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X-ray Fluorescence Spectrometry of Some "Cerrado Soils" in Brazil

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Abstract More than 50 million ha of Cerrado region in Brazil is estimated to be developed as farmland. Since Cerrado soils include various soil types, a great number of soil samples should be analyzed for better land use and better soil management. In this study, 64 soil samples were analyzed by X-ray fluorecence spectrometry (XFS) and chemical analyses to estimate the elemental composition of Cerrado soils and to examine the applicability of XFS to them.

Higher concentrations of exchangeable Al were found only in the soils of pH (N-KCl) lower than 4.5. The Al concentrations increased exponentially with decreasing in soil pH. The linear correlation between soil pH (X) and exchangeable Al (Y, mg/100g dry soil) was highly significant ($\log Y=8.430-1.983X$, $r=0.982$, $n=30$) in the mineral soils.

The concentrations of skeletal elements (Si, Al, Fe and Ti) were very similar through horizons in most of the Cerrado soils. However, the elemental compositions were location-specific and did not always relate to the soil type. The analytical results indicated that the composition of skeletal elements was determined mainly by the parent materials.

Although K, Ca, Mg, P, Zn and Mn tended to accumulate in the surface horizons, the variation among horizons was much smaller than that among the sampling sites. The soils in Brasilia contained generally very low amount of these nutrient reserves. High linear correlation coefficients between total and available nutrient contents of Ca, Mn, Mg and P indicated that concentrations of these available nutrients in soils could be estimated from XFS data.
Key words; available nutrients, Cerrado, soil fertility, soil elements, X-ray fluorescence spectrometry

INTRODUCTION

One of the major constraints to limit agricultural production in the Cerrado region in Brazil is reported to be in the soils (LOPES and COX, 1977, Goedert, *et al*, 1982) ; low fertility status, Al-toxicity, low water retention capacity and so on. In order to establish a productive, stable and efficient agricultural system in this region, proper soil management on the basis of the informations of the soil properties is indispensable.

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The soil survey has been intensively undertaken in the Cerrado region. Although soil surveys attempt to provide the facts about many different soil properties, not all of which are closely related to soil management for agricultural production. Further, each soil map unit may include not only one kind of soil as defined by a classification system but most frequently includes many different kinds of soil (BOUL and COUTO, 1978).

Soil management practice, however, is site-specific. Even in the Cerrado region where dark red latosol and red yellow latosol are dominant soil types (GOEDERT *et al* 1982), the soil properties may be different from place to place. Moreover, more than 50 million ha of Cerrado region including various soil types is estimated to be developed as farmland (GOEDERT *et al*, 1980). Therefore, a great number of soil samples should be analyzed for better land use and better soil management.

In the Cerrado region, dry spell is one of the serious problem in the crop production during rainy season. This problem can be partially overcomed by amendment of the subsoils (RITCHEY *et al*, 1980). This fact indicates that properties of subsoils also should be taken into consideration. However, there is little informations available on properties of the subsoils in Cerrado region.

X-ray fluorescence spectrometry (XFS) will be useful for obtaining informations on soil properties. It is a rapid and reliable method for quantitative determination of chemical composition of soils (YAMASAKI, 1978, YAMASAKI *et al*, 1980). By applying XFS to soil, we can obtain informations on elemental composition of soils, amount of nutrient reserves and presence of toxic and valuable elements in soils. The objectives of this research are to estimate the elemental composition and the amount of nutrient reserves of some Cerrado soils by applying XFS and to examine the applicability of this method for obtaining informations on properties of Cerrado soils.

Table 1. Outlines of the soil samples and sampling sites

No.	Soil sample	parent materials	vegetation	altitude, m
1	Dark red latosol	The Tertiary sediments	Cerrado, pasture	1000
2	Red yellow latosol	The Tertiary sediments	Cerrado	1000
3	Red yellow latosol	The Tertiary sediments	grassland	1000
4	Red yellow latosol	The Tertiary sediments	grassland	1000
5	Plinthic yellow latosol	The Tertiary sediments	Cerradão	1000
6	Low humic gley soil	The Tertiary sediments	humic grassland	1000
7	Organic soil	The Quarternary sediments	grassland	950
8	Quartz sandy soil	The Tertiary/Quarternary sediments	Cerrado	1000
9	Dark red latosol	The Tertiary sediments	Cerrado	—
10	Dark red latosol	The Tertiary sediments	Cerrado, pasture	720
11	Red yellow latosol	The Tertiary sediments	Cerrado	640
12	Humic gley soil	sediments derived from basic rocks	humic grassland	720
13	Dusky red latosol	sediments derived from basic rocks	Cerrado	800
14	Dusky red latosol	sediments derived from basic rocks	Cerradão	820
15	Dusky red latosol	sediments derived from basic rocks	semi-deciduous forest	740

MATERIALS AND METHODS

Soil samples

The samples of Cerrado soils were collected from Brasilia, DF. and Goias State, Brazil at the beginning of December, 1981. The sampling sites were selected to cover the major soil types in the area. General description of each sampling site and soils is shown in Table 1. The soil samples were air-dried, passed through a 2 mm sieve, and used for XFS and chemical analysis.

