Appendix 3.
A STATISTICAL PROCEDURE FOR ENHANCING SOIL SURVEYS FOR SOIL FERTILITY INVESTIGATIONS

Agronomists requiring more information for designing field fertilizer trials are faced with the problem of how much to sample, and even how to go about soil sampling. In soil survey, particularly, precision is generally, but often erroneously, associated with sample density; much sampling and many analyses are demanded for surveys with large mapping scales.

The approach advocated by Cochrane (1969) for enhancing soil surveys for fertility investigations is to examine and sample 12 to 18 soil profiles or topsoil samples over a relatively constant soil unit. Once these samples have been analyzed chemically (and this analysis should be as complete as possible), the chemical analytical data might be analyzed statistically to establish means, standard deviations, and a correlation matrix. This can then be scrutinized and interpreted to help understand soil fertility problems according to the following procedure to identify probable toxicity and nutrient problems, always bearing in mind the crop and its genetic make-up in terms of nutrient tolerances and demands:

I. Methodic scrutiny of the statistical data.
   A. Inspect means, maximums, minimums, and standard deviations to:
      1. Identify probable and possible toxicity problems (Al, Mn, Fe) from the soil analytical figures.
      2. Identify probable and possible deficiency problems in the same way.
      3. Note circumstances that could give correlations with little implication insofar as soil properties are concerned, including those populations with small standard deviations compared with their means (perhaps those with a standard deviation less than 20% of the mean).
   B. Inspect the correlation matrix for possible meaningful correlations, in the sense of A-3 above, and list both positive and negative correlations in order of significance. It has been well known for many years that relationships exist between the availability of certain major and minor nutrients. The presence of strong correlations within this sample may indicate that the relationships in question may apply to the specific soil under study.

II. Interpretation.
   A. In the event of a probable toxicity problem:
      1. a. For Al, calculate liming needs according to the equation of Cochrane et al. (1980).
         b. For Mn, "guesstimate" liming needs.
         c. For Fe toxicity, ensure that the soil is well drained.
      2. Then reconsider the implication of these treatments on the deficiencies and their correlations. There is a possible implication that a positive correlation between two elements will mean that raising one will increase the availability of the other if it is not in short supply, or cause more serious deficiency if it is in short supply. For a negative correlation, the reverse situation would apply.
   B. In the event of probable deficiency problems:
      1. Consider first the implication of any actions that will probably be taken to solve a toxicity problem, if such exists.
      2. Starting with the most serious problem, estimate a fertilizer application for adequate correction. If this probable deficiency is correlated with another, consider possible effects of the correction.
      3. Continue this process for other deficiencies, in descending order of apparent importance.

The procedure was applied to land system No. 201, land facet No. 1, the principle soils (Haplustox) of CIAT's Carimagua station located in the eastern plains of Colombia; the. correlation matrix of the soil analytical data has been recorded in the tables in this Appendix. The procedure was also followed experimentally for a limited number of other soils, including soils from central Brazil and northern Bolivia. In short, while the methodology is still in an experimental stage, it indicated the presence of:

1. Toxicity problems for Al and Fe (the latter if soils used were under wet conditions).
2. Probable nutrient problems for P, K, Ca, and Mg.
3. Possible nutrient problems for Mn, Zn, and B.

Recommendations from the Statistical Procedure

K deficiency. The addition of K might aggravate the Mg deficiency problem. Therefore K and Mg should be added together.

Possible Mn, Zn, and, B deficiencies. The correlations of these elements with others are not as highly significant as others and could probably be field tested without too much problem. For example, the negative correlation between Zn and pH (in H,O) is probably only significant if major changes take place in pH. Although S levels appear moderate, availability could be questioned. The positive correlation between P and Cu levels should be borne in mind. In this respect, the type of P fertilizer to be applied must be considered in the light of its ability to supply other nutrients (such as S and Ca in the case of single superphosphate), apart from the effect of the fertilizer components on leaching.

Thus, it is clear that fertilizer trials should be designed to take liming, P, K, and Mg treatments into account and, if possible, Mn, Zn, B, and possibly S and even Cu. The soils should be well drained and not used for wetland crops to avoid Fe toxicity problems.

