Soil Brief *Jamaica 1*

JAMAICA

A reference soil of the Limestone Region

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ISRIC

International Soil Reference and Information Centre

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ISRIC Soil Monolith:

Number	*FAO-Unesco*	*Soil Taxonomy*
JM 4	Ferric Acrisol	Typic Paleudult

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CONTENTS

TABLES

PHOTOGRAPHS

ABSTRACT

A representative soil, occurring on old lacustrine terraces of inland basins in the Central and Eastern Limestone Sub-region of Jamaica was studied. The soil is representative of the deep, moderately well drained, prominently mottled, red acid clays of the Worthy park series.

The climate of the inland basins (Lluidas Vale) is of tropical monsoon type and classified as Am in the Köppen system. The climate at Worthy park, where this soil was studied, is generally favourable for rain-fed agriculture in the period of April to November. The parent material underlying this soil consists of lacustrine sediments derived from acid, pre-weathered andesitic tuffs over hard dolomitic limestone. Nature of the parent material and soil hydrology, as reflected by the strongly mottled appearance of the subsoil, have influenced the development of this soil.

The soil is classified as a Ferric Acrisol (FAO-Unesco, 1988) or Typic Paleudult (USDA Soil Taxonomy, 1992). Major crops in the area are sugar cane and citrus, mostly grown on plantations. The reference profile was taken in an area of rough pasture.

Limitations of this soil for agriculture are related to unfavourable subsoil characteristics, such as low to very low base saturation, moderate to high aluminium saturation, low air capacity and low moisture holding capacity. This results in poor rooting conditions, low moisture availability, low level of available nutrients, high acidity and Al-toxicity. A land evaluation study indicated that this soil could successfully sustain the following crops and land use practises: rice (medium input), sugar cane (high input), pineapple (medium input), improved pasture (high input), forestry (medium input) and natural forest (low input).

Management should be directed towards conservation and improvement of the organic matter rich topsoil. Successful cultivation of this soil requires, for most crops, a medium to high level of input. It is recommended to improve rooting conditions and soil fertility by liming and fertilizing the soil.

FOREWORD

The objective of a Soil Brief is to provide a description of a reference soil for a specific agro-ecological zone. The Soil Brief comprises a text with data annexes.

The text includes graphical presentations and provides a description and discussion of the major characteristics of the soil, its classification, an evaluation of land qualities, and attention is given to special topics such as erosion, and soil formation. Data available from field, laboratory and office work are presented in annexes.

The Soil Brief is written for soil scientists and other interested people. For the latter the information in the annexes is often too detailed and therefore requires explanation in the text. For the soil scientist, the text part can be helpful as it summarizes the important soil characteristics and land qualities, relevant aspects of soil management and processes of soil formation. Furthermore, it provides access to additional information about research and discussions which cannot be stored in the computerized database.

The authors are grateful to staff members of the International Soil Reference and Information Centre (ISRIC) for preparation of the monolith and physical, chemical and mineralogical analyses of the samples. Special thanks go to Mr. N.H. Batjes for his assistance in carrying out the land evaluation with the use of JAMPLES, to Messrs. E.M. Bridges and A.E. Hartemink for valuable comments on this paper and to Mr. J.H. Kauffman for his ideas regarding development of the Soil Brief concept.

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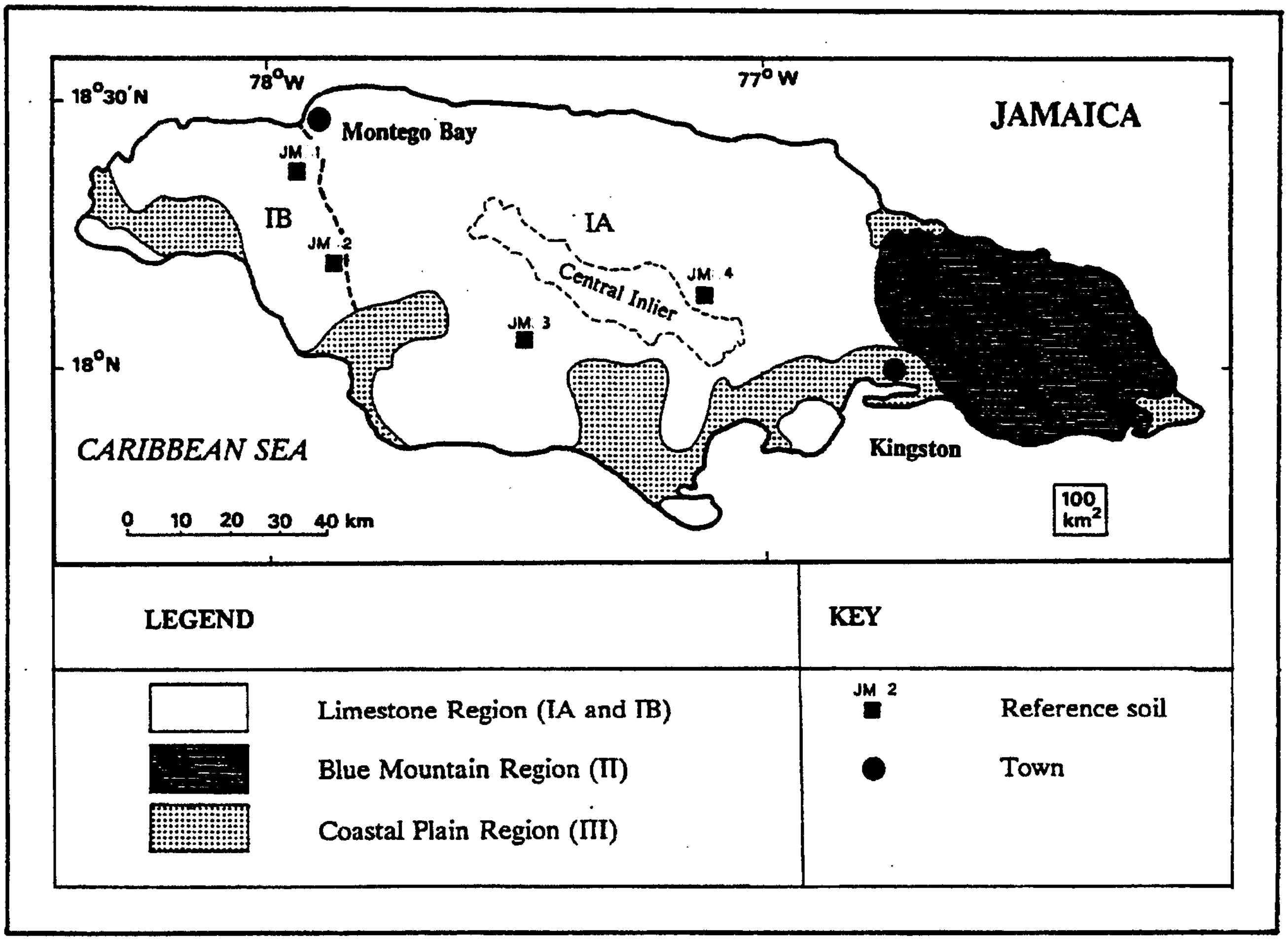


Figure 1 Major physical regions of Jamaica.

