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CHARACTERIZATION OF PHYSICAL AND CHEMICAL PROPERTIES OF VARZEA SOILS OF GOIAS STATE OF BRAZIL

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ABSTRACT: Brazil has approximately 30 million hectares of lowland areas, known locally as "Varzea," distributed throughout the country. Soils in these areas have the potential to support agricultural production, but very little is known about their fertility. The current experiment was undertaken to characterize the chemical and physical properties of representative "Varzea" soils collected at 0-20, 20-40, 40-60, and 60-80 cm depth intervals from 23 sites in Goias State of Brazil. Organic matter contents averaged 42 g/kg in the surface 20 cm of soil and should make a significant contribution to overall nutrient availability. Soil pH increased slightly with depth from a mean value of 5.2 in the surface 20 cm of soil to a mean value of 5.4 in the 60-80 cm depth interval. Several soils had exchangeable Al values $\geq$ 1.0 cmol Al/kg, but soil Al saturation was generally less than the 60% level frequently associated with Al toxicity. However, cereal and legume production could benefit from lime addition in many of these soils. Although base saturation was fairly low in some soils, exchangeable Ca and Mg levels were, in general, adequate throughout the profile. Extractable P levels were adequate in most surface soil samples. Extractable K levels in these soils were generally low, and the application of K fertilizers should be beneficial, especially in conjunction with lime addition. The high clay content "Varzea" soils of the Brazilian lowlands have some drainage problems but generally exhibit favorable chemical properties for crop production when compared to soils of the well-drained Cerrados.

INTRODUCTION

In Brazil, there are about 30 million hectares of lowlands, known locally as "Varzea" (1). These areas are distributed throughout the country and generally have favorable climatic conditions for crop production. Due to poor drainage, lowland rice is a suitable crop to plant on these soils during the rainy season. At present, only 1.3 million hectares of the "Varzea" land is under rice cultivation. During dry periods, other crops can be planted in rotation, provided there is adequate drainage.

Soils of the "Varzea" generally have good initial soil fertility; but within two to three years after the start of cultivation, fertility declines. Characterization of the chemical and physical properties of soils can provide useful information about their agronomic behavior. Little information is available concerning the chemical and physical properties of "Varzea" soils. This study was undertaken to characterize the chemical and physical properties of representative "Varzea" soils in the state of Goias, Brazil. The information obtained in this study can be used to develop sound agronomic management practices for these soils.

MATERIALS AND METHODS

Soil samples were collected from 23 different locations covering 15 municipalities in Goias State of central Brazil. Most of the sampling areas were under rice cultivation in the previous year, except numbers 7, 8, 11, 17, and 23 were under natural pasture, and numbers 12, 16, and 21 were under natural vegetation and never used for cultivation. Exact information about the taxonomy of these soils is not available, but most of the soils would be classified as low humic gleys (1).

Soil samples were collected at 0-20, 20-40, 40-60, and 60-80 cm depths. After collection, samples were air-dried and ground to pass a 2-mm sieve.

Particle size analysis was carried out by the pipette method (2). Organic matter was determined by dichromate oxidation (Walkley-Black), and cation exchange capacity by extraction with 1 M NH_4OAc buffered at pH 7. The pH was measured in a 1:2.5 soil-water suspension. Phosphorus and K were extracted by the Mehlich 1 extractant (0.05 M HCl + 0.0125 M H_2SO_4). Phosphorus was determined colorimetrically (3), and K by flame photometry. Calcium, Mg, and Al were extracted with 1 M KCl. Aluminum was determined by titration with NaOH (4), and Ca and Mg by titration with EDTA (5). A detailed description of soil chemical analysis methods, which are commonly used in all soil analysis laboratories in Brazil, can be found elsewhere (2,6).

Mean, standard deviation (SD) and minimum and maximum values were calculated for each soil physical and chemical property at each of the four soil depths. Simple correlation coefficients (r) among soil properties at each soil depth were determined.

RESULTS AND DISCUSSION

The chemical and physical properties of soil samples from the 23 locations are given by depth interval in Tables 1-4. The soils, in general, had a heavy texture, with clay contents ranging from 120 to 715 g/kg across all soils and depths. Mean clay contents across all soils were essentially constant with depth and ranged from 422 to 438 g/kg over the four depth intervals. The data in Tables 1-4 were used to make the following observations concerning properties of "Varzea" soils.

Organic Matter: Soil organic matter is a major component of biogeochemical cycles of the major nutrient elements, and the quantity and quality of soil organic matter both reflect and control crop productivity (7). Organic matter content in the soils under study varied from 7 to 135 g/kg in the top 0-20 cm soil layer, 5 to 115 g/kg in the 20-40 cm soil depth, 5 to 135 g/kg in the 40-60 cm soil depth, and 5 to 90 g/kg in the 60-80 cm soil depth, respectively. This means there is great variability in organic matter content of "Varzea" soils. Vitorello et al. (8) also reported a great variation in organic matter content of forest and cultivated acid soils of Brazil.

