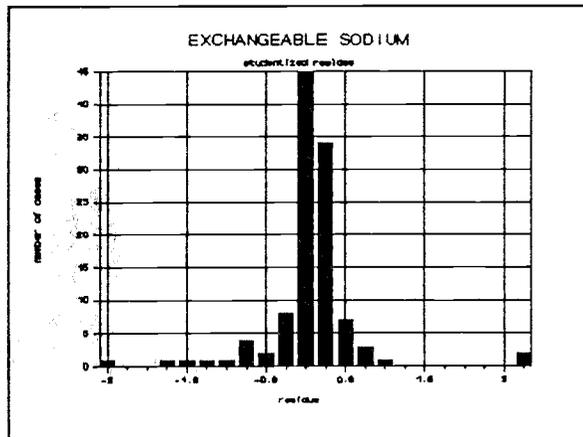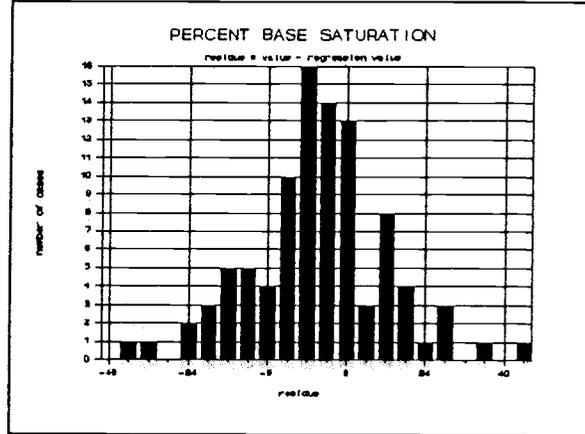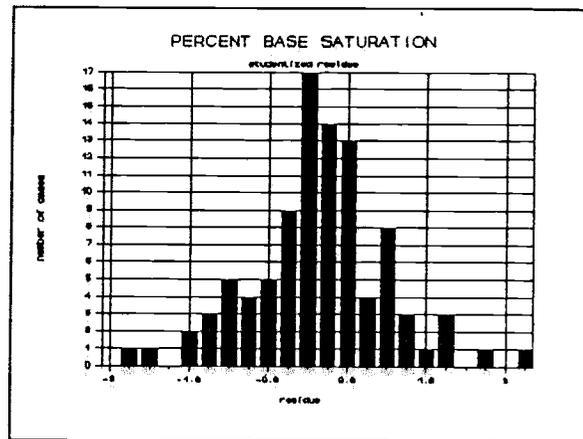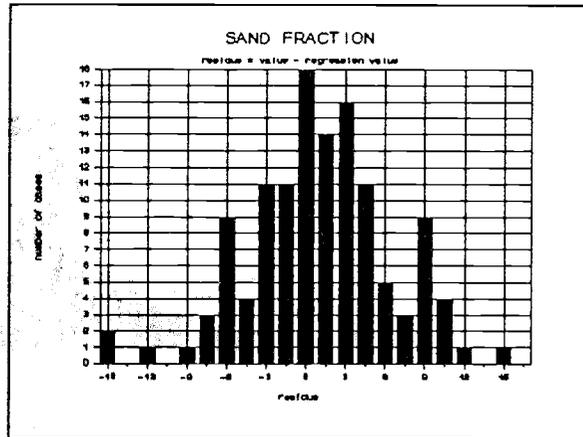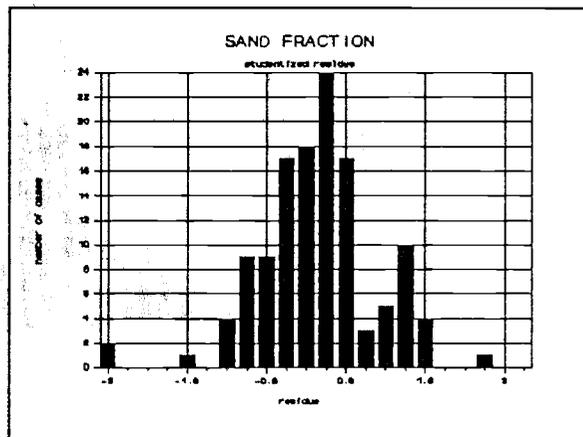
Figure 36:

Figure 37:

Figure 38:

Figure 39:

Figure 40:

CLAY FRACTION

Figure 41:

CLAY FRACTION
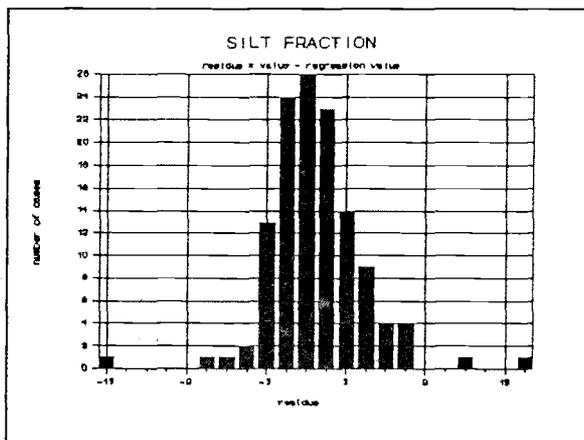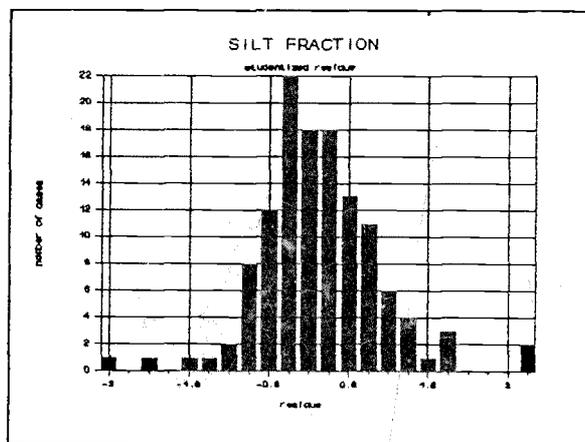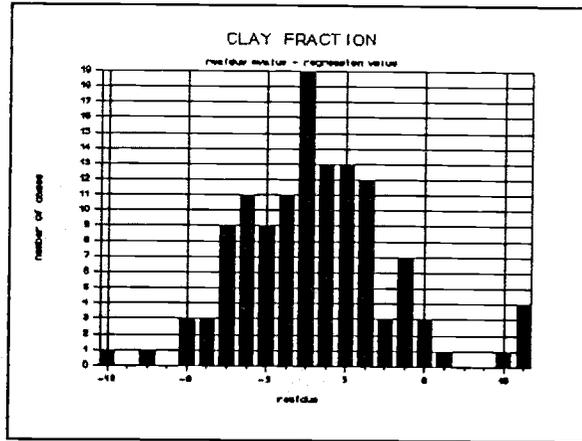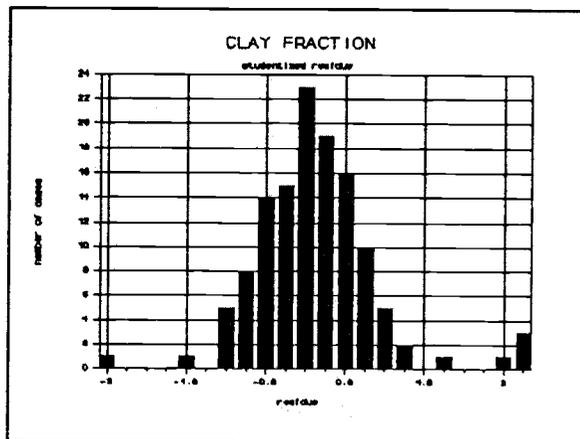
Figure 42:

Figure 43:

Figure 44:

CEC clay (org. C corrected)

Figure 45:

CEC clay (org. C corrected)

32
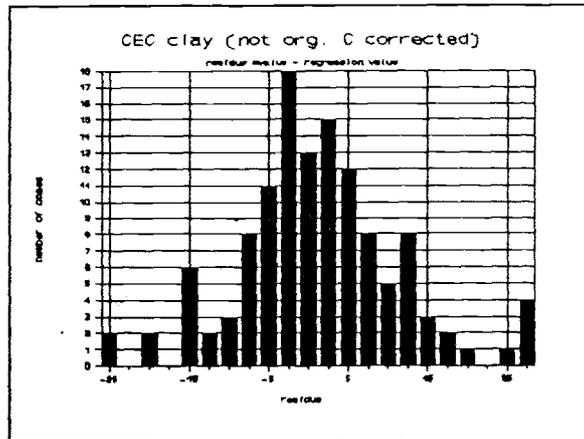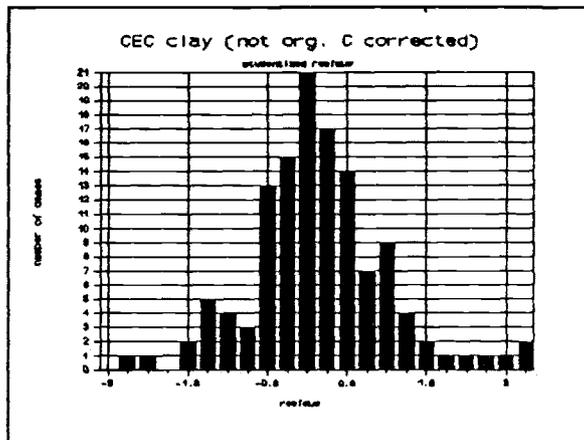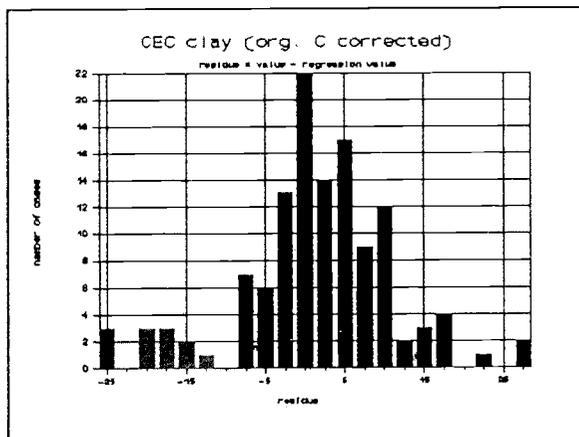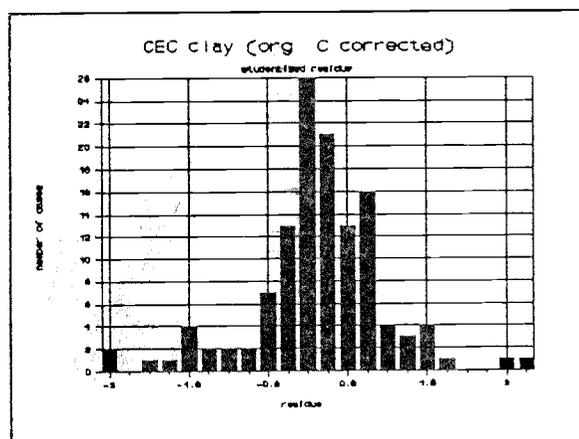
Figures 46-60:   Scatter plots of residuals against regression values.

Figure 46:
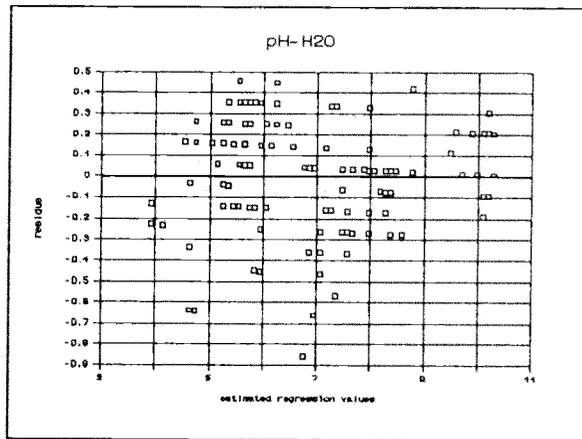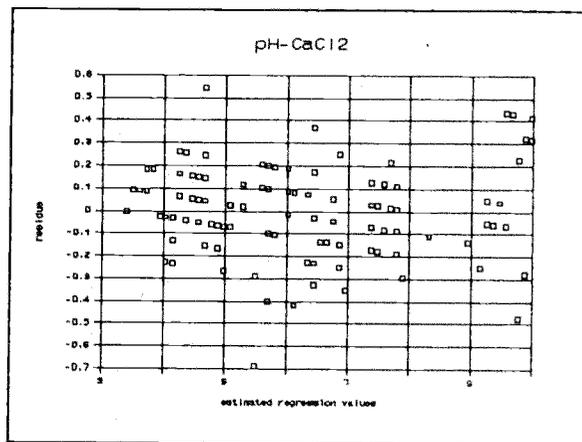
pH-H2O

Figure 47:

pH-CaCl2

Figure 48:

ELECTRIC CONDUCTIVITY

Figure 49:

ORGANIC CARBON

Figure 50:

CATION EXCHANGE CAPACITY

Figure 51:

EXCHANGEABLE CALCIUM

Figure 52:

EXCHANGEABLE MAGNESIUM

Figure 53:

EXCHANGEABLE POTASSIUM

Figure 54:

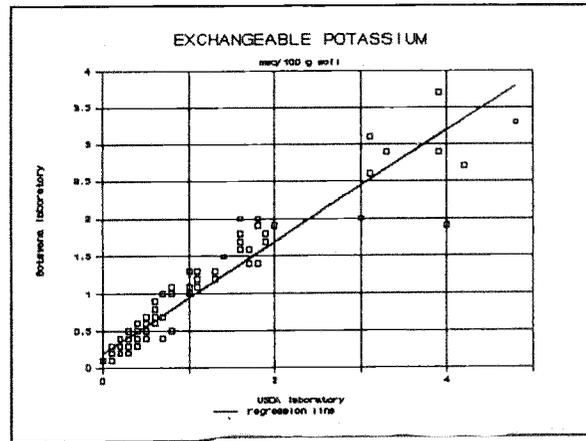

EXCHANGEABLE SODIUM

Figure 55:

PERCENT BASE SATURATION

37
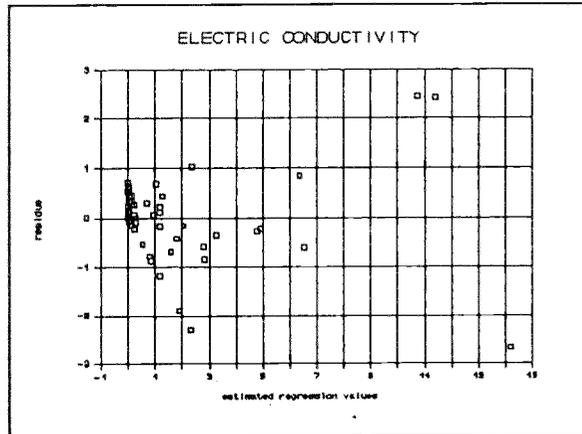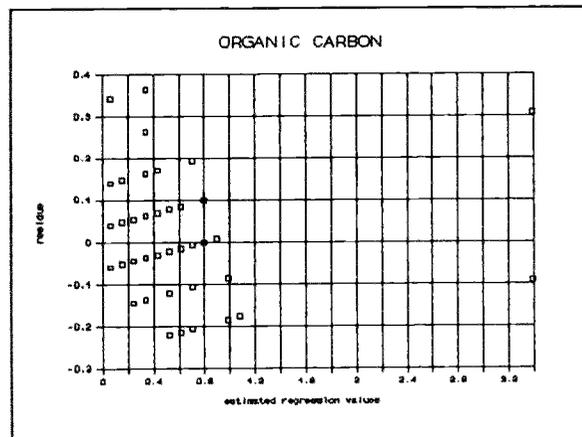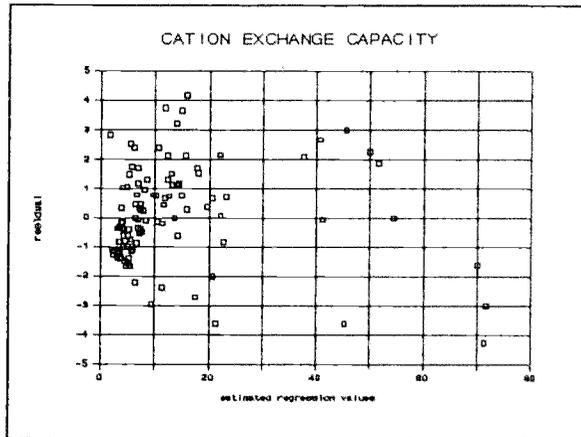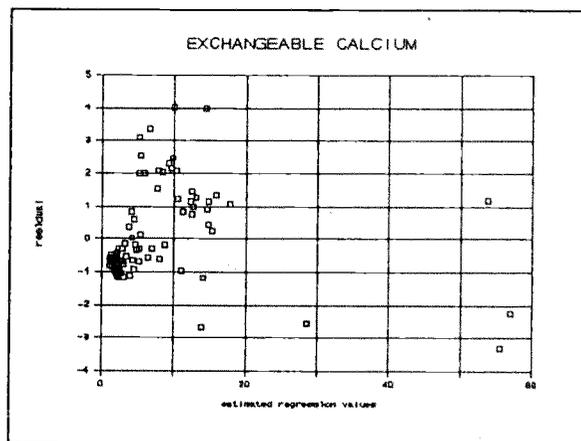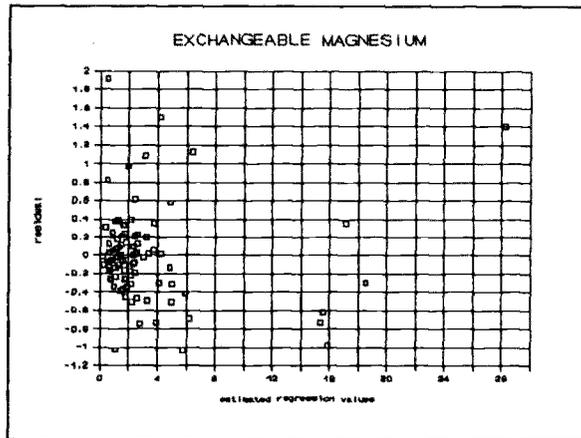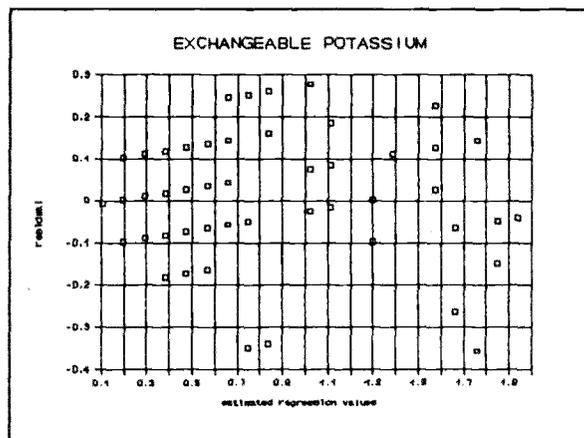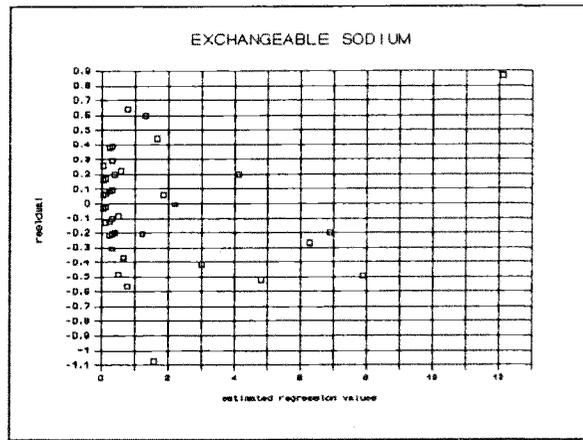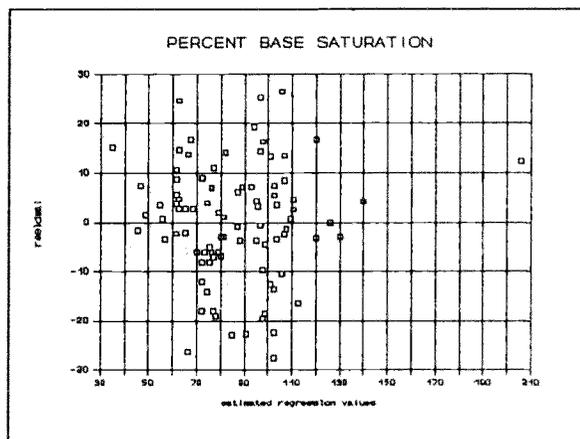
Figure 56:

Figure 57:

Figure 58:

CLAY FRACTION

Figure 59:

CEC clay (org. C corrected)

Figure 60:

CEC clay (not org. C corrected)
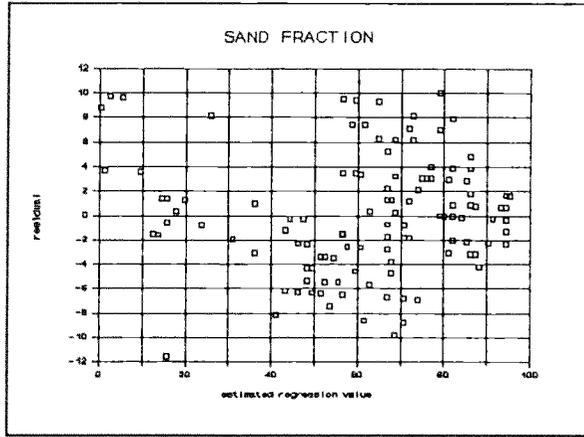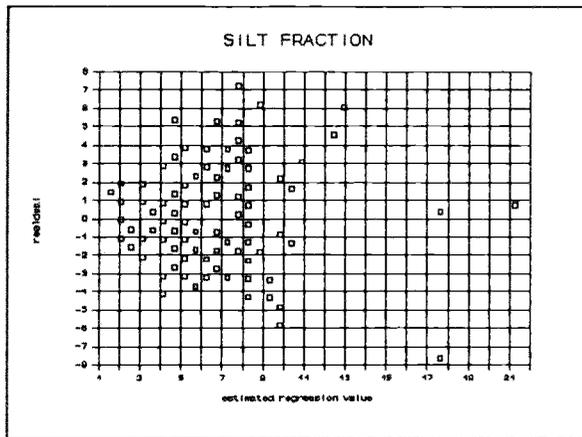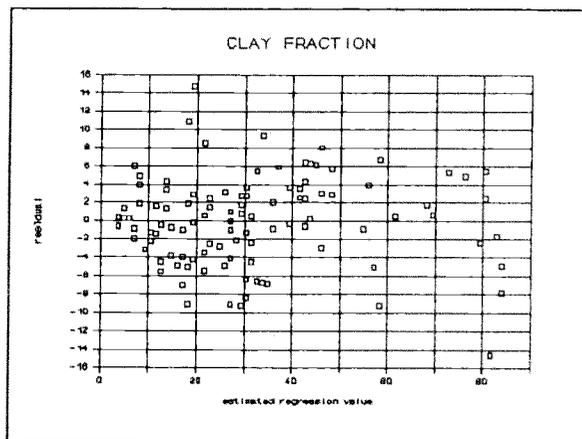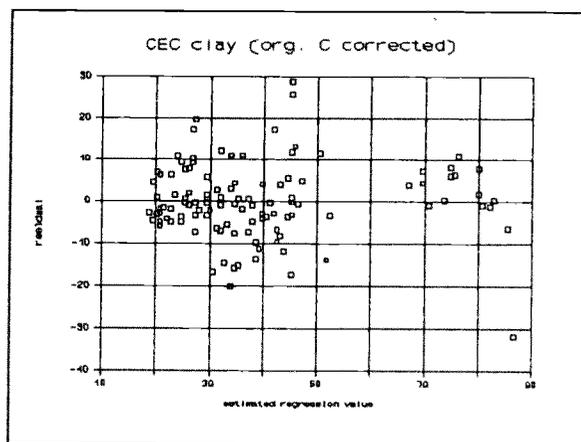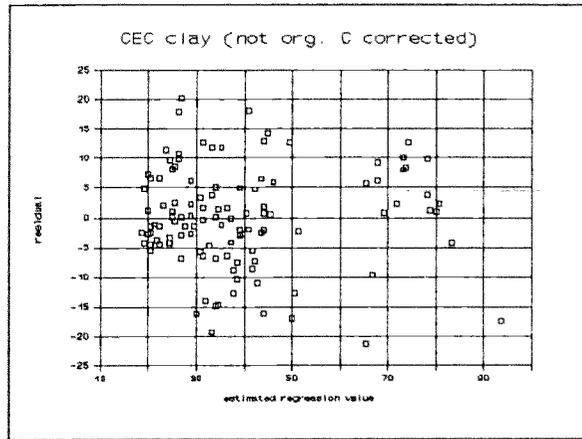
APPENDIX II

DATA SET USED FOR STATISTICAL ANALYSIS

EAST AFRICAN REGIONAL SOIL CORRELATION MEETING

30. March to 10.April 1987 at GABORONE BOTSWANA

Comparison of laboratory results between Botswana Soil Survey Laboratory (bot) and USDA Soil Survey Laboratory (usda)

Methods:

	Botswana lab	USDA lab
El. conductivity:	saturated paste extract	saturated paste extract
Org. carbon	: modified Walkley&Black	Walkley&Black and tot. org. C
CEC	: Ammonium acetate pH 7.0	Ammonium acetate pH 7.0
Exch. cations	: Ammonium acetate extract	Ammonium acetate extract
Particle size	: Hydrometer method	Pipette method

Dimensions:

El. conductivity: mS/cm
Organic carbon : weight % of <2mm fraction
CEC   : meq/100g soil
Exch. cations : meq/100g soil
Particle size : weight % of <2mm fraction

Calculated parameters:

Percent base saturation (PBS): sum exch. cations * 100 / CEC

CEC-clay organic carbon corrected: (CEC - 4 * org. C) * 100 / clay
CEC-clay not corrected   : CEC * 100 / %clay

Abbreviations:

bot   : Botswana laboratory
usda   : USDA laboratory

CECclay bot c / usda c : CEC-clay organic carbon corrected
CECclay bot nc / usda nc: CEC-clay not corrected

BOTSWANA SOIL SURVEY REFERENCE: SH 901

USDA PEDON REFERENCE NUMBER: 001

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	8.3	8.0	7.6	7.8	0.5	0.3	0.9	1.1
b	8.1	8.0	7.6	7.8	1.0	1.2	0.9	0.8
c	8.4	8.1	7.8	7.8	1.0	1.5	0.7	0.7
d	8.1	7.9	7.8	7.8	2.9	4.1	0.7	0.7
e	7.8	7.7	7.6	7.8	4.7	6.2	0.7	0.7
f	7.7	7.7	7.7	7.7	5.9	8.2	0.5	0.5
g	7.9	7.6	7.7	7.8	4.5	6.0	0.3	0.4

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	39.8	41.0	38.8	–	10.4	12.9	1.5	1.4	0.3	0.1	128	–
b	41.7	49.6	45.5	–	13.1	17.2	0.9	0.6	0.6	0.3	144	–
c	48.6	49.9	51.3	–	18.2	20.3	0.7	0.6	2.2	2.4	149	–
d	53.8	54.6	47.2	–	25.5	25.1	1.0	0.7	4.3	5.3	145	–
e	52.2	54.8	52.8	–	27.0	26.9	1.1	0.8	6.0	6.9	166	–
f	53.5	56.7	73.5	–	27.8	27.8	1.3	1.0	6.7	7.6	204	–
g	54.5	60.0	46.9	–	29.6	31.0	1.2	1.1	7.4	8.7	156	–

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	37	43	9	9	54	42	66	88	74	98
b	37	36	12	14	52	50	74	93	81	100
c	33	36	8	15	60	49	77	95	82	101
d	29	31	9	15	62	54	83	96	87	102
e	23	24	7	16	70	60	70	87	74	92
f	21	20	9	18	70	61	74	89	77	92
g	18	18	4	18	78	64	68	91	70	94

BOTSWANA SOIL SURVEY REFERENCE: MC 901

USDA PEDON REFERENCE NUMBER: 002

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	6.9	6.6	5.9	5.8	0.5	-	0.6	0.4
b	6.7	6.0	5.3	5.8	0.2	-	0.7	0.4
c	6.5	6.0	5.4	5.4	0.2	-	0.5	0.4
d	6.7	6.3	5.8	5.8	0.7	-	0.4	0.4

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	8.5	5.3	4.5	4.6	1.4	1.0	0.6	0.5	0.1	0.0	78	115
b	8.0	6.1	4.4	4.9	1.3	1.1	0.6	0.4	0.1	0.0	80	105
c	8.5	6.1	5.1	4.2	1.5	1.1	0.4	0.2	0.1	0.0	84	90
d	9.8	8.0	5.9	6.5	1.5	1.4	0.3	0.2	0.1	0.0	80	101

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	83	81	5	9	12	10·	59	37	73	52
b	79	78	8	10	14	12	47	37	59	50
c	80	76	6	8	15	16	46	28	57	38
d	73	71	5	8	22	21	37	30	45	38

BOTSWANA SOIL SURVEY REFERENCE: SH 902

USDA PEDON REFERENCE NUMBER: 003

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	5.4	5.3	4.5	4.7	-	-	0.3	0.3
b	4.3	5.6	3.8	5.3	-	-	0.5	0.4
c	6.7	6.2	5.7	5.7	-	-	0.2	0.3
d	6.3	6.7	5.7	6.2	-	-	0.3	0.2
e	7.3	6.9	6.4	6.4	-	-	0.2	0.3
f	7.7	7.1	6.6	6.5	-	-	0.3	0.2

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	3.6	2.7	1.7	1.4	0.5	0.5	0.5	0.3	0.2	0.0	81	81
b	6.5	6.2	3.6	3.9	1.4	1.7	0.6	0.6	0.1	0.0	87	100
c	7.4	5.9	4.2	3.8	1.7	1.8	0.5	0.5	0.1	0.0	88	103
d	7.4	6.4	4.4	4.3	1.9	2.1	0.5	0.5	0.2	0.0	95	108
e	7.8	6.7	4.9	5.0	1.9	2.2	0.6	0.5	0.1	0.0	96	115
f	12.1	11.6	7.3	8.2	2.8	3.5	0.5	0.5	0.2	0.0	90	105