1 PHYSICAL REGIONS OF JAMAICA

1.1 General

Jamaica can be broadly divided into three major physical regions (fig. 1):

I -The Limestone Region
II -The Blue Mountain Region
III -The Coastal Plain Region

The Limestone Region
This is by far the largest physical region and comprises the generally wet central and western uplands underlain mostly by hard Tertiary limestones. The Limestone Region consists of three inter-related zones:

1) The actual *limestone belt* which is characterized by a distinctive karst topography, features developed as a result of rock dissolution, without a clear surface drainage pattern. Strongly weathered red and brown fine-textured soils are predominant.

2) The so-called *inliers* appearing mostly as relatively small pockets within the limestone belt. They generally consist of unconsolidated, Cretaceous rocks. Inliers have been formed by local uplift followed by erosion of the overlying rocks and subsequent exposure of the underlying, older rocks. The largest inlier of the Limestone Region is the Central Inlier (fig. 1).

3) The *inland basins*, occurring as relatively large depressions in the limestone belt in which younger and often less permeable limestone rocks are exposed. However, these rocks are mostly covered by basin floor deposits originating from the rock inliers. Such deposits often form an impermeable layer which cause flooding after heavy rains.

The Blue Mountain Region
This relatively cool, high rainfall region occupies the elevated eastern part of the island. The area is dominated by the rugged Blue Mountain massif (highest peak is about 2250 m a.s.l.), a large inlier consisting of older, Cretaceous rocks on which stony and shallow soils have developed.

The Coastal Plain Region
Situated mainly in the southern part of the island, this region is shielded from the northeasterly rain-bearing monsoon winds. It covers the dry, flat to gently undulating coastal plains formed by lacustrine/marine and river sediments. The major soils of this region are of alluvial origin and have considerable potential for agriculture. They include cracking clays (Vertisols) and stratified loamy soils with a dark humic surface horizon (Phaeozems). Saline soils occur near the coast.

1.2 The Limestone Region

1.2.1 General

The Limestone Region is subdivided into a central and eastern zone, in which pure limestones are predominant (Sub-region IA), and a western zone in which chalky limestones with chert occur (Sub-region IB). The difference between the two sub-regions lies in the mineral composition and physical characteristics of the limestone rock, which influence karst development. Geological structure and landscape pattern of the two sub-regions are shown in figures 2 and 3.

1.2.2 The Central and Eastern Limestone Area (Sub-region IA)

The physiography of the sub-region is characterized by steep-sided humid tropical karst, which is also known as cockpit-karst or cone-karst. This type of karst is characterised by a series of cone-shaped hills seperated from each other by multi-sided, closed depressions ("cockpits") producing a hummocky landscape (see photos 1 and 4). This landscape type is best exemplified by the inaccessible limestone hills of the Cockpit Country in the western part of the sub-region.
The extreme purity (insoluble residues average only 0.4% by weight) and well-jointed nature of the limestone of this sub-region permits rapid dissolution and subsequent karstification (see glossary) of the limestone. This leads to intense weathering of the overlying material including desilification (loss of silica) and residual enrichment of Al-oxides. These processes finally result in the formation of bauxite. The Jamaican bauxites, which are generally of high quality, are typically confined to the hard pure limestones of sub-region IA.
Profile JM 3 (Andriesse & Scholten, 1982) is representative of the well drained, intensely weathered red clays developed over bauxite. The predominant mineral in the clay fraction is gibbsite.

Profile JM 4, discussed in this Soil Brief, is included as a reference soil as it forms a clear example of the strongly acid, red-grey mottled red (kaolinitic) clays developed from re-deposited andesitic material in inland basins underlain by limestone. Parent material and soil hydrology are dominant factors in formation of this soil.

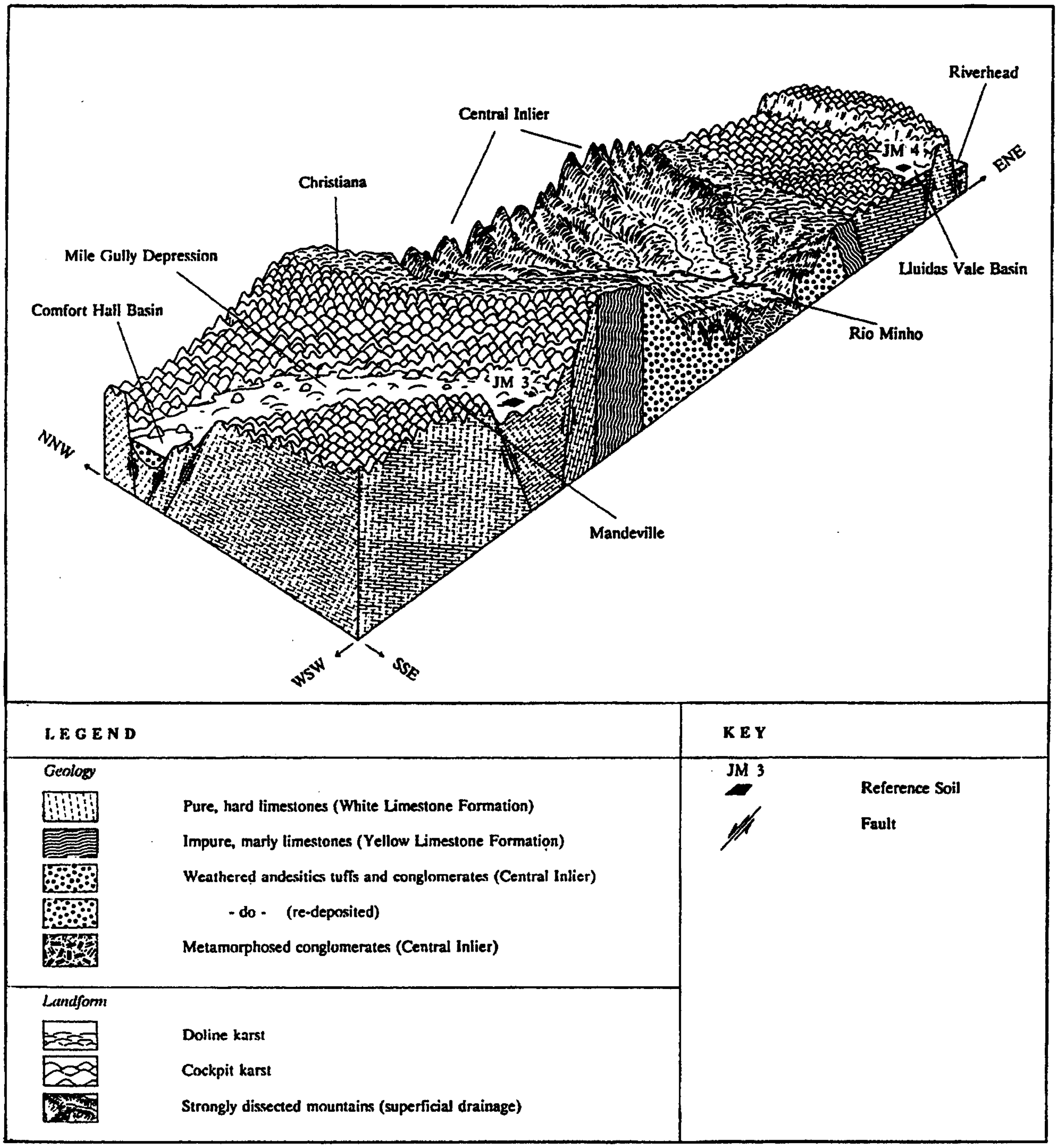


Figure 2 Schematic block-diagram showing geological structure and landscape pattern of Sub-region IA.

1.2.3 The Western Limestone Area (Sub-region IB)

The less pure, chalky limestones of sub-region IB contain appreciable amounts of chert as a result of silicification in the past (Scholten & Andriesse, 1982). Solubility is reduced by incomplete re-crystallization of the limestone as it is younger in age. Consequently, karst processes have acted more slowly and the general karst topography is less pronounced with relatively gentle slopes and low relief (fig. 3).

Soils tend to be moderately weathered with relatively large proportions of 2:1 clays and a well developed soil structure.

Profile JM 1 is a representative of the well drained, strongly acid, brownish yellow clay soils of the Burnt Ground series (Scholten & Andriesse, 1982). It is a predominant soil in relatively low-lying areas with a gentle doline karst topography in which accumulation of

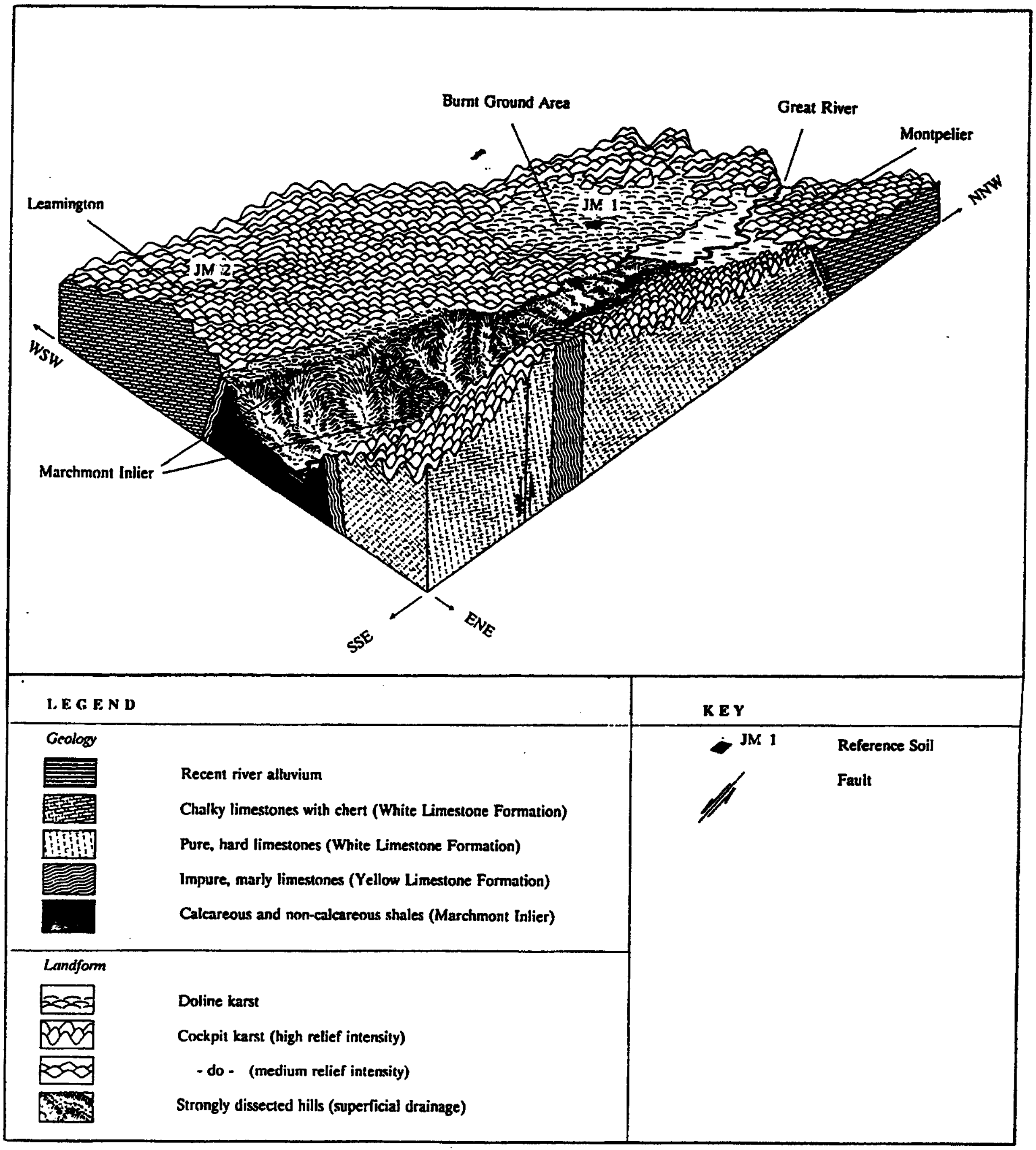


Figure 3 Schematic block-diagram showing geological structure and landscape pattern of Sub-region IB.

limestone weathering residue has taken place. Doline-karst, which has a relatively low relief intensity is typically confined to the areas underlain by less permeable limestones, e.g. the younger, chert-rich limestones (White Limestone Formation) of the Western Limestone Area (fig. 3) and the marly limestones of the Yellow Limestone Formation (fig. 2 and 3). Burnt Ground soils have severe limitations for agriculture because of their strong acidity and high levels of exchangeable aluminium.

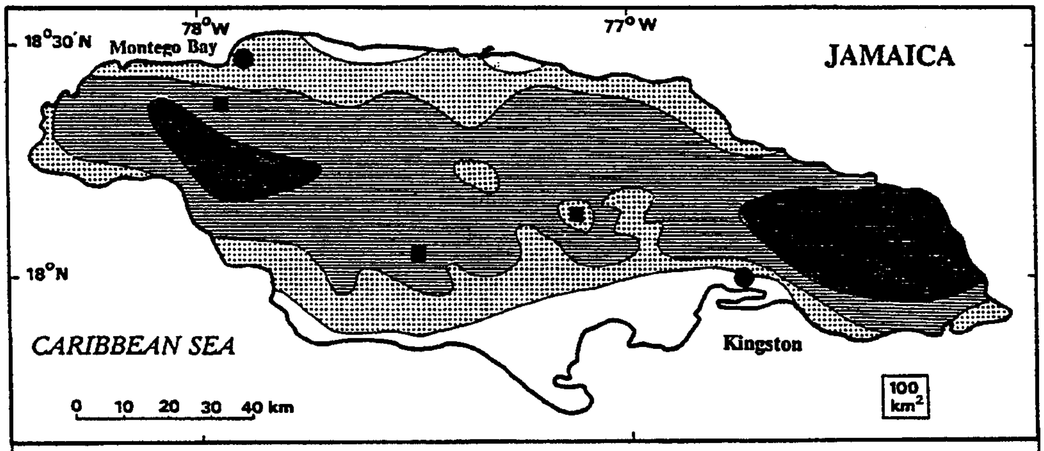
Profile JM 2 is an example of the well drained, reddish yellow stony clays developed on cherty limestone depressions in between limestone hills (Scholten & Andriesse, 1986). These soils are younger and therefore less weathered than the Burnt Ground soils. They occur in small patches in between limestone hills and their stoniness make these soils of limited importance for agriculture.

1.3 Climate

Jamaica has a humid tropical climate, which is moderated by the influence of the sea. Temperatures are high and equable throughout the year (mean daily temperatures range from 21-25 °C). Annual rainfall is relatively high. Dependable rainfall, which is the minimum amount exceeded in a given time period in 75% of the years, ranges from 537 (minimum of Dry zone) to 5332 mm/yr (maximum of Very wet zone), (Batjes, 1994). The elevated, mountainous nature of the island's interior has a marked influence on temperature and rainfall patterns creating different climatic zones on the island. This is shown in the agro-climatic zones map of Jamaica (fig. 4).

The major part of the Limestone Region falls within the Wet zone (W). The Blue Mountain Region and Coastal Plain Region broadly correspond with the eastern part of Very wet zone (V) and the southern part of the Dry (D) and Intermediate (I) zones.

All reference soils, except JM 4, occur in the Wet zone or Very wet zone. The climate of these two zones is classified as Tropical Rainforest (Af), according to the Köppen System. JM 4 lies in the Intermediate zone (fig. 4) as it is located in one of the inland basins (Lluidas Vale). The mean dependable annual rainfall in this agro-climatic zone (I), is 1308 mm (Batjes, 1994). Inland basin areas tend to receive somewhat less rainfall than the surrounding hills and have a Tropical Monsoon climate (Am) according to Köppen.



LEGEND

	MOISTURE AVAILABILITY ZONE	ANNUAL R75/PET RATIO
(white)	Dry zone (D)	0.30 ≤ R75/PET < 0.50
(dotted)	Intermediate zone (I)	0.50 ≤ R75/PET < 1.00
(hatched)	Wet zone (W)	1.00 ≤ R75/PET < 1.50
(black)	Very wet zone (V)	1.50 ≤ R75/PET < 5.00

Note: R75 is the minimum amount of rainfall surpassed in 75% of the years; PET is potential evapo-transpiration.

Figure 4 General agro-climatic zones map of Jamaica (after Batjes, 1994).

2 REFERENCE SOIL JM 4

2.1 Occurrence and Extent

Reference soil JM 4 is representative of the deep, moderately well drained, prominently mottled, red acid clays of the Worthy Park series (photos 2 and 3). These soils occur on old lacustrine terraces in inland basins of the Central and Eastern Limestone Sub-region. Similar soils have been mapped as Rosemere Variant I series in the Riverhead area, east of the Lluidas Vale basin (SSU, 1990).

2.2 Environment

2.2.1 Climatic conditions

Rainfall, evaporation and temperature data representative for JM 4 were available for a 30 year-period from the weather station at Worthy Park (370 m a.s.l.) located at about 0.5 km from the soil profile site. The data are presented in a summarized format in figure 5 and on the ISIS Data Sheet (Annex 1).

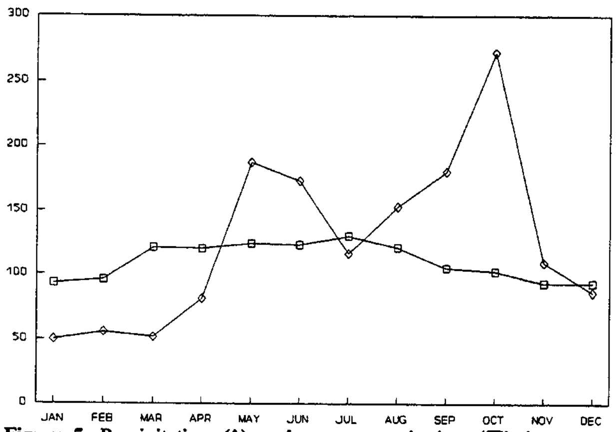


Figure 5 Precipitation (◊) and evapotranspiration (□) in mm at Worthy Park, Parish of St. Catherine.

Rainfall at Worthy Park is generally sufficient for rainfed agriculture during the period April to November. The length of this period permits rainfed cultivation of two crops with a short to medium growing period. The period December to April is relatively dry with evaporation exceeding rainfall. The dry period does not allow successful cultivation of rainfed annual crops. Grass and deep rooting crops such as citrus and sugar cane, however, can be grown provided they are established in the rainy season.
Mean daily temperatures range from 21-22°C (December to February) to 24-25°C (August to September). Mean daily relative humidity over the year at Worthy Park is 83% with a diurnal range from 93% (early morning) to 73% (early afternoon).

Northeast trades blow throughout the year. The average wind speed over the year is 2.2 m/s. The area is partly protected from the wind due to the sheltered position of the Lluidas Vale inland basin. Hurricanes occur infrequently, mainly during the period of July to November. The probability of hurricanes hitting Jamaica once a year is 15 percent. The last hurricane in Jamaica was in September 1988 (Gilbert).

2.2.2 Geology

The parent material of JM 4 is derived from purplish grey, acid, pre-weathered andesitic tuffs. These alluvial fan materials of Cretaceous age, were deposited into the inland basin and subsequently re-worked in a lacustrine or shallow marine environment. This re-worked, fine-textured material is often referred to as Old Alluvium (RRC, 1958-70). Under the Old Alluvium is hard dolomitic limestone which forms the permeable floor of the inland basin.

2.2.3 Landscape

JM 4 occurs on a high, slightly dissected, almost level to undulating lacustrine terrace overlying permeable karstified limestone in the Lluidas Vale inland basin (fig. 2). Maximum slopes are 7%. The inland basin is surrounded by hilly cockpit-karst developed from hard Tertiary limestone (photos 1 and 4).

2.2.4 Hydrology

The basin is drained by widely spaced, moderately incised valleys, while internal drainage through sinkholes prevails where limestone rock crops out. The valleys drain in the Rio Cobre river which flows through the Lluidas Vale inland basin and disappears in a sinkhole at the basin's eastern margin.
After heavy showers, these soils may be temporarily waterlogged, due to low permeablity. It is likely, as no groundwater table was observed, that at least part of the prominent mottles of the subsoil are relics.

2.2.5 Vegetation and land use

The natural vegetation consisted largely of wet evergreen forest but it was cleared during the last century. The site has been under rough pasture since 20 years. Major crops in the area include sugar cane and citrus, mostly grown on plantations.

2.3 The Soil

2.3.1 General characterization

JM 4 is moderately well drained, firm, dark red (2.5YR 3/6) clay overlying a dense, very strongly acid, clayey subsoil with prominent red-grey mottles (photos 3 and 5). Key properties are given in table 1.

Table 1 Key properties of profile JM 4.

Key property:	
Texture	clayey throughout, but sharp increase with depth, from 45% (topsoil) to 85% in subsoil and gradually decreasing to about 60-65% in lower subsoil
Organic C	high (3.6%) in the topsoil
Soil reaction ($pH-H_2O$)	strongly acid in topsoil, very strongly acid in subsoil($pH-H_2O$ 4.1)
Effective cation exchange capacity	medium in topsoil (14 $cmol_c\ kg^{-1}$) and subsoil (between 10 to 17 $cmol_c\ kg^{-1}$)
Sum of bases	medium (12 $cmol_c\ kg^{-1}$) in topsoil, low to very low (0.3-5.2 $cmol_c\ kg^{-1}$) in subsoil
Al saturation	low (4%) in topsoil, moderate to high (40-70%) in subsoil
Base saturation	high (70%) in topsoil, medium (40%) in upper subsoil and very low (2-4%) in lower subsoil
Clay mineralogy	mainly kaolinite with appreciable amounts of 1:2 clays (smectite-chlorite); in the lower subsoil presence of swelling 2:1 clays (smectite)
Air capacity (% by vol, pF0 - pF2)	low (8-9%) in topsoil, very low (2-4%) in subsoil
Available water capacity (% by vol: pF2 - pF4.2)	medium (13%) in topsoil, low to very low (5-6%) in subsoil

Starting at a depth of 40 cm JM 4 has a polygonal, plinthite-like pattern of red and light grey mottles (photo 3 and 5). The pattern consists of weakly cemented red ped cores and light grey ped surfaces. The light grey parts which have lost iron and are associated with old shear planes, readily slake when submersed in water. Colour contrasts increase gradually with depth.

A conspicuous characteristic of the mottled subsoil is its extremely low base saturation and high Al-saturation (fig. 6). In addition, the subsoil has an unfavourable pore size distribution with mainly micro-pores. Consequently, air capacity as well as moisture holding capacity are both very low (fig. 7). Rooting and biological activity in the subsoil are very low.

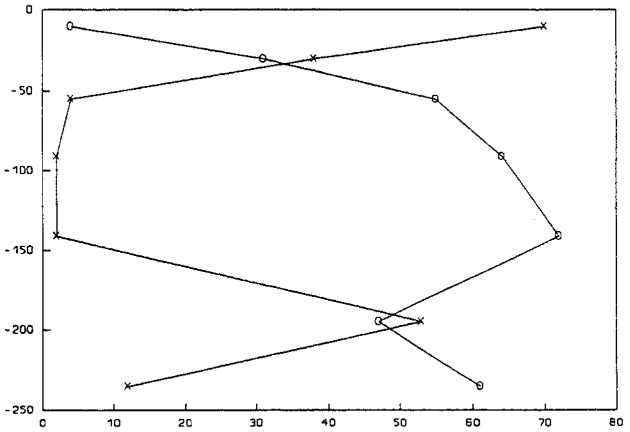


Figure 6 Base saturation percentage (x) and Aluminium saturation percentage (o) versus soil depth.

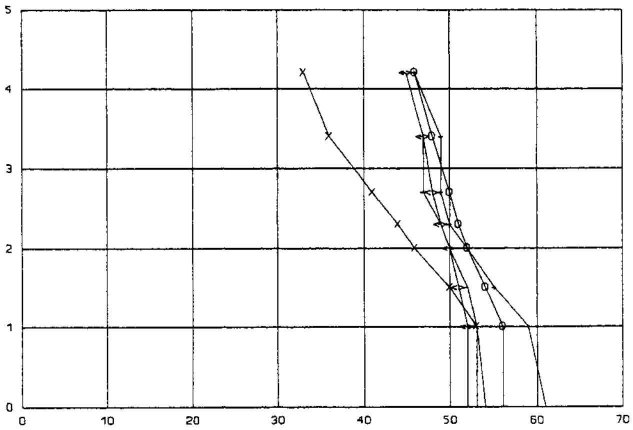


Figure 7 Moisture retention curves (water content in vol. % versus suction in log cm) at depths 0-21 cm (x), 21-40 cm (+), 40-70 cm (o), 70-112 cm (-) and 112-170 cm (<>) in profile JM 4.

2.3.2 Soil classification

FAO-Unesco (1988)

The sharp increase in clay content in the upper subsoil and the presence of clay skins as observed in the field and in micromorphological studies, indicate an argic-B horizon. This feature, in addition to the absence of a ferralic horizon, the low cation exchange capacity and low base saturation in the argic horizon places JM 4 in the *Acrisols*. The soil keys out as a *Ferric Acrisol* due to its prominent coarse grey-red mottles (ferric properties) in the subsoil which do not harden on exposure after repeated drying and wetting *(Plinthic)* nor reflect actual wetness conditions *(Gleyic)*.

USDA-Soil Taxonomy (1992)

JM 4 qualifies as a *Udult* as it has an argillic horizon with a very low base saturation at a depth of 125 cm below the upper boundary, and an udic soil moisture regime. The soil belongs to the *Paleudults* in view of its gradual clay increase to a depth of 150 cm. In the absence of any other diagnostic feature (the prominent grey-red mottling of the subsoil does not qualify as plinthite) the soil keys out as a *Typic Paleudult (clayey, mixed, isohyperthermic)*.

2.3.3 Soil formation

Major factors influencing soil formation include the mineralogical composition of the weathered parent material (derived from andesitic, acid tuffs), the somewhat limited permeability of the underlying dolomitic limestones and the low topographical position of the soil (basin floor). Such conditions create an acid weathering environment of moderate intensity, favouring the formation of clayey soils rich in kaolinite, however still containing appreciable amounts of 2:1 lattice clay minerals (smectite-chlorite and smectite).

Similar soils, belonging to the Worthy Park series or related series, have been found in inland basins or depressions on Old Alluvium e.g. at Riverhead, east of the Lluidas Vale Basin (SSU, 1990) and at Comfort Hall in the Parish of Manchester (see fig. 2). These soils show a catenary relationship with the more strongly weathered soils appearing in smaller basins and at shorter distance from the surrounding limestone. This relationship, added to the presence of re-deposited weathered materials (derived from tuffs) and conglomerates (originating from the Central Inlier) in inland basins and depressions throughout the bauxite area, supports the alluvial theory of the origin of Jamaican bauxite proposed by Zans (1958). He argues that alumino-silicate sediments, from Late Cretaceous to Middle Eocene rocks, were transported into limestone terrain via a subterranean karst system and subsequently altered to bauxite by intense tropical weathering.

The prominent mottling of the subsoil indicates redistribution of iron and manganese compounds. The plinthite-like mottling pattern, which consists of weakly cemented red ped cores and light grey ped surfaces, has been referred to as pseudo-plinthite (Daugherty & Arnold, 1982).
Pseudo-plinthite develops as a result of iron accumulation and segregation but, unlike true plinthite, does not harden irreversibly upon drying. The capability of soil material to harden appears to be related to the Fe_o/Fe_d ratio or active iron ratio (Fe_o = iron determined with the oxalate method and Fe_d = iron determined with the dithionite-method). This ratio indicates the relative crystallinity of the iron present, with high ratios representing high amounts of amorphous iron. Daugherty & Arnold (1982) found that plinthite identified in the field had ratios of < 0.05 while soils with pseudo-plinthite had ratios of > 0.05. Active iron ratios of the pseudo-plinthite of JM 4 range between 0.07 (upper-part) and 0.05 (lower part) which more or less corresponds to the tentative classification by Daugherty & Arnold (1982).

The formation of pseudo-plinthite has stopped, possibly as a result of climatic changes or due to river incision in the Lluidas Vale basin by the Rio Cobre and its tributaries. The pseudo-plinthite of JM 4 can therefore considered as a relic. This is further supported by preliminary micromorphological evidence, indicating the presence of distinct degradation features in the pseudo-plinthite matrix.

The dark, humus-rich, relatively sandy surface horizon which has a rather high nutrient status is an indication of the long cultivation history of JM 4. Additional evidence is provided by the anomalously high SiO_2/Al_2O_3 ratio (more than 2.5 times that of the underlying Bt horizon) which is likely to be the result of prolonged cultivation and burning of sugar cane stubble. Burning of this crop releases large amounts of (amorphous) silica which precipitates in the soil as small opal phytoliths.

2.4 General Land Suitability

2.4.1 Major constraints for agriculture

For the purpose of highlighting major soil and land constraints, a qualitative evaluation of the relevant land qualities was made using 'STRESS', an ALES model (ISRIC, in prep.; Rossiter, 1990) based on the Framework for Land Evaluation, (FAO, 1976, 1983).
The result of a 'STRESS'-evaluation is a severity level rating of 22 land qualities, ranking from *not* limiting to *severely* limiting. The major constraints for rainfed agriculture, resulting from this evaluation, are:
- low availability of plant nutrients (in subsoil)
- strong soil acidity
- high levels of exchangeable aluminium

2.4.2 Introduction to JAMPLES

Crop and land use performance is assessed using the Jamaica Physical Land Evaluation System (JAMPLES). This is an interactive software package developed in Jamaica and designed for the appraisal of the physical suitability of land units for specific crop/management systems (land utilization types) (Batjes & Bouwman, 1989). For technical documentation reference is made to Technical Soils Bulletins No. 15 and 16 of the Jamaica Soil Survey Project (SSU, 1989a and 1989b).

2.4.3 Land qualities and limitations

Land qualities and limitations of JM 4 pertaining to maize cultivation under current conditions are presented in Annex 2 (JAMPLES - Explanatory Notes and Tables). In Annex 3, evaluations for a wide range of crops is presented. Limitations largely relate to aforementioned, unfavourable subsoil characteristics, as follows:

Photo 1: Landscape of JM4 consisting of undulating lacustrine terrace in inland basin surrounded by hilly cockpit-karst.

Photo 2:
Sampling of soil monolith JM4.

Photo 3: Soil profile JM4.

Photo 4: Mature cockpit-karst landscape developed over hard limestone near St.Johns, just North of Lluidas Vale.

Photo 5: Prominently mottled upper part (120-150 cm) of Btg3 horizon of JM4.

* *Unfavourable pore size distribution* (near-absence of medium and large pores). Consequently, both moisture holding capacity and air capacity are low. These factors, lead to the following soil physical limitations:
a) poor rooting conditions
b) low moisture availability.

* *Low level of available nutrients.* This refers in particular to low levels of calcium, magnesium and phosphorous in the profile. JM 4 has a low nutrient availability and calcium deficiency.

* *Strong acidity and high levels of exchangeable aluminium* (subsoil Al-sat. of 70-75%); such levels are harmful to many crops. Aluminium toxicity may restict effective rooting depth.

Both drought problems and rooting problems have been reported from JM 4 and other related soils (SSU, 1990; Phillip Clarke, pers. comm.).

2.4.4 Land suitability

Suitability classes for selected crops produced within specific technical and socio-economic settings (Major Kind of Land Use: MLU) are presented in Table A-2 (Annex 2). More specific information regarding the land suitability rating in JAMPLES is given in Annex 2.

A few additional remarks are made here. The main subclasses reflecting the major limitations of the envisaged land-use are f - limiting soil fertility (chemically poor subsoil), p - soil physical limitation (dense, poorly rootable subsoil, prone to periodical waterlogging) and, in a few cases, r - low water availability. Relatively successful crop/MLU combinations are rice/MLU-C, sugar cane/MLU-D, forestry/MLU-B, natural forest/MLU-A, pineapple/ MLU-B and improved pasture/MLU-B, improved pasture/MLU-C, and improved pasture/MLU-D.

2.4.5 Soil management aspects

Soil management should be directed towards conservation of the topsoil. Manual land clearing methods, not leading to loss or compaction of topsoil, are preferable to mechanical methods. Clearing by burning is not recommended, as this exposes the soil. In order to avoid soil physical deterioration, the soil should as much as possible be kept under a vegetative cover throughout the year. This can be done using cover crops or intercropping techniques. Successful cultivation of this soil requires, for most crops, a medium to high level of inputs. It is advisable to apply lime and fertilizer (calcium and phosphorous) in order to improve rooting conditions and, at the same time, increase water holding capacity and air capacity. Deep-ploughing and liming using dolomitic limestone has been started on a trial basis in the area (Phillip Clarke, pers. comm.).

A rule of thumb for application of dolomitic limestone, often used as a measure of the lime requirement for very acid tropical soils, is an application of 1.65 t ha^{-1} of $CaCO_3$-equivalent for every 10 mmol kg^{-1} of soil of exchangeable aluminium (Landon, 1991). Strict application of this rule may have adverse effects on some acrisols (e.g. structure decline). Aluminium is not present in available form in soils having a pH above about 5.2. Liming to higher pH values than 5.2-5.5 should be avoided as this may cause soil structural problems and cation imbalances. Correction of soil pH through liming should be done slowly but continously. An even distribution of limestone (preferably well before planting/sowing) is important. Ideally, lime added should be incorporated into the topsoil. If urea is to be applied, the application should be kept apart from the limestone application, to avoid volatilization losses of ammonia promoted by a (temporarily) rise in pH. Lime could be applied after harvest and urea before or at time of planting or sowing. In addition, urea should be incorporated into the soil and not be broadcasted.
Application rate of the soluble Triple Super Phosphate fertilizer depends on the type of crop to be grown. If lowering of exchangeable aluminium levels through raising soil pH (with dolomitic limestone applications) is not (economically) feasible, use of Rock Phosphate could be more effective and economical for acid soils. However, this should not be used if limestone is to be applied because Rock Phosphate is only soluble at low pH values. Sound soil fertility management would include conservation of soil organic matter, a major source of natural soil fertility (with respect to nutrient supply and exchange capacity), for example, by incorporating crop residues into the soil.

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Annex 1 ISIS Data Sheet JM 4

ISIS 4.0 data sheet of monolith JM004 Country : JAMAICA

Page : 1
Print date (dd/mm/yy) : 10/06/94

FAO/UNESCO (1988) : Ferric Acrisol
USDA/SCS SOIL TAXONOMY (1992) : Paleudult, Typic, clayey, kaolinitic, isohyperthermic
LOCAL CLASSIFICATION : Worthy Park series

DIAGNOSTIC CRITERIA
USDA/SCS (1992) : Soil moisture regime : udic
FAO (1974) & USDA (1975) : Diagnostic horizons : argillic
: Diagnostic properties : ferric properties, mottles with chroma <2
: Soil moisture regime : udic

LOCATION : Jamaica, St. Catherine, Lluidas Vale Basin, Worthy Park
Latitude : 18° 8'10'' N Longitude : 77° 9'12'' W Altitude : 370 (m.a.s.l.)
AUTHOR(S) : Hennemann, G.R. Date (mm.yy) : 11.89

GENERAL LANDFORM : basin Topography :
PHYSIOGRAPHIC UNIT : remnant of lacustrine terrace
SLOPE Gradient : 1% Aspect : Form : concave
POSITION OF SITE : flat
MICRO RELIEF Kind : level Pattern : none Height (cm) : 0
SURFACE CHAR. Rock outcrop : nil Stoniness : nil
Av.Size (cm) : 0
Cracking : nil Slaking/crusting : nil
Salt : nil Alkali : nil
SLOPE PROCESSES Soil erosion : nil Aggradation : nil
Slope stability : stable

PARENT MATERIAL 1 : lacustrine sediments derived from : acidic tuff
Texture : loamy
Weathering degree : high Resistance :
Remarks :

EFFECTIVE SOIL DEPTH(cm) : 112

WATER TABLE Depth(cm) : no watertable observed Kind : no watertable observed
DRAINAGE : moderately well
PERMEABILITY : moderate No slow permeable layer(s) cm
FLOODING Frequency : nil Run off : medium
MOISTURE CONDITIONS PROFILE : 0 - 225 cm moist

LAND USE : semi natural grassland,grazed; no irrigation; Rotation : not relevant
Landuse/vegetation remarks : Sugar cane and buildings on nearby land

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CLIMATE : Köppen: Am
Station: WORTHY PARK 18 8 N/ 77 9 W 370 m a.s.l 0.5 km of site Relevance: very good

	No. years of record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
pot.evapotransp. mm		93	96	121	120	124	123	130	121	105	102	93	93	1321
precipitation mm		50	56	52	81	187	173	116	153	180	272	109	86	1527
T mean °C		22.2	21.3	22.2	22.9	23.9	24.4	24.7	24.6	23.9	23.1	23.1	21.7	23.2
bright sunshine %		58	57	54	54	45	43	47	46	49	42	46	50	49
windspeed $m\ s^{-1}$		2.0	2.2	2.2	2.2	2.4	2.8	2.8	2.2	2.0	2.0	1.8	1.8	2.2
relative humidity %		81	80	79	78	83	82	81	82	84	85	84	82	82

PROFILE DESCRIPTION :

Ap 0 - 21 cm. very dark greyish brown (10 YR 3.0/2.0, moist) slightly gravelly clay; moderate medium to coarse subangular blocky into fine to medium granular structure; slightly sticky, plastic, friable, hard; none mottles; common to many, very fine to fine continuous exped interstitial pores; many very fine roots throughout and common fine roots throughout; few medium spherical hard ferruginous nodules and very few medium angular hard siliceous nodules; very few medium strongly weathered andesite fragments and (porphyritic) fragments; very frequent worm channels and coprogenic elements; non calcareous (HCl) throughout; clear, smooth boundary to

Bt 21 - 40 cm. dark red (2.5 YR 3.0/6.0, moist) clay; fine to medium subangular blocky structure; sticky, plastic, firm; few coarse faint diffuse mottles (10 YR 6.0/6.0); patchy pressure cutans on pedfaces; common to many, very fine to fine continuous exped interstitial pores; common fine roots between peds and few fine roots between peds; no inclusions; no fragments; very frequent worm channels and coprogenic elements; non calcareous (HCl) throughout; gradual smooth boundary to

Btg1 40 - 70 cm. dark red (2.5 YR 3.0/6.0, moist) clay; medium to coarse subangular blocky to angular blocky structure; sticky, plastic, firm; many coarse distinct clear mottles (10 YR 6.0/6.0) and common coarse prominent sharp mottles (2.5 Y 7.0/2.0); patchy pressure cutans on pedfaces; common very fine discontinuous inped tubular pores; slightly porous; few very fine roots between peds; no inclusions; no fragments; few worm channels and coprogenic elements; non calcareous (HCL) throughout; gradual smooth boundary to

Btg2 70 - 112 cm. dark red (2.5 YR 3.0/6.0, moist) clay; medium to coarse subangular blocky and platy structure; slightly sticky, slightly plastic, friable; many coarse distinct clear mottles (10 YR 6.0/6.0) and many coarse prominent sharp mottles (2.5 Y 7.0/2.0); broken pressure cutans on pedfaces; few fine discontinuous inped tubular pores; slightly porous; few very fine roots; very few medium spherical soft ferruginous nodules and hard inclusions; no fragments; non calcareous (HCl) throughout; gradual smooth boundary to

Btg3 112 - 170 cm. light gray (2.5 Y 7.0/2.0, moist) clay; medium to coarse subangular blocky and platy structure; slightly sticky, slightly plastic, very friable; common coarse distinct clear mottles (10 YR 6.0/6.0) and many coarse prominent sharp mottles (10 R 4.0/6.0); broken pressure cutans; few fine discontinuous inped tubular pores; slightly porous; nil roots; very few medium spherical hard ferruginous nodules; no fragments; no biological activity; non calcareous (HCl) throughout;

2Cg 170 - 220 cm. light gray (2.5 Y 7.0/2.0, moist) clay; sticky, firm

C 220 - 250 cm. dark reddish gray (5 YR 4.0/2.0, moist) olive gray (5 Y 5.0/2.0, dry) clay; sticky, friable

ANALYTICAL DATA :

Hor. no.	Top - Bot	>2 mm	2000 1000	1000 500	500 250	250 100	100 50	TOT SAND	50 20	20 2	TOT SILT	<2 µm	DISP	BULK DENS	pF- 0.0	1.0	1.5	2.0	2.3	2.7	3.4	4.2
Ap	0 - 21	0	4	4	4	5	4	23	7	26	32	45	23	1.17	54	53	50	46	44	41	36	33
Bt	21 - 40	0	1	1	1	1	1	3	3	5	8	90	0	1.08	61	59	55	52	50	49	49	46
Btg1	40 - 70	0	0	0	1	1	2	2	2	6	8	89	0	1.33	56	56	54	52	51	50	50	46
Btg2	70 - 112	0	0	1	1	2	2	7	3	9	12	81	0	1.33	53	53	52	50	49	47	47	45
Btg3	112 - 170	0	1	1	1	2	2	6	7	12	20	75	0	1.33	52	52	51	50	49	48	48	45
2Cg	170 - 220	0	0	3	5	8	5	29	9	10	20	51	39	0.00	0	0	0	0	0	0	0	0
C	220 - 230	0	1	2	4	4	4	11	9	16	26	63	35	0.00	0	0	0	0	0	0	0	0

remarks (hor. 1 - 7): Particle Size Distribution deferrated; only total sand determined (TSA)

Hor. no.	pH- H2O	KCl	CaCO3 %	ORG- C %	MAT. N %	EXCH CAT. Ca	Mg	K	Na	sum	EXCH AC. H+Al	Al	CEC soil	clay	OrgC	ECEC	BASE