Cochrane et al. (9) reported organic matter levels in soils from the lowlands of tropical America. These authors classified soils as high, medium, and low in organic matter if they contained > 45 g/kg, 45-15 g/kg, and < 15 g/kg, respectively. According to this classification, 61% of the "Varzea" soils had high organic matter contents in the surface 20 cm, 26% had medium organic matter contents, and only 13% of the soils were low in organic matter.

Correlation coefficients relating soil properties by depth interval are given in Tables 5-8. Organic matter was strongly correlated ($P < 0.01$) with CEC and total acidity (data not shown) in all depth intervals. These results suggest that the more acidic soils had a higher organic matter content. This may prove to be beneficial,

TABLE 1. Chemical and Physical Properties of Varzea Soils (0-20 cm depth)

No.	Municipality	O.M.	pH	P	K	Ca	Mg	Na	Al	Al[a] Sat	Ca/Mg	Ca/K	Mg/K	Sand	Silt	Clay
		g/kg	H_2O	---mg/kg--		--------cmol/kg---------				%				------g/kg-----		
1	Goiania	36	5.4	36.7	49	4.0	2.4	0.9	0.5	6	1.7	30.8	18.5	348	245	405
2	Goianira	23	5.1	20.4	43	3.0	2.2	0.6	1.1	16	1.4	27.3	20.0	467	195	335
3	Formoso do Araguaia	45	5.7	12.0	62	3.2	2.5	0.6	0.1	2	1.3	21.3	16.7	400	235	365
4	Itumbiara	135	3.3	12.3	39	6.5	1.4	48.0	14.0	20	4.6	65.0	14.0	55	355	590
5	Guapo	22	5.9	8.0	72	3.7	1.0	1.3	0.2	3	3.7	20.6	5.6	520	225	250
6	Parauna	85	5.1	18.8	175	4.8	3.7	0.7	0.9	9	1.3	10.7	8.2	100	210	690
7	Varjao	34	5.0	2.4	35	1.1	0.4	0.8	2.3	49	2.8	12.2	4.4	358	245	390
8	Nova Gloria	23	5.1	3.0	19	4.6	2.8	1.2	0.3	3	1.6	92.0	56.0	598	175	190
9	Goiania	13	4.8	58.4	66	4.9	2.7	0.9	0.8	8	1.8	28.8	15.9	505	205	280
10	Uruana	66	4.4	4.9	43	0.2	0.7	0.4	2.0	59	0.3	1.8	6.4	502	245	220
11	Panama	60	5.5	24.4	172	6.7	2.9	0.9	0.8	7	2.3	15.2	6.6	180	215	575
12	Panama	30	5.3	6.8	31	3.9	2.4	0.8	1.6	18	1.6	55.7	34.3	231	182	580
13	Cachoeira Dourada	37	5.7	23.1	235	10.5	4.9	3.4	0.2	1	2.1	17.5	8.1	196	297	505
14	Cachoeira Dourada	37	5.5	2.8	84	2.8	2.1	0.6	0.3	5	1.3	12.7	9.6	190	265	545
15	Itumbiara	9	5.1	25.4	261	8.9	3.0	0.6	0.2	1	3.0	13.3	4.5	312	265	420
16	Itumbiara	25	5.6	17.9	179	10.9	3.8	1.2	0.3	2	2.9	23.7	8.3	250	334	400
17	Itumbiara	18	5.3	4.7	39	4.5	1.2	0.8	2.4	27	3.8	45.0	12.0	146	200	650
18	Acreuna	37	5.9	16.6	113	9.6	7.1	1.4	0.2	1	1.4	33.1	24.5	181	249	570
19	Acreuna	61	5.5	34.7	109	8.4	5.6	0.6	0.5	3	1.5	30.0	20.0	87	319	594
20	Montividiv	44	5.0	4.2	47	1.6	1.6	0.2	2.0	36	1.0	13.3	13.3	418	141	441
21	Rio Verde	29	5.0	0.9	16	0.5	0.8	0.1	1.9	57	0.6	12.5	20.0	587	37	377
22	Rio Verde	64	5.8	9.3	58	4.4	4.1	0.3	0.2	2	1.1	29.3	27.3	648	192	160
23	Alvorada	7	4.9	2.1	17	0.4	0.8	0.1	0.9	40	0.5	10.0	20.0	764	40	175
Min.		7	3.3	0.9	16	0.2	0.4	0.1	0.1	1	0.3	1.8	4.4	55	37	160
Max.		135	5.9	58.4	261	10.9	7.1	48.0	14.0	59	4.6	92.0	56.0	764	355	690
Mean		42	5.2	15.2	85	4.7	2.6	2.9	1.5	16	1.9	27.0	16.2	350	220	422
SD		28	0.6	14.1	71	3.2	1.7	9.9	2.8	19	1.1	20.7	11.7	199	77	160

[a]Al sat. = (Al/Ca+Mg+K+Na+Al)100

TABLE 2. Chemical and Physical Properties of Varzea Soils (20-40 cm depth).

