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SOILS OF THE CENTRAL PLATEAU OF BRAZIL

and

Extension of Results of Field Research Conducted

Near Planaltina, Federal District, to Them

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Cornell and North Carolina State Universities, with support by the Agency for International Development of the United States, are cooperating with the Department of Agricultural Research of the Brazilian Ministry of Agriculture on field research to determine requirements of soils of the Central Plateau of Brazil for crop production. The field research is conducted on land of the Estacão Experimental de Brasilia of the Ministry of Agriculture near the municipality of Planaltina, Federal District.

The experimental site was selected to represent the highly weathered and leached soils of good structure but very low fertility known to be extensive in central Brazil. The soil is classified by Brazilian pedologists as Latosol Vermelho Escuro distrofico, textura argilosa, fase Cerradão (Dark Red Latosol, dystrophic, clayey texture, Cerradão phase). The soil would probably be classified as a Typic Haplustox, fine, isohyperthermic, kaolinitic by Soil Taxonomy of the United States. The site is on a gently sloping geomorphic surface at an elevation of about 1000 m. It is about 850 or 900 m northeast of the base of a sharp escarpment that rises to an older erosion surface about 150 meters higher than the experimental site. The vegetation of the site before clearing is believed to have been a moder-

ately tall and thick stand of twisted trees and shrubs with grass, which is known as Cerradão. This is considered by Brazilian authorities to indicate somewhat better soil fertility than the lower and thinner stands of the same species, known as cerrado, which is more extensive on the plateau.

Although soil analytical data and crop performance under experiments confirm favorable physical soil conditions and very low fertility at the experimental site, questions could be raised about how representative the site may be of extensive areas of the central plateau. The position of the site relative to the escarpment to higher land could suggest moisture relationships atypical of much of the plateau. The vegetation could suggest soil fertility somewhat better than normal for soils of the plateau. The Mapa Esquematico de Solos, Regioes Norte, Meio-Norte e Centro-Oeste do Brasil (Divisão de Pedologia e Fertilidade do Solo, 1966) indicates that the "dark red clayey Latosols" mapped at the experimental site are extensive on the plateau. The degree of similarity in various properties that affect management needs, however, was not certain. The map also indicates that other extensive areas in central Brazil are Latosols but are "yellowish red", "medium textured", or both. The degree to which these differences in color or texture might be associated with differences in requirements for cropping was in doubt. These and other uncertainties suggested a need to investigate the soils of reasonably extensive areas for some distance from the experimental site and appraise the probability that the experimental results could be extended to them.

In early March, 1973, Professors Drosdoff and Cline of Cornell discussed the need for such a study with Professor C. B. McCants of North Carolina State University. It was agreed that Professor Buol of North Carolina State Univer-

sity and Professor Cline of Cornell should spend two weeks in the area if arrangements necessary to make the study productive could be made including participation of Brazilian soil scientists.

Cooperation of Brazilian Authorities

Contacts with Brazilian authorities were made through Mr. George Naderman of Cornell and Dr. Robert Cate of North Carolina State University, who were stationed in Brasilia. The proposal was endorsed enthusiastically by Dr. Roberto Meirelles de Miranda, Director of the Office of Research and Experimentation, and Mr. Nathaniel Bloomfield, Director of Soil Research, for the Brazilian Ministry of Agriculture. Under their authority, four of the leading soil scientists of Brazil were released from their regular duties to collaborate in the study:

Marcello N. Camargo
Clotario Olivier da Silveira
Jorge Olmos Iturri Larach
Paulo Klinger Tito Jacomine

These four scientists advised on routes of travel to use the time most profitably, traveled with Professors Buol and Cline, and explained soil conditions, geology, vegetation, and land use throughout the route. Their professional contributions were invaluable. Their companionship made the travels most enjoyable. The Ministry of Agriculture also furnished a vehicle to supplement that obtained through the USAID Mission. It is appropriate to acknowledge here the grateful appreciation of the authors of this report to the Ministry of Agriculture and the Brazilians concerned for many material contributions to the study as well as many personal courtesies. It is also appropriate to acknowledge the very considerable assistance of the USAID Mission, Mr. Naderman, and Dr. Cate.

Activities During The Study Period

Professors Cline and Buol arrived in Brasilia on the morning of Monday, May 28, 1973. In the afternoon, they were briefed on the cerrado and related vegetative associations during a trip northeast of Brasilia with Dr. George Eiten, an ecologist of the University of Brasilia. Late in the afternoon, they visited the Experimental Station of Brasilia near Planaltina and examined the soil at the experimental site.

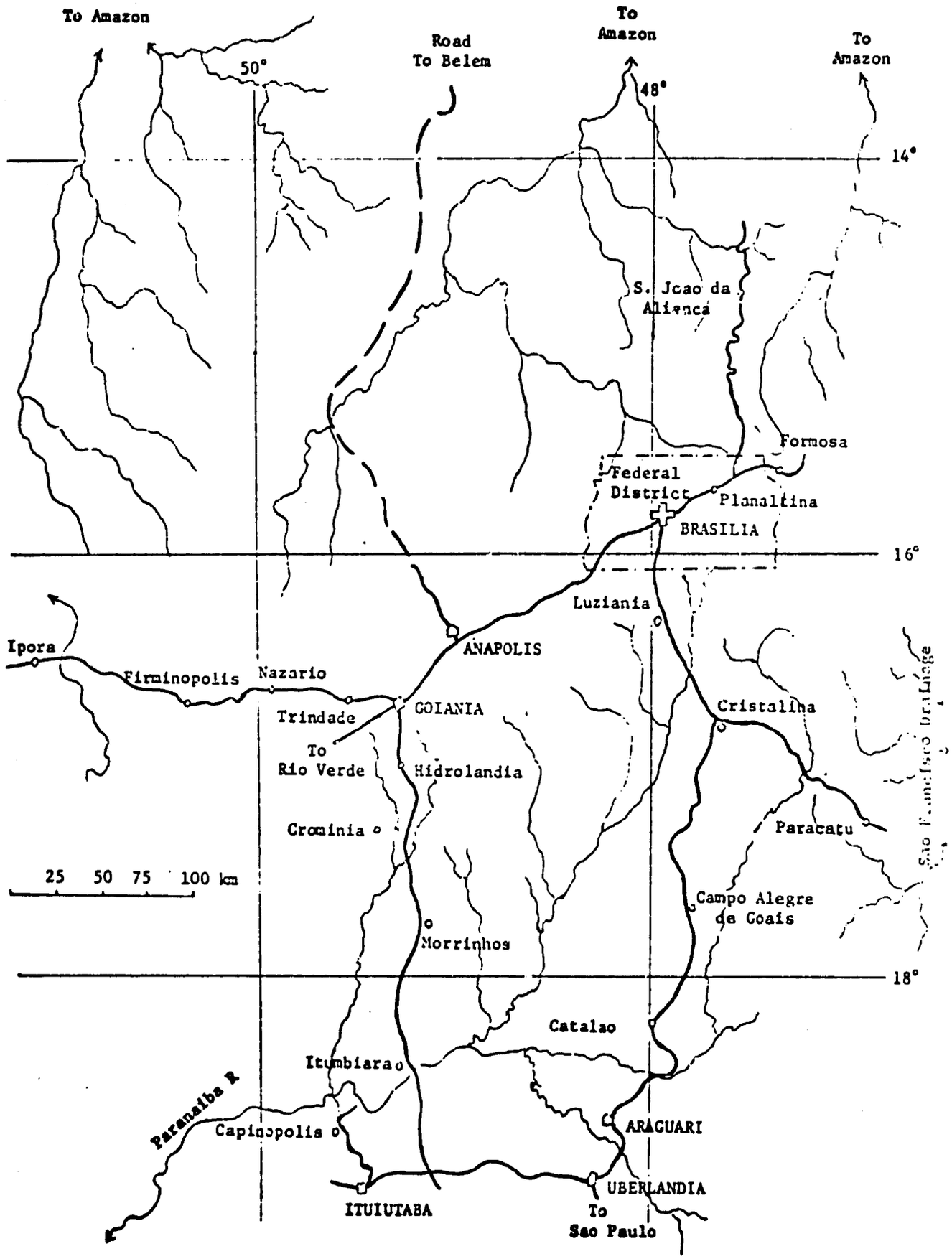
The morning of Tuesday, May 29 was spent at the Ministry of Agriculture with Brazilian authorities, Mr. Naderman, and Dr. Cate developing details of the itinerary for the remainder of the period. This was modified only slightly as the study progressed. The itinerary followed is outlined below. Travel routes are shown by the heavy solid lines on the route map on Page 5. During the period, Drs. Cline and Buol traveled approximately 2700 km, reaching points 200 km SSE, 370 km S, 330 km WSW, and 160 km NNE of Brasilia. The travel included areas of the Sao Francisco, Parana, Araguaia, and Tocantins drainage basins. Except for travel in the Federal District with Mr. Naderman, Dr. Cate, and their associates during the last two days, the four Brazilian soil scientists named earlier served as guides and provided running commentary on soil conditions, geomorphology, geology, vegetation, and land use while traveling and at study stops.