X-ray Fluorescence Spectrometry (XFS)

The air dried soils were dried at 110℃ for 24 hours and grinded in a tungsten carbide container by a vibrating sample mill (Heiko TI-100) for 3 min. About 4 g of the fine powder of soil sample was then pelletised under the pressure of 300 kg/cm^2. X-ray fluorescence spectrometry of the pelltised soil samples were carried out by an automatic X-ray fluorescence spectrometer (Toshiba AFV-777). The analytical conditions are shown in Table 2.

Chemical Analysis

To obtain the calibration curves for each element, the fused soil samples were prepared for 15 representative soil samples. The fine soil powder (1.5 g) were thoroughly mixed with 5 g of solder glass (Toshiba TGF-102) and fused in a platinum dish by using a high frequency heating furnace at 1100℃ for 4 min. The fused soil samples thus prepared were dissolved into concentrated HCl and evaporated to dryness at 100℃. The residue was dissolved with conc. HCl and filtered through Toyo No. 5C filter paper. Total Si content was calculated from the silica content estimated gravimetrically by ashing the residue. Total Fe, Ti, Ca, Mg, Mn and Zn contents of the filtrates were determined by an atomic ab-

Table 2. Analytical conditions for X-ray fluorescence spectrometry

Element	Incident X-ray[1]			2θ	Detector[2]	PHA[3]		Slit[4]	crystal	Coefficient of[5] determination r^2
	Tube	kV	mA			Base	Window			
Fe	W	25	20	57.510	SC	200	400	F	LiF	0.988
Mn	W	50	40	62.960	SC	150	500	C	LiF	0.983
Ti	W	50	40	86.120	SC	200	400	F	LiF	0.947
Ca	Cr	40	35	113.200	PC	250	300	F	LiF	0.999
K	Cr	40	35	136.800	PC	200	300	F	LiF	0.994
S	Cr	40	35	110.675	PC	200	250	F	Ge-111	—
P	Cr	40	35	140.848	PC	200	200	C	Ge-111	0.999
Si	Cr	40	35	107.980	PC	150	250	C	EDDT	0.973
Al	Cr	40	35	142.504	PC	150	250	F	EDDT	0.998
Mg	Cr	40	35	136.820	PC	250	250	F	ADP	0.994
Zn	W	50	40	scan	SC	200	>200	C	LiF	0.992

1) Tube: W=tungsten, Cr=chromium, kV=tube voltage, mA=tube current
2) Detector: SC=scintillation counter, PC=proportional counter
3) PHA: pulse height analyzer
4) Slit: F=fine (0.15°), C=coarse (0.50°)
5) Multiple correlation between X-ray fluorescene intensity and element concentration determined chemically.

sorption spectrophotometer (Hitachi 208). Total K and Na contents of the filtrates were analysed by a flame photometer (Eiko FLA). Total Al content was determined by a colorimetric aluminon method (YUAN and FISKELL, 1959) with some modifications. Total P content was determined by a modified MURPHY and RILEY's (1959) colorimetric method after digestion of soils with 1 : 1 nitric acid-sulfuric acid mixture. Total organic C and N contents were determined by a CN coder (Yanaco MT500)

The pH of the soil suspension (1:2.5 H_2O or N-KCl) was measured with a glass elec-

Table 3. Properties of some Cerrado soils (Brasilia)