No.	Municipality	O.M.	pH	P	K	Ca	Mg	Na	Al	Al[a] Sat	Ca/Mg	Ca/K	Mg/K	Sand	Silt	Clay
		g/kg	H_2O	---mg/kg--		--------cmol/kg----------				%				------g/kg------		
1	Goiania	9	6.3	14.1	25	4.6	4.1	1.3	0.1	1	1.1	76.7	68.3	450	180	370
2	Goianira	20	5.3	16.8	29	2.8	2.1	0.6	1.2	18	1.3	40.0	30.0	459	160	365
3	Formoso do Araguaia	18	3.9	4.0	20	1.8	2.1	0.4	0.1	2	0.9	36.0	42.0	459	200	325
4	Itumbiara	115	3.6	3.8	33	3.5	0.9	26.0	5.5	15	3.9	43.8	11.3	52	358	590
5	Guapo	11	6.3	5.6	68	3.9	2.1	1.2	0.1	1	1.9	22.9	12.4	419	260	310
6	Parauna	24	5.4	4.7	101	4.9	5.5	1.0	0.9	7	0.9	18.9	21.2	100	185	715
7	Varjao	13	5.2	1.7	23	0.7	0.4	0.5	2.2	57	1.8	11.7	6.7	499	160	341
8	Nova Gloria	16	5.2	1.7	12	4.0	2.9	0.6	0.2	3	1.4	133.3	96.7	660	166	145
9	Goiania	12	4.9	69.6	39	3.8	2.4	0.8	1.0	12	1.6	38.0	24.0	554	200	245
10	Uruana	21	4.4	3.3	25	0.2	0.8	0.2	1.7	57	0.3	2.9	11.4	563	165	265
11	Panama	55	5.6	13.8	70	6.0	3.4	0.9	1.4	12	1.8	35.3	20.0	181	220	590
12	Panama	23	5.4	6.4	31	5.2	3.5	0.6	1.4	13	1.5	74.3	50.0	232	155	590
13	Cachoeira Dourada	29	5.6	12.0	78	7.5	2.9	2.5	0.2	2	2.6	37.5	14.5	200	284	515
14	Cachoeira Dourada	41	5.7	3.3	41	2.2	1.8	0.7	0.6	11	1.2	20.0	16.4	200	252	547
15	Itumbiara	36	5.3	22.1	199	8.4	2.9	0.6	0.2	2	2.9	16.5	5.7	272	275	435
16	Itumbiara	18	5.9	15.6	144	13.3	4.9	1.3	0.2	1	2.7	36.0	13.2	234	362	410
17	Itumbiara	10	5.7	1.4	14	5.0	2.4	0.6	0.7	8	2.1	125.0	60.0	120	254	676
18	Acreuna	21	5.9	11.7	97	7.6	7.1	1.1	0.2	1	1.1	30.4	28.4	213	217	570
19	Acreuna	46	5.7	23.7	74	8.5	7.4	0.6	0.4	2	1.2	44.7	39.0	73	338	589
20	Montividiv	26	4.9	1.7	27	0.9	0.9	0.1	2.6	57	1.0	12.9	12.9	451	142	407
21	Rio Verde	20	5.1	0.2	12	0.5	0.2	0.1	1.3	62	2.5	16.7	6.7	571	47	382
22	Rio Verde	37	5.7	4.7	23	1.7	1.9	0.1	0.3	7	0.9	28.3	31.7	612	240	140
23	Alvorada	5	4.9	1.7	14	0.4	0.9	0.1	1.0	41	0.4	10.0	22.5	713	46	230
Min.		5	3.6	0.2	12	0.2	0.2	0.1	0.1	1	0.3	2.9	5.7	52	46	140
Max.		115	6.3	69.6	199	13.3	7.4	26.0	5.5	62	3.9	133.3	96.7	713	362	715
Mean		27	5.3	10.2	52	4.2	2.8	1.8	1.0	17	1.6	39.6	28.0	356	212	424
SD		24	0.7	12.8	47	3.2	2.0	5.3	1.2	21	0.9	33.6	22.7	201	83	164

[a]Al sat. = (Al/Ca+Mg+K+Na+Al) 100

TABLE 3. Chemical and Physical Properties of Varzea Soils (40-60 cm depth).