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	87	85	5	5	8	10	30	15	44	27
b	79	71	4	6	18	23	28	20	37	27
c	76	73	4	5	21	22	30	21	36	27
d	75	68	4	6	22	26	31	21	34	24
e	72	66	5	8	24	26	28	21	33	25
f	63	62	4	12	32	27	35	41	37	44

BOTSWANA SOIL SURVEY REFERENCE: PS 901

USDA PEDON REFERENCE NUMBER: 004

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	4.1	4.5	3.8	4.2	1.3	1.5	0.5	0.4
b	5.9	5.8	5.0	5.2	0.4	0.1	0.4	0.4
c	5.6	5.5	4.7	4.9	0.6	0.1	0.2	0.4
d	5.3	5.1	4.6	4.7	0.7	0.1	0.2	0.3
e	5.3	5.2	4.5	4.7	0.6	0.0	0.2	0.3
f	5.6	5.2	4.5	4.7	0.6	0.0	0.3	0.2

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	5.0	2.9	1.6	1.3	0.6	0.5	0.6	0.4	0.2	0.0	60	76
b	5.9	3.9	2.5	2.2	1.3	1.2	0.7	0.5	0.1	0.0	78	100
c	7.4	4.8	1.8	1.5	1.9	1.8	0.6	0.5	0.1	0.0	59	79
d	7.9	4.5	1.9	1.5	2.0	1.7	0.6	0.4	0.2	0.0	59	80
e	6.7	4.3	1.7	1.4	1.7	1.5	0.4	0.3	0.2	0.0	60	74
f	6.8	6.2	1.6	1.7	1.5	1.6	0.3	0.3	0.2	0.0	53	58

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
ps901a	81	72	5	17	15	11	23	12	34	26
b	74	64	5	17	20	19	21	12	29	21
c	69	59	4	15	27	27	21	12	27	18
d	66	58	5	15	29	27	23	12	27	17
e	64	60	5	15	31	25	18	12	21	17
f	68	53	5	18	27	29	22	19	25	22

BOTSWANA SOIL SURVEY REFERENCE: MA 901

USDA PEDON REFERENCE NUMBER: 005

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	6.7	8.2	5.8	7.4	1.9	2.6	0.6	0.6
b	9.7	9.4	8.9	9.1	2.0	3.6	0.3	0.3
c	10.0	9.8	9.3	9.7	1.4	2.3	0.1	0.3
d	10.1	9.9	9.6	9.8	0.9	2.0	0.1	0.2
e	9.9	9.8	9.5	9.4	1.4	1.5	0.2	0.2
f	10.0	9.7	9.3	9.3	1.7	1.6	0.2	0.2
g	9.6	9.2	8.8	8.9	1.0	0.9	0.2	0.2

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	4.3	8.8	8.3	5.0	1.4	1.4	0.5	0.8	7.0	2.8	400	114
b	13.6	14.5	13.1	13.4	1.5	1.9	2.0	1.8	13.0	13.4	218	210
c	15.7	15.3	26.1	32.5	1.7	2.3	1.9	1.8	14.0	15.6	278	341
d	16.1	16.3	18.3	15.7	1.4	1.8	2.0	1.6	16.4	17.2	237	223
e	19.6	18.8	8.5	9.1	1.2	1.6	2.0	1.8	19.2	19.6	158	171
f	14.7	18.1	10.1	11.9	1.0	1.4	1.4	1.7	13.4	13.2	176	156
g	18.7	21.8	7.9	5.2	1.5	1.7	1.9	2.0	15.4	13.7	143	104

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	79	78	8	8	13	14	15	47	33	64
b	57	62	5	10	38	28	33	47	36	51
c	51	54	6	14	43	32	34	44	37	47
d	43	49	8	14	49	37	31	42	33	44
e	33	41	14	20	54	40	35	45	36	47
f	44	46	12	18	44	36	31	48	33	51
g	34	26	17	23	49	51	36	41	38	43

BOTSWANA SOIL SURVEY REFERENCE: MA 902

USDA PEDON REFERENCE NUMBER: 006

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	5.7	5.7	5.1	5.2	–	–	3.5	5.4
b	7.0	6.7	6.1	6.1	–	–	0.4	0.5
c	7.5	7.2	6.4	6.5	–	–	0.2	0.3
d	7.7	7.4	6.8	6.8	–	–	0.1	0.2
e	8.0	7.7	7.1	6.9	–	–	0.1	0.1
f	8.2	8.0	7.5	7.4	–	–	0.1	0.1

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	14.5	20.7	11.2	15.2	2.0	2.9	0.4	0.7	0.3	0.1	96	91
b	15.7	14.8	12.0	12.0	3.4	3.6	0.6	0.5	0.3	0.0	104	109
c	15.1	14.2	12.3	10.9	3.4	3.4	0.6	0.5	0.3	0.1	110	105
d	13.6	13.8	11.7	11.2	3.0	3.2	0.6	0.6	0.3	0.1	115	109
e	12.6	11.9	11.6	9.8	2.6	2.5	0.6	0.5	0.3	0.2	120	109
f	13.2	12.5	13.6	13.7	2.3	2.3·	0.6	0.5	0.3	0.1	127	133

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	69	66	12	19	19	16	-37	-6	76	132
b	63	67	3	7	34	26	40	49	46	57
c	64	66	3	8	34	26	41	50	45	55
d	65	66	2	9	33	26	39	51	41	54
e	70	71	3	6	27	23	46	51	47	52
f	70	71	7	7	23	23	55	53	57	55

BOTSWANA SOIL SURVEY REFERENCE: TO 901

USDA PEDON REFERENCE NUMBER: 007

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	4.0	4.4	3.9	4.3	–	4.6	8.0	8.2
b	3.8	3.7	3.6	3.7	–	2.4	6.8	6.4
c	3.9	3.9	3.7	3.8	–	2.9	3.7	3.7
d	3.7	3.7	3.4	3.6	–	1.5	1.5	2.1
e	3.9	3.9	3.4	3.6	–	1.1	0.6	0.7
f	4.3	4.4	3.9	4.1	–	0.7	0.4	0.4

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	41.0	44.8	18.8	19.7	5.5	6.7	1.6	1.7	0.8	0.6	65	64
b	44.8	41.3	13.8	13.4	4.3	4.6	1.0	1.0	0.4	0.3	44	47
c	43.4	44.4	17.2	17.5	5.5	6.4	1.1	1.0	0.6	0.4	56	57
d	24.1	23.2	9.2	7.9	2.4	2.4	0.8	0.6	0.6	0.2	54	48
e	14.5	12.4	7.8	5.7	1.9	1.7	0.5	0.4	0.3	0.0	72	63
f	24.0	24.7	15.5	16.8	3.8	4.4	1.0	0.8	0.3	0.1	86	89

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	9	1	25	27	67	72	12	17	62	63
b	5	2	19	24	76	74	25	21	59	56
c	12	3	27	17	62	80	47	37	71	55
d	15	6	4	39	81	54	19	27	30	43
e	40	46	17	18	44	36	27	27	33	35
f	17	16	18	33	65	51	35	45	37	48

BOTSWANA SOIL SURVEY REFERENCE: PA 901

USDA PEDON REFERENCE NUMBER: 008

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	5.4	5.6	4.8	5.0	-	-	0.5	0.6
b	5.7	5.4	4.5	4.7	-	-	0.3	0.4
c	5.6	5.1	4.3	4.5	-	-	0.2	0.2
d	5.7	5.1	4.3	4.4	-	-	0.2	0.2
e	5.5	5.0	4.0	4.3	-	-	0.2	0.1
f	5.7	5.1	4.1	4.3	-	-	0.2	0.1