Discussion

The recommendations from the statistical procedure compare well with actual findings from CIAT's experimental work over the past 12 years: Al toxicity and low levels of P and bases (K, Ca, and Mg) were found to be the major limiting factors for many arable crops (Spain, 1976). Fe toxicity was reported for flooded rice (Howeler, 1973). Ngongi et al. (I 977) found K and S deficiency problems in cassava. Howeler et al. (1977) also describe lime by Zn, Mn, B, and Cu interactions in cassava; further, they found that high liming rates reduced yields by inducing Zn deficiency and possibly Mn and B deficiencies. Much costly experimental work went into establishing these and similar results (reported in CIAT's annual reports); had the statistical sampling procedure discussed in this Appendix been incorporated into the initial soil survey study of the region, the soil fertility specialists would have saved both time and costs. There is clearly a critical need to improve the role soil surveys play in providing a basis for soil fertility investigations, especially when carried out on undeveloped lands.

Table A3-1. Soil analytical data of samples of 18 profiles throughout land facet No. 1. Land System 201: horizon A.

Sample no.	pH H_2O	pH KCl	OM	P	Al	Ca	Mg	K	Na	CEC	% Al S	B	Zn	Mn	Cu	Fe	S	Mo
1	4.8	3.9	1.7	1.5	1.4	0.09	0.02	0.05	0.03	1.59	90	0.26	0.40	1.8	0.36	24.4	5.0	1.04
2	4.7	3.7	5.3	1.7	3.8	0.07	0.01	0.01	0.03	3.92	98	0.32	0.55	2.3	0.53	15.4	4.5	1.31
3	4.6	3.6	4.2	1.6	3.8	0.15	0.02	0.10	0.03	4.10	93	0.30	0.55	4.0	0.53	23.4	4.5	1.23
4	4.6	3.7	3.8	1.5	2.8	0.10	0.02	0.10	0.04	3.06	93	0.35	0.60	2.1	0.36	38.4	6.0	1.18
5	4.4	3.6	4.3	2.1	3.6	0.12	0.02	0.14	0.04	3.92	93	0.26	0.70	3.3	0.71	58.4	7.0	1.24
6	4.4	3.7	3.8	1.0	3.1	0.08	0.01	0.07	0.03	3.29	95	0.30	0.55	1.9	0.53	40.0	3.5	1.01
7	4.5	3.7	4.5	1.8	3.0	0.11	0.02	0.11	0.03	3.27	93	0.24	0.50	5.9	0.53	16.8	3.0	1.04
8	4.3	3.6	3.6	1.2	3.7	0.11	0.02	0.09	0.03	3.95	94	0.26	0.55	3.9	0.71	39.0	5.0	1.17
9	4.5	3.6	3.6	1.5	2.6	0.12	0.02	0.07	0.03	2.84	93	0.23	0.60	2.8	0.53	44.0	6.0	1.36
10	4.6	3.7	3.5	1.5	2.3	0.14	0.02	0.07	0.03	2.56	91	0.28	0.60	2.6	0.35	50.4	6.0	1.27
11	4.7	3.8	3.4	4.8	2.0	0.18	0.02	0.11	0.05	2.36	87	0.23	0.60	2.2	4.94	60.0	8.0	0.99
12	4.5	3.8	3.9	1.4	2.5	0.08	0.02	0.07	0.03	2.70	94	0.24	0.75	1.9	0.36	51.6	8.0	1.20
13	4.8	3.7	3.3	1.2	2.9	0.08	0.01	0.06	0.07	3.12	95	0.25	0.50	2.4	0.71	24.4	5.0	1.01
14	4.8	3.6	2.8	1.7	2.5	0.09	0.01	0.05	0.03	2.68	94	0.30	0.50	3.6	0.53	39.0	7.0	1.31
15	4.6	3.9	4.8	1.0	2.6	0.09	0.02	0.10	0.03	2.84	93	0.17	0.50	2.8	0.71	41.2	4.5	1.36
16	4.4	3.8	4.1	1.1	2.9	0.09	0.03	0.10	0.03	3.15	93	0.23	0.45	2.6	0.90	66.8	4.5	1.36
17	4.7	3.7	3.5	1.7	2.7	0.08	0.01	0.08	0.03	2.90	94	0.22	0.45	2.8	0.53	26.8	6.0	1.29
18	4.7	3.7	3.9	1.1	2.8	0.07	0.01	0.06	0.04	2.98	95	0.28	0.40	1.5	0.53	49.6	5.0	1.40

Table A3-2. Preliminary description of analytical results from Table A3-1.