No.	Municipality	O.M.	pH	P	K	Ca	Mg	Na	Al	Al[a] Sat	Ca/Mg	Ca/K	Mg/K	Sand	Silt	Clay
		g/kg	H_2O	---mg/kg--		--------cmol/kg----------				%				------g/kg------		
1	Goiania	5	6.5	11.3	19	4.2	3.8	1.1	0.0	0	1.1	84.0	76.0	537	130	315
2	Goianira	7	5.2	14.3	29	2.5	2.5	0.6	1.3	19	1.0	35.7	35.7	472	156	370
3	Formoso do Araguaia	10	5.5	1.3	8	2.5	3.0	0.4	0.1	2	0.8	125.0	150.0	392	195	400
4	Itumbiara	80	3.6	5.2	47	3.3	2.0	36.0	6.0	13	1.7	27.5	16.7	36	364	600
5	Guapo	13	6.1	4.0	66	2.7	1.5	1.1	0.1	2	1.8	15.9	8.8	457	212	320
6	Parauna	20	5.5	4.1	94	5.7	6.4	0.7	0.6	4	0.9	23.8	26.7	130	155	715
7	Varjao	8	5.2	1.4	23	0.8	0.8	0.5	2.2	50	1.0	13.3	13.3	474	151	366
8	Nova Gloria	10	5.5	1.8	8	3.4	2.1	0.5	0.2	3	1.6	170.0	105.0	698	145	125
9	Goiania	14	5.0	64.8	35	3.9	3.0	0.7	0.8	9	1.3	43.3	33.3	596	120	270
10	Uruana	11	4.2	1.8	17	0.2	0.7	0.2	2.1	65	0.3	4.0	14.0	599	140	245
11	Panama	135	5.4	9.8	78	6.6	3.8	1.1	1.7	13	1.7	33.0	19.0	241	245	505
12	Panama	19	5.8	4.1	43	6.0	5.0	0.6	0.5	4	1.2	54.6	45.5	143	285	540
13	Cachoeira Dourada	21	5.9	4.8	94	6.8	4.7	4.0	0.1	1	1.5	28.3	19.6	200	285	515
14	Cachoeira Dourada	30	5.4	2.8	43	2.8	2.1	0.5	1.0	14	1.3	25.5	19.1	161	260	579
15	Itumbiara	16	5.3	18.6	187	7.7	3.2	0.8	0.2	2	2.4	16.0	6.7	239	230	520
16	Itumbiara	14	6.0	14.0	136	15.5	6.4	1.4	0.1	0	2.4	44.3	18.2	231	316	440
17	Itumbiara	9	5.8	3.0	10	5.1	2.8	0.6	0.4	5	1.8	170.0	93.3	130	235	640
18	Acreuna	16	6.1	18.0	105	9.9	9.7	1.1	0.2	1	1.0	36.7	35.9	192	228	580
19	Acreuna	41	5.8	21.9	97	8.6	6.5	0.3	0.3	2	1.3	34.4	26.0	89	303	608
20	Montividiv	22	5.0	1.3	23	0.7	1.2	0.1	2.5	53	0.6	2.9	5.0	449	123	428
21	Rio Verde	16	5.1	0.2	8	0.2	0.6	0.1	1.3	60	0.3	10.0	30.0	541	57	402
22	Rio Verde	30	5.8	4.2	19	1.5	1.5	0.1	0.2	6	1.0	30.0	30.0	640	240	120
23	Alvorada	6	4.9	1.0	12	0.6	0.8	0.1	1.2	44	0.8	20.0	26.7	606	50	340
Min.		5	3.6	0.2	8	0.2	0.6	0.1	0.0	0	0.3	2.9	5.0	36	50	120
Max.		135	6.5	64.8	187	15.5	9.7	36.0	6.0	65	2.4	170.0	150.0	698	364	715
Mean		24	5.4	9.3	55	4.4	3.2	2.3	1.0	16	1.3	45.6	37.2	359	201	432
SD		29	0.6	13.7	47	3.7	2.3	7.4	1.3	22	0.6	47.3	35.8	207	82	159

[a]Al sat. = (Al/Ca+Mg+K+Na+Al) 100

TABLE 4. Chemical and Physical Properties of Varzea Soils (60-80 cm depth).

