A COMPARISON OF THE SOILS OF TROPICAL LATIN AMERICA AND TROPICAL AUSTRALIA

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ABSTRACT

This paper describes the contrasting soil properties between the areas concerned with improved tropical pastures in Australia and its counterparts in Latin America. In Australia the predominant soils are Alfisols and Vertisols, with smaller proportion of Entisols, Aridisols, Ultisols and Oxisols. In Latin America, Oxisols and Ultisols predominate; smaller areas of Alfisols, Inceptisols and Entisols also occur. Climate in Australia is characterized by six to eight months of dry season, with cool temperatures including common frosts as far north as 17°S. In Latin America the savanna regions have four to six months of dry season, no frosts, while the upper Amazon basin and other regions have no significant dry season. The predominant vegetation in the Australian tropics with 500 mm annual rainfall is woodland savannas. Soil pH values in the Alfisol and Vertisol regions of Australia range from 5.5 to 9.0. These soils do not present Al toxicity problems and their supply of exchangeable bases is generally high. High levels of exchangeable Na are common in some subsoils. The P fixation capacity of these soils as well as many Australian Ultisols is low. Nevertheless P and S deficiencies are widespread and Mo and Zn deficiencies are important in many areas. In the savannas and jungles of Latin America, soil pH ranges from 3.8 to 5.5, with higher exchangeable Al saturation and common Al toxicity. Exchangeable base status is low and no exchangeable Na is present. P fixation is high in Oxisols and Ultisols, except those with sandy topsoil texture. In addition to P, Ca and Mg, K and S deficiencies are widespread, and micronutrient deficiencies common but less well characterized. N deficiency is acute in both Australia and Latin America. In general, Australian Alfisols and Vertisols present more serious physical limitations than chemical ones, while in Latin America the dominant Oxisols and Ultisols present more serious limitations related to acid soil infertility. Direct extrapolation from one continent to another is therefore limited. Tropical legume species adapted to Australian conditions are not likely to be successful in most Oxisols and Ultisols of Latin America, and viceversa.

The tropical portions of Australia and Latin America contain the largest areas in the world devoted to extensive beef cattle production. These areas are characterized by their vastness, low population density, soils of low native fertility, and considerable distance from main markets. These limitations make pasture-based beef production the main agricultural activity, unless relatively high investments in fer-

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tilizers and infrastructure permit profitable crop production. In Latin America the largest expanses occur in the savannas of the Llanos of Colombia and Venezuela, and the Cerrado of Brazil; also in the Amazon basin and other rain forests which have been cleared for agriculture, and on many hillsides on the lower slopes of the Andes. In Australia, the region capable of supporting improved tropical pastures is usually defined as that receiving more than 500 mm annual rainfall, and this paper will concentrate on this area. Tropical Latin America has large areas of more fertile soils devoted primarily to crop production, and coastal desert strips. Tropical Australia has small high rainfall areas devoted to sugar cane production and other crops, and a vast interior desert area.

The two continents have been closely linked in terms of tropical pasture development. The growth of the beef industry in tropical Australia is relying on the introduction, adaptation and widespread use of pasture legume species collected from Latin America and grasses mainly from Africa. Likewise, more recent efforts in tropical Latin America are based on the Australian experience, either in terms of research strategy or by attempts to directly adapt Australian cultivars to Latin America. This relationship suggests the need for quantifying the physical similarities and differences between these two continents in order to gain a better understanding of the kind and degree of possible extrapolation. The purpose of this paper is to compare the soil environment of tropical Latin America and tropical Australia with particular reference to their role in pasture production for cattle. For uniformity, soil taxonomy terminology (60) is used in this paper. The main definitions appear in Appendix 1 and the translation of Australian terminology to soil taxonomy equivalents is shown in Appendix 2.

CLIMATE

Australia

The Australian tropics comprise approximately 227 million ha, about 32% of the country. The most striking feature is their general aridity. About 44% of tropical Australia has annual rainfall greater than 500 mm; only 12% receives more than 1000 mm (Fig. 1). Areas receiving more than 1500 mm are confined to far northern Cape York Peninsula and a narrow zone fringing the northeast coast where a few small areas receive as much as 4000 mm. This "wet coast" area occupies less than 1 million ha.

Annual rainfall decreases with increasing distance from the coast. Figure 2 shows a transect from Townsville on the coast, southwestwards to Charters Towers (125 km inland) and Hughenden (300 km inland) near the arid limit. Figure 2 also shows an example of the wet coastal area at Innisfail.

More important than total rainfall is its seasonal distribution and variability. All areas have a strongly summer-dominant rainfall pattern. In general, areas with mean annual rainfall of about 1500 mm or more have a plant growing season of more than six months. With the exception of the wet coast which has a udic soil moisture regime (<three months dry season), all areas above the 500 mm isohyet can be classified as ustic. Towards this lower limit, the length of season during which useful pasture growth occurs is three months or even less, denoting an aridic soil moisture regime. However, variability of rainfall is high over all except the northern extremities, and the irregular incidence of tropical cyclones and rain depressions may lead to extreme intensities being registered in near-coastal regions.

Mean annual temperatures in tropical Australia are above 22°C with sufficiently low variability in northern near-coastal areas to classify the soil temperature regime as isohyperthermic. Most areas in the inland portions of tropical Australia have a hyperthermic soil temperature regime. In the eastern parts, frosts may occur over inland regions as far north as about 17°S; hence the growing period of tropical pasture species may be restricted by low night temperatures.

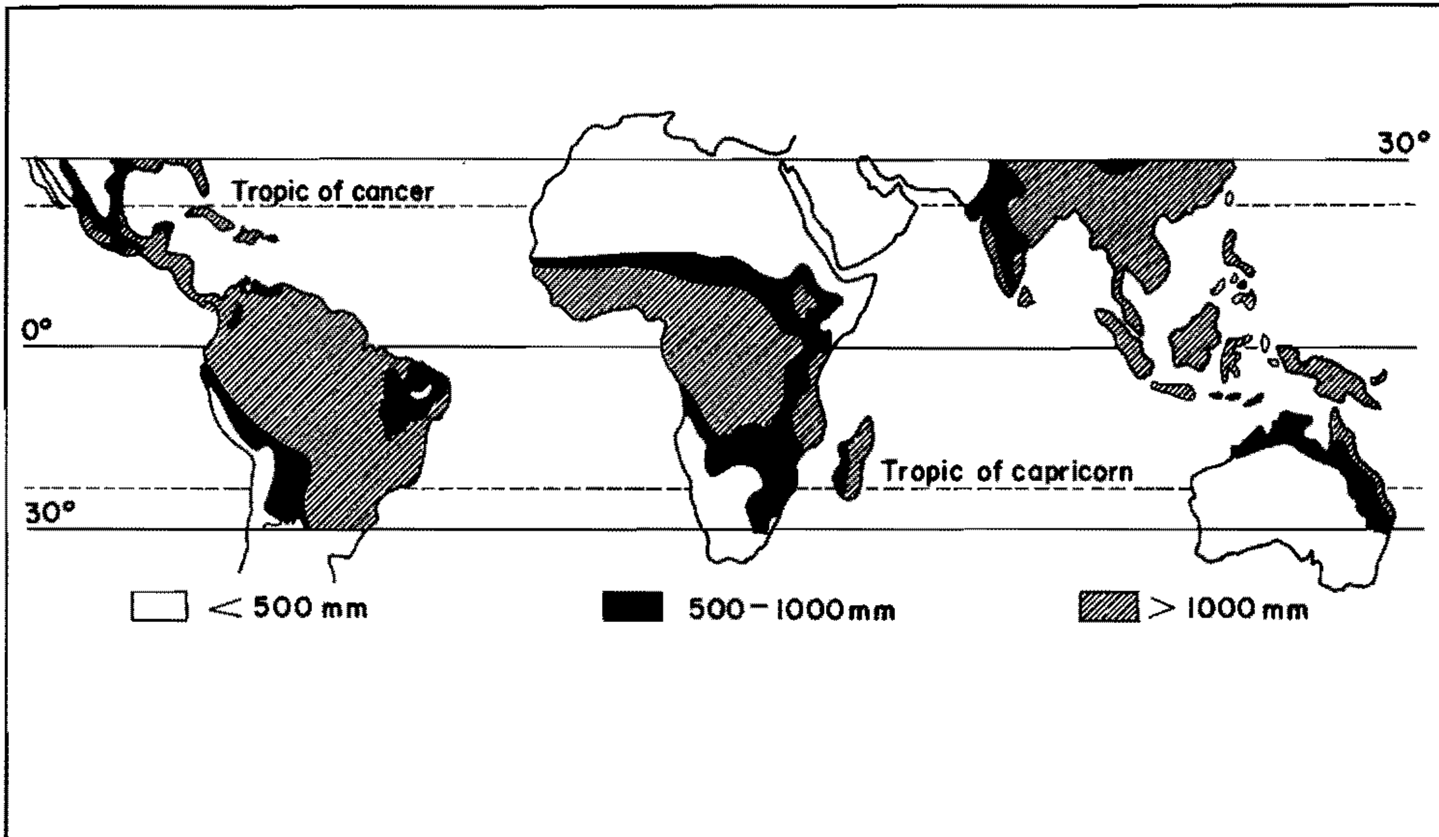


Figure 1. Annual rainfall regimes of tropical and subtropical regions of the world (25).

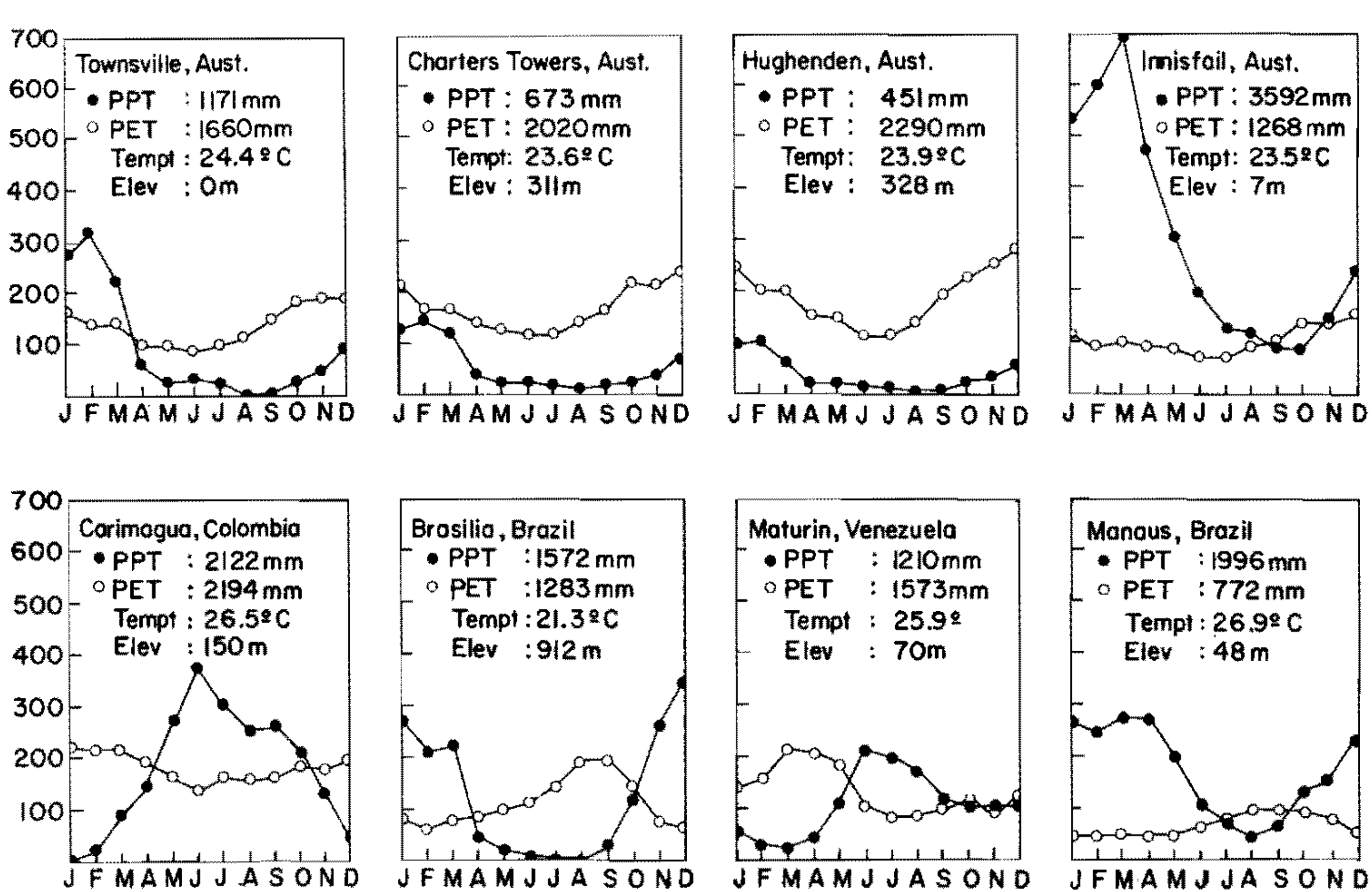


Figure 2. Climatic summary of four locations of tropical Australia and tropical Latin America.

Latin America

Tropical Latin America covers about 1514 million ha, or 77% of the land of the countries south of the U.S. border. Climatically, it is more complex than tropical Australia, and in general more humid. Over 90% of tropical America receives more than 500 mm annual rainfall and more than 70% receives in excess of 1000 mm. Vast areas in the Amazon basin have annual rainfall in excess of 2000 mm.

Much of the land area lies in equatorial latitudes, and in fact the region has the earth's greatest continental extent of humid tropical climates, areas in which plant growth is restricted by moisture stress only for very short periods of the year. These areas have a udic soil moisture regime and encompass about 42% of tropical America. Another 43% has an ustic soil moisture regime which can be divided into two broad groups: (1) Areas with more than 1000 mm/yr with a four to six month-long dry season when pastures suffer serious water stress; this includes most of the savannas, the eastern Amazon, and most of Central America. (2) Sub-humid regions (<1000 mm) with strongly seasonal and highly variable rainfall. This includes northeast Brazil, southern Bolivia-northern Paraguay and central Mexico, with smaller areas in Venezuela, Colombia and sub-coastal Peru (Fig. 1). Here, plant growing seasons are always less than about six months and may be as little as three months. About 7% of the region consists of seasonally flooded plains with a strong dry season as well. Examples of these are the Llanos of Casanare-Apure in Colombia and Venezuela, the Pantanal of Brazil and Paraguay, and the Guayas basin in Ecuador. The remaining 7% are deserts, the principal one in northern Mexico, followed by the coast of Peru, and the Guajira Peninsula in Colombia and Venezuela, all with aridic soil moisture regimes.

Although there are a few areas in lowland Latin America where low temperatures may inhibit plant growth (chiefly in temperate southern Brazil), low temperatures induced by high altitudes are common in much of the Andean region and to a lesser extent in parts of Central America and the Caribbean.

Figure 2 shows climatic summaries of four stations representing three savanna regions and one jungle region where pasture production is important. Unlike the Australian data in the same figure, these stations are not representative of the entire Latin American tropics because of the wide variety of climatic regimes in this continent.

VEGETATION

There are a number of differences between the vegetation of tropical Latin America and tropical Australia. Some of these are to be expected in view of the marked climatic differences just described. Thus in Latin America there are vast areas of tropical rain forests (550 million ha) whereas in tropical Australia the wet coast rain forest area comprises less than 1 million ha.

The greater part of the Australian tropics is covered by savannas (Eucalypt woodlands) which decrease in tree density with decreasing rainfall. A characteristic feature of these woodlands is their prominent grass canopy, consisting of species of genera *Heteropogon, Themeda, Sorghum* and others. Some of the more open woodlands, particularly those on very infertile or poorly drained soils, bear resemblance to the widespread Cerrado formations of Brazil. Australia has no counterparts to the Latin American dry thorn scrubs with their prominent cacti, such as the widespread Caatingas of northeast Brazil. Nor does it have any equivalent of grassland areas such as the Llanos. The extensive treeless grassland areas of tropical Australia are mostly located below 500 mm of annual rainfall, although small areas do occur on Vertisols in the sub-humid lands of central Queensland and adjacent to the southern part of the Gulf of Carpentaria. Finally, it may be noted that nearly all the Australian communities are evergreen or semievergreen, and there are no counterparts of the subalpine communities such as the Páramos of the Andean region or the pine forests of Mexico and Central America.

GEOMORPHOLOGY

Although the two continents have some common features, there are a number of strongly contrasting geomorphic aspects. Tropical Australia is largely dominated by lowlands; areas exceeding 600 m in elevation are largely confined to parts of northeast Queensland and those exceeding 1000 m occur only as a narrow and irregular subcoastal zone in the same region. Elsewhere, extensive plains interrupted only by low-elevation ranges, tablelands or their dissected remnants are the characteristic feature of the landscape.

In contrast, while much of tropical Latin America consists of vast depositional plains or little-disturbed old erosion surfaces, there are also the spectacular mountain chains of the Andes and their continuation in Central America and Mexico. There is no active vulcanism in tropical Australia, nor are there any widespread recent pyroclastic deposits, nor any evidence of Pleistocene glacial or periglacial features. Volcanic activity is prominent in southern Mexico, throughout Central America, and in parts of Colombia, Ecuador, Peru, Bolivia and the Caribbean.

Widespread old erosion surfaces occupy vast areas in parts of Latin America, particularly on tectonically stable or uplifted areas such as the Brazilian and Guayana shields. The oldest of these surfaces are Mesozoic and the more recent, late Tertiary (34). Similar old surfaces are present in many parts of tropical Australia (21, 67) although their present extent is not on such a grand scale as in Brazil. In contrast, the much more active Tertiary and Quaternary geologic history of Central America and the Andean Region has produced youthful and often extremely unstable landscapes which have no counterparts in tropical Australia.

Within tropical Australia the chief physiographic contrasts are afforded by the uplifted, relatively youthful, dissected lands adjacent to the northeast coast, and to a lesser extent the lower but strongly dissected sandstone plateaux of the northeast part of the Northern Territory and the Kimberley region of northern Western Australia.

SOIL FORMATION

In both regions the main soil determinants are climate, geomorphic history, and parent material. Although in most instances these closely interact, in some circumstances one or other of these factors may assume dominance. From a consideration of the climatic factor alone it might be expected that Latin America would possess a much greater area of leached, highly weathered soils, and this is true. The main exceptions occur in those high rainfall areas that possess youthful, unstable slopes where erosion has not permitted deep weathered soils to accumulate, and those areas of relatively recent deposition where time has been insufficient for the formation of highly leached and weathered profiles.

Differences in geomorphic history between various parts of the two regions have had a marked impact on soil formation. This is particularly evident in parts of tropical Australia where many soils are relict and obviously formed under vastly different environmental conditions than those of today. The most striking examples are the occurrences of deep oxic Alfisols that are now found in present rainfall regimes of 700 mm or less. Similar examples are present in the drier areas of northeast Brazil (28). The effect of paleoclimates is more difficult to evaluate in those large areas of Latin America that presently have a humid climate. In particular this applies to vast areas of Brazil with old stable landscapes and a seasonally humid climate; there it is difficult to know if the deep, highly weathered soils owe their character to present environmental conditions or to more extreme leaching conditions of the past. Probably the best example of geomorphic history influencing soil formation is to be found in Central America where the youthful nature of much of the landscape, brought about largely by its active or recent volcanic history, has lead to the widespread occurrence of relatively juvenile soils that are to at least some degree independent of present climate.

The role of parent material assumes major importance in many areas of both regions, irrespective of climate. The more striking examples are usually afforded by more extreme kinds of parent materials. Thus soils formed from basalt in both continents tend to have distinctive characteristics but which may vary depending on the rainfall regime (24). Soil formed from volcanic ash in Andean South America and in Central America have characteristics not found in Australia. At the other end of the parent material spectrum the widespread occurrence of siliceous sandstones in subhumid tropical Australia has given rise to a characteristic suite of soils (mostly Entisols), as have siliceous sand deposits (e.g. old beach ridges and coastal dunes) in humid climates given rise to Spodosols in tropical Queensland and eastern Brazil.

Between these parent material extremes, there are many other soil parent materials that tend to produce characteristic soils in any given climatic environment. This is particularly evident in the subhumid, seasonal climates. Examples are many Alfisols in tropical Australia and eastern Brazil formed on intermediate igneous and metamorphic rocks, and the widespread Vertisols formed on more basic and often calcareous parent materials in subhumid tropical Australia, Mexico and Central America.

SOIL DISTRIBUTION

Sufficient information is now available to compare soil occurrence and distribution between the two continents in a generalized way. Table 1 shows the distribution of soil orders between the Tropics of Cancer and Capricorn in both continents, calculated from the FAO World Soil Map sheets (15, 16, 17), the Soil Map of Australia (61), with modifications by the authors, and converted to soil taxonomy equivalents.

Table 1 shows a major contrast between

Table 1. Comparative distribution of soil orders in tropical America and Australia (23° N-23° S). Calculated from the World Soil Maps of South America, Mexico and Central America and Australia (15, 16, 17) with author's modifications and converted to soil taxonomy equivalents.

	Tropical America		Tropical Australia	
Order	Million ha.	%	Million ha.	%
Oxisols	513	34	0.2	-
Ultisols	371	24	7.5	3
Alfisols	192	13	54.9	25
Inceptisols	168	11	2.6	1
Entisols	130	9	93.1	42
Mollisols	82	6	-	-
Aridisols	35	2	33.4	15
Vertisols	20	1	31.4	14
Histosols	3	-	-	-
Spodosols	-	-	0.8	-
Total	1514	100	224	99

the two continents. Oxisols and Ultisols cover by far the largest areas of tropical Latin America, followed by Alfisols, Inceptisols, Entisols and Mollisols, with minor occurrences of the other soil orders. In tropical Australia, Entisols, Aridisols and Vertisols are the dominant soils of the huge interior desert while in the region with more than 500 mm annual rainfall Alfisols predominate, followed by Entisols, Vertisols, Ultisols and Inceptisols, with very much smaller areas of Aridisols, Spodosols and Oxisols.

Figure 3 shows the geographical distribution of soil orders in tropical Australia and Figure 4 is its counterpart for tropical Latin America. The definition of soil taxonomic terms appears in Appendix 1 and the conversion to Australian soil terminology is shown in Appendix 2.

Oxisols and Ultisols

For several reasons it is appropriate that these two orders be considered together. Firstly, it is becoming increasingly apparent that in many tropical areas it is often difficult to distinguish between them (23). The second reason concerns the fact that most Oxisols and Ultisols are chemically and mineralogically similar, presenting similar problems of soil acidity and low nutrient availability.

Figure 3 shows that Oxisols are of very minor occurrence in tropical Australia (0.2 million ha), the chief forms being those formed on basalt under moderate to high rainfall in north Queensland, locally known as Krasnozems (24). Small areas of Oxisols also occur associated with Ultisols and Inceptisols on other parent materials in the higher rainfall areas of north Queensland, and some near the lower rainfall limit of 500 mm. The later are probably relict soils, product of a previous climate.

In tropical South America Oxisols are the dominant well drained soils of the areas affected by the Guayanan and Brazilian shields, including the Cerrado, the Llanos and the eastern Amazon basin. Calculations from the FAO-UNESCO (15) map show a total of 609 million ha of Oxisols. However, Sánchez and Buol (53) have claimed that large areas of the upper Amazon basin of Peru consist of Ultisols rather than Oxisols as presently shown in the FAO maps. Ultisols and acid Inceptisols are also extensive in the Amazon of Colombia (3). The revised Oxisol area of tropical America is thus reduced to 513 million ha. Oxisols of tropical South America occur on many of the widespread old erosion surfaces, although they have also been identified as occupying large areas on more recent depositional plains. Few of these soils have any counterparts in tropical Australia. A widespread soil formed on basalt in Brazil —the Latosol Roxo— is morphologically unlike any present in north Queensland. In contrast to South America, Oxisols are scarce in Mexico, Central America and the Caribbean, covering only 0.6 million ha, slightly more than tropical Australia.

Ultisols in tropical Australia are confined to the higher rainfall areas near the coast. Although most are highly weathered soils with oxic chemistry and mineralogy, they possess a characteristic clay increase with depth, which separate them from the Oxisols. Most are formed on acidic parent materials on landscapes that range from youthful to very old. The most common forms are Red and Yellow Podzolic soils and Xanthozems on acid igneous rocks, and Red and Yellow Earths on sedimentary rocks and sediments.

Ultisols are extensive in tropical Latin America, covering 371 million ha. They are fairly common in the higher rainfall areas of Central America (about 20 million ha) but are more widespread on gently sloping outwash plains of the Amazon and Orinoco basins, and on more dissected parts of the Brazilian and Guayanan shields. Most Ultisols of tropical South America bear a close morphological similarity to those of northeast Australia.

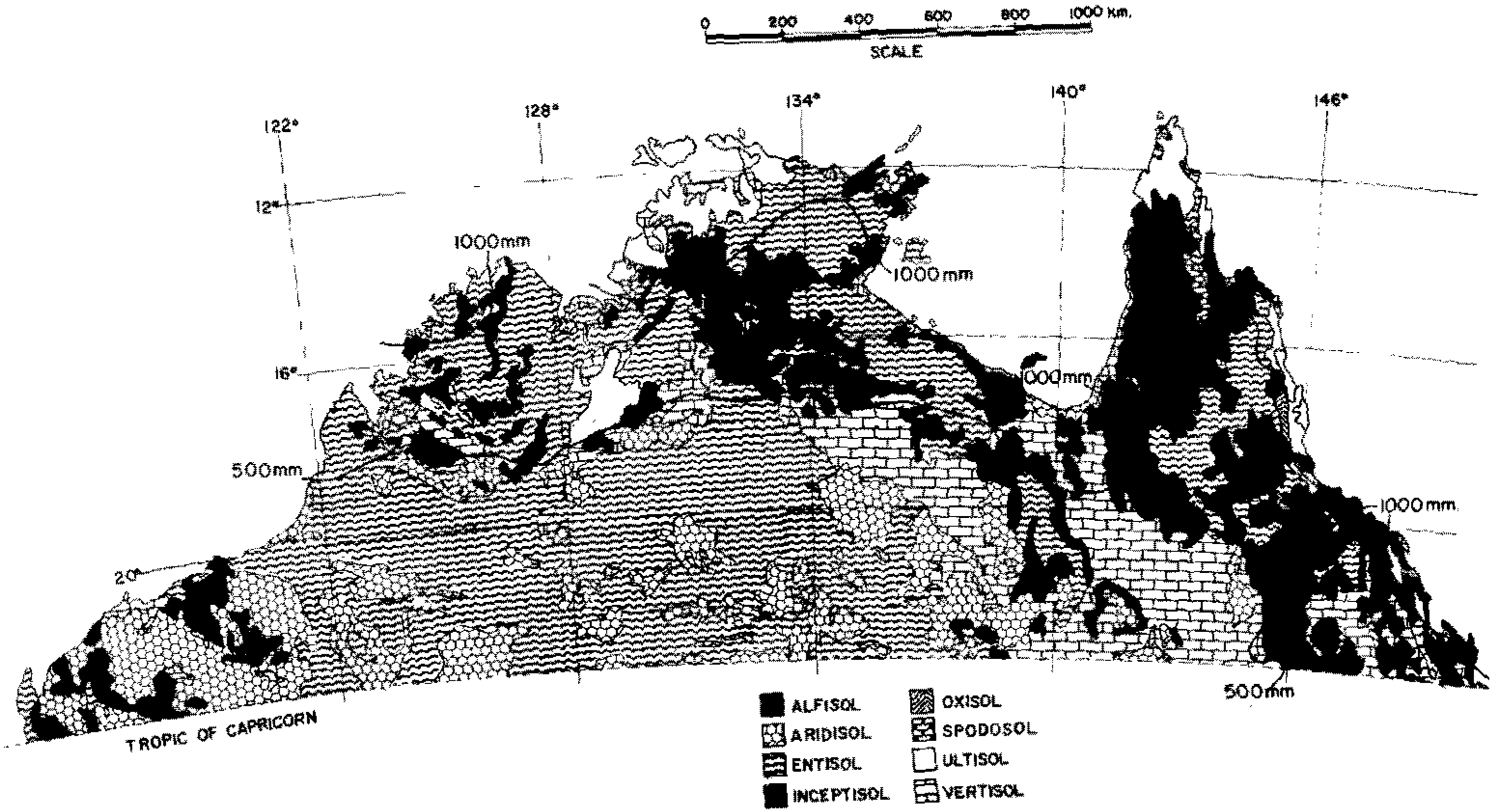
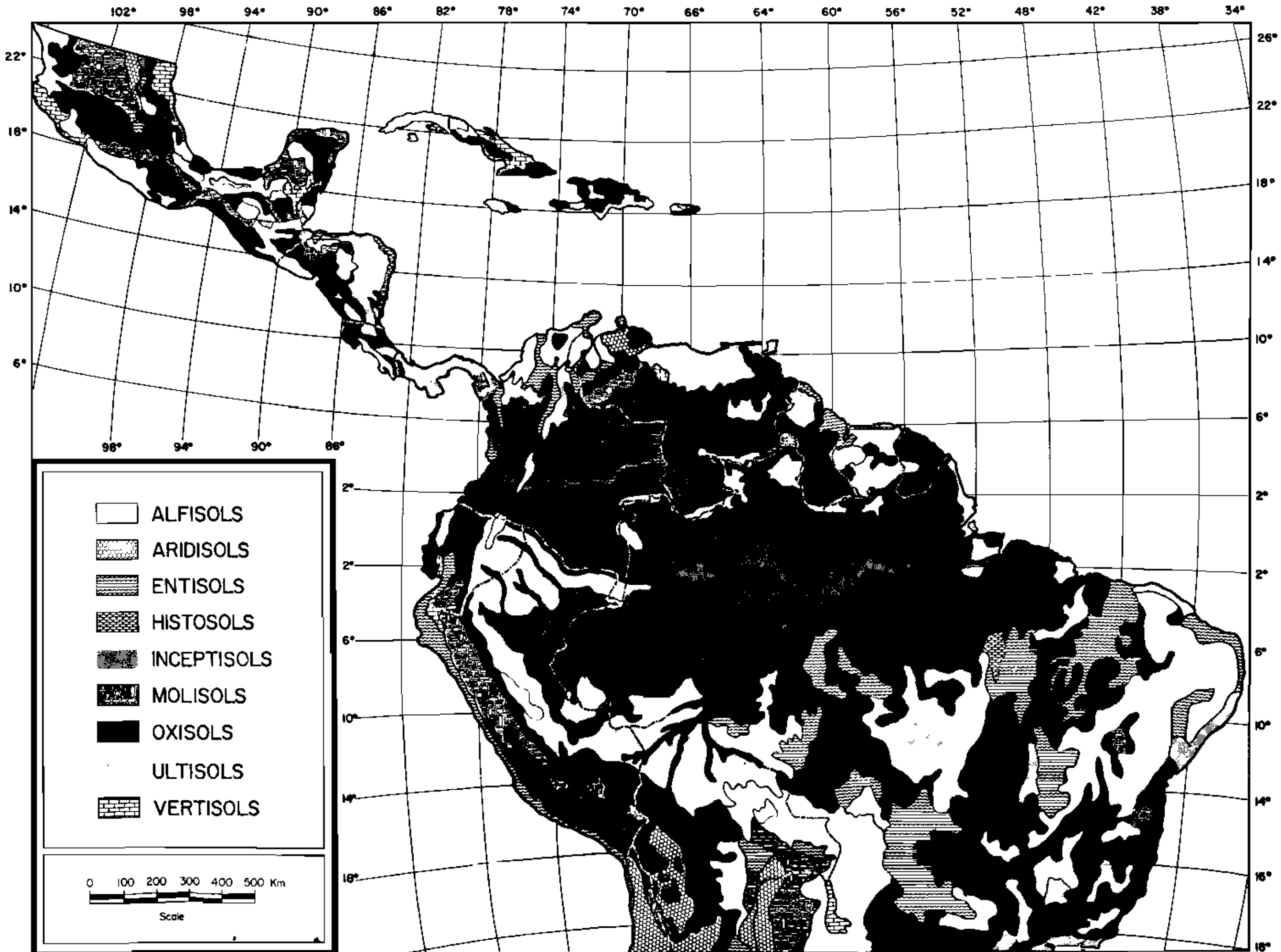


Figure 3. Soil map of tropical Australia


ALFISOLS
ARIDISOLS
ENTISOLS
HISTOSOLS
INCEPTISOLS
MOLISOLS
OXISOLS
ULTISOLS
VERTISOLS
0 100 200 300 400 500 Km
Scale

Alfisols

The most characteristic feature of the Australian tropics is the dominance of Alfisols, particularly in Queensland. Nearly all occur in ustic climates with a pronounced seasonal rainfall. Alfisols occur on an extremely wide variety of landforms which may range from mid or late Tertiary surfaces to recent alluvial plains and dissected hilly areas. The majority of the soils are locally known as Red, Yellow and Grey Earths (many of these have oxic properties), Solodics, Non-Calcic Brown soils, Euchrozems, and some Red and Yellow Podzolics.

Perhaps the most striking feature of the Australian Alfisols is the widespread occurrence of sodic forms (Natrustalfs) which are particularly prominent in the subhumid areas of Queensland. These are locally known as Solidized Solonetz and Solodic soils, occasionally Soloths. In total, Alfisols occupy about 55 million ha in the Australian tropics.

Alfisols are also common in the lower rainfall areas of tropical Mexico, Central America and the Caribbean (32 million ha), derived from generally basic parent materials, but in tropical South America they occupy 160 million ha, mostly in the less-humid regions, such as in northeast Brazil, the north coast of Colombia and western Venezuela. In northeast Brazil they occur on a wide range of land forms and parent materials. In more dissected areas of igneous rocks they often resemble their Australian counterparts. On the more basic gneisses and metasediments of the Brazilian shields, islands of Alfisols are found in oceans of Oxisols. These are the Non-Calcic Brown soils which are morphologically very similar to those in Australia.

Mention must also be made of the Terra Roxa Estruturada (Rhodic subgroups of Peleustalfs, Paleudalfs or Paleudults) which although occupying only relatively small areas in the south of Brazil, is a most important agricultural soil. Formed mostly on basalt, these soils bear a close morphological resemblance to the eutrophic Krasnozems of north Queensland. Finally, it is noteworthy that in some less humid parts of northeast Brazil (Bahia, Pernambuco and Ceará) sodic Alfisols (Natrustalfs) occur that are very similar to those in tropical Australia.

Vertisols

Vertisols are an important and characteristic feature of the soil landscapes of tropical Australia, particularly in the subhumid regions where they occur widely on basic igneous rocks such as basalt, on felspathic or calcareous sedimentary rocks, and on alluvial deposits derived from base-rich parent rocks.

Some Vertisols occur in regions with as much as 1500 mm rainfall but all areas are characterized by extremely seasonal rainfall conditions. The darker forms are known as Black Earths and those with higher chroma, Grey, Brown or Red Clays. In Central Queensland vast areas of Vertisols occur immediately below the 500 mm rainfall limit adopted for this study.

In Mexico and Central America Vertisols are also common in the less humid regions where they occur mainly on calcareous and volcanic rocks or derived alluvial material. In sharp contrast, Vertisols are only sparingly present in South America, and almost all are in lower rainfall regions. The chief occurrences are in coastal Ecuador and adjacent northern Peru, western Venezuela and small areas in Colombia.

Entisols

Large areas of tropical Australia are occupied by Entisols, mostly sandy soils of the suborder Psamments. They are found on dissected upland areas of sandstone, quartzite and other mainly siliceous rocks. Most soils in these situations are shallow. Elsewhere on old outwash fans deeper

Entisols are locally prominent (called Earthy and Siliceous Sands). At the 500 mm rainfall limit, old wind modified sand sheets and occasional dunes occur (e.g. near Broome in Western Australia). Small areas of Entisols formed on low terraces of streams (the classic alluvial soils of the suborder Fluvents) occur widely throughout the region.

Many of the large areas of Entisols in Latin America are very different to those occurring in tropical Australia. Thus in central and eastern Brazil where Entisols are widespread the chief forms are deep Oxic Quartzipsamments (Areias Quartzisosas). These are deep red or yellowish sands formed from siliceous parent materials on old erosion surfaces. In stark contrast, considerable areas of shallow gravelly Entisols occur throughout the steeper parts of the Andean system and other mountainous areas. Finally, extensive areas (in aggregate) of Fluvents are associated with many of the major river systems.

Entisols do not occupy large areas in Mexico, Central America and the Caribbean, although shallow gravelly kinds are probably common on the lower-rainfall mountainous areas and Fluvents are locally important associated with major streams.

Inceptisols

In tropical Australia Inceptisols are only common in two localities. In the high rainfall areas of northeast Queensland they occur associated with Oxisols and Ultisols on metamorphic rocks. The chief forms are Dystropepts (acid young tropical soils). The other main area of occurrence is in some lower rainfall parts of northern Australia where they occur as shallow soils formed on basalt and are associated with Alfisols. These forms are mostly Ustropepts (non-acid Inceptisols).

In contrast, Inceptisols are widespread soils in Andean South America and the mountainous areas of Mexico, Central America and the Caribbean. Andepts (volcanic ash soils) are of particular importance in the latter area, and also in parts of Colombia, Ecuador, Peru and Bolivia. Other Inceptisols (mainly Dystropepts) are common in these mountainous areas, as well as on the more hilly areas of eastern Brazil. Finnaly it is likely that large areas of Aquepts (wet Inceptisols) occur in the extensive seasonally flooded areas areas of the Llanos, the Guayas basin, the Pantanal and along the major river systems.

Aridisols

The small areas of Aridisols in tropical Australia above the 500 mm isohyet shown in Figure 3 all consist of highly saline soils (Salorthids) that occur on coastal saltpans and estuarine flats that are occasionally flooded by tidal waters. Elsewhere in tropical Australia below the 500 mm rainfall limits Aridisols are extensive in the desert areas.

In South America similar saline soils occur fringing parts of the coastline in eastern Venezuela, the Guayanas and northern Brazil. Elsewhere in tropical Latin America, Aridisols are limited to the Mexican, Peruvian and Guajira deserts.

Spodosols

Small areas of these soils occur in the wetter areas of Queensland, mainly adjacent to the coast where they have formed in sand sheets, old beach ridges and modified dunes. These are the classic tropical Podzols. However, many are giant forms similar to those described by Thompson and Hubble (66). Similar soils occur as narrow fringes to a number of parts of the coast of Brazil. Spodosols are also known to occur on coarse-textured alluvial materials in parts of the Amazon basin (35, 53).

Mollisols

Although these very fertile soils are rare in tropical Australia, they are locally important in subhumid parts of tropical Latin America, where they cover 82 million ha. Particular examples are in Central Mexico and the Yucatan Peninsula, in some drier inter-andean valleys of Peru and Colombia (including the Cauca Valley), in northwest Argentina and in northern Paraguay.

Histosols

The organic soils occur in small localized areas of both continents, none of them large enough to appear at the 1:5 million scale used in the FAO maps.

SOIL PHYSICAL PROPERTIES

The remainder of this paper confines the comparison to the tropical pasture areas of Australia with > 500 mm annual rainfall with the savannas and jungle areas of tropical America. Thus, the desert interior of tropical Australia, the Andean region, northeast Brazil, and most of Central America and the Caribbean are excluded from this discussion.

Water stress

Although in both regions water is a limiting factor during parts of the year, the magnitude of seasonal water stress is more pronounced in Australia, due to the generally longer dry season as shown in Figure 2. This is particularly acute in the Alfisol and Vertisol regions, where yearly variability in duration and intensity of drought stress is probably greater than in the savannas and jungles of Latin America.

Paradoxically, Vertisols and many Alfisols have a higher water holding capacity than Oxisols and Ultisols at the same clay content, because in the Oxisols in particular the kaolinitic clay particles are often bound by iron oxides and hydroxides into sand-sized granules, which gives them excellent structural properties, but lower water retention (52). Table 2 shows the available water ranges observed in Oxisols of Brazil and oxic Alfisols in North Queensland. In contrast, data for Australian Vertisols and those from other areas of the world are in the order of 10 to 25%. Consequently the predominant non-oxic Alfisols and Vertisols of tropical Australia store more water than the Latin American Oxisols and Ultisols, but the availability of water from rainfall is more restricted in Australia.

Table 2. **Available soil water ranges (0.1 - 15 bars, by weight) of Oxisols of the Cerrado of Brazil and oxic Alfisols from Australia (Red Earths and Yellow Earths) (38 and J. Williams, unpublished data).**

Order	% Clay	% available H_2O
Oxisols (Brazil):		
(44 topsoils)		
	<18	4.9
	18-35	8.5
	35-60	8.8
	>60	9.1
Alfisols (Australia):		
(18 topsoils)		
	5-15	11.9
	15-30	8.1
(14 subsoils, 90-120 cm)	22-55	8.1

In the highly variable rainfall environment of the subhumid Australian tropics there is extreme variation in pasture production among years. McCown (42) has shown that differences among soils in available soil water storage capacity have a substantial influence on growing season length. McCown *et al.*, (43) suggested that examination of the salt profile affords a simple means to define the depth limits to wetting. No such problems occur to a significant extent in the acid soil regions of tropical America.

Soil structure

Oxisols, because of their strong degree of granulation have excellent physical properties, which favor air and water movement, makes tillage possible soon after a heavy rain, and the uniform texture and structure with depth allows uniform percolation which makes them more tolerant (but not immune) to erosion than most other soils. Similar properties apply to some oxic subgroups of Alfisols and Ultisols, including those Krasnozems and Euchrozems in Australia which are Alfisols. These are the ultimate soils in terms of desirable physical properties.

Ultisols, particularly those with sandy topsoils are subject to soil compaction and erosion in both continents, but these limitations are minor compared with the difficult physical properties of two abundant groups of soils in Australia: the sodic Alfisols (Natrustalfs) and the Vertisols.

Alfisols known in Australia as Solodics, Solidized Solonetz and Soloths have massive sandy A horizons underlain by extremely dense clayey subsoils. When these subsoils are high in exchangeable Na content they have low permeability to water and hence plant rooting depth is inhibited. In spite of this limitation, tropical legumes of the genus *Stylosanthes* can persist in such soils.

Vertisols present even more severe physical limitations to pasture growth. Because of their shrink-swell properties and the hot dry environment where they occur, Vertisols with more than about 60% clay dry very rapidly at the surface, and form crusts and a loose mulch below this which impede seedling emergence of pasture species with small seeds (37). In all Vertisols, nearly all legume species currently used in tropical Australia simply do not persist (5). The reasons are not well understood but salinity may be a factor since many Australian Vertisols contain appreciable amounts of salts at relatively shallow depths, and there is evidence that many tropical pasture legumes have low tolerance to salinity (51).

Laterization

The specter of laterization of tropical soils is still a concern in the minds of many agricultural scientists and administrators. The fallacy of this argument has been documented previously (52, 53). It should be pointed out that in both tropical Australia and Latin America, laterite formation poses no threat to development since they occur in a minor proportion of the areas, usually in predictable topographic positions (at the break of slopes) which protects slopes against further erosion and provides valuable low-cost road building materials widely used in both continents.

Consequently, it can be generalized that the soil physical properties of the savannas and jungle areas of Latin America are far superior to those of most of tropical Australia in terms of rainfall supply and distribution, soil structure, and lack of physical restrictions to plant growth.

SOIL FERTILITY

Just as one can generalize that soils in tropical America are superior in physical properties, the opposite situation occurs in terms of soil chemical properties. In general, soils of tropical Australia are chemically more desirable than those of tropical Latin America. Evidence for this is provided in Tables 3 and 4 which show some properties of representative soils from both regions. The following discussion is largely based on these tables.

Soil acidity and aluminum toxicity

The most striking soil fertility contrast between the two regions is in terms of soil acidity. Tropical Australia generally lacks highly acid soils. The vast majority of surface soil pH values range between 5.5 and 6.5, with higher values present in calcareous Vertisols. At these pH ranges exchangeable Al is absent or very low and thus there is no danger of Al toxicity (30). Table 3 shows the

Table 3. **Selected topsoil chemical properties of representative soils of the tropical pasture area of Queensland, Australia.**

Soil & No.	Location	pH	Org. C	Clay	Exchangeable cations: Al	Ca	Mg	K	ECEC	Al sat.	Reference
			—— % ——		———— meq/100 g				————	%	
ALFISOLS:											
Solodic (T30)	Lansdown Sta.	5.3	1.6	9	0.2	1.4	0.7	0.11	2.7	9	*
Red Earth (T256)	Redlands Sta.	6.3	0.5	16	0.1	1.4	0.6	0.10	2.1	2	*
Yellow Earth (T255)	Redlands Sta.	6.0	0.4	10	0.1	0.4	0.2	0.04	0.7	14	*
Euchrozem (T93)	Talavera	6.6	2.5	40	0.0	16.3	7.3	1.75	25.8	0	9,10
VERTISOLS:											
Grey Clay (T13)	Hughenden	7.6	0.4	56	0.0	35.0	5.5	1.80	45.3	0	9,10
Grey Clay (B297)	Mt. Coolon	8.6	1.6	32	0.0	22.0	5.6	1.50	29.5	0	9,10
ENTISOLS:											
Siliceous Sand (T76)	Wenlock	5.9	0.4	2	0.0	0.7	0.3	0.02	1.0	0	26
ULTISOLS:											
Yellow Earth (T137)	McDonnell	4.9	1,3	10	0.9	0.1	0.1	0.02	1.1	77	*
Red Earth (T241)	Tully	4.6	3.6	22	1.4	0.6	0.5	0.13	3.3	42	9,10
OXISOLS:											
Krasnozem (T62)	Malanda	5.4	8.0	66	0.8	1.3	1.6	0.26	4.0	20	9,10
Krasnozem (T84)	Gregory Falls	5.5	6.7	63	0.04	2.5	1.4	0.17	4.1	1	9,10
Xanthozem (248)	Lake Tinaroo	5.2	3.6	19	0.5	2.1	1.4	0.18	4.2	11	9,10

* Analyzed at CIAT except for Org. C and clay which were done in Australia.

Table 4. **Selected topsoil* chemical properties of representative soils of savannes and jungle areas of tropical Latin America.**

Soil & No.	Location	pH	Org. C	Clay	Exchangeable cations Al	Ca	Mg	K	ECEC	Al sat.	Reference
			—%—		——meq/100g——					%	
OXISOLS:											
Haplustox	Carimagua, Colombia	4.5	3.2	35	3.5	0.5	0.3	0.08	4.5	78	58
Haplustox (LVE)	Brasilia, Brazil	4.9	1.8	45	1.9	0.2	0.2	0.10	2.4	79	12
Yellow Latosol (28)	Paragominas, Brazil	4.4	1.3	74	1.4	0.7	0.3	0.07	2.4	58	14
Acrustox (C)	Caicara, Venezuela	4.5	0.4	24	1.0	0.3	0.1	0.10	1.6	63	56
Haplorthox (T.A.)	La Libertad, Colombia	4.4	2.7	25	2.2	0.4	0.4	0.06	3.1	71	19
Eutrustox (1)	Capinópolis, Brazil	5.4	2.8	40	0.6	7.5	2.1	0.53	10.7	25	44
ULTISOLS:											
Paleustult	Jusepín, Venezuela	4.7	0.9	24	0.5	0.5	0.1	0.01	1.1	43	13
Paleudult (Y-13)	Yurimaguas, Peru	4.0	1.2	9	2.3	0.2	0.2	0.10	2.9	79	57
Paleudult (P-2)	Pucallpa, Peru	4.4	1.6	42	3.4	2.5	1.3	0.41	4.2	81	45
Palehumult (F-3)	Quilichao, Colombia	4.1	4.1	71	2.7	0.7	0.5	0.36	4.2	64	8
Paleudult (2)	Echaporã, Brazil	4.9	0.5	16	0.4	1.0	0.1	0.10	1.6	62	36
Paleustult (1)	Pres Murtinho, Brazil	4.7	1.0	18	0.8	0.2	0.2	0.06	1.3	63	14
ALFISOLS:											
Paleustalf (4)	Maracaibo, Venezuela	5.7	0.8	7	0.1	1.7	0.7	0.33	7.9	1	47
Tropaqualf (Y-7)	Yurimaguas, Peru	5.0	1.2	53	7.4	11.4	6.3	0.67	25.8	29	53

* When first horizon was < 10 cm, data was weighed with second horizon to depth of no less than 20 cm

generally high pH values, low exchangeable Al and low Al saturation levels of Australian Alfisols, Vertisols, Entisols and even some Oxisols. It also includes an important exception, the Ultisols from the better watered regions, which present chemical properties very similar to their Latin American counterparts (Table 4). Even in these truly acid Australian Ultisols, no major deleterious effects of Al toxicity on pasture growth have been detected (63, 64), and the lime responses that have been recorded have been attributed to overcoming Ca deficiency (27, 62, 63, 64).

In contrast, tropical Latin America is dominated by highly acid soils with pH ranging from 3.8 to 5.5 with Al saturation values commonly over 60%, a generally accepted critical level for Al toxicity (30). In these soils, acidity adversely affects plant growth because of Al or Mn toxicity as well as Ca and Mg deficiencies.

These differences also apply to subsoil properties, which perhaps are more critical since it is very difficult to correct them by management. Figure 5 shows the dramatic contrast in pH and Al saturation with depth at two experiment stations of each continent. Soil pH is uniformly low and Al saturation high with depth in the Oxisol and Ultisol of Latin America, almost ideal in the Alfisol of the Redlands Station in Australia, and undesirably alkaline in the subsoil of the Alfisol at Lansdown.

In both continents, liming tropical pastures has to be minimized because of its high cost in relation to beef production. The accepted strategy is to select and utilize pasture species tolerant to the major soil stresses (59, 68). Australian scientists have successfully developed cultivars of species such as *Stylosanthes humilis* (Aubl.) Sw., *Stylosanthes hamata* (L.) Taub., *Stylosanthes scabra* Vog. and *Macroptilium atropurpureum* (DC.) Urb. for their soils which range, as stated, from pH 5.5 to 6.5 (1, 22). Latin American scientists have found that commercial cultivars of these species are not always well adapted to Oxisols and Ultisols with pH lower than 5.5. Pasture legume species more tolerant to stronger Al

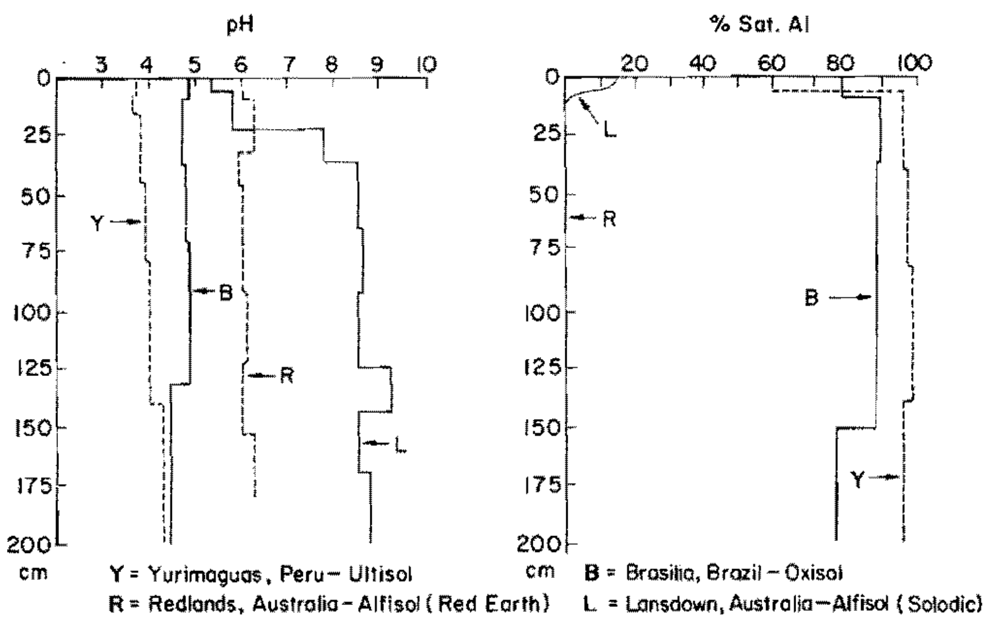


Figure 5. Soil acidity profile of two Australian Alfisols and an Ultisol and Oxisol from Latin America (9, 12, 45).

toxicity include *Stylosanthes capitata* Vog. *Zornia* spp., *Desmodium ovalifolium* Vahl. and some *Centrosemas* (8).

Exchangeable bases

The supply of Ca and Mg is generally higher in the Australian than Latin American soils as shown in Tables 3 and 4. Straightforward Ca and Mg deficiencies are common in Oxisols and Ultisols of Latin America, and are readily corrected by applying 0.1 to 0.5 t/ha of dolomitic lime (58). These rates are sufficient to overcome Ca and Mg deficiencies without altering significantly the pH and Al saturation of the soil. Mg deficiencies can be directly overcome by Mg fertilization. In Australia, Ca deficiencies have been reported in Ultisols of high rainfall areas, where apparently the response to lime could be attributed to Ca fertilization or increased Mo availability in the case of legumes. Mg deficiencies are rare in tropical Australia, but are very common in the savannas and jungles of tropical America.

Figure 6 shows the distribution of exchangeable bases with depth in four characteristic soils. The uniformly low Ca, Mg and K status of the Oxisol and Ultisol is in sharp contrast to the ample levels found in many Australian Alfisols. The Natrustalf from Lansdown depicts an inversion of the Ca:Mg ratio in the subsoil, which may negatively affect plant growth, as well as the previously mentioned increase in Na with depth.

Comparison of K status between the continents is less straightforward. Considering a generally accepted critical level of 0.2 meq K/100 g many, but not all, Alfisols, Ultisols, Oxisols and Entisols of both continents are K deficient, in contrast with the high levels observed in the Vertisols. K responses by tropical pastures in Australia have been commonly recorded on the high rainfall Ultisols and Oxisols (33), but responses on Alfisols have been much more variable. In some soils there may be plant uptake from nonexchangeable sources, but in other Alfisols this does not occur (4) and significant pasture responses have been recorded (20).

In tropical America, K is often a neglected element in pasture fertilization, particularly in Ultisols and Oxisols. Successful production of species adapted to high soil acidity has been possible when K deficiencies have been corrected, usually by modest applications (8, 45).

Organic carbon and nitrogen

There are no major differences between tropical Australia and Latin America in these two parameters. Data in Tables 3 and 4 show that the main soils in both continents have low to medium OM contents, in predictable amounts as a function of climate, vegetation and soil texture. In general, soils of both continents are severely deficient in N, except for some Vertisols and virgin rain forest soils.

Phosphorus

Australian soils are generally very deficient in P, and so are the soils from the savanna and jungle regions of tropical America. Direct comparison of available P levels between the two continents is not possible, because the extraction methods are different. Australian scientist use 0.01 *N* H_2SO_4 extractant and they consider 15-20 ppm P as the critical level for most tropical pasture legumes. Data show that P deficiency is acute in all tropical Australian soils except for most Vertisols and soils derived from basalt (Euchrozems and some Krasnozems) which can be Alfisols or Oxisols (4). Latin American scientists use a wide range of soil extractants such as the Olsen bicarbonate method, the North Carolina dilute double acid, and Bray I and II. The only well established critical levels are related to cereal crops, such as 15 ppm P for Olsen in Peru, 10 ppm P for the North Carolina method in Brazil and 15 ppm P for Bray II in Colombia. The critical levels for tropical pasture species are likely to be

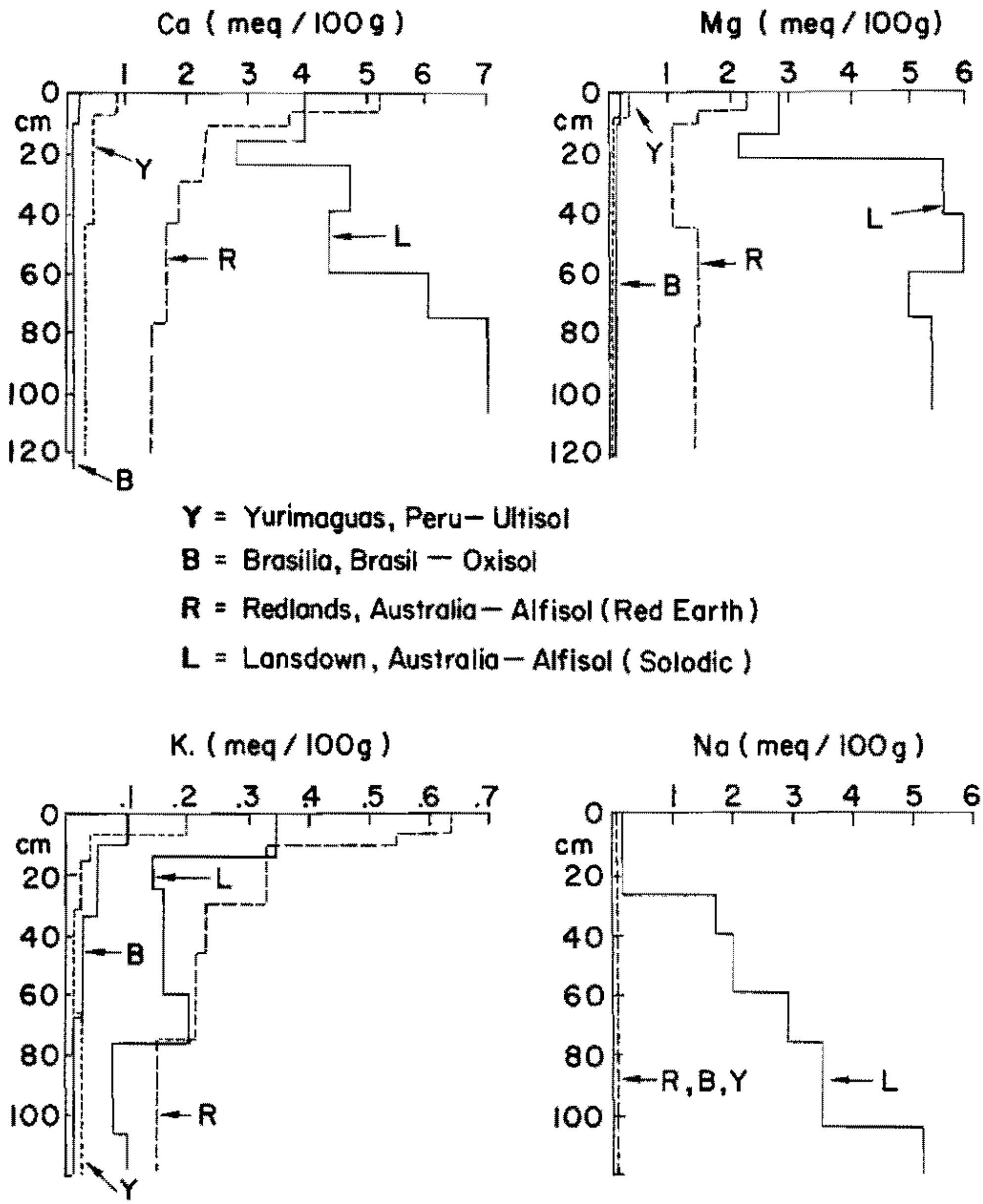


Figure 6. Profile of exchangeable bases in two Australian Alfisols and two Latin American acid soils (9, 12, 45).

lower. Preliminary data show that the Bray II critical levels for adapted tropical pasture legumes is in the order of 3 to 7 ppm P (8). Soil test summaries such as those of the Cerrado of Brazil (39), Colombia (40) and Peru (6) show that the Oxisol and Ultisol regions are extremely deficient in available P.

The big difference between the two continents is the capacity of the soils to fix P, that is to make P applications largely unavailable to plants. Figures 7 and 8 show P fixation curves of representative topsoil samples analyzed according to the Fox and Kamprath (18) method. From Figure 7 it appears that all except one of the samples (which represent common tropical Australian soils) have low fixation capacities, requiring less than 70 ppm P to reach a level in the soil solution of 0.05 ppm P, which is probably adequate for pasture growth. In contrast, most of the Oxisols and Ultisols of Latin America require 3 to 5 times more P to reach a similar level (Fig. 8). The important exception in Australia is also an Oxisol (Gregory Falls Krasnozem). It is derived from basalt and has a high oxide content.

In soils high in Fe and Al oxides such as some Oxisols, Ultisols and oxic Alfisols, P fixation generally increases with increasing clay content (48, 38, 55). This can be observed in Figure 8 where the Brasilia and

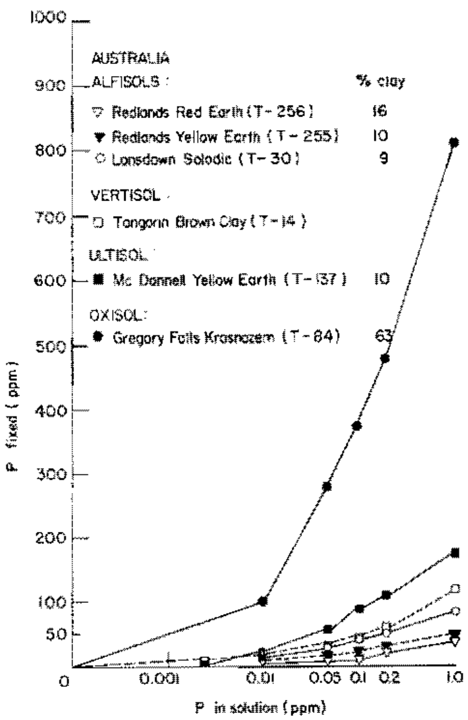


Figure 7. **Examples of P sorption isotherms of representative soils in tropical Australia.**

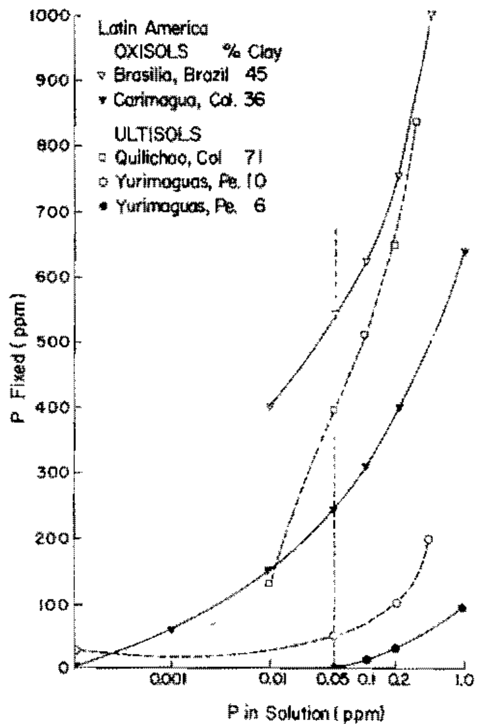


Figure 8. **Examples of P sorption isotherms of representative soils in Tropical America (7, 45).**

Carimagua Oxisols and the Quilichao and Yurimaguas Ultisols have totally different P fixation curves and clay contents. Soils low in Fe and Al hydroxides such as the Lansdown Solodic generally have low P fixation capacity.

It can be concluded therefore, that while both regions suffer from acute P deficiency in most of their soils, the amounts of fertilizer P needed to overcome the deficiencies are likely to be higher in Latin America because of the generally higher P fixation capacity of the widespread Oxisols and Ultisols (except the sandy ones).

Sulfur

S deficiencies are considered widespread in both the Australian and Latin American tropics (29, 30). This is an important reason why SSP and not TSP is the main form of P used in Australia.

The evidence in tropical Australia suggests that S deficiencies are more frequent on soils with limited capacity to sorb, and hence retain S, and where seasonal leaching occurs. Even though input of S from rainfall may be low, in some soils (e.g. Oxisols and some Ultisols) high levels of sorbed sulfate can occur in subsoils (49). Recent studies (50) suggest a critical level of 4 ppm of SO_4-S (extracted by the phosphate method) in the entire profile for tropical pastures.

S deficiencies are widespread but not universal in Oxisols and Ultisols of Latin America, with significant responses observed in tropical pastures (7, 41, 65). There is also evidence of sulfate accumulation in subsoils with relatively high S sorption capacity, typical of some Oxisols, Ultisols and oxic Alfisols (32).

Micronutrients

Information on micronutrients is less well defined in both regions, apart from the fact that deficiencies of Zn, Cu, B, and Mo have been reported in both tropical Australia and tropical America (4, 11).

In tropical Australia molybdenized simple superphosphate has been widely used to correct possible Mo deficiencies (22) but responses have not been well documented. They are more acute in high P fixing soils (Oxisols and some Ultisols) since they also fix the molybdate anion by the same mechanism (33). However, there are important species differences. For example there are no known field responses to Mo recorded for the genus *Stylosanthes* in Australia (33). In Latin America Mo deficiencies occur in Oxisols and Ultisols (11, 46) but the response data are very limited.

Deficiencies of Zn, Cu and B are poorly characterized in terms of geographical distribution and economic importance. Of these Zn is probably the most important in Ultisol and Oxisol regions of Latin America (11). Mn deficiency as well as toxicities are also known to occur. The same applies to Fe deficiency both in calcareous and extremely acid soils. Cu and Zn deficiencies have been recorded in the high rainfall Ultisols and Entisols of tropical Australia (33). There is much need for establishing critical levels both in soil and pasture tissue in order to better characterize the micronutrient limitations of tropical Australia and Latin America.

CONCLUSION

Soils of tropical Australia and tropical Latin America share the common problem of low native fertility, but for different reasons. The most widespread Australian soils have more severe water stress but enjoy a higher base status than their Latin American counterparts. Although N, P and S deficiencies are widespread in both continents, the generally higher P fixation, lower K status and Al toxicity of Oxisols and Ultisols intensifies the acuteness of low fertility in Latin America. There is nothing unique about the differences described in this paper that cannot be inferred by soil taxonomy, supplemented by rather simple soil fertility analyses. Alfisols, Ultisols or Oxisols are similar, regardless of where they occur. There are strong similarities between the small region of high rainfall Oxisols and Ultisols of North Queensland with the vast areas of the same soils in Latin America, and likewise between the dominant Alfisols and Vertisols of Australia with their less widespread counterparts in tropical Latin America.

The adaptation of tropical legumes to low input management is very much soil and climate dependent. Some of the most important tropical pasture legumes in Australia today are *M. atropurpureum, Centrosema pubescens* Benth., *S. guianensis, S. humilis* and *S. hamata*. The latter two *Stylosanthes* species are well adapted to Alfisols with severe water stress, low P status and low Al stress. They are likely to be adapted to similar conditions in tropical America, but less likely to Oxisols and

Ultisols with their higher Al stress. On the other hand *C. pubescens* and *S. guianensis* adapted to more acid rain forest Ultisol and Oxisol conditions in North Queensland may have a strong potential for the Amazon Jungle. However *M. atropurpureum* cv. Siratro is well adapted to higher pH Oxisol areas of the Brazilian Cerrado.

These statements are limited to edaphic adaptation, which includes climate to a certain extent. Many other factors affect species adaptation, particularly pest and diseases, seed production potential, etc. They must also be included when considering the transfer of technology from one region to another. For example, lack of persistence of Australian cultivars of *S. guianensis* in tropical America is primarily due to their susceptibility to anthracnose (caused by *Colletotrichum gloeosporoides*), rather than lack of adaptation to acid soil stresses.

In conclusion, it can be generalized that soil conditions for tropical pasture production in Australia and Latin America are different enough to preclude direct extrapolation of results from one continent to another. However, each continent also has small areas of soils which are very similar to vast areas of the other.

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Appendix 1. **Simplified definition of Soil Taxonomy terminology used in this paper, as applied to the tropics (52).**

SOIL ORDERS:

Oxisols: Soils with an oxic horizon of low activity clays ($<$16 meq/100 g clay), consisting of mixtures of kaolinite, iron oxides and quartz, low in weatherable minerals. Usually deep, well drained, red or yellow soils, excellent granular structure, acid, very low fertility, uniform properties with depth. Formerly known as Latosols, Lateritic soils.

Ultisols: Soils with an argillic horizon (20% increase in clay content) with less than 35% base saturation in the control section. Usually deep, well drained red or yellow soils, higher in weatherable minerals than Oxisols, with less desirable physical properties, but still acid and low in native fertility. Formerly known as Red Yellow Podzolic soils, and some Latosols and Lateritic soils.

Alfisols: Soils with an argillic horizon with more than 35% base saturation. Similar to Ultisols except for considerably higher native fertility. Formerly known as: Eutrophic Red Yellow Podzolics, Non Calcic Browns, Planosols, Terra Roxa Estruturada, Red Earths, Yellow Earths, Solodics.

Aridisols: Soils of aridic soil moisture regimes, with horizon differentiation. Generally high native fertility.

Entisols: Soils with such slight or recent development that only an ochric (yellowish) epipedon or simple man-made horizons have formed.

Vertisols: Heavy, cracking clayey soils with more than 35% clay and $>$50% of 2:1 clay minerals. Usually shrink and swell with changes in moisture content, have gilgai microrelief and slickensides on peds. Generally high native fertility.

Inceptisols: Young soils with a cambic horizon but no other diagnostic horizon. Native fertility variable.

Mollisols: Soils with a mollic epipedon (high in organic matter, soft when dry and $>$50% base saturation). Very high native fertility. Known as Chernozems, Rendzinas, Brunizems.

Spodosols: Soils with a spodic horizon (of Fe and organic matter accumulation) usually developed from sandy materials. Very low native fertility. Known as Podzols.

Histosols: Organic soils ($>$20% OM).

SOIL MOISTURE REGIMES:

Udic: The subsoil is dry (>15 bars) for less than 90 cumulative days during the year.

Ustic: The subsoil is dry for more than 90 cumulative days but less than 180 cumulative days or 90 consecutive days.

Aridic: The subsoil is dry for more than 180 cumulative days and moist for less than 90 consecutive days during the year.

Aquic: The subsoil is saturated with water long enough to cause soil reduction.

SOIL TEMPERATURE REGIMES:

Isohyperthermic: The mean annual temperature of the soil at 50 cm is > 22°C with less than 5°C variation between the three warmest and the three coldest months.

Hyperthermic: Same as above but with more than 5°C variation between the three warmest and three coldest months.

Appendix 2. **Approximate correlation between some Australian great soil groups (61). Soil Taxonomy orders and great groups, and FAO mapping units (25).**

Australian Great Groups	Soil Taxonomy		FAO World Soil Map
	Order	Great Group	
Siliceous Sands	Entisols:	Quartzipsamment	Eutric Regosol, Cambic Arenosol
Earthy Sands	Entisols:	Quartzipsamment	Cambic Arenosol
Grey, Brown and Red Clays	Vertisols:	Chromustert	Chromic Vertisol
Solodized Solonetz and Solodic soils	Alfisols:	Natrustalf, Paleustalf, Haplustalf	Orthic Solonetz, Albic Luvisol
Soloths	Alfisols:	Paleustalf, Natrustalf, Haplustalf	Albic Luvisol, Orthic Solonetz, Solodic Planosol
Red Earths	Alfisols & Ultisols:	Paleustalf, Haplustalf Paleustult, Paleudult	Eutric Nitosol, Ferric Luvisol, Dystric Nitosol
Yellow Earth	Alfisols & Ultisols:	Haplustalf, Paleustalf, Paleustult, Plinthustalf	Ferric, Albic and Plinthic Luvisols, Ferric Acrisol
Grey Earths	Alfisols:	Paleustalf, Tropaqualf	Albic Luvisol, Gleyic Luvisol
Euchrozems	Alfisols & Inceptisols:	Rhodustalf, Paleustalf, Ustochrept, Ustropept	Chromic Luvisol, Eutric Nitosol Chromic Cambisol

Appendix 2. Continued

Australian Great Groups	Soil Taxonomy		FAO World Soil Map
	Order	Great Group	
Xanthosems	Oxisols & Ultisols:	Haplorthox, Haplustox, Palehumult, Acrohumox	Xanthic Ferralsol, Humic Ferralsol, Humic Acrisol
Krasnozems	Oxisols & Alfisols:	Acrohumox, Acrorthox, Eutrustox, Paleustalf	Humic Ferralsol, Rhodic Ferralsol, Eutric Nitosol
Red Podzolic soils	Alfisols & Ultisols:	Paleustalf, Paleudult, Haplustult, Tropudult	Albic Luvisol, Ferric and Orthic Acrisols, Dystric Nitosol
Yellow Podzolic soils	Alfisols & Ultisols:	Haplustalf, Haplustult, Paleustalf	Albic Luvisol, Orthic and Ferric Acrisol
Gleyed Podzolic soils	Ultisols:	Paleaquult, Albaquult	Gleyic Acrisol, Dystric Planosol
Podzols	Spodosols:	Tropohumod, Troporthod Haplohumod	Humic and Orthic Podzols
Humic gleys	Ultisols & Inceptisols:	Paleaquult, Albaquult, Haplaquept	Gleyic Acrisol, Dystric Gleysol