No.	soil	horizon	depth cm	soil colour	soil texture	pH		Exch. Al mg/100g
						H_2O	KCl	
1	dark red latosol	A_1	0- 20	5YR3/3	SL	4.92	3.90	3.9
		A_3	20- 30	5YR3/6	SL	4.85	3.84	6.3
		B_1	30- 70	2.5YR4/8	SL	4.82	4.01	3.0
		B_2	70-110+	2.5YR4/8	SL	4.71	4.11	1.9
2	red yellow latosol	A_1	0- 15	7.5YR3/2	C	5.39	4.42	0.4
		A_3	15- 40	5YR4/4	C	5.40	4.40	0.5
		B_1	40- 70	5YR4/6	C	5.08	4.85	0.2
		B_{21}	70-140	5YR5/8	C	5.20	5.75	0.5
		B_{22}	140-230	5YR5/8	C	5.45	6.30	0.7
		B_3CA	230-250+	5YR5/8	C	5.52	6.50	0.7
3	red yellow latosol	A_1	0- 15	10YR3/4	SL	4.79	3.80	9.2
		A_3	15- 30	10YR3/4	SL	4.79	3.75	10.4
		B_1	30- 60	10YR4/6	SL	5.06	3.94	4.3
		B_2	60-120+	10YR7/8	SL	5.18	3.92	4.9
4	red yellow latosol	A_1	0- 15	10YR3/3	SL	4.82	3.80	6.8
		A_3	15- 25	10YR4/4	SL	4.83	3.81	8.0
		B_1	25- 70	10YR5/8	SL	4.97	3.92	5.1
		B_2	70-120+	10YR6/8	SL	5.07	3.90	5.1
5	plinthic yellow latosol	A_1	0- 15	10YR3/1	SiCL	4.70	3.71	11.4
		A_3	15- 30	7.5YR5/8	SL	4.70	3.66	14.2
		B_1	30- 60	10YR5/2	SL	4.88	3.80	11.1
		B_2	60-100	10YR7/3	SL	4.93	3.76	10.1
6	low humic gley soil	A_1	0- 20	2.5YR3/1	SL	4.09	3.51	13.5
		A_3	20- 30	2.5Y5/1	SL	4.40	3.53	14.0
		C_1	30- 60	2.5Y7/2	SL	5.05	3.65	13.3
		C_2	60-120	2.5Y7/2	SL	4.95	3.65	12.7
7	organic soil	A_1	0- 50	N1.5	C	4.70	3.86	16.4
		C_1	50- 55	5Y4/1	C	4.59	3.72	22.4
		II A	55- 70	N1.5	C	4.30	3.61	40.6
		II C	70- 90	2.5Y8/2	C	4.86	3.55	27.1
8	quartz sandy soil	A_1	0- 20	10YR2/2	S	5.10	3.84	6.4
		A_3	20- 60	10YR4/2	S	5.09	4.00	3.1
		C_1	60-100	10YR6/3	S	4.57	4.05	1.6
		C_2	100-130	2.5Y8/2	S	5.12	4.29	0.7

trode pH meter. Exchangeable Al was extracted with N-KCl (pH 7.0) from the soils (1:2.5 N-KCl) and determined by a modified YUAN and FISKELL's (1959) colorimetric aluminon method.

Available P content was determined by Bray-P2 method (BRAY and KURTZ, 1945). Available Ca, Mg, Mn, Zn and Cu were extracted with 0.2N-HCl from the soils (1:5 0.2N-HCl, 30min-shaking) and determined by atomic absorption spectrophotometry. Available K and Na in the 0.2N-HCl extracts were determined by flame photometry.

RESULTS AND DISCUSSION

Soil Properties

Some properties of the soil samples collected from Brasilia and Goias State are shown in

Table 4. Properties of some Cerrado soils (Goiania)

No.	soil	horizon	depth cm	soil colour	soil texture	pH		Exch. Al mg/100g
						H_2O	KCl	
9	dark red latosol	A_1	0- 20	2.5YR2/2	C	5.45	4.37	0.8
		A_3	20- 40	2.5YR2/4	C	5.30	4.26	0.9
		B_1	40- 90	2.5YR3/4	C	5.40	4.89	0.1
		B_2	90-140$^+$	2.5YR3/6	C	5.47	5.72	0.0
10	dark red latosol	A_1	0- 20	5YR3/3	C	5.59	4.49	0.3
		A_3	20- 30	2.5YR3/2	C	5.42	4.31	0.8
		B_1	30- 60	2.5YR3/4	C	5.46	4.65	0.1
		B_{21}	60-100	2.5YR3/6	C	5.42	5.39	0.0
		B_{22}	100-185	2.5YR3/6	C	5.58	6.12	0.1
		IIC	185-230	2.5YR3/6	C	5.46	6.10	0.0
11	red yellow latosol	A_1	0- 20	7.5YR3/4	SL	5.65	4.55	0.1
		A_3	20- 35	7.5YR4/4	SL	5.44	4.80	0.1
		B_1	35- 85	7.5YR4/6	SL	5.70	5.84	0.0
		B_2	85-140	10YR4/6	L	6.19	6.82	0.1
12	humic gley	A_1	0- 20	2.5Y2/2	CL	6.04	4.80	0.0
		Cg_1	20- 50	5Y5/1	C	6.18	4.37	0.2
		Cg_2	50- 80	5Y4/1	C	6.85	5.12	0.0
		Cg_3	80- 90	5BG5/1	C	7.50	5.89	0.0
13	dusky red latosol	A_1	0- 20	7.5R2/3	C	5.22	4.13	2.1
		A_3	20- 40	7.5R3/3	C	5.17	4.23	1.4
		B_1	40- 80	10R2/3	C	5.34	4.42	0.8
		B_2	80-140	10R3/4	C	5.50	5.03	1.0
14	dusky red latosol	A_1	0- 20	2.5YR2/3	C	7.22	6.90	0.0
		A_3	20- 40	2.5YR2/4	C	6.40	5.40	0.0
		B_1	40- 90	2.5YR3/4	C	6.43	5.63	0.2
		B_2	90-150	2.5YR3/4	C	6.15	5.69	0.1
15	dusky red latosol	A_1	0- 20	2.5YR3/3	C	5.88	5.31	0.2
		A_3	20- 40	2.5YR3/4	C	5.20	4.16	1.0
		B_1	40-100	1R3/5	C	5.22	4.60	0.3
		B_2	100-150	1YR3/5	C	4.99	5.14	0.2