Itinerary:

Tuesday, May 29. Planned itinerary. Studied soils at the Experiment Station of Brasilia, including three sites for which laboratory data are published in Technical Bulletin No. 8 of Equipe de Pedologia e Fertilidade do Solo, Ministerio da Agricultura. Site No. 1 of that bulletin is at the edge of the experimental area used by Cornell and North Carolina State Universities.

Wednesday, May 30. Traveled SSE of Brasilia to Paracatu, Minas Gerais, via Cristalina. 245 km by odometer. Seven soil study stops.

ROUTE MAP
SOIL STUDIES CENTRAL BRAZIL



Thursday, May 31. Retraced route to Cristalina and traveled southward to Uberlandia in the Minas Gerais "Triangle." 410 km by odometer. Five soil study stops, at one of which a sample was taken for analyses.

Friday, June 1. Traveled westward in the "Triangle" to Ituiutaba, with a side trip to Capinopolis and beyond to the plain of the Paranaiba River. 287 km by odometer. Eight soil study stops at one of which a set of three samples was taken.

Saturday, June 2. Traveled from Ituiutaba northward to Goiania, Goias. 368 km by odometer. Four soil study stops, at two of which sets of three samples were taken for analyses.

Sunday, June 3. Traveled from Goiania westward to Ipora and returned. 472 km by odometer. Four soil study stops.

Monday, June 4. Traveled from Goiania northwestward to Brasilia with a side trip at Anapolis northward for 30 km. 278 km by odometer. Four soil study stops, at one of which a set of three samples was taken for analyses.

Tuesday, June 5. Traveled northeastward past Planaltina and thence northward to a point 48 km north of S. Jaoa da Alianca, and returned. 418 km by odometer. Four soil study stops at one of which a set of three samples was taken for analyses.

Wednesday, June 6. Investigated soils for potential experimental sites in the Federal District, including a) Tamandua Experimental Farm, b) areas thought to be the property of the University of Brasilia, and c) property of the technical school, Colegio Agricola de Brasilia, adjacent to the Experiment Station of Brasilia. About 185 km traveled.

Thursday, June 7. Reviewed observations and tentative conclusions with Brazilian soil scientists. Investigated soils of the area adjacent to the experimental site; conferred with Brazilian authorities at the Ministry of Agriculture.

Friday, June 8. Met with Dr. Meirelles. Conferences with Cornell and North Carolina State personnel stationed at Brasilia. Studied potential experimental sites on the high erosion surface on the Experimental Station of Brasilia, and collected a set of three soil samples from one site.

Saturday, June 9. With Dr. Cate and James Wolf, investigated the farm of the University of Brasilia as a potential experimental site. Studied landscapes and land use in and adjacent to Brasilia National Park in the northwestern corner of the Federal District. Consulted with Dr. Cate and Mr. Naderman. Departed for New York at 7 p.m.

Field Observations

The terminology of the Brazilian pedological investigations (Divisão de Pedologia e Fertilidade do Solo, 1966) is used in the remainder of this report to permit easy reference to Brazilian publications. Approximate equivalents of Brazilian soil names in Soil Taxonomy of the United States are given for the principal kinds of soil in the area studied based on field observations and available laboratory data.

1. Dark Red Latosols - 4 main varieties plus phases of each based on vegetative type

    a. Dystrophic, clayey
    b. Dystrophic, loamy
    c. Eutrophic, clayey
    d. Eutrophic, loamy

2. Red-Yellow Latosols - 4 main varieties plus phases of each based on vegetative type

    a. Dystrophic, clayey
    b. Dystrophic, loamy
    c. Eutrophic, clayey
    d. Eutrophic, loamy

The dystrophic varieties of both Dark Red and Red-Yellow Latosols probably include both Haplustox and Acrustox great groups of U. S. Soil Taxonomy. Acrustox have a cation retention capacity (from NH_4Cl) no greater than 1.5 me per 100 g of clay in some subhorizon of the oxic horizon, or have no more than 1.5 me of extractable bases plus extractable aluminum per 100 g of clay. Some of the dystrophic varieties of the region retain more than 1.5 me of cations per 100 g of clay and have more than 1.5 me of extractable bases plus aluminum (Table 2). These would be Haplustox. Others retain more than 1.5 me of cations but have less than 1.5 me of extractable bases plus aluminum per 100 g of clay (Table 1). These would be Acrustox. Most of the dystrophic varieties may be intergrades between the two great groups.

The eutrophic varieties are probably Haplustox by these criteria. The eutrophic varieties have relatively high base status approaching that of Eutrustox, but chromas within the upper 25 cm of most are too high (4.0 or more) to qualify for the mollic epipedon required in that great group. They may represent an unrecognized intergrade subgroup between Haplustox and Eutrustox. The clayey varieties are in very fine and fine families. The loamy varieties are probably mainly in fine loamy families. Distinctions between the Dark Red and Red-Yellow Latosols would probably be made at the series level in U. S. Soil Taxonomy.

3. Dusky Red Latosols (Latosol Roxo) - 2 main varieties and phases based on vegetative type

   a. Eutrophic, clayey
   b. Dystrophic, clayey

The eutrophic variety is probably a Typic Eutrustox, very fine or fine, kaolinitic or mixed, isohyperthermic, in the area studied. (See Moura and Buol, 1972.) The dystrophic variety is probably in the Haplorthox great group.

4. Red Yellow Podzolic Equivalents, eutrophic, clayey

These soils of relatively high base status are probably mainly Ustalfs, though some have mollic epipedons. If Ustalfs, they are probably predominantly Paleustalfs, though some may qualify as Rhodustalfs. Soils called Red Yellow Podzolic (not "Equivalents") by the Brazilian soil survey were not seen but are possibly Paleustults or Rhodustults.

5. Lithosolic Soils With Low Content of Calcium

These range from soils in which saprolite that retains rock structure extends to the surface (Ustorthents) to soils that have thin cambic horizons above saprolite (Ustoxic Dystropepts and Oxic Ustropepts mainly). They are

common on the sloping to steep dissection forms at the junction of different erosion surfaces and occupy large dissected areas where flat surfaces of divides have been reduced or eliminated.

Field Observations

The landforms of the region are classic examples of the results of multiple geomorphic erosion cycles. Throughout the area studied, at least two, in most places three, and in some places four distinct erosion surfaces are evident. The observations of this study are consistent in principle with the conclusions reported by Feuer (1956), who confined his studies to the Federal District itself.

The oldest erosion surface occupies the highest parts of divides between major rivers. These are the nearly level to gently sloping "chapadas" that mark the skyline at elevations of about 1000 to 1200 meters in the Federal District. Their elevations decrease gradually downstream. The high plateau above the experimental site and headquarters on the Experiment Station of Brasilia is a remnant of this surface. The soil on the highest surface is predominantly a deep Dark Red or Red-Yellow Latosol characterized by very strong ultrafine granular structure, high permeability, and extremely low fertility. These soils range in texture from fine loamy (loam to sandy loam) varieties to very fine but friable clays, depending on the amount of quartz sand inherited from the parent material. The surface is believed to be a former peneplain, and the soil material has undoubtedly been shifted about during peneplanation; so there is no certainty that it was derived from rock which was once part of the stratum that underlies any specific site. On a scale of several kilometers, there are clear relationships to the country

rock of the area.