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	2.4	2.1	1.0	1.4	0.6	0.7	0.1	0.1	0.1	0.0	75	105
b	2.3	2.3	0.8	0.9	0.8	1.0	0.1	0.0	0.1	0.0	78	83
c	2.6	1.8	0.7	0.3	0.8	0.8	0.1	0.0	0.1	0.1	63	67
d	2.2	2.5	0.6	0.3	1.1	1.2	0.1	0.0	0.1	0.1	87	64
e	3.2	3.2	0.4	0.2	1.2	1.3	0.2	0.2	0.1	0.1	58	56
f	3.1	2.3	0.3	0.0	1.1	0.8.	0.2	0.2	0.1	0.1	53	48

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	92	93	3	2	5	5	0	-7	44	47
b	88	89	4	3	9	8	8	9	26	29
c	91	90	2	3	8	8	24	13	35	23
d	88	84	2	3	11	13	13	13	20	19
e	88	85	1	3	11	12	25	23	28	26
f	84	83	3	3	13	14	21	13	24	16

BOTSWANA SOIL SURVEY REFERENCE: PA 902

USDA PEDON REFERENCE NUMBER: 009

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	7.1	7.0	6.6	7.0	0.0	0.3	0.9	1.0
b	7.9	7.6	7.2	7.4	0.3	0.3	0.5	0.8
c	8.1	7.8	7.4	7.4	0.2	0.4	0.5	0.8
d	8.1	8.1	7.3	7.5	0.3	0.3	0.6	0.8
e	8.2	8.0	7.5	7.6	0.3	0.4	0.7	0.8
f	8.3	8.3	7.5	7.5	0.3	0.4	0.7	0.8

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	62.4	76.1	54.8	65.8	14.9	17.4	1.8	1.9	0.3	0.7	115	113
b	63.9	77.6	54.8	68.2	14.6	16.8	1.6	1.6	1.0	1.3	113	113
c	68.5	77.6	55.0	62.0	14.9	17.0	1.7	1.6	1.9	2.0	107	106
d	67.1	79.0	52.2	64.0	15.0	18.1	1.6	1.7	2.6	3.3	106	110
e	67.5	81.8	53.4	66.3	15.8	18.7	1.7	1.9	3.5	5.0	110	112
f	68.8	79.5	60.3	54.1	17.5	18.8	1.8	1.6	4.3	4.5	122	99

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	16	15	8	15	77	70	76	103	82	108
b	15	16	5	17	81	67	75	112	79	116
c	4	16	10	13	86	71	76	104	80	109
d	12	14	6	15	83	71	77	107	81	111
e	13	10	6	17	81	73	79	108	83	112
f	11	13	11	14	79	74	84	104	88	108

BOTSWANA SOIL SURVEY REFERENCE: F 901

USDA PEDON REFERENCE NUMBER: 010

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	7.4	7.4	6.7	6.9	-	0.1	0.9	0.9
b	7.0	6.9	6.1	6.5	-	0.2	0.6	0.7
c	6.7	6.8	6.1	6.4	-	0.2	0.5	0.6
d	6.8	6.5	6.2	6.1	-	0.2	0.4	0.4
e	6.9	6.6	6.2	6.2	-	0.2	0.3	0.3
f	7.4	7.2	6.7	6.8	-	0.2	0.4	0.4
g	7.4	7.3	6.6	6.9	-	0.2	0.2	0.2

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	10.5	9.4	9.9	8.1	1.3	0.4	0.5	0.5	0.2	0.0	113	96
b	11.1	11.2	11.7	10.1	2.0	4.0	0.2	0.2	0.1	0.1	126	129
c	13.7	12.4	12.2	10.3	2.2	2.5	0.2	0.1	0.2	0.1	108	105
d	14.6	13.2	13.9	10.5	2.3	2.5	0.2	0.1	0.2	0.1	114	100
e	17.3	14.3	16.3	11.3	2.5	2.6	0.2	0.1	0.2	0.1	111	99
f	17.7	16.0	20.0	13.9	2.7	2.7	0.3	0.2	0.2	0.1	131	106
g	20.7	12.3	20.1	10.4	2.9	2.0	0.3	0.2	0.2	0.1	114	103

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	59	68	11	14	30	18	23	32	35	52
b	58	60	13	14	29	26	30	32	38	43
c	55	56	6	13	38	31	31	32	36	40
d	50	55	6	12	43	34	30	34	34	39
e	47	52	7	11	47	37	34	35	37	38
f	43	48	8	12	49	40	33	36	36	40
g	44	63	5	12	51	25	39	45	41	49

BOTSWANA SOIL SURVEY REFERENCE: F 902

USDA PEDON REFERENCE NUMBER: 011

Sample	pH-H2o		pH-CaC12		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	6.6	6.0	5.3	5.4	-	-	0.4	0.4
b	5.5	5.7	4.7	5.1	-	-	0.1	0.3
c	5.1	5.0	4.4	4.4	-	-	0.1	0.2
d	5.2	4.9	4.0	4.3	-	-	0.1	0.2
e	5.2	4.8	4.0	4.2	-	-	0.2	0.1
f	6.0	5.3	4.6	4.6	-	-	0.1	0.1

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	4.1	2.7	1.5	1.9	0.5	0.5	0.2	0.2	0.1	0.0	55	96
b	2.5	2.8	1.5	1.8	0.6	0.6	0.1	0.1	0.1	0.0	93	89
c	2.6	2.3	0.8	0.9	0.5	0.7	0.1	0.1	0.0	0.0	54	74
d	1.7	1.9	0.5	0.5	0.4	0.6	0.1	0.1	0.0	0.0	59	63
e	2.0	1.9	0.7	0.5	0.5	0.6	0.1	0.1	0.0	0.0	65	63
f	1.8	1.8	0.7	0.5	0.6	0.9	0.1	0.1	0.0	0.0	78	83

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	83	85	4	10	13	5	19	22	32	53
b	88	84	2	10	10	6	21	26	25	45
c	84	86	4	8	13	6	17	26	20	40
d	83	84	4	10	12	6	11	19	14	33
e	88	86	6	9	6	5	20	28	33	35
f	86	81	7	15	6	4	22	36	28	46

BOTSWANA SOIL SURVEY REFERENCE: F 903

USDA PEDON REFERENCE NUMBER: 012

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	5.9	6.5	4.8	5.6	-	-	0.4	0.6
b	5.8	7.5	4.7	6.6	-	-	0.4	0.6
c	6.2	7.9	4.6	7.0	-	-	0.3	0.4
d	7.0	5.3	5.6	4.5	0.1	-	0.3	0.3
e	7.9	5.6	6.5	4.8	0.2	0.1	0.3	0.3
f	8.2	5.6	6.8	4.9	0.5	0.1	0.1	0.3

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	6.4	9.0	2.7	3.4	1.3	1.8	0.3	0.4	0.0	0.1	67	63
b	9.0	11.3	3.6	4.2	2.1	2.7	0.4	0.5	0.0	0.2	68	67
c	11.0	10.0	4.9	3.7	3.0	2.5	0.2	0.3	0.7	0.3	80	68
d	15.6	11.8	7.1	4.9	4.2	3.3	0.2	0.2	1.4	0.8	83	78
e	18.5	15.2	10.0	6.7	5.7	4.5	0.2	0.1	1.9	1.4	96	84
f	20.1	16.4	10.4	8.7	5.5	5.3	0.3	0.1	2.1	1.8	91	97