Tables 3 and 4, respectively. Soil colour, soil texture, pH and exchangeable Al content widely varied among the sampling sites, but they were very similar through horizons in each sampling site.

Most of the soils showed strong acidity, especially in A horizons. Some subsoils (No.2, 10 and 11) showed higher pH in N-KCl suspension than that in water suspension. Higher concentrations of exchangeable Al (greater than 1 mg/100 g dry soil) were found only in the soils of pH (KCl) lower than 4.5.

Strong acid soils are widely distributed in Cerrado region. Al toxicity in these acid soils is estimated as one of the major limiting factors in crop production. As shown in Tables 3 and 4, exchangeable Al concentration is negligible in the soils of pH (KCl) higher than 4.5. The Al toxicity, if any, will appear in the soils pH (KCl) lower than 4.5.

The concentrations of exchangeable Al increased exponentially with decreasing in soil pH (KCl). The linear correlation between soil pH (KCl) and logarithum of exchangeable Al concentration was highly significant, especially in the mineral soils of pH (KCl) lower than 4.5 (Fig. 1). This relationsip is valid even in the quartz sandy soil of low total Al content (Table 5).

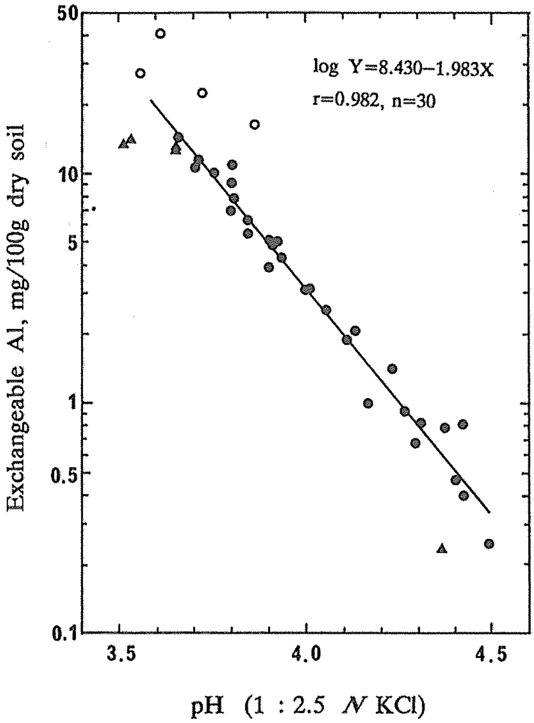

Fig. 1. Relationship between pH (X) and exchangeable Al concentration (Y) in some Cerrado soils of lower pH than 4.5. The equation for only mineral soils (●)is shown in the figure. The equation for all the soils including organic soil (○)and humic grey soil (▲) was as follows; log Y=8.542−2.012X (r=0.961, n=39).

Elemental Composition

Tables 5 and 6 show the concentrations of major mineral elements in the soils collected from Brasilia and Goias State, respectively. The determination was carried out by XFS and the elemental concentrations were estimated using the calibration curves obtained from the chemical analyses of the same soil samples. Coefficients of determination in the correlation between X-ray intensity and the value determined chemically in 15 representative soil samples are shown in Table 2. The coefficients are high enough to characterize elemental composition of soils, though precision of the determination will be improved by employing a glass beads technique (YAMASAKI *et al*, 1980).

A skeleton of mineral soil is usually composed of oxides of Si, Al, Fe and Ti. As shown in Tables 5 and 6, concentrations of skeletal elements were found to be 9.7-43.6% Si, 1.6-20.3% Al, 0.7-20.9% Fe and 0.4-3.8% Ti. The elemental composition of soil skeleton was quite location specific. Even in the soils which belong to the same soil type and found under the similar climatic and topographic conditions as No. 2 and No. 3, the elemental composition varied greatly place to place. It did not always relate to soil type.