In a large part of the area studied, the first erosion surface terminates abruptly at an escarpment of some 100 to 150 meters drop to a second gently sloping to sloping surface as one proceeds from the center of a divide toward major streams. It is presumed that uplift of the land occurred after the first surface was cut. The streams of the region, given new power, may be assumed to have incised themselves into the first surface, and subsequently lateral erosion cut a second surface into the weathering rock beneath the first. The modern escarpment marks the extent to which that cutting has proceeded. The time interval since most of the second surface was cut has been great enough that the kinds of soils on it are mainly indistinguishable in the field and by conventional laboratory determinations from the very old soils of the first surface.

The escarpments in the central part of the plateau commonly have little soil development in the weathered rock material. Resistant rock strata crop out in places or have a thin covering of weathered soil material. In other places less resistant rock is weathered deeply, and the saprolite extends to depths of several meters, with thin or no soil at the surface. These are the Lithosolic Soils delineated by the Brazilian soil survey on the schematic soil map made in cooperation with USAID (Divisão de Pedologia e Fertilidade do Solo, 1966). Where the divides are narrow, dissection has reduced the upland surfaces to the point that extensive areas dominated by these thin hilly and steep soils are delineated on the soil map. Where the divides are broad, these kinds of soil occupy strips too narrow to delineate at the map scale and are included in areas of Dark Red and Red-Yellow Latosols.

In the central part of the plateau, the second surface is currently being dissected, presumably as a consequence of more recent uplift. This third "surface" is exhibited as valley slopes of perhaps 8 to 20 percent gradient that parallel narrow flood plains and associated small alluvial fans. This youngest erosion surface has less acid, more fertile soils than those of the adjacent first and second surfaces and is commonly marked by larger more vigorous vegetation. These are the principal sites on which the "Red Yellow Podzolic Equivalents, eutrophic" soils (Alfisols) are found.

The area studied can be divided roughly into four sections having somewhat different associations of soils. Differences among them appear to be related in part to differences of parent rock and variations of the geomorphic landforms on them. These are described briefly in the following order and may be identified from the descriptions on the route map of Page 5.

1. Eastern section including the routes that include the Federal District and routes traveled a) northeastward about 150 km, b) southeastward to Paracatu, and c) southward to Catalao.

2. Southern section including the Minas Gerais "triangle" and adjacent areas to the north as far as Catalao and approaching Morrinhos.

3. Western section including Morrinhos, Anapolis, Goiania, and westward to Ipora, which is within the Araguaia drainage basin.

4. Northeastern section including the Tocantins drainage area north and south of S. Joao da Alianca.

Eastern Section

In this section, three erosion surfaces are well developed, and in general, the soils on gently sloping surfaces are predominantly very old, essentially devoid of weatherable minerals, and very low in bases. Dystrophic

Dark Red or Red-Yellow Latosols having gentle slopes occupy extensive areas and dominate the first and second erosion surfaces. Lithosolic soils occupy the escarpments that separate erosion surfaces and are extensive along major rivers. The third erosion surface is small in area. The more fertile Red Yellow Podzolic soils are absent or small in extent. The area is underlain by Precambrian metamorphic rocks, including schists, phyllites and quartzite.

Clayey Dark Red Latosols appear to predominate on the first and second erosion surfaces in the Federal District and in surrounding areas northward to the dissection of the Tocantins drainage and southeastward almost to Cristalina. In many places they merge with a strip of Red-Yellow Latosols as one approaches the top of the escarpment to the lower surface.

Near the edges of erosion surfaces, subangular or rounded laterite fragments of gravel size, commonly with some quartzite fragments, form a stone line several centimeters thick a meter or more below the soil surface and several hundred meters from the break in slope to a lower surface. The layer of fragments in these places commonly increases in thickness toward the escarpment and is exposed at the surface where the slope breaks sharply downward. At least in some places, the laterite fragments on the first surface appear to be relicts of a massive cap, for the fragments near the escarpment are large and subangular, and some fit together with faces that are mirror images of each other. On the second surface, the laterite pieces tend to be smaller, more rounded, and gravel-like in form. This leads to the hypothesis that a laterite cap on the upper surface is disintegrating and that the laterite gravel on the lower surface may be detritus from it. Laterite fragments are not common in the soil at distances more than several hundred meters from escarpments between erosion surfaces.

These relationships are by no means consistent. Red-Yellow Latosols occupy all of the first or second surface in some places. On the Experiment Station, for example, Red-Yellow Latosols occupy all of the high surface and a belt on the second surface at the base of the escarpment, merging down slope on the second surface with the Dark Red Latosol of the experimental site. In some places only Dark Red Latosols were seen on both surfaces.

From Cristalina to Paracatu, Red-Yellow Latosols are much more prominent than nearer Brasilia, and from Cristalina to Catalao they dominate. Latosols of loamy texture are prominent near Cristalina and are common in other places along the route where quartzite is the exposed country rock. The geomorphic relationships and the occurrence of laterite fragments near slope breaks are remarkably consistent.

The significance of the soil color differences is not evident. Physically, both Dark Red and Red-Yellow Latosols are friable, porous, permeable, and highly aggregated. No consistent differences were noted in land use or in vegetative type along the route. Only a few cultivated fields were seen. Most of the area is unimproved cerrado, used for extensive grazing or idle.

Southern Section

The route from Catalao through Uberlandia and Ituiutaba to Morrinhos is in a region where sandstone overlies diabase. Dissection of the Paranaiba drainage has cut through the sandstone into the diabase. The weathered diabase gives rise to Dusky Red Latosols, many of which are eutrophic (Eutrustox). These are the kinds of soil on which much of the agriculture of the State of Sao Paulo is based.

This section of the area, has a distinctive soil pattern. Dark Red and some Red-Yellow Latosols occupy the highest erosion surface, which is about

300 or 400 meters lower than the highest surface at Brasilia. (The high surface in the two places may not be products of the same erosion cycle; or the lower elevation in the south may be a result of the general slope down the major rivers.) These soils tend to be loamy varieties related to the sandstone, but clayey varieties are present. Geologists have speculated that the area had received aeolian deposits. These soils also tend to have higher base status than those north of Catalao. Many are eutrophic varieties, though cation exchange capacity is very low. The native vegetation is the cerrado type, but trees and shrubs are not so crooked and deformed as near Brasilia.

Many of the slopes from the high to the lower surface have eutrophic varieties of Red Yellow Podzolic soils (Alfisols). These slopes are less steep than the escarpments farther north. Semideciduous forest is predominant on these slopes, reflecting higher fertility according to the Brazilian authorities. The steeper slopes have Lithosolic soils.

On the areas of exposed diabase in the valleys are Dusky Red Latosols, many of them eutrophic (Eutrustox). Some are more than 90 percent base saturated in both surface and subsoil and have cation exchange capacities much higher than the Dark Red or Red-Yellow Latosols (Moura and Buol, 1972). These are productive soils and are used for a variety of crops, including sugar cane. The native vegetation was semideciduous forest.

More of the Dark Red and Red-Yellow Latosols are cropped in this than in the eastern section described above, though their use is much less intensive than that of the Dusky Red Latosols or of the more gently sloping parts of eutrophic "Red Yellow Podzolic Equivalents." In one section of 20 km, for example, fields within sight of the road were estimated to

aggregate 400 ha. "Improved" pastures are common on the Dark Red and Red Yellow Latosols in this area, unlike the eastern section of the study area.

Laterite gravel is present near the edges of the highest surface in some places but is much less common than in the eastern section. Where it was seen, it rested mainly on the top of the saprolite, and its topography did not conform with the soil surface. Wedge-shaped layers extending back from the edge of the erosion surface into the soil to form a stone line were not seen, though they may be present. Laterite was seen in too few places to justify hypotheses about its origin.

Western Section

From near Morrinhos to Goiania, westward beyond Firminopolis, and eastward beyond Anapolis, the route was on Precambrian schists, phyllites, and similar rocks, with some quartzite locally. West of Firminopolis, Devonian sandstone caps the highest surfaces but the road is on Precambrian rock.