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	79	72	4	10	16	18	29	36	39	50
b	69	61	4	11	26	28	28	32	34	41
c	53	61	4	10	43	29	23	29	25	35
d	46	53	4	9	50	38	29	28	31	31
e	42	43	5	9	54	48	32	29	35	31
f	44	48	5	10	51	42	39	36	39	39

BOTSWANA SOIL SURVEY REFERENCE: M 901

USDA PEDON REFERENCE NUMBER: 013

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	8.3	8.1	7.3	7.4	0.1	0.2	0.4	0.5
b	8.1	7.7	7.1	6.9	0.1	0.1	0.3	0.3
c	7.6	7.0	6.8	6.5	0.1	0.2	0.3	0.3
d	6.1	5.7	4.8	5.0	-	-	0.3	0.3
e	5.7	5.1	4.6	4.5	-	-	0.2	0.3
f	5.4	5.0	4.5	4.4	-	-	0.1	0.2
g	5.7	5.6	4.7	5.0	-	-	0.1	0.2

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	4.3	4.0	5.4	5.1	0.4	0.4	0.4	0.2	0.0	0.0	144	143
b	3.5	3.1	4.1	3.3	0.4	0.4	0.3	0.1	0.0	0.0	137	123
c	3.1	3.6	3.0	2.6	0.8	0.9	0.3	0.2	0.0	0.2	132	108
d	3.1	3.8	1.0	1.3	0.9	1.0	0.6	0.5	0.0	0.0	81	74
e	4.6	0.4	1.2	1.2	1.1	1.1	0.4	0.2	0.0	0.0	59	625
f	4.0	4.1	1.3	1.6	0.0	1.0	0.3	0.2	0.0	0.0	40	68
g	3.8	4.6	1.9	2.5	0.9	1.0	0.3	0.2	0.0	0.1	82	83

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	90	85	4	8	6	7	40	27	74	55
b	91	85	2	8	8	8	31	25	47	41
c	90	81	3	9	7	10	27	23	44	35
d	84	80	5	8	11	12	17	22	28	32
e	86	78	4	7	10	14	33	-6	45	3
f	89	78	3	11	9	15	38	22	47	28
g	78	74	9	15	13	15	23	25	29	31

BOTSWANA SOIL SURVEY REFERENCE: L 901

USDA PEDON REFERENCE NUMBER: 014

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	6.2	5.6	4.9	4.8	-	-	0.4	0.5
b	6.0	5.5	4.8	4.8	-	-	0.3	0.4
c	6.0	5.4	4.7	4.9	-	-	0.3	0.3
d	6.1	5.5	4.9	5.1	-	-	0.2	0.3
e	6.3	5.7	5.2	4.8	-	-	0.2	0.3

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	2.1	2.2	0.8	1.0	0.4	0.5	0.2	0.2	0.0	0.0	67	77
b	3.7	4.4	1.2	1.7	1.1	1.5	0.3	0.2	0.0	0.0	70	77
c	4.7	5.0	1.6	2.0	1.5	1.8	0.2	0.1	0.0	0.0	70	78
d	6.9	6.7	2.2	2.4	2.2	2.4	0.2	0.1	0.0	0.1	67	75
e	8.1	7.3	2.8	2.8	2.8	2.7	0.3	0.1	0.0	0.3	73	81

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	81	76	9	11	10	9	1	2	20	24
b	71	64	9	11	20	25	11	11	19	18
c	63	59	9	12	28	30	12	13	17	17
d	49	52	9	14	42	37	13	15	16	18
e	45	51	10	33	45	36	15	17	18	20

BOTSWANA SOIL SURVEY REFERENCE: L 902

USDA PEDON REFERENCE NUMBER: 015

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	5.8	5.5	4.9	5.1	-	-	0.8	1.1
b	5.9	5.4	5.2	5.6	-	-	0.4	0.5
c	6.3	5.8	5.6	5.8	-	-	0.2	0.4
d	6.6	6.8	5.7	5.9	-	-	0.2	0.3
e	6.8	6.8	6.0	5.9	-	-	0.2	0.2
f	6.7	6.8	5.9	4.6	-	-	0.1	0.2

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	3.3	3.9	1.3	1.7	0.5	0.5	0.4	0.3	0.0	0.0	67	64
b	3.9	3.3	1.6	1.5	0.7	0.7	0.7	0.5	0.0	0.0	77	82
c	3.3	3.3	1.7	1.4	0.6	0.7	0.6	0.5	0.0	0.0	88	79
d	3.7	3.0	1.3	1.6	0.6	0.7	0.4	0.3	0.0	0.0	62	87
e	3.6	3.4	1.5	1.6	0.9	0.8	0.4	0.2	0.0	0.0	78	76
f	3.8	2.9	1.5	1.7	0.8	0.8	0.3	0.2	0.0	0.0	68	93

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	66	56	15	14	18	11	-6	-5	18	36
b	64	70	15	16	22	16	9	8	18	21
c	68	66	10	15	22	18	8	9	15	18
d	63	67	12	15	25	19	10	10	15	16
e	69	67	11	15	20	19	14	14	18	18
f	66	66	10	8	24	19	12	11	16	15

BOTSWANA SOIL SURVEY REFERENCE: G 901

USDA PEDON REFERENCE NUMBER: 016

Sample	pH-H2o bot	pH-H2o usda	pH-CaCl2 bot	pH-CaCl2 usda	EC bot	EC usda	org. C bot	org. C usda
a	5.9	5.4	4.5	4.6	-	-	0.2	0.3
b	5.9	5.3	4.5	4.8	-	-	0.2	0.4
c	5.9	5.4	4.8	4.8	-	-	0.2	0.3
d	5.6	5.3	4.7	4.8	-	-	0.2	0.3
e	5.8	5.4	4.7	4.8	-	-	0.2	0.3
f	5.6	5.3	4.7		-	-	0.2	0.2
g						-	0.1	0.2

Sample	CEC bot	CEC usda	Ca bot	Ca usda	Mg bot	Mg usda	K bot	K usda	Na bot	Na usda	PBS bot	PBS usda
a	3.9	4.4	1.9	1.9	0.7	0.6	0.4	0.3	0.0	0.0	77	64
b	4.7	4.2	2.2	2.3	0.7	0.7	0.4	0.3	0.0	0.0	70	79
c	4.8	4.7	1.8	1.8	1.2	1.2	0.4	0.3	0.0	0.0	71	70
d	4.5	4.8	1.5	1.4	1.9	1.6	0.4	0.3	0.0	0.0	84	69
e	6.4	5.7	1.4	1.4	2.3	2.4·	0.4	0.3	0.0	0.0	64	72
f	6.9	5.7	1.4	1.2	2.6	2.7	0.4	0.3	0.0	0.0	64	74
g	5.1		1.2		2.2		0.1		0.0		69	

Sample	Sand bot	Sand usda	Silt bot	Silt usda	Clay bot	Clay usda	CEC clay bot c	CEC clay usda c	CEC clay bot nc	CEC clay usda nc
a	82	81	4	8	15	11	19	28	27	39
b	80	81	3	8	17	11	19	23	28	37
c	80	79	5	7	16	14	23	26	31	35
d	79	75	3	7	18	18	18	20	25	26
e	70	70	5	7	26	23	20	20	25	25
f	69	70	4		27	23	23	21	26	25
g	74		4		23	20	19		23	

BOTSWANA SOIL SURVEY REFERENCE: D 901

USDA PEDON REFERENCE NUMBER: 017

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	5.2	5.0	4.3	4.4	-	-	0.2	0.3
b	4.9	4.5	4.0	4.0	-	-	0.1	0.2
c	4.6	4.4	3.8	3.9	-	-	0.1	0.1
d	4.7	4.3	3.9	3.9	-	-	0.0	0.1
e	5.0	4.5	4.0	4.0	-	-	0.0	0.1