However, the concentration of skeletal elements were found to be very similar through horizons in most of the Cerrado soils (Tables 5 and 6). This indicates that analysis of surface soils is enough to characterize soil skeleton. The exceptions were the soils No. 7 and 10. The differences in parent materials have been maintained in the composition of skeletal

Table 5. Elemental composition of some Cerrado soils (Brasilia) determined by X-ray fluorescence spectrometry

(dry soil basis)

No.	soil	horizon	Si %	Al %	Fe %	Ti %	K ppm	Ca ppm	Mg ppm	P ppm	Zn ppm	Mn ppm
1	dark red latosol	A_1	29.0	7.8	3.8	1.2	1010	170	441	306	20	84
		A_3	28.8	8.2	3.0	1.2	1020	tr*	439	239	20	52
		B_1	25.9	8.9	3.2	1.3	1110	tr	527	215	18	33
		B_2	28.0	8.9	3.2	1.3	1180	tr	573	183	25	25
2	red yellow latosol	A_1	14.0	18.6	7.9	2.1	500	250	226	332	29	66
		A_3	14.0	19.3	7.9	2.1	480	tr	212	239	27	60
		B_1	12.9	20.0	8.0	2.2	460	tr	261	231	16	76
		B_{21}	13.8	20.3	8.0	2.2	460	tr	230	207	25	66
		B_{22}	13.8	20.1	8.3	2.2	460	tr	228	183	20	66
		B_3CA	14.3	20.0	8.3	2.2	460	tr	230	175	23	76
3	red yellow latosol	A_1	26.8	11.3	2.7	1.4	730	tr	374	207	25	19
		A_3	26.6	12.7	2.3	1.5	640	tr	402	175	31	14
		B_1	23.9	14.4	2.3	1.6	650	tr	443	137	20	11
		B_2	25.9	15.1	2.0	1.6	620	tr	378	122	33	6
4	red yellow latosol	A_1	28.0	9.5	3.3	1.3	910	150	436	272	18	36
		A_3	28.0	10.2	2.9	1.3	930	tr	428	191	29	19
		B_1	25.3	11.3	3.0	1.4	1080	tr	484	160	23	11
		B_2	26.1	14.0	2.4	1.5	770	tr	443	130	37	6
5	plinthic yellow latosol	A_1	27.0	12.2	1.8	1.5	720	tr	402	215	33	14
		A_3	27.8	13.8	1.1	1.6	680	tr	454	115	27	6
		B_1	25.0	14.9	1.0	1.6	710	tr	393	115	31	3
		B_2	26.8	16.0	1.1	1.6	720	tr	363	93	37	3
6	low humic gley soil	A_1	28.6	11.5	1.5	1.5	650	tr	378	168	27	11
		A_3	28.8	13.1	1.0	1.5	610	tr	460	115	27	6
		C_1	25.5	15.2	0.9	1.7	600	tr	505	115	29	3
		C_2	28.2	14.7	1.0	1.7	590	tr	499	100	29	tr
7	organic soil	A_1	23.0	7.1	0.9	0.8	820	150	274	2203	25	38
		C_1	30.7	13.6	1.0	1.3	3370	tr	963	191	23	tr
		IIA	21.6	6.8	0.9	1.0	1280	tr	369	358	23	33
		IIC	32.0	14.3	0.8	1.5	1300	tr	638	79	25	tr
8	quartz sandy soil	A_1	43.3	1.6	0.8	0.4	300	tr	55	122	tr	11
		A_3	43.6	1.6	0.7	0.4	270	tr	37	79	3	5
		C_1	42.0	2.7	0.7	0.5	310	tr	46	93	3	tr
		C_2	43.5	1.8	0.8	0.5	280	tr	49	65	6	27

*tr: <100ppmCa, <1ppmZn or <1ppmMn

elements. This may be attributed to the different parent materials mixed in layers of these sites which is possibly due to erosion and deposition.

The similar elemental composition was found among different soil types; red yellow latosol (No. 3 and 4), plinthic yellow latosol (No. 5) and low humic gley soil (No. 6). In these soils, not only skeletal elements but also other elements were similarly contained (Tables 5 and 6). Since these soils were found in the close vicinity, the parent materials (The Tertiary sediments) are supposed to be the same. These facts indicate that the composition of skeletal elements of the soils is mainly determined by the parent materials and is not much affected by other soil formation factors.

Table 6. Elemental composition of some Cerrado soils (Goiania) determined by X-ray fluorescence spectrometry

(dry soil basis)