In most places, three erosion surfaces can be identified. The general geomorphic landform patterns are similar to those described for the eastern section, but there are differences in detail. West of Firminopolis in the Araguaia drainage area, four surfaces are evident. The upper three are distinctive, each occupying extensive areas. The lowest consists of narrow areas where streams are incised into the third surface. South of Goiania, there are less extensive areas of the highest surface along the route and escarpment faces are less distinct than near Brasilia. The valley sides are moderately sloping in many places, and soils on them had developed beyond the "Lithosolic" stage at several sites examined.

The soil pattern also differs from that near Brasilia. Dark Red and Red-Yellow Latosols dominate on the undissected parts of the first and second erosion surfaces, but for reasons that are not evident, eutrophic varieties are common. Dystrophic varieties are also present, however. On the moderately sloping areas of valley sides, eutrophic "Red Yellow Podzolic Equivalents" (Alfisols) are prominent members of the soil association. In a number of places, soils that would be classified as Dark Red Latosols were found to contain unusual amounts of magnetic material, though in amounts less than that characteristic of the Dusky Red Latosols farther south. One has a distinct impression that soils of a large part of this section contain significantly more bases than do soils of the eastern section.

The vegetation appears to be consistent with somewhat higher base status than farther east. South of Goiania semideciduous forest is prominent on the valley slopes. Molasses grass, which is reputed to be an indicator of the presence of bases, is common in many unimproved pastures on the first and second erosion surfaces. Larger and thicker stands of shrubs of the vegetative type known as "cerradão" are more prominent than in the eastern section where "cerrado" or "campo cerrado" is predominant. Both west and east of Goiania, semideciduous forest is a conspicuous if not dominant vegetative type, though "cerradão" and in some places "cerrado" occupy the higher older surfaces.

The amount of cultivated land is also substantially greater than in the eastern section, and improved pastures were noted in several places. Travelers on the main roads south, west, and east of Goiania receive a distinct impression of a developing agriculture, unlike the eastern section.

Northwestern Section

This is the area within the Tocantins drainage along the route traveled northeastward from the Federal District. The area seen is small and might not deserve separate treatment in a report of this kind. It is unique in several respects, however, and may be indicative of conditions farther north in the area that drains northward to Belem.

The upper reaches of tributaries of the Tocantins River are deeply entrenched into the plateau 50 km south of S. Joao da Alianca. The divides have vegetation and soil very much like those of the eastern section described earlier, but they become progressively narrower northward as relief between plateau summits and valley floors increases. The Precambrian country rock is replaced by Silurian shale and limestone north of S. Joao da Alianca.

In the valleys well below the plateau summit are moderately sloping erosion surfaces on which Dark Red and Red-Yellow Latosols appear to predominate. These surfaces are narrow in some places but one or more kilometers wide in others. Forests follow the rivers, and appear to form progressively wider belts extending well onto the sloping surface as one proceeds northward. Species characteristic of the Amazon basin were pointed out.

Ranches and some farms are common on the lower surface. Improved pasture was noted in a number of places. The area gives the impression of being in the process of development, with cattle prominent in the enterprises. A cooperative settlement of Belgian immigrants displaced from the former Congo was made in this area. It is reputed to have fared poorly, though it is still operating. Some cultivated fields were noted on the plateau, but most of the agriculture appears to be in the valleys. One gains an impression of somewhat greater fertility of soils on the valley surface than of soils on the plateau, but this is unsubstantiated.

Comparison of the Soil at the Experimental Site with Extensive Kinds of Soil in Surrounding Areas of the Central Plateau

This discussion compares the soil at the experimental site mainly with the Dark Red and Red-Yellow Latosols. These two kinds of soil, including their clayey and loamy as well as eutrophic and dystrophic varieties, are predominant in the area studied. They have been identified as dominant kinds of soil on a very large aggregate area by the Brazilian Soil Survey (Divisão de Pedologia e Fertilidade do Solo, 1966), occupying extensive tracts from Sao Paulo in the South to Para in the North and from Minas Gerais in the East to Mato Grosso in the West. For purposes of this report, however, comparisons are confined mainly to the areas of Goias and Minas Gerais having pronounced dry seasons and "dominantly" "cerrado" or "cerradão" vegetative types. Even with this restriction, the area represented is immense. Projections may be possible, but with less certainty, to other kinds of soil or to other areas having pronounced dry season.

The laboratory data cited are mainly by methods of Equipe de Pedologia e Fertilidade do Solo of Brazil (EPFS). Table 1 compares unpublished data generated by methods of the Beltsville Soil Survey Laboratory of the Soil Conservation Service and by Brazilian laboratory methods for paired samples of the same dystrophic, clayey Dark Red Latosol located 100 m on the left side of the road 7.1 km toward Planaltina from the entrance to the Brasilia Experiment Station, Federal District. The Brazilian methods appear to give more complete dispersion for particle size analysis. The SCS methods for cation exchange capacity give the higher values, largely because the $BaCl_2$-triethanol amine methods used gives higher "extractable acidity" than the 1N KCl extraction of Al plus H used by EPFS. pH in water and in KCl (not

Table 1. A comparison of analytical data on paired samples of the same soil horizons by methods of the U. S. Soil Conservation Service (SCS) and the Brazilian Equipe de Pedologia e Fertilidade do Solo (EPFS).

Horizon	Depth (cm)	Clay (%)		Water Dispersible Clay (%)		Silt (%)		Org. Carbon (%)	
		SCS	EPFS	SCS	EPFS	SCS	EPFS	SCS	EPFS
A1	0-10	72	78	8.2	35	10	9	3.2	3.4
A3	10-30	68	81	6.8	25	12	8	2.1	2.0
B1	30-65	72	83	tr.	1	8	7	1.4	1.1
B21	65-140	68	84	0.1	0	13	7	0.9	0.8
B22	140-235	45?	81	0.2	16	24	8	0.8	0.7
B23	235-310	--	86		53	--	6	0.5	0.5

Depth (cm)	Exchangeable Cations (me/100 g)						CEC (sum) (me/100 g)		Base Sat'n (%)	
	Ca + Mg		Na + K		Al[2/]					
	SCS[1/]	EPFS	SCS[1/]	EPFS	SCS	EPFS	SCS[3/]	EPFS[4/]	SCS	EPFS
0-10	0.74	0.4	0.17	0.19	1.1	1.0	20.6	12.7	5	13
10-30	0.05	0.3	0.06	0.09	0.7	0.6	14.7	7.9	<1	5
30-65	0.04	0.2	0.02	0.04	0.2	0.2	11.0	4.6	<1	4
65-140	0.02	0.2	0.01	0.04	0.1	0.0	8.7	3.2	<1	6
140-235	0.01	0.2	0.01	0.04	tr.	0.0	6.4	1.6	<1	13
235-310	0.01	0.3	0.01	0.04	tr.	0.0	5.5	1.3	<1	23

1/ Second rerun, NH_4OAC pH 7.0

2/ "Extractable" Al by 1N KCl in both procedures

3/ Extractable Acidity by $BaCl_2$-triethanol amine, pH 8.2 + bases by NH_4OAC, pH 7.0

4/ Sum of bases plus Al plus H, the latter two by 1N KCl extraction

shown in Table 1) differed only slightly for most samples, but they differed enough that the change from negative to positive ΔpH in KCl relative to water was found at 65 cm depth by SCS and at 140 cm by EPFS. The data reported from EPFS in this report may be interpreted in the context of these relationships to data more familiar to U. S. readers. It should be noted that the very low extractable aluminum plus bases for this profile would place the soil in Acrustox, though cation exchange capacity is higher than normal for these soils. Methods used by the Soil Conservation Service Laboratories may be found in "Soil Survey Investigations Report No. 1" (Soil Conservation Service, 1967). Those used by EPFS may be found in Boletim Tecnico No. 8 (Equipe de Pedologia e Fertilidade do Solo, 1966).