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	1.1	1.1	0.5	0.5	0.2	0.2	0.1	0.1	0.0	0.1	73	82
b	1.2	1.1	0.3	0.2	0.2	0.1	0.1	0.1	0.0	0.0	50	36
c	1.0	1.0	0.3	0.2	0.1	0.1	0.1	0.1	0.0	0.1	50	50
d	1.1	1.1	0.4	0.1	0.2	0.1	0.1	0.1	0.0	0.0	64	27
e	1.0	0.8	0.4	0.2	0.2	0.2	0.1	0.1	0.0	0.0	70	63

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	97	94	1	4	3	2	1	15	42	
b	94	93	2	5	4	2	13	35	28	
c	95	93	1	5	4	2	14	27	29	
d	94	93	2	5	4	2	15	46	31	
e	94	92	1	4	5	3	14	24	21	

BOTSWANA SOIL SURVEY REFERENCE: DU 901

USDA PEDON REFERENCE NUMBER: 018

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	10.1	9.6	10.0	9.7	86.7	105.7	0.3	0.6
b	10.5	10.0	10.4	9.9	33.5	48.2	0.1	0.2
c	10.4	9.9	10.2	9.8	42.7	51.7	0.1	0.2
d	10.3	9.8	10.1	9.6	42.1	64.2	0.1	0.2
e	10.5	9.9	10.3	9.9	31.3	47.4	0.4	0.1

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	5.8	6.0	37.1	–	0.7	0.3	2.7	4.2	6.8	80.9	816	–
b	8.2	7.8	34.8	–	2.4	0.4	2.9	3.3	5.3	37.8	554	–
c	6.9	6.8	23.9	–	1.2	1.3	1.9	4.0	1.6	45.9	414	–
d	5.0	5.2	30.2	–	2.4	0.4	2.6	3.1	2.8	44.1	760	–
e	7.5	6.6	29.6	–	4.1	4.0	2.9	3.9	4.1	43.9	543	–

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	60	66	12	12	29	22	11	22	20	28
b	64	67	4	8	32	25	24	29	26	31
c	72	68	2	8	26	24	24	26	27	28
d	78	80	2	4	20	15	22	31	25	34
e	55	59	10	11	35	31	20	16	21	21

BOTSWANA SOIL SURVEY REFERENCE: DU 902

USDA PEDON REFERENCE NUMBER: 019

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	8.8	8.5	7.9	7.8	0.5	0.2	0.2	0.4
b	9.2	8.5	7.6	7.9	1.7	1.3	0.1	0.3
c	9.7	9.4	8.2	8.3	2.2	3.5	0.1	0.2
d	10.3	10.0	9.5	9.5	13.8	14.3	0.1	0.2
e	10.5	10.0	10.0	9.5	30.9	29.3	0.0	0.1

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	2.9	2.1	20.7	–	0.7	0.7	0.4	0.4	0.2	0.4	759	–
b	1.6	1.5	32.2	–	0.7	0.5	0.4	0.3	0.4	0.5	2106	–
c	1.2	1.1	33.1	–	0.7	0.7	0.4	0.4	0.5	1.7	2892	–
d	6.5	6.4	31.4	–	1.8	2.2	2.0	3.0	2.6	15.7	582	–
e	10.2	10.1	16.9	–	1.6	1.2	3.3	4.8	3.8	30.7	251	–

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	95	93	1	5	4	2	33	62	83	100
b	96	93	1	5	4	2	10	65	44	88
c	93	93	1	4	6	3	5	25	19	39
d	67	73	5	5	28	23	21	26	24	28
e	69	68	1	7	30	25	32	41	34	41

BOTSWANA SOIL SURVEY REFERENCE: N 901

USDA PEDON REFERENCE NUMBER: 020

Sample	pH-H2o		pH-CaCl2		EC		org. C	
	bot	usda	bot	usda	bot	usda	bot	usda
a	8.1	8.1	7.5	7.4	0.6	0.2	0.6	0.5
b	8.5	8.2	7.7	7.6	0.4	0.2	0.4	0.5
c	8.3	7.7	7.9	7.7	3.4	3.0	0.4	0.7
d	8.3	7.7	7.9	74.7	7.2	8.0	0.8	0.9
e	9.8	9.3	9.2	9.2	13.2	13.5	0.4	0.7
f	9.9	9.8	9.3	9.2	11.5	17.8	0.1	0.2

Sample	CEC		Ca		Mg		K		Na		PBS	
	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda	bot	usda
a	7.2	7.1	6.6	7.0	1.1	1.0	0.6	0.5	0.1	0.2	117	123
b	9.1	7.6	20.0	-	1.5	1.6	0.7	0.7	0.2	0.3	246	-
c	4.2	5.7	36.8	-	2.5	2.2	0.7	0.6	0.2	0.8	957	-
d	13.0	10.4	36.8	-	4.7	6.2	1.3	1.1	2.1	5.1	345	-
e	15.3	14.4	34.7	-	7.5	6.9	3.1	3.1	10.6	23.5	365	-
f	14.5	13.5	32.7	-	2.2	2.4	3.7	3.9	8.1	22.1	322	-

Sample	Sand		Silt		Clay		CEC clay			
	bot	usda	bot	usda	bot	usda	bot c	usda c	bot nc	usda nc
a	84	87	3	7	13	6	39	78	55	118
b	87	85	0	7	13	9	56	70	71	88
c	62	70	9	15	29	15	5	27	14	38
d	44	44	22	40	34	16	28	45	38	65
e	49	88	7	9	44	4	28	366	34	411
f	50	56	5	27	45	17	30	77	32	79

BOTSWANA SOIL SURVEY REFERENCE: MA 903

USDA PEDON REFERENCE NUMBER: 021

Sample	pH-H2o bot	usda	pH-CaCl2 bot	usda	EC bot	usda	org. C bot	usda
a	6.3	5.9	5.8	5.7	--	1.0	3.3	3.7
b	6.5	6.6	6.0	6.1	--	0.2	0.9	1.2
c	6.8	7.1	6.2	6.5	--	0.1	0.9	0.5
d	7.2	7.3	6.5	6.7	--	0.1	0.3	0.3
e	7.3	7.3	6.5	6.7	--	0.1	0.2	0.2
f	7.2	7.2	6.4	6.6	--	0.1	0.1	0.2

Sample	CEC bot	usda	Ca bot	usda	Mg bot	usda	K bot	usda	Na bot	usda	PBS bot	usda
a	17.6	22.4	12.8	15.3	3.2	4.2	1.4	1.8	0.0	0.5	99	97
b	21.9	24.1	15.8	16.1	4.7	5.2	1.3	1.3	0.1	0.2	100	95
c	22.2	23.4	15.2	16.2	4.7	5.4	1.3	1.3	0.1	0.2	96	99
d	21.2	21.6	15.5	16.0	4.5	5.4	1.2	1.3	0.1	0.3	100	106
e	20.1	20.7	14.3	14.2	4.3	4.6	1.1	1.1	0.2	0.3	99	98
f	19.5	18.5	13.4	13.3	3.8	4.0	1.1	1.0	0.1	0.3	94	101

Sample	Sand bot	usda	Silt bot	usda	Clay bot	usda	CEC clay bot c	usda c	bot nc	usda nc
a	60	56	9	19	31	25	9	37	57	90
b	45	49	10	15	45	37	38	56	49	66
c	47	47	11	13	43	40	47	49	52	58
d	46	48	4	13	51	39	39	52	42	55
e	48	51	9	11	44	38	44	53	46	55
f	55	57	6	9	39	34	48	53	50	54