No.	soil	horizon	Si %	Al %	Fe %	Ti %	K ppm	Ca ppm	Mg ppm	P ppm	Zn ppm	Mn ppm
9	dark red latosol	A_1	17.3	6.7	11.8	3.7	810	590	544	2593	41	1835
		A_3	16.5	6.7	13.4	3.7	380	100	306	1351	35	718
		B_1	16.8	7.0	13.2	3.7	360	tr*	283	776	11	579
		B_2	15.4	7.3	13.7	3.7	340	tr	288	586	18	521
10	dark red latosol	A_1	25.3	7.4	4.9	1.1	5900	610	929	487	47	347
		A_3	24.1	8.6	5.5	1.2	5710	410	809	449	23	347
		B_1	21.8	10.3	6.4	1.3	6290	100	786	297	20	264
		B_{21}	21.6	10.8	6.9	1.3	6580	100	757	264	33	244
		B_{22}	18.8	11.6	8.5	1.3	6940	tr	759	323	16	249
		IIC	19.1	12.0	7.8	1.3	7460	tr	753	323	27	860
11	red yellow latosol	A_1	26.1	4.3	7.3	2.9	420	380	328	546	11	285
		A_3	27.6	4.3	7.0	2.8	390	tr	264	376	27	196
		B_1	23.2	5.6	8.5	3.3	380	tr	312	376	13	194
		IIB2	22.3	6.0	9.0	3.4	390	tr	288	376	8	238
12	humic gley soil	A_1	32.0	3.8	3.8	3.0	530	2600	1340	1339	70	1926
		Cg_1	28.2	7.2	4.5	2.4	2100	1260	1344	349	66	487
		Cg_2	25.9	8.5	3.3	2.4	2460	1920	1940	323	62	634
		Cg_3	29.6	6.6	2.6	2.8	4950	3030	2831	394	72	729
13	dusky red latosol	A_1	10.3	7.0	20.4	3.6	510	200	734	1764	37	1212
		A_3	10.3	6.9	20.4	3.6	490	310	668	1870	31	1233
		B_1	10.0	7.2	20.6	3.6	440	170	720	1259	33	1153
		B_2	9.7	7.4	20.9	3.5	430	160	691	1106	27	1090
14	dusky red latosol	A_1	11.8	6.6	17.9	3.8	650	7960	691	1764	35	1250
		A_3	11.8	7.2	18.6	3.7	480	1840	617	1461	33	1300
		B_1	11.2	7.5	18.9	3.7	420	1070	571	1168	23	1172
		B_2	10.9	7.7	19.3	3.6	400	410	569	948	27	1053
15	dusky red latosol	A_1	19.1	8.8	10.4	2.1	3780	680	561	394	57	662
		A_3	21.8	7.6	9.2	2.2	3300	300	533	412	47	840
		B_1	17.3	9.9	11.1	2.0	3630	130	601	332	39	667
		B_2	17.8	10.5	11.4	1.9	3900	tr	611	289	39	608

*tr: <100ppmCa

Varied concentrations of K, Ca, Mg, P and Mn in the soils were observed (Tables 5 and 6). Although these elements, except K, tended to accumulate in the surface horizon, the variation among horizons was much smaller than that among the sampling sites. The soils in Brasilia contained generally very low amount of these nutrients, but some other Cerrado soils in Goias State contained relatively high amount of the nutrients.

Total K content of the soils was generally very low, but high in the soils No. 10, 12 and

Table 7. Organic carbon, total N and available nutrient concentions of some Cerrado soils (Brasilia) (dry soil basis)

No.	soil	horizon	organic C, %	total N, %	Bray-P ppm	0.2NHCl soluble nutrients, ppm						
						K	Na	Ca	Mg	Zn	Mn	Cu
1	dark red latosol	A_1	1.49	0.07	3.6	45	4	17	23	2.1	23.3	1.5
		A_3	1.20	0.05	1.4	22	3	7	4	2.0	11.1	1.4
		B_1	0.67	0.02	1.2	8	4	4	2	0.8	4.7	0.9
		B_2	0.04	0.01	1.0	5	4	4	2	1.0	2.9	1.1
2	red yellow latosol	A_1	2.63	0.12	8.0	47	4	48	59	4.8	5.4	0.7
		A_3	1.91	0.08	1.8	27	3	2	7	1.8	4.1	0.4
		B_1	1.32	0.04	1.7	7	3	1	2	2.9	1.7	0.3
		B_{21}	0.86	0.04	1.1	3	3	2	1	1.5	0.6	0.4
		B_{22}	0.61	0.01	1.3	5	3	2	1	2.2	0.5	0.3
		B_3CA	0.47	0.01	1.9	1	3	1	1	2.5	0.3	0.3
3	red yellow latosol	A_1	1.57	0.08	1.9	26	4	14	5	4.0	2.8	1.8
		A_3	1.46	0.07	1.4	11	5	3	2	3.3	1.0	1.7
		B_1	0.67	0.03	1.5	4	5	3	1	1.7	0.6	0.7
		B_2	0.44	0.02	1.2	3	3	3	1	4.0	0.4	0.6
4	red yellow latosol	A_1	1.60	0.07	4.7	22	5	12	8	1.8	1.8	1.8
		A_3	1.32	0.06	1.4	11	6	3	2	1.9	1.9	1.7
		B_1	0.72	0.03	1.3	5	3	2	1	2.3	2.3	0.8
		B_2	0.43	0.02	1.1	3	3	1	1	1.6	1.6	0.6
5	plinthic yellow latosol	A_1	1.75	0.08	5.6	23	5	14	3	3.1	0.7	1.9
		A_3	0.96	0.04	2.9	11	6	4	2	2.2	0.3	1.0
		B_1	0.54	0.02	2.6	6	4	3	2	7.8	0.4	0.7
		B_2	0.25	—	2.2	9	5	2	2	5.7	0.3	0.5
6	low humic gley soil	A_1	2.06	0.09	3.1	12	4	2	3	3.2	0.9	2.3
		A_3	1.33	0.13	2.4	10	5	1	2	2.2	0.3	1.7
		C_1	0.40	0.02	3.2	4	10	1	2	0.5	0.4	0.9
		C_2	0.26	0.01	2.5	3	4	0	1	3.1	0.4	0.9
7	organic soil	A_1	12.42	0.57	11.7	8	5	16	5	2.7	1.6	0.2
		C_1	3.18	0.07	3.8	2	4	2	1	4.3	0.4	0.7
		II A	12.58	0.41	2.7	6	4	5	2	3.5	0.6	0.3
		II C	0.15	0.01	2.8	3	3	0	1	4.3	0.2	0.2
8	quartz sandy soil	A_1	1.53	0.07	7.0	22	2	2	6	3.1	1.9	0.2
		A_3	0.40	0.01	3.0	3	2	1	1	2.2	0.3	0.1
		C_1	0.18	—	2.0	1	2	1	1	7.9	0.2	0.2
		C_2	0.13	—	2.5	1	3	1	1	1.9	0.2	0.2