Soil at the Experimental Site

The soil is a Dark Red Latosol, dystrophic, clayey, cerradão phase, by the classification of EPFS. A detailed description of a profile at the edge of the experimental site is given for profile 1 in Boletim Tecnico No. 8 (Equipe de Pedologia e Fertilidade do Solo, 1966). It has a dusky red (10R 3/4, moist) Ap horizon about 10 cm thick that grades through a transitional A_3 horizon 25 cm thick to a dark red (10R 3/6 to 10R 4/6) B horizon. The solum extends to a depth of more than 2 m. The soil is a clay throughout, but it "feels" like a loam or fine sandy loam. Examination with a hand lens reveals that most of the "sand" that is felt consists of very strong ultrafine granules less than 0.5 mm in diameter, which require vigorous rubbing for several minutes while wet to be destroyed. This is the only visible structure below the Ap horizon. The soil mass is very friable when moist. It is very porous. Unpublished data from the experimental site show bulk densities of 1.05 g/ml

at 7.5 cm and 0.95 g/ml at 60 cm depth.

Selected analytical data for profile No. 1 at the experimental site are given in Table 2. The complete set of data and analytical methods are given in Boletim Tecnico No. 8 cited above.

The soil is a clay throughout by mechanical analysis, but soil texture is near the clay loam limit of the clay textural class. Some clayey textured varieties of Dark Red Latosols have 70 percent or more clay but have consistence similar to this soil. Some loamy varieties may have less than 20 percent clay. The low water dispersible clay of Table 2 is characteristic of these soils.

The pH in 1N KCl in Table 2 is less than pH in water to the depth sampled. The available data for most soils of this kind show pH in KCl less than that in water in the upper horizons but greater than that in water at depths of 1 m or deeper.

The relatively high organic carbon to depths of a meter and more in Table 2 is characteristic of this kind of soil. The low cation exchange capacity of Table 2 is also characteristic. If one assumes that the CEC of the organic fraction is about 350 me/100 g of carbon (200 + me/100 g of O.M.), the residual CEC attributable to the inorganic fraction is about 8 me/100 g of clay. These or lower values appear to be characteristic of this kind of soil.

The extremely low percentage base saturation and exchangeable Ca + Mg and K values in Table 2 are characteristic of the dystrophic varieties. Note the similarity to values for comparable horizons in Table 1. "Aluminum saturation" of the order of 20 percent in Table 2 is characteristic of data for many sites of dystrophic varieties, but exchangeable Al is less than 1 me in many places (Table 7). Shallow rooting of Al-sensitive crops is common on this kind of soil.

Table 2. Selected analytical data for a Dark Red Latosol at the experimental site on the Experiment Station of Brasilia. (From EPFS Boletim Tecnico No. 8.)

Horizon	Depth	Sand[1/]	Silt[1/]	Clay[1/]	Water Dispersible Clay[1/]	pH H_2O	pH KCl
	cm	%	%	%	%		
Ap	0-10	36	19	45	14	4.9	4.2
A3	10-35	33	18	48	6	4.8	4.3
B1	35-70	35	18	47	1	4.9	4.2
B21	70-150	35	18	47	0	5.0	4.2
B22	150-260	39	19	42	0	4.6	4.4

Depth	C	N	CEC	Base Sat.	Exchangeable Ca + Mg	Exchangeable K	Exchangeable Al	Exchangeable H	Al Sat.
cm	%	%	me	%	me	me	me	me	%
0-10	1.8	0.21	10.2	5	0.4	0.10	1.9	7.8	19
10-35	1.2	0.08	8.1	4	0.2	0.05	2.0	5.8	25
35-70	0.9	0.05	7.1	4	0.2	0.03	1.6	5.2	23
70-150	0.7	0.05	6.1	3	0.2	0.01	1.5	4.4	25
150-260	0.3	0.03	3.6	6	0.2	0.02	0.7	2.7	19

[1/] Unpublished data from reanalysis of samples in July 1973, courtesy M. N. Camargo, E.P.F.S.

X-ray traces by Dr. Buol of North Carolina State University for samples from the site of profile 1, without determination of amorphous components, are interpreted very roughly as indicating about 80 percent kaolinite and traces of a 2:1/2:2 interlayered mineral and gibbsite. Data of Dr. Weaver of Cornell using centrifugation for particle size analysis, citrate-bicarbonate-dithionate for free iron and aluminum oxides; extraction with boiling 0.5 NaOH for amorphous material; X-ray diffraction; and differential thermal analyses were used on samples from the same site for the unpublished estimates of Table 3.

Table 3. Particle size distribution of the fraction finer than 2 mm and mineralogical estimates for the clay fraction of the soil at the experimental site.

	Fraction less than 2 mm			Clay Fraction				
Depth	Sand	Silt	Clay	Free Fe_2O_3	Free Al_2O_3	Gibbsite	Amorphous	Kaolinite + chlorite
cm	%	%	%	%	%	%	%	%
0-15	31	13	56	10.4	2.1	7	34	47
45-60	32	14	54	10.6	2.1	4	35	48

In preliminary unpublished studies of phosphorus reactions, Mr. Yost of North Carolina State University found that the following amounts of phosphorus (as P) were required to give the indicated levels of P in soil solution:

P in Solution (ppm)	P required to be added to soil (ug/g of soil)
0.05	530
0.10	630
0.20	760

Preliminary results of field experiments indicate that without phosphorus fertilization corn essentially does not grow and that amounts of P_2O_5 approaching 300 kg/ha are necessary in the first year of cropping to approach maximum yields. With adequate phosphorus and an adequate supply of other nutrients and water, however, yields of more than 6 metric tons of 15.5 percent moisture corn grain/ha have been obtained. The soil has high phosphorus fixing capacity.

Preliminary results of the experiments at this site and observations elsewhere on the station indicate that other nutrients limit yields or are likely to do so as cropping continues. Nitrogen has been supplied in amounts adequate for corn yields of about 3 or 4 metric tons per hectare from mineralization of native organic matter for the first crop on newly cleared land. It should become more critical with continued cropping. Potassium is needed for response to other nutrients. Zinc is known to be seriously limiting.

The low levels of calcium and magnesium may imply deficiencies of these elements as nutrients. The dominance of exchangeable aluminum in relation to bases appears to be a major factor restricting root systems of crops that are not aluminum tolerant. Root systems of corn, for example, tend to be concentrated in the shallow zone in which lime can be incorporated. This has important implications for the ability of plants to obtain moisture during even a few weeks of dry weather. The 6-ton yields mentioned above were possible in 1972-73 only because supplemental irrigation was used during a short period without rain during the normally rainy season. Under these circumstances, moisture is a very critical factor.

Unpublished preliminary studies of soil water at the site by Mr. Wolf in 1972 gave the soil water contents at the tensions shown in Table 4.

Table 4. Soil water contents at selected tensions for 2 depths on a Dark Red Latosol.

Tension (bars)	Water content (% by volume) 0-45 cm depth	45-105 cm depth
1/13 - 1/10 (1 day after saturation)	35.6	34.0
1/9 - 1/7 (2-3 days after saturation)	33.6	32.4
1	24.5	22.0
15	19.0	19.0

The study showed that when evaporation and transpiration were reduced to near zero (covered plots), the soil continued to lose water for at least six days, presumably by deep percolation under the force of gravity. This makes application of the concept of field capacity uncertain. One day after saturation, soil water tensions were in the 1/13 to 1/10 bar range given in Table 4, which should approach the upper limit of "available water." Consecutive values in each column of Table 5 represent the accumulated amounts of water that would be removed as the soil is dewatered from tensions of 1/13-1/10 bar.

Table 5. Accumulated millimeters of water removed as soil of the experimental site is dewatered from tension in the range of 1/13 to 1/10 bar to the indicated tensions, assuming three different effective depths of rooting.

Tension	Effective Depth of Rooting 30 cm	60 cm	90 cm
(bars)	(mm)	(mm)	(mm)
1/9-1/7	6	11	16
1/2	24	52	83
1	33	68	104
15	50	97	144

This illustrates the significance of restriction of root systems. Shallow-rooted corn wilted by the end of a six-day dry period during 1972-73. The data also indicate that the capacity of the upper meter of soil to supply water is relatively low considering the apparent field physical condition (less than 0.16 cm/cm) and that 1/3 of this is held at tensions greater than 1 bar. Considering losses by deep drainage as well as these factors, water can be a critical factor for crop growth, even during the relatively short dry periods that occur during most rainy seasons.