No.	Municipality	O.M.	pH	P	K	Ca	Mg	Na	Al	Al[a] Sat	Ca/Mg	Ca/K	Mg/K	Sand	Silt	Clay
		g/kg	H_2O	---mg/kg--		---------cmol/kg----------				%				------g/kg------		
1	Goiania	7	6.4	16.9	23	3.8	4.2	1.1	0.0	0	0.9	63.3	70.0	604	105	280
2	Goianira	7	5.1	13.1	27	3.6	4.7	0.6	0.9	9	0.8	51.4	67.1	483	152	365
3	Formoso do Araguaia	8	4.9	0.9	6	2.7	2.2	0.4	0.1	2	1.2	135.0	110.0	344	190	460
4	Itumbiara	90	3.8	2.4	43	3.5	1.0	34.0	4.3	10	3.1	31.8	9.1	35	360	605
5	Guapo	5	6.1	5.5	66	2.4	1.4	1.0	0.1	2	1.7	14.1	8.2	516	176	296
6	Parauna	20	5.5	4.7	97	6.9	6.7	1.0	0.6	4	1.0	27.6	26.8	110	185	705
7	Varjao	7	5.3	1.2	27	1.1	1.2	0.5	1.9	40	0.9	15.7	17.1	491	130	374
8	Nova Gloria	12	5.7	1.4	8	3.2	2.6	0.5	0.2	3	1.2	160.0	130.0	683	145	145
9	Goiania	9	5.1	114.3	29	4.6	4.2	0.8	0.8	8	1.1	65.7	60.0	579	130	265
10	Uruana	9	4.3	1.7	17	0.2	1.0	0.2	2.1	59	0.2	4.0	20.0	603	145	245
11	Panama	90	5.4	14.8	58	6.8	4.8	0.8	1.5	11	1.4	48.6	34.3	202	245	545
12	Panama	19	5.9	4.5	47	6.7	5.4	0.7	0.3	2	1.2	55.8	45.0	190	273	540
13	Cachoeira Dourada	17	5.8	4.1	90	6.5	5.2	3.5	0.1	1	1.3	28.3	22.6	220	270	510
14	Cachoeira Dourada	19	5.5	1.4	45	2.7	2.2	0.5	0.6	10	1.2	22.5	18.3	189	237	575
15	Itumbiara	16	5.2	16.6	156	6.7	3.2	0.9	0.2	2	2.1	16.8	8.0	235	180	540
16	Itumbiara	12	6.1	13.7	148	15.9	6.6	1.4	0.1	0	2.4	41.8	17.4	218	310	445
17	Itumbiara	7	5.9	4.4	12	5.3	3.3	0.6	0.2	2	1.6	176.7	110.0	120	200	680
18	Acreuna	12	6.3	26.9	117	10.8	9.4	1.2	0.1	0	1.2	36.0	31.3	212	192	596
19	Acreuna	37	5.8	32.4	101	8.0	7.0	1.0	0.2	1	1.1	30.8	26.9	85	302	605
20	Montividiv	20	5.0	0.9	23	0.9	1.0	0.1	2.8	58	0.9	15.0	16.7	442	107	452
21	Rio Verde	13	5.2	0.1	8	0.2	0.7	0.1	0.8	44	0.3	10.0	35.0	509	63	428
22	Rio Verde	25	5.7	4.6	16	1.3	1.2	0.1	0.3	10	1.1	32.5	30.0	654	205	140
23	Alvorada	5	4.9	0.9	12	0.6	0.8	0.1	1.2	44	0.8	20.0	26.7	605	80	291
Min.		5	3.8	0.1	6	0.2	0.7	0.1	0.0	0	0.2	4.0	8.0	35	63	140
Max.		90	6.4	114.3	156	15.9	9.4	34.0	4.3	59	3.5	176.7	130.0	683	360	705
Mean		20	5.4	12.3	51	4.5	3.5	2.2	0.8	14	1.3	48.0	40.9	362	190	438
SD		23	0.6	23.9	46	3.7	2.4	7.0	1.1	20	0.7	46.8	34.7	209	77	163

[a]Al sat. = (Al/Ca+Mg+K+Na+Al) 100

TABLE 5. Simple correlation coefficients (r) among soil chemical and physical properties at 0-20 cm depth

Properties	O.M.	pH	P	K	Ca	Mg	Na	Al	Al Sat.	Ca/Mg	Ca/K	Mg/K	Sand	Silt
O.M.	1													
pH	-0.49*	1												
P	-0.08NS	0.06NS	1											
K	-0.03NS	0.31NS	0.39NS	1										
Ca	0.08NS	0.29NS	0.48*	0.76**	1									
Mg	0.05NS	0.49*	0.44*	0.55**	0.78**	1								
Na	0.71**	-0.72**	-0.03NS	-0.11NS	0.16NS	-0.13NS	1							
Al	0.72**	-0.83**	-0.14NS	-0.26NS	-0.04NS	-0.31NS	0.95*	1						
Al Sat.	0.04NS	-0.51*	-0.48*	-0.53**	-0.72**	-0.68**	-0.01NS	0.27NS	1					
Ca/Mg	0.26NS	-0.19NS	0.08NS	0.22NS	0.43*	-0.11NS	0.56**	0.51*	-0.27NS	1				
Ca/K	0.17NS	-0.20NS	-0.40NS	-0.32NS	0.20NS	0.12NS	0.41NS	0.35NS	-0.29NS	0.34NS	1			
Mg/K	-0.14NS	0.05NS	-0.14NH	-0.46*	-0.07NS	0.20NS	-0.05NS	-0.08NS	-0.15NS	-0.30NS	0.76**	1		
Sand	-0.51*	0.02NS	-0.22NS	-0.47*	-0.58**	-0.40NS	-0.35NS	-0.30NS	0.34NS	-0.47*	-0.10NS	0.32NS	1	
Silt	0.42*	-0.03NS	0.35NS	0.48*	0.66**	0.41NS	0.41NS	0.26NS	-0.50*	0.54**	0.13NS	-0.32NS	-0.69**	1
Clay	0.44*	-0.05NS	0.12NS	0.36NS	0.41NS	0.32NS	0.24NS	0.26NS	-0.19NS	0.33NS	0.05NS	-0.27NS	-0.93**	0.38NS