15 in Goias State. Total Ca concentration was high on the sites No. 12 and 14, but all the soils in Brasilia contained trace amount of Ca. Total Mg concentration was remarkably high in No. 14 and remarkably low in No. 8 (quarts sandy soil). Total P concentration was high in the soils No. 9, 13, and 14, but very low in the soils in Brasilia except the surface horizon of the organic soil. Concentration of total Zn and Mn were significantly low in the soils collected in Brasilia.

Organic C, Total N and Available Nutrients.

Tables 7 and 8 show the concentrations of organic C, total N and available nutrients in some Cerrado soils collected from Brasilia and Goias State, respectively. These concentrations varied considerably among soils, though they were higher in A horizons of most of the

Table 8. Organic carbon, totalN and available nutrient concentrations of some Cerrado soils (Goiania) (dry soil basis)

No.	soil	horizon	organic C, %	total N, %	Bray-P ppm	0.2NHCl soluble nutrients, ppm						
						K	Na	Ca	Mg	Zn	Mn	Cu
9	dark red latosol	A_1	3.83	0.22	10.4	226	5	35	123	4.8	185.9	9.5
		A_3	1.94	0.09	7.2	28	2	18	10	0.7	60.7	7.6
		B_1	1.23	0.05	1.9	16	2	13	9	0.8	41.5	7.3
		B_2	0.81	0.02	2.0	6	3	2	5	1.1	30.2	6.2
10	dark red latosol	A_1	1.81	0.10	3.7	62	3	189	58	6.2	47.1	2.5
		A_3	1.74	0.09	3.2	56	3	39	59	1.9	35.7	8.2
		B_1	0.90	0.04	1.4	44	2	14	15	1.8	25.5	0.5
		B_{21}	0.63	0.02	1.1	46	2	16	15	1.3	25.8	0.1
		B_{22}	0.30	0.01	1.2	12	3	10	6	1.2	11.2	1.4
		II C	0.19	0.01	1.9	11	5	14	9	1.3	24.4	0.4
11	red yellow latosol	A_1	1.77	0.08	2.9	63	2	59	68	2.2	27.2	3.4
		A_3	0.95	0.04	3.3	49	3	12	8	6.1	8.5	2.7
		B_1	0.69	0.02	2.3	10	2	4	4	1.2	5.6	1.9
		II B2	0.31	0.01	1.9	13	4	3	10	0.8	9.9	1.7
12	humic gley soil	A_1	2.57	0.16	14.8	98	20	848	326	7.3	331.0	8.3
		Cg_1	0.44	0.02	1.2	11	212	88	323	3.5	45.1	5.0
		Cg_2	0.31	0.01	1.8	15	348	854	664	2.7	42.6	5.6
		Cg_3	0.16	—	1.4	19	337	1011	807	3.1	64.6	4.1
13	dusky red latosol	A_1	2.09	0.09	12.1	44	5	129	22	11.5	111.3	5.3
		A_3	2.36	0.11	17.2	29	4	70	7	3.2	111.0	5.0
		B_1	1.54	0.06	2.7	13	3	6	4	1.9	64.0	4.8
		B_2	0.99	0.04	1.5	5	3	4	2	0.5	45.8	4.8
14	dusky red latosol	A_1	3.88	0.29	13.4	210	11	3264	373	3.2	247.5	1.0
		A_3	2.16	0.13	3.7	76	4	312	112	1.3	149.1	2.7
		B_1	1.20	0.05	2.8	30	3	151	110	0.8	76.5	3.5
		B_2	0.68	0.02	2.6	10	3	23	48	0.8	40.7	3.1
15	dusky red latosol	A_1	1.62	0.08	2.3	63	2	241	87	5.1	66.8	4.6
		A_3	1.74	0.10	1.9	30	2	29	32	4.7	81.3	4.4
		B_1	0.86	0.02	3.2	10	2	12	11	1.0	43.2	4.1
		B_2	0.56	0.02	0.7	8	2	7	26	0.7	43.7	3.0