Dystrophic Dark Red and Red-Yellow Latosols of the Central Plateau

During the study, eleven profiles each of Dark Red and Red-Yellow Latosols were examined. Seventeen of these twenty-two profiles were considered dystrophic; five were either "eutrophic" or at least had higher pH by indicators in the field than the others. Fourteen were clayey varieties; eight were loamy. Of eighteen profiles tested, the pH in KCl was clearly higher than in water at a depth below 1 m in ten profiles. The pH was clearly higher in water in two and was about the same as in KCl in six. Of the eight profiles in which the pH in KCl was equal to or less than that in water, seven were Dark Red Latosols and four of these approached eutrophic varieties.

Except for color and textural variations, all of the twenty-two soil profiles examined were remarkably similar in morphology to the Dark Red Latosol at the experimental site. All had very strong ultrafine granular structure and required prolonged kneading in the hand when wet to exhibit consistence indicative of the actual clay content. All were very porous, and the pores were primarily fine and very fine voids among ultrafine granules.

Some of the Dark Red Latosols examined in areas south and west of Goiania and from Goiania to Anapolis contained more magnetic material than farther east. Among these were some in which pH by indicator tests increased to near 6.0 in the subsoil below 1 m. These soils were found in areas identified on the 1:5,000,000 schematic soil map as eutrophic varieties with dystrophic soils as subordinate associates. In these areas farming is more highly developed generally than further east, though not necessarily so at the sites examined. On the basis of field evidence, however, it is very difficult to identify any morphological property or set of properties that would suggest soil behavior and management needs under intensive cropping significantly different than would be expected at the experimental site.

Table 6 presents a summary of analytical data for seven clayey Dark Red Latosols and seven clayey Red-Yellow Latosols sampled and analyzed by EPFS. Only soil profiles from Minas Gerais, Goias, and the Federal District under "cerrado" vegetation, among those for which data were available, are included. This selection was used to confine the data to that for extensive soils and environmental conditions that closely resemble those at the experimental site.

Little data for loamy varieties of Dark Red and Red-Yellow Latosols were available for sites in this same region. Data for one profile of a loamy Dark Red Latosol and for five profiles of loamy Red-Yellow Latosols are included in Table 6. Five of these six profiles are from Sao Paulo, outside the general region to which this report applies. The data for them appear to be reasonable values in relation to those for the clayey varieties within the region. They are used here as approximations of expected values for similar kinds of soil within the region. The locations

of sample sites and published sources for each follow.

Dark Red Latosols, clayey

EPFS Tech. Bul. 11, profile 1 - Boa Esperanca, Minas Gerais
EPFS Tech. Bul. 11, profile 2 - Formiga, Minas Gerais
EPFS Tech. Bul. 11, profile 4 - Paraopeba, Minas Gerais
EPFS Tech. Bul. 11, profile 5 - Silvania, Goias
EPFS Tech. Bul. 11, profile 6 - Brasilia, Federal District
EPFS Tech. Bul. 11, profile 7 - Brasilia, Federal District
EPFS Tech. Bul. 8, profile 2 - Brasilia Expt. Sta., Federal District

Dark Red Latosol, loamy

EPFS Tech. Bul. 11, profile 8 - Nova Granada, Sao Paulo

Red-Yellow Latosols, clayey

EPFS Tech. Bul. 11, profile 11 - Formiga, Minas Gerais
EPFS Tech. Bul. 11, profile 12 - Alpinopolis, Minas Gerais
EPFS Tech. Bul. 11, profile 13 - Almenara, Minas Gerais
EPFS Tech. Bul. 11, profile 16 - Virgem da Lopa, Minas Gerais
EPFS Tech. Bul. 11, profile 17 - Itinga, Minas Gerais
EPFS Tech. Bul. 8, profile 3 - Brasilia Expt. Sta., Federal District
EPFS Tech. Bul. 8, profile 4 - Brasilia Expt. Sta., Federal District

Red-Yellow Latosols, loamy

EPFS Tech. Bul. 8, profile 5 - Brasilia Expt. Sta., Federal District
EPFS Tech. Bul. 11, profile 18 - Franca, Sao Paulo
EPFS Tech. Bul. 11, profile 19 - Pirassununga, Sao Paulo
EPFS Tech. Bul. 11, profile 20 - Sales de Oliveira, Sao Paulo
EPFS Tech. Bul. 11, profile 21 - Botucatu, Sao Paulo

The data for profile 1 of EPFS Tech. Bul. 11, representing the experimental site, are given in Table 2 and are not included in the means for clayey Dark Red Latosols in Table 6. Data for the profile reported in Table 1 are also excluded.

The values for total clay, water dispersible clay, and cation exchange capacity of Table 2, representing the experimental site, are within the range of the means plus or minus the standard deviations of these properties for the seven clayey Dark Red Latosols of Table 6. Organic carbon in the surface soil of the profile at the experimental site is lower than the mean

Table 6. Mean and standard deviations of selected characteristics of the indicated groups of Dystrophic Dark Red and Red-Yellow Latosols reported in Technical Bulletins Nos. 8 and 11 of EPFS, Brazil.

Horizon or Depth	No. of Sites	Clay Total	Clay Water dispersible	Organic carbon	Cation Exchange Capacity (sum)	Base saturation	pH H_2O
		%	%	%	me/100 g	%	(range)
			Dark Red Latosols, clayey				
Surface	7	60±17	20±7	2.4±0.3	10.2±1.2	11±5	4.3-5.2
75 cm	7	63±15	*	0.9±0.3	5.2±1.9	14±11	4.6-5.8
		* None in 5 out of 7 samples; 24 and 27 respectively in the other 2					
			Dark Red Latosol, loamy (from Sao Paulo)				
Surface	1	19	5	0.9	4.8	11	4.3
75 cm	1	24	7	0.3	2.5	15	4.9
			Red-Yellow Latosols, clayey				
Surface	7	47±8	13±7	1.7±0.6	8.6±3.5	7±4	4.2-5.1
75 cm	7	53±8	*	0.7±0.3	4.4±1.9	9±5	4.5-6.0
		* None in 4 out of 7 samples; 12, 24, and 27 respectively in the other 3					
			Red-Yellow Latosols, loamy (4 of 5 from Sao Paulo)				
Surface	5	21±7	5±3	0.8±0.1	4.0±0.5	13±4	4.4-5.2
75 cm	5	26±8	4±3	0.4±0.3	2.4±0.4	17±5	4.5-5.6

of seven profiles minus the standard deviation in Table 6, but the distribution with depth is similar. Mean base saturation values of the seven profiles is slightly higher both in the surface soil and at 75 cm depth than for the soil at the experimental site, but both are low in absolute terms. pH in water in Table 2 is well within the range of the seven profiles in Table 6. None of the differences noted suggest that management needs should be greatly

different at the experimental site than for areas represented by the seven profiles of Table 6.

The data for seven clayey Red-Yellow Latosols of Table 6 likewise so closely resemble data for comparable horizons of the experimental site (Table 2) that one could not predict different management needs or performance. If these seven profiles are representative of clayey Red-Yellow Latosols, they do appear to contain measurably less clay and less organic carbon than the clayey Dark Red Latosols, but they are very much like the soil at the experimental site in those properties and in base saturation.

The loamy varieties of both Dark Red and Red-Yellow Latosols (Table 6) appear not only to contain less clay than either the clayey varieties of Table 6 or the soil at the experimental site but also to have significantly less organic carbon. Less organic matter and less clay are reflected in lower cation exchange capacity of both the surface and subsoil. These differences might be expected to be reflected in the detail of some management requirements, such as amounts or frequency of fertilization, but they do not suggest major differences from the experimental site in the principle kinds of management needed.

Exchangeable aluminum is of particular interest. Data available for this property of the clearly dystrophic profiles of Table 6 are summarized in Table 7 for the surface soil and at a depth of 40 cm. The latter depth was chosen to represent a potentially limiting zone for root development immediately below a depth to which lime might feasibly be incorporated. One soil of Table 6 which had relatively high base saturation, approaching a eutrophic variety, was omitted.

Table 7. Exchangeable Al, percent Al-saturation, and percent base saturation in surface soils and at a depth of 40 cm in Dark Red and Red-Yellow Latosols having base saturation less than 20 percent. (From EPFS Boletim Tecnico, Nos. 8 and 11.)