*,**Significant at the 5 and 1% probability levels, respectively. NS = Not significant.

TABLE 6. Simple correlation coefficients (r) among soil chemical and physical properties at 20-40 cm depth.

Properties	O.M.	pH	P	K	Ca	Mg	Na	Al	Al Sat.	Ca/Mg	Ca/K	Mg/K	Sand	Silt
O.M.	1													
pH	-0.41NS	1												
P	-0.05NS	0.09NS	1											
K	0.11NS	0.31NS	0.31NS	1										
Ca	0.10NS	0.46*	0.37NS	0.77**	1									
Mg	-0.02NS	0.50*	0.31NS	0.52*	0.76**	1								
Na	0.83**	-0.51*	-0.08NS	-0.04NS	0.01NS	-0.16NS	1							
Al	0.68**	-0.65**	-0.18NS	-0.28NS	-0.34NS	-0.45*	0.78**	1						
Al Sat.	-0.12NS	-0.39NS	-0.32NS	-0.44*	-0.67**	-0.65**	-0.08NS	0.47*	1					
Ca/Mg	0.52*	-0.09NS	0.10NS	0.40NS	0.42*	-0.11NS	0.61**	0.37NS	-0.18NS	1				
Ca/K	-0.10NS	0.18NS	-0.03NS	-0.26NS	0.22NS	0.21NS	0.04NS	-0.17NS	-0.44*	0.12NS	1			
Mg/K	-0.26NS	0.17NS	-0.05NS	-0.36NS	0.06NS	0.28NS	-0.16NS	-0.33NS	-0.41*	-0.27NS	0.85**			
Sand	-0.52*	-0.15NS	-0.03NS	-0.47*	-0.59**	-0.52**	-0.37NS	-0.18NS	0.42*	-0.45*	-0.09NS	0.15NS	1	
Silt	0.53**	0.14NS	0.24NS	0.52**	0.69**	0.43*	0.43*	0.02NS	-0.64**	0.52*	0.12NS	-0.09NS	-0.68**	1
Clay	0.38NS	0.14NS	-0.07NS	0.32NS	0.42*	0.46*	0.25NS	0.19NS	-0.25NS	0.30NS	0.09NS	-0.12NS	-0.92**	0.37NS

*,**Significant at the 5 and 1% probability levels, respectively. NS = Not significant.

TABLE 7. Simple correlation coefficients (r) among soil chemical and physical properties at 40-60 cm soil depth.

Properties	O.M.	pH	P	K	Ca	Mg	Na	Al	Al Sat.	Ca/Mg	Ca/K	Mg/K	Sand	Silt
O.M.	1													
pH	-0.26NS	1												
P	-0.01NS	0.03NS	1											
K	0.17NS	0.20NS	0.22NS	1										
Ca	0.14NS	0.47*	0.30NS	0.71**	1									
Mg	0.08NS	0.51*	0.29NS	0.56**	0.84**	1								
Na	0.43*	-0.58**	-0.06NS	0.01NS	-0.01NS	-0.07NS	1							
Al	0.46*	-0.85**	-0.15NS	-0.15NS	-0.36NS	-0.38NS	0.79**	1						
Al Sat.	-0.10NS	-0.58**	-0.28NS	-0.34NS	-0.63**	-0.62**	-0.08NS	0.46*	1					
Ca/Mg	0.24NS	0.27NS	0.22NS	0.55**	0.67**	0.29NS	0.19NS	-0.17NS	-0.67*	1				
Ca/K	-0.18NS	0.30NS	-0.06NS	-0.37NS	0.10NS	0.07NS	-0.08NS	-0.33NS	-0.44*	0.24NS	1			
Mg/K	-0.25NS	0.26NS	-0.11NS	-0.49*	-0.07NS	-0.04NS	-0.14NS	-0.34NS	-0.33NS	-0.05NS	0.89**	1		
Sand	-0.38NS	-0.07NS	0.04NS	-0.53**	-0.59**	-0.59**	-0.37NS	-0.14NS	0.44*	-0.43*	0.04NS	0.15NS	1	
Silt	0.44*	0.11NS	-0.04NS	0.44*	0.61**	0.45*	0.47*	0.11NS	-0.60**	0.63**	0.04NS	0.11NS	-0.76**	1
Clay	0:28NS	0.03NS	-0.06NS	0.47*	0.45*	0.54**	0.25NS	0.14NS	-0.25NS	0.23NS	-0.10NS	-0.16NS	-0.93**	0.47*

*,**Significant at the 5 and 1% probability levels, respectively. NS = Not significant.