Variable	No. of samples	Mean	S.D.	Preliminary description[a]
pH H_2O	18	4.58888889	0.15296631	L
pH KCl	18	3.71111111	0.09633818	L
OM	18	3.77777778	0.77955912	M
P	18	1.63333333	0.84575062	VL
Al	18	2.83333333	0.62778790	H
Ca	18	0.10277778	0.02986352	VL
Mg	18	0.01722222	0.00574513	VL
K	18	0.08000000	0.02970443	VL
Na	18	0.03500000	0.01043185	L
CEC	18	3.06833333	0.63078149	VL
% Al S	18	93.22222222	2.28950433	T
B	18	0.26222222	0.04236474	L
Zn	18	0.54166667	0.09275204	VL
Mn	18	2.80000000	1.05160941	VL
Cu	18	0.79722222	1.04454778	M
Fe	18	39.42222222	15.12222967	T
S	18	5.47222222	1.39823652	M
Mo	18	1.20944444	0.13798859	M

a. T = toxic (Fe under poorly drained conditions), VL = very low, L = low, M = moderate, H = high.

Table A3-3. Correlation coefficients of analytical data in Table A3-1 (prob >IRI under HO:RHO = 0;N = 18).

pH H_2O

pH H_2O	K	CEC	Mg	Al	Zn	OM	Fe	Na	Mn	pH KCl	P	S	Cu	Ca	B	% Al S	Mo
1.00000	-0.51784	-0.50621	-0.50573	-0.47983	-0.42151	-0.39190	-0.39049	-0.36863	-0.28889	-0.24837	-0.21219	-0.17724	-0.12865	-0.12162	0.11296	-0.09331	-0.05605
0.0000	0.0277	0.0321	0.0323	0.0439	0.0815	0.1077	0.1091	0.1322	0.2450	0.3203	0.3979	0.4817	0.6109	0.6307	0.6554	0.7127	0.8252

pH KCl

pH KCl	CEC	Al	B	Mn	%Al S	Mg	Zn	pH H_2O	Cu	Ca	Mo	OM	Fe	P	K	S	Na
1.00000	-0.63468	-0.62896	-0.45320	-0.42386	-0.35855	0.27161	-0.25235	0.24837	0.21836	-0.17493	-0.16766	-0.12967	-0.10884	0.06738	-0.06167	-0.04124	0.00000
0.0000	0.0047	0.0052	0.0589	0.0796	0.1440	0.2756	0.3124	0.3203	0.3840	0.4875	0.5061	0.6081	0.6673	0.7905	0.8079	0.8709	1.0000

OM

OM	Al	CIC	% Al S	PH H_2O	MO	S	Zn	Mn	K	Na	pH KCl	P	Cu	Ca	Mg	B	Fe
1.00000	0.69754	0.69746	0.48412	-0.39190	0.35423	-0.29741	0.27389	0.24755	0.18036	-0.14467	-0.12967	-0.10141	-0.07283	-0.07047	-0.05108	-0.03048	-0.02820
0.0000	0.0013	0.0013	0.0418	0.1077	0.1492	0.2307	0.2114	0.3220	0.4739	0.5668	0.6081	0.6889	0.7740	0.7811	0.8405	0.9044	0.9116

P

P	Cu	Ca	% Al S	S	MO	Na	K	Zn	Al	Fe	pH H_2O	CEC	Mg	OM	B	pH KCl	Mn
1.0000	0.91160	0.70180	-0.66023	0.53307	-0.37181	0.29336	0.29268	0.26245	-0.25703	0.23322	0.21219	-0.20299	0.10492	-0.10141	-0.09905	-0.06738	0.02381
0.0000	0.0001	0.0012	0.0029	0.0227	0.1287	0.2374	0.2385	0.2927	0.3032	0.3517	0.3979	0.4192	0.6786	0.6889	0.6958	0.7905	0.9253

Al

Al	CEC	OM	% Al S	pH KCl	pH H_2O	Mn	S	B	Cu	P	Zn	Fe	MO	K	Mg	Ca	Na
1.0000	0.99585	0.69754	0.64936	-0.62896	-0.47983	0.39115	-0.34735	0.30669	-0.26771	-0.25703	0.21215	-0.20332	0.20258	0.13564	-0.11960	-0.07739	-0.06287
0.0000	0.0001	0.0013	0.0035	0.0052	0.0439	0.1085	0.1579	0.2158	0.2828	0.3032	0.3980	0.4184	0.4201	0.5915	0.6364	0.7602	0.8043