soils. All the Brasilia soils contained scarce amount of available nutrients, while the soils in Goias State were generally rich in these nutrients compared with Brasilia soils.

The concentrations of the available P, exchangeable K, Ca, Mg and some trace elements are reported to be very low in Cerrado soils (Lopes and Cox, 1977). Our results on Brasilia soils are in good agreement with this report. Even though the availability of these nutrients were very low, we can expect some nutrient supply from the soils by increasing the availability through use of mycorrhyza or nutrient-deficiency tolerant crops or other means, if the soils contain nutrient reserves as a potential source. But if not, these nutrients must be applied as fertilizers. X-ray fluorescence spectrometry of soils can offer the informations on potential nutrient reserves in soils. Table 5 showed that Brasilia soils generally contained very low amount of total K, Ca, Mg, P and Mn. For these soils, application of these nutrients is essential to increase crop productivity.

The amount of available nutrients in soils is supposed to be related to the total nutrient content of the soils. If there is a close relationship between total and available nutrient content, we will be able to estimate available nutrient content from XFS data of soils. In order to examine this possibility, coefficients of linear correlations between two parameters were calculated. Relatively high correlation coefficients were obtained for Ca ($r=0.982$, $n=64$), Mn ($r=0.873$, $n=60$), Mg ($r=0.855$, $n=64$) and P ($r=0.745$, $n=64$). On the other hand, K ($r=0.048$, $n=64$) and Zn ($r=0.228$, $n=63$) showed very low correlation coefficients. An approximation of the available Ca, Mn, Mg and P contents of Cerrado soils from the XFS data is possible.

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数種ブラジル・セラード土壌の蛍光X線分析

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ブラジルの広大な荒地セラードで，5000万 ha 以上の規模の農業開発が進行している。セラード土壌では，低肥沃度，土壌酸性，低保水性などの土壌に主として起因する種々の作物生育阻害要因により，作物の生産性が制約されていると考えられる。従って，この地域の適正な土地利用計画や土壌管理計画の策定に対しては，膨大な点数の土壌情報の収集が必要と考えられるので，土壌含有元素について迅速な測定が可能である蛍光X線分析法の利用を検討した。

ブラジルのゴイアス州およびブラジリア地区から土壌試料を収集し，セラード土壌の元素組成や可給態養分を推定するとともに，これらの分析に蛍光X線分析法を適用しうるか否かを検討した。土壌試料は，上記地区の15地点から主要土壌型を網羅する64点採取し，蛍光X線分析と化学分析により測定した。

土壌の骨格元素 (Si, Al, Fe および Ti) の濃度は，大部分のセラード土壌において，層位間の変動は極めて小さかったが，地点間の差異は大きく，土壌型とは必ずしも関係していなかった。これらの分析結果から土壌の骨格元素の組成は，主として土壌母材によって決定されており，他の土壌生成因子の影響は比較的小さいものと考えられた。

セラード土壌の主要な作物生育阻害要因と考えられている置換性 Al 濃度は，いずれの土壌でも pH 4.5 (1 : 2.5N-KCl) 付近より pH が低下するに従って指数関数的に増加した。鉱質土壌では，置換性 Al 濃度 (Y, Almg/100g 乾土) と土壌 pH (X, 1 : 2.5 NKCl) との間に $\log Y=8.430-1.983X$ ($r=0.982$, $n=30$) の非常に高い関係が認められた。

K, Ca, Mg, P, Zn および Mn は表層土壌に集積する傾向が認められたが，その層位間差異は採取地点間差異よりも小さいものであった。またブラジリア地区の土壌ではこれらの元素濃度が著しく低く，作物の生育阻害要因となっているものと考えられた。Ca, Mn, Mg および P については，土壌中の全濃度と可給態濃度との間に比較的高い相関が認められたことから，蛍光X線分析法によりこれらの元素の全濃度を測定することにより，可給態濃度を推定することが可能であると結論した。

キーワード：可給態養分，セラード，土壌肥沃度，土壌元素，蛍光X線分析