TABLE 8. Simple correlation coefficients (r) among soil chemical and physical properties at 60-80 cm soil depth.

Properties	O.M.	pH	P	K	Ca	Mg	Na	Al	Al Sat.	Ca/Mg	Ca/K	Mg/K	Sand	Silt
O.M.	1													
pH	-0.36NS	1												
P	-0.05NS	0.06NS	1											
K	0.10NS	0.34NS	0.13NS	1										
Ca	0.12NS	0.50*	0.24NS	0.81**	1									
Mg	0.02NS	0.57**	0.33NS	0.65**	0.85**	1								
Na	0.65**	-0.53**	-0.08NS	0.02NS	-0.01NS	-0.17NS	1							
Al	0.56**	-0.80**	-0.13NS	-0.28NS	-0.38NS	-0.47*	0.67**	1						
Al Sat	-0.10NS	-0.54**	-0.23NS	-0.45*	-0.62**	-0.60**	-0.09NS	0.58**	1					
Ca/Mg	0.53**	-0.11NS	-0.01NS	0.44*	0.44*	0.08NS	0.73**	0.25NS	-0.49*	1				
Ca/K	0.13NS	0.19NS	0.04NS	-0.33NS	0.08NS	0.07NS	-0.08NS	-0.32NS	0.42*	0.11NS	1			
Mg/K	-0.26NS	0.16NS	0.07NS	-0.49*	-0.08NS	0.03NS	-0.21NS	-0.36NS	-0.30NS	-0.17NS	0.94**	1		
Sand	-0.48*	-0.04NS	0.09NS	-0.57**	-0.59**	-0.51*	-0.38NS	-0.06NS	0.43*	-0.55**	-0.03NS	0.23NS	1	
Silt	0.58**	0.03NS	-0.05NS	0.49*	0.59**	0.40NS	0.52*	0.07NS	-0.55**	0.72**	0.02NS	-0.22NS	-0.75**	1
Clay	0.35NS	0.04NS	-0.11NS	0.48*	0.47*	0.47*	0.24NS	0.05NS	-0.28NS	0.35NS	-0.09NS	-0.19NS	-0.95**	0.51*

*,**Significant at the 5 and 1% probability levels, respectively. NS = Not significant.

since soluble organics can partially ameliorate Al toxicity (10).

Soil pH: Soil pH measurements may be used as an initial basis for the prediction of the chemical behavior of soils, particularly in relation to nutrient availability and the presence of toxic elements. Soil pH varied from 3.3 to 5.9 in the 0-20 cm interval, 3.6 to 6.3 in the 20-40 cm interval, 3.6 to 6.5 in the 40-60 cm interval, and 3.8 to 6.4 in the 60-80 cm interval. Overall soil pH values for each depth were 5.2 for 0-20 cm depth, 5.3 for 20-40 cm, 5.4 for 40-60 cm, and 5.4 for the 60-80 cm interval. The degree of soil acidity is often described quantitatively as slightly acid (pH 6 to less than 7), moderately acid (pH 5.5 to 6.0), strongly acid (pH 5.0 to 5.5), very strongly acid (pH 4.5 to 5.0), and extremely acid (less than pH 4.5) (11). In general, the soils in this study were strongly acid, and liming should improve crop production. Soil pH was positively correlated with exchangeable Ca and Mg ($P < 0.05$) and negatively correlated ($P < 0.01$) with exchangeable Al (Tables 5-8)

Phosphorus, Potassium, Calcium, Magnesium, and Sodium: Extractable P, K, Ca, Mg, and Na values varied 65-fold, 16-fold, 55-fold, 18-fold, and 480-fold, respectively, in the 0-20 cm soil layer. Overall, P, K, Ca, and Na values were higher in the top 20 cm of soil when compared to the other three depths, but Mg content increased with increasing soil depth. Cochrane et al. (9) defined soil P levels in tropical soils in the following manner: high > 7 mg P/kg, medium 3-7 mg P/kg, and low < 3 mg P/kg. Using this scale, 61% of the surface soil samples had high P, 17% had medium P, and 22% had low P.

Cochrane et al. (9) classified K levels in tropical soils as follows: high > 117 mg K/kg, medium 59-117 mg K/kg, and low < 59 mg K/kg. By this classification, 22% of the soils had high K, 26% medium K, and 52% low K. These results suggest that K may become yield limiting in these soils after a few growing seasons.