Ca

Ca	% Al S	P	Cu	K	Mg	Zn	S	Mn	Fe	MO	pH KCl	pH H_2O	Na	Al	OM	B	CEC
1.00000	-0.74945	0.70180	0.62916	0.53712	0.45904	0.35925	0.31892	0.29595	0.27365	-0.24370	-0.17493	-0.12162	0.08497	-0.07739	-0.07047	-0.07026	0.00120
0.0000	0.0003	0.0012	0.0052	0.0215	0.0553	0.1431	0.1971	0.2331	0.2719	0.3298	0.4875	0.6307	0.7375	0.7602	0.7811	0.7818	0.9962

Mg

Mg	K	% Al S	pH H_2O	Fe	Ca	B	pH KCl	Na	Zn	Mn	Cu	Al	P	CEC	S	MO	OM
1.00000	0.58597	-0.53168	-0.50573	0.46522	0.45904	-0.31150	0.27161	-0.24537	0.22998	0.20446	0.14959	-0.11960	0.10492	-0.06466	0.06306	0.05730	0.05108
0.0000	0.0106	0.0232	0.0323	0.0517	0.0553	0.2083	0.2756	0.3264	0.3586	0.4157	0.5535	0.6364	0.6786	0.7988	0.8037	0.8213	0.8405

K

K	Mg	Ca	pH H_2O	% Al S	Fe	Mn	B	Zn	Cu	P	CEC	OM	Al	Mo	S	Na	pH KCl
1.00000	0.58597	0.53712	-0.51784	-0.47572	0.42874	0.40863	-0.32721	0.29891	0.29859	0.29268	0.21411	0.18036	0.13564	-0.13203	0.11330	0.07593	-0.06167
0.0000	0.0106	0.0215	0.0277	0.0460	0.0758	0.0922	0.1850	0.2282	0.2288	0.2385	0.3936	0.4739	0.5915	0.6015	0.6544	0.7646	0.8079

Na

Na	Mo	Cu	pH H_2O	P	Mg	Mn	S	OM	% Al S	Ca	K	Al	CEC	Fe	Zn	B	pH KCl
1.00000	-0.42703	0.38571	0.36863	0.29336	-0.24537	-0.23057	0.19156	-0.14467	-0.09852	0.08497	0.07593	-0.06287	-0.04067	0.03431	0.01520	-0.01331	0.00000
0.0000	0.0772	0.1139	0.1322	0.2374	0.3264	0.3573	0.4464	0.5668	0.6973	0.7375	0.7646	0.8043	0.8727	0.8925	0.9523	0.9582	1.0000

Continued

Table A3-3 Continued.

CEC

CEC	Al	OM	pH KCl	% Al S	pH H_2O	Mn	S	B	Zn	Cu	K	P	Mo	Fe	Mg	Na	Ca
1.00000	0.99585	0.69746	-0.63468	0.58192	-0.50621	0.42060	-0.32152	0.28345	0.24457	-0.21485	0.21411	-0.20299	0.17732	-0.16440	-0.06466	-0.04067	0.00120
0.0000	0.0001	0.0013	0.0047	0.0113	0.0321	0.0822	0.1932	0.2544	0.3280	0.3919	0.3936	0.4192	0.4815	0.5145	0.7988	0.8727	0.9962

% Al S

% Al S	Ca	P	Al	Cu	CEC	Mg	OM	K	S	Fe	pH KCl	Mo	B	Na	pH H_2O	Zn	Mn
1.00000	-0.74945	-0.66023	0.64936	-0.64663	0.58192	-0.53168	0.48412	-0.47572	-0.39302	-0.39126	-0.35855	0.35791	0.30997	-0.09852	-0.09331	-0.07387	0.00733
0.0000	0.0003	0.0029	0.0035	0.0037	0.0113	0.0232	0.0418	0.0460	0.1066	0.1084	0.1440	0.1448	0.2106	0.6973	0.7127	0.7708	0.9770