		Surface Soil			At 40 cm		
Kind of Soil	No.	Exch. Al	Al Sat.	Base Sat.	Exch. Al	Al Sat.	Base Sat.
		(me/100 g)	(%)	(%)	(me/100 g)	(%)	(%)
Dark Red Latosol							
clayey	6	1.8±0.8	20±8	8±3	0.9±0.4	16±11	10±4
Red-Yellow Latosol							
clayey	3	1.4±0.4	18±5	7±3	0.8±0.6	15±5	10±4
loamy	4	0.9±0.4	21±7	13±5	0.7±0.2	20±11	14±6

If the percentage Al saturation for comparable horizons of Tables 7 and 2 are compared, the differences for surface soils are not striking. At 40 cm depth, aluminum saturation is distinctly less in the loamy varieties than at the experimental site. As the data were tabulated, it was noted that exchangeable Al decreased more rapidly with depth in most of the soils for which data are summarized than in the soil at the experimental site. It decreased to zero in some horizon above 1 m in two of the profiles. This may be a significant difference from the soil at the experimental site, but it would be necessary to confirm that the analytical methods were, indeed, comparable and that they consistently measured a property that is reflected in restricted root growth.

It will be noted in Table 7 that Al saturation exceeds base saturation in the surface soils and at 40 inches in all of the examples. Zandstra (1971) found that a function expressing the ratio of the cube root of exchangeable Al to the square root of exchangeable divalent cations is a more reliable

criterion of root inhibition than absolute values of exchangeable Al. If that finding holds for these soils, toxicity of Al would be expected below the depth to which lime can feasibly be incorporated by conventional field operations in all of these soils.

Estimates of kinds of clay minerals in the soil at the experimental site have been presented earlier in this report. They are repeated in Table 8 for comparison with other unpublished data for Dark Red and Red-Yellow Latosols. Grateful acknowledgement is given to Dr. W. Moura of the Federal University of Vicosa for providing unpublished data on the five soils from the Minas Gerais Triangle.

The methods used by Dr. Moura are comparable though not identical to those used by Weaver. The fact that Dr. Moura worked with the fraction finer than .001 mm and Dr. Weaver, with that finer than .002 mm should also contribute to differences. Irrespective of slight differences of procedures, kaolinite appears to be the dominant mineral in the fractions analyzed for both Dark Red and Red-Yellow Latosols at the Experiment Station of Brasilia and in the "Triangle" of Minas Gerais. At both locations, gibbsite appears to be generally more abundant and amorphous material less abundant in the Red Yellow than in the Dark Red Latosols if one compares only samples analyzed by one of the two workers. Pratt and Alvahydo (1966) reported kaolinite and gibbsite as the main clay minerals identified in Red-Yellow Latosols of Sao Paulo. They did not mention analyzing for amorphous material.

The cation exchange capacity of the fraction finer than 2μ as determined by Dr. Moura ranges from 4.1 to 6.1 among the five samples (Table 8), which is less than the calculated estimate of 8 me/100 g of clay at the experimental site. The assumed value of 350 me/100 g of organic carbon in

Table 8. Composition and selected properties of the clay fractions of soils at the Experiment Station of Brasilia and in the "Triangle" of Minas Gerais.

Kind of Soil	Horizon or Depth	Size Fraction	Free Fe_2O_3	Amorphous	Gibbsite	Kaolinite	CEC <2μ	Spec. Surf.
	(cm)	(mm)	(%)	(%)	(%)	(%)	(me/100 g)	(m^2/g)
			Dark Red Latosols					
Clayey, dystrophic[1/]	0-15	<.002	10.4	34	7	47[3/]	---	---
	45-60	<.002	10.6	35	4	48[3/]	---	---
Clayey, dystrophic[2/]	B21	<.001[4/]	7.0	9	19	42	4.3	86
Loamy, dystrophic[2/]	B21	<.001[4/]	5.7	17	6	45	6.1	99
Loamy, eutrophic[2/]	B21	<.001[4/]	5.6	16	5	46	5.3	94
			Red Yellow Latosols					
Clayey, dystrophic[1/]	0-15	<.002	12.2	20	20	45[3/]	---	---
	45-60	<.002	12.2	21	21	42[3/]	---	---
			Dusky Red Latosol					
Clayey, dystrophic[2/]	B21	<.001[4/]	16.0	8	32	14	4.3	86

1/ Analytical data by R. M. Weaver, Cornell University, on samples from the Experiment Station of Brasilia

2/ Analytical data by W. Moura, Federal University of Vicosa, on samples from the "Triangle" of Minas Gerais

3/ Reported as kaolinite plus chlorite

4/ Except for CEC, which was determined for the fraction finer than 2μ

carbon in that estimate may be too low. In the deepest horizon of Table 2, in which organic carbon is least, the calculated CEC of the clay fraction is about 6 me.

There is little basis in the data of Table 8 or in other clues to the nature of the clay fraction for predicting significant differences in soil behavior or management requirements between the Dark Red and Red-Yellow Latosols, or between the soil at the experimental site and the Dark Red and Red-Yellow Latosols of the surrounding region.

Data that bear on soil moisture relationships are scarce except for those reported in a preceding section for the experimental site. Moisture equivalent is reported by EPFS. Of twenty profiles of Dark Red and Red-Yellow Latosols, moisture equivalent varied by no more than two percent among horizons at the surface, at 40 cm, and at 75 cm in seventeen of the twenty profiles. This property appears to be extraordinarily uniform with depth. There is, as would be expected, a close relationship between moisture equivalent and clay percentage, as shown in Table 9. No consistent differences were noted between Dark Red and Red-Yellow Latosols of similar clay percentages, but the loamy varieties of both had distinctly lower moisture equivalents than the clayey varieties. The soil at the experimental site falls within the class having 40 to 60 percent clay and had a moisture equivalent of 22 or 23 in all horizons above 150 cm.

Table 9. Relationships of moisture equivalent and clay percentage in twenty surface soils of Dark Red and Red-Yellow Latosols.

	Percent Clay			
	<20	20 to 40	40 to 60	60 to 80
No. of samples	3	5	8	4
Moisture equivalent (%)	11±2	17±5	23±4	34±1

Although the loamy varieties have lower moisture equivalents than the clayey varieties, the Brazilian authorities were not certain that loamy varieties might not supply as much, or even more, moisture for plant growth during periods of low rainfall. The "Red and Yellow sands," which have very low clay contents, are known to be drouthy soils. One might assume that the Latosols having less than 20 percent clay, and which are, in a sense, intergrades to the sands, may have intermediate moisture supplying capabilities. This would appear to be a reasonable assumption, but it is not known to be true.

Eutrophic Dark Red and Red-Yellow Latosols

A few sets of unpublished data for eutrophic soils were examined during the study trip. These are not available at this time, but notes about unpublished data for the three eutrophic profiles in the vicinity of Anapolis and discussions with Brazilian authorities indicate the following:

1. Cation exchange capacity is as low as in dystrophic varieties--about 8 or 10 me/100 g in the surface soil, decreasing with depth.

2. Organic carbon is comparable to that in dystrophic varieties--1.5 to 2 percent in surface horizons and lower but significant amounts to depths of a meter or more.

3. Silica/alumina ratios of the clay fraction are low and comparable to those in dystrophic varieties.

4. Water dispersible clay is low, as in dystrophic varieties.

5. Base saturation may be relatively low or may be high in the uppermost horizon, but if it is low, it increases with depth. It is as much as 80 percent or more in some horizons of some profiles but on a low CEC base.

6. pH in KCl is commonly higher than in water at depths mainly greater than 1 m.

7. Exchangeable Al is distinctly lower in horizons having base saturation of 40 percent or more than in comparable horizons of dystrophic varieties.

From the limited information available, one may possibly expect significantly deeper rooting of aluminum sensitive crops, somewhat greater drouth resistance because of it, and less response to liming. One may expect phosphorus, potash, and nitrogen deficiencies to be critical under intensive cropping. Zinc may well be limiting as well in many areas. Judging from agricultural development where these soils are prevalent, it would appear that they may be more productive than dystrophic varieties under low levels of management for either crops or pastures. These expectations are by no means certainties. In the absence of information to the contrary one would expect many of the principles of soil fertility established for the experimental site to be applicable with modifications for higher base status, lower exchangeable aluminum, and deeper rooting of aluminum sensitive crops.

Eutrophic Red Yellow Podzolic Soils (Alfisols)

These soils occupy very limited areas in the eastern section but may be important in the western section of the area studied. The experimental station at Goiania, for example, appears to be at least partly on these soils, and there was evidence that they are common in the area dominated by semi-deciduous forest. Much of the area they occupy appears to have slopes too steep for easy cultivation.

One set of analytical data seen (for the Goiania Station) showed somewhat higher cation exchange capacity and significantly higher base saturation in the B horizon than in comparable horizons of dystrophic Dark Red or Red-Yellow Latosols. The sum of cations in the subsoil at the Goiania site, for example is about 11 me/100 g compared to values 1/2 that in subsoils of clayey Dark Red Latosols. Base saturation for the argillic horizon of this

profile was about 80 percent.

The information about this kind of soil is too limited for more than conjecture about applying results of the work at Planaltina to them. One would expect results of the nitrogen experiments to have some applications in these areas. If data from parts of Sao Paulo far from the area studied can be applied, exchangeable aluminum may be high in absolute values even though exchangeable bases are also relatively high. This is uncertain. (See Commissao de Solos, 1960, profile 1, p. 91 and profile 3, p. 105.) Phosphorus fixation may be less, but that too is uncertain. No relevant information about moisture characteristics is at hand.

Supplemental Laboratory Work

Six sets of soil samples were taken during the study for selected laboratory determinations to supplement the information available. These have not reached the laboratory at this writing, and a supplementary report will be issued when the data are available.

Each of the six sets consists of samples from 0 to 20, 40 to 60, and 100 to 120 cm depths taken by bucket auger in undisturbed areas. The sites were chosen to represent the following:

1. A Dark Red Latosol, clayey texture, cerrado vegetation in the southern section of the study area.
2. A Dark Red Latosol, loamy (medium) texture, cerrado-forest transition in the southern section of the study area
3. A Dark Red Latosol, clayey texture, cerradão vegetation in the western section of the study area
4. A Red-Yellow Latosol, clayey texture, cerrado vegetation, representing the yellow end of the range in the western section of the study area
5. A Red-Yellow Latosol, clayey texture, campo cerrado vegetation in in the northeastern section of the study area

6. A Red-Yellow Latosol, loamy (medium) texture, campo cerrado vegetation on the Experiment Station of Brasilia, representing a potential experimental site on the highest erosion surface.

Conclusions

1. The results of the cooperative soil research at the site currently used on the Experiment Station of Brasilia (Estacão Experimental da Brasilia) should apply in principle to an immense area on the central plateau of Brazil.

2. Applications of the results may vary in detail on different kinds of soil of the plateau.

   a. The evidence indicates that the experimental results may be transferred directly to the dystrophic clayey Dark Red Latosols, with only such special adaptations of farming practice as may be needed to accommodate the effects of past land use, local environmental and topographic conditions, resources and skills of farm operators, and the like for specific sites. The aggregate area of these soils is very large. The topographic position of the experimental site is similar to that which farmers now cultivating soil in the valleys first encounter as they extend their operations to the less fertile soils of higher-lying land.

   b. The evidence indicates that the experimental results may be transferred similarly to most, but not necessarily all, areas of dystrophic, clayey, Red-Yellow Latosols. (See Conclusion No. 4 also.) The exceptions would appear to be mainly some areas that have evidence of excessive wetness at times, presumably during or following periods of high rainfall. These exceptions are mainly at places where seep-

age occurs, such as areas at the base of escarpments and on the lower-lying parts of very long slopes. Some nearly level areas that do not receive water from adjacent higher-lying land but have little runoff or lateral seepage may also have similar problems. The aggregate area to which results should apply directly is very large. The principal fertility problems should be similar on the periodically wet areas to those of better-drained sites, but water control should present special problems during the rainy season.

c. The loamy (medium textured) dystrophic varieties of both Dark Red and Red-Yellow Latosols have lower organic matter, lower exchange capacity, and possibly different moisture relations than their clayey equivalents. Some differences of needs in practice when the research results are applied should be expected, although the principles established should apply generally. Rates and timing of nitrogen applications, for example, may need to be different than on the clayey varieties, especially during the first few years of cropping. Large differences in requirements for phosphorus and zinc, however, would not be anticipated. Liming practice may need to be modified slightly. The data show significantly lower moisture equivalents for the loamy varieties, but it is by no means certain that their capacities to supply moisture for plants is less than that of the clayey soils. There was some feeling on the part of Brazilian authorities that water supplying potential might even be better. (See Conclusion No. 4 also.)

d. Eutrophic varieties of both Dark Red and Red-Yellow Latosols not only have higher base status than their dystrophic equivalents but

should also have lower exchangeable aluminum and less restricted rooting in the subsoil. This implies that not only liming needs may be different but also soil moisture problems may not be so great. It is possible that phosphorus management may differ as well. Nevertheless, the principles that apply to the dystrophic varieties should apply to the eutrophic soils also.

e. The needs for culture of eutrophic "Red Yellow Podzolic Equivalents" (Alfisols) may be significantly different in detail from those of the Latosols. The information available is inadequate to do more than speculate about most of these potential differences. It is likely, for example, that the nitrogen fertilizer practice needed may be similar to that at the experimental site, but the needs for lime and phosphorus could be different.

3. Whether or not the different vegetative types (cerrado, cerradão, campo cerrado, semideciduous forest) are reliable indicators of inherent differences in fertility needs for farming remains unresolved. Experience of Brazilian authorities would indicate that soils under cerradão, for example, may have enough higher native fertility to be significant for a few years cropping in primitive systems that lack fertility inputs from outside sources. This is not likely to be evident for more than a few years. In systems that employ fertilization, the difference is not likely to be measurable in crop response, if it exists. Soils under semideciduous forest may have greater advantages for primitive systems. They are not likely to differ enough from those under cerrado vegetation to materially affect fertilizer practice in modern systems unless the forest is associated with eutrophic soils, as it commonly is.

4. Enough uncertainty exists about the relationships between the clayey soil at the experimental site and loamy varieties, Red-Yellow Latosols, and soils that do not lie near an escarpment to a higher surface to justify a satellite experiment to test potential differences. A site for a satellite experiment was located on the highest erosion surface on the Experimental Station. Local scientists indicated that similar sites are receiving considerable attention from persons seeking to establish large-scale farming operations in the region. The soil is a loamy Red-Yellow Latosol. It has been suggested that a simple experiment be establishment on it to test crop behavior with selected phosphorus-lime treatments used at the main site, and that soil moisture relations be followed during the cropping season. Water for irrigation is not available at the site. Any differences found would be potentially the result of confounded effects of soil differences related to soil color and soil texture, of topographic position, and of lack of irrigation. If significant differences were found and could not be explained by observations and data, it may be important to locate other sites through which the effects of confounded factors can be resolved.
5. An attempt should be made to assemble the information available about the response of crops to fertilization, liming, and water control on the eutrophic varieties of Dark Red and Red-Yellow Latosols. Data may be available from experiment stations at other places, such as Anapolis, and may indicate what differences in needs for farming practice, if any, exist between these soils and dystrophic varieties.
6. The capacity of the Dark Red and Red-Yellow Latosols to supply water for plants during relatively short dry periods in the rainy season appears to

be one of the very critical factors in crop production. It is suggested that Brazilian authorities may wish to investigate the feasibility of constructing small ponds or reservoirs on suitable land forms of these soils to supply water for supplemental irrigation during the rainy season. The climatic data seen suggest that small ponds should be full at most times during the rainy season and that if enough water can be impounded for even one irrigation it might make the difference between a reasonable yield and crop failure.

7. The feasibility of developing a viable agriculture on the dominant soils of the region will, in our judgment, depend on the skill and resources of farm operators for applying intensive inputs of fertility, lime, and water control and on the economics of returns from intensive systems. It would, in our judgment, be a disservice to people who lack such skills and resources to encourage them to undertake farming on these soils. For these reasons, we believe that the experimental program should be oriented to systems that employ intensive inputs, but without prejudice as to whether those inputs are applied to small or large farming operations.

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