Tropical soils have been classified in the following manner relative to exchangeable Ca: high > 4 cmol Ca/kg, medium 0.4 to 4 cmol Ca/kg, and low < 0.4 cmol Ca/kg (9). Using this scale, 52% of the soils had high levels of Ca, 44% had medium levels, and only 4% had a low Ca content. All soils had exchangeable Ca levels greater than the 0.02 cmol Ca/kg level associated with Ca deficiency in Brazilian soils (12).

Magnesium contents in tropical America soils have been classified in the following manner: high > 0.8 cmol Mg/kg, medium 0.2 to 0.8 cmol Mg/kg, and low < 0.2 cmol Mg/kg (9). According to this classification, 83% of the soil samples from the 0-20 cm depth had high levels of Mg, and 17% had medium levels. These soils had favorable Ca/Mg ratios (Tables 1-4) and would not be susceptible to Mg deficiency.

Average extractable Na values were 2.9 cmol Na/kg in the top layer, 1.8 cmol Na/kg in the 20-40 cm soil layer, 2.3 cmol Na/kg in the 40-60 cm soil layer, and 2.2 cmol Na/kg in the 60-80 cm soil layer (Tables 1-4). These average values were strongly influenced by Sample 4, which had extremely high extractable Na values. In general, Na values were relatively low in the other soils and should not pose any problems for crop production (1).

Calcium, Mg, and K cation ratios for these soils are shown in Tables 1-4. Eckert and McLean (13) have reported that, in general, there is no ideal basic cation saturation ratio for crop production. However, other investigators have attempted to use cation saturation ratios for soil test interpretation (14,15). In acid soils, the cation saturation ratios associated with sufficiency reflect concern for low levels of Ca and Mg and imbalance in the Ca/Mg ratio (16,17). A Ca/K ratio of 5 is considered to be adequate (16), while Rosalem (17) proposed a Mg/K adequacy value of 0.6 for Brazilian oxisols. The Ca/K and Mg/K ratios reported in Tables 1-4 are much higher than these baseline levels. The concern in these soils should be for K, rather than Ca and Mg, since many of these soils have rather low levels of K. Addition of lime should be coupled with application of K to avoid K deficiencies. Although the data is not shown, Zn levels in several of these soils were below the critical level of 1 mg Zn/kg established by Fageria (1). Zinc deficiencies could also result from liming these soils.

Exchangeable Aluminum and Soil Aluminum Saturation: Exchangeable Al values ranged from 0.0 to 14 cmol Al/kg across all soils and depths. Exchangeable Al decreased with soil depth. The 0-20 cm samples had a mean exchangeable Al level of 1.5 cmol Al/kg, while the mean value in the 60-80 cm depth interval was 0.8 cmol Al/kg. Lopes and Cox (18) considered exchangeable Al levels > 1 cmol Al/kg to be toxic to many crops. Approximately one-third of the soils in this study had exchangeable Al values ≥ 1 cmol Al/kg.

Cochrane (19) considered soil Al saturation to be a better predictor of Al toxicity in tropical soils than exchangeable Al. Soil Al saturation values ranged from 0 to 65% across all soils and depths. Mean soil Al saturation by depth interval increased slightly with depth. Sanchez et al. (20) suggested that soils with Al saturation ≥ 60% would be toxic to many crops. In the current study, only three subsurface samples had soil Al saturation levels ≥ 60%. While Al toxicity may not be a general problem. low base saturation levels (data not shown) in many of these soils would indicate the potential benefit of liming to cereal and legume production.

CONCLUSIONS

The high clay content "Varzea" soils of the Brazilian lowlands have some drainage problems but generally exhibit favorable chemical properties for crop production when compared to soils of the well-drained Cerrados. Organic matter contents averaged 42 g/kg in the surface 20 cm of soil and should make a significant contribution to overall nutrient availability. Soil pH increased slightly with depth from a mean value of 5.2 in the surface 20 cm of soil, to a mean value of 5.4 in the 60-80 cm depth interval. Several soils had exchangeable Al values ≥ 1.0 cmol Al/kg, but soil Al saturation was generally less than the 60% level frequently associated with Al toxicity. However, cereal and legume production could benefit from lime addition in many of these soils. Although base saturation was fairly low in some soils, exchangeable Ca and Mg levels were, in general, adequate throughout the profile. This is in marked contrast to Cerrado soils, where low levels of exchangeable Ca and Mg in the subsoil can pose Ca and Mg deficiency problems (19). Although 61% of the surface soils had high levels of extractable P, application of P would be advisable. Extractable K levels in these soils were generally low. and the application of K fertilizers should be beneficial, especially in conjunction with lime addition.

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