B

B	pH KCl	K	Mg	% Al S	Al	CEC	Cu	Fe	Mn	pH H_2O	Zn	P	Mo	Ca	S	OM	Na
1.00000	-0.45320	-0.32721	-0.31150	0.30997	0.30669	0.28345	-0.24936	-0.24028	-0.12543	0.11296	0.10230	-0.09905	-0.08430	-0.07026	-0.05848	-0.03048	-0.01331
0.0000	0.0589	0.1850	0.2083	0.2106	0.2158	0.2544	0.3183	0.3389	0.6199	0.6545	0.6863	0.6958	0.7395	0.7818	0.8177	0.9044	0.9582

Zn

Zn	S	pH H_2O	Ca	Fe	K	OM	P	pH KCl	CEC	Mg	Al	Cu	B	Mo	% Al S	Na	Mn
1.00000	0.56508	-0.42151	0.35925	0.33984	0.29891	0.27389	0.26245	-0.25235	0.24457	0.22998	0.21215	0.12543	0.10230	-0.09001	-0.07387	0.01520	0.00603
0.0000	0.0145	0.0815	0.1431	0.1677	0.2282	0.2714	0.2927	0.3124	0.3280	0.3586	0.3980	0.6200	0.6863	0.7225	0.7708	0.9523	0.9811

Mn

Mn	pH KCl	CEC	K	Al	Fe	S	Ca	pH H_2O	OM	Na	Mg	B	Cu	Mo	P	% Al S	Zn
1.00000	-0.42386	0.42060	0.40863	0.39115	-0.33897	-0.31604	0.29595	-0.28889	0.24755	-0.23057	0.20446	-0.12543	-0.10849	-0.08067	0.02381	0.00733	0.00603
0.0000	0.0796	0.0822	0.0922	0.1085	0.1588	0.2014	0.2331	0.2450	0.3220	0.3573	0.4157	0.6199	0.6683	0.7503	0.9253	0.9770	0.9811

Cu

Cu	P	% Al S	Ca	S	Na	Fe	Mo	K	Al	B	pH KCl	CEC	Mg	pH H_2O	Zn	Mn	OM
1.00000	0.91160	-0.64663	0.62916	0.41015	0.38571	0.37432	-0.36646	0.29859	-0.26771	-0.24936	0.21836	-0.21485	0.14959	0.12865	0.12543	-0.10849	-0.07283
0.0000	0.0001	0.0037	0.0052	0.0909	0.1139	0.1259	0.1347	0.2288	0.2828	0.3183	0.3840	0.3919	0.5535	0.6109	0.6200	0.6683	0.7740

Fe

Fe	S	Mg	K	% Al S	pH H_2O	Cu	Zn	Mn	Ca	Mo	B	P	Al	CEC	pH KCl	Na	OM
1.00000	0.52054	0.46522	0.42874	-0.39126	-0.39049	0.37432	0.33984	-0.33897	0.27365	0.25749	-0.24028	0.23322	-0.20332	-0.16440	0.10884	0.03431	-0.02820
0.0000	0.0268	0.0517	0.0758	0.1084	0.1091	0.1259	0.1677	0.1698	0.2719	0.3023	0.3369	0.3517	0.4184	0.5145	0.6673	0.8925	0.9116

S

S	Zn	P	Fe	Cu	% Al S	Al	CEC	Ca	Mn	OM	Na	pH H_2O	K	Mo	Mg	B	pH KCl
1.00000	0.56508	0.53307	0.52054	0.41015	-0.39302	-0.34735	-0.32152	0.31892	-0.31604	-0.29741	0.19156	0.17724	0.11330	0.08071	0.06306	-0.05848	-0.04124
0.0000	0.0145	0.0227	0.0268	0.0909	0.1066	0.1579	0.1932	0.1971	0.2014	0.2307	0.4464	0.4817	0.6544	0.7502	0.8037	0.8177	0.8709

Mo

Mo	Na	P	Cu	% Al S	OM	Fe	Ca	Al	CEC	pH KCl	K	Zn	B	S	Mn	Mg	pH H_2O
1.00000	-0.42703	-0.37181	-0.36646	0.35791	0.35423	0.25749	-0.24370	0.20258	0.17732	-0.16766	-0.13203	-0.09001	-0.08430	0.08071	-0.08067	0.05730	-0.05605
0.0000	0.0772	0.1287	0.1347	0.1448	0.1492	0.3023	0.3298	0.4201	0.4815	0.5061	0.6015	0.7225	0.7395	0.7502	0.7503	0.8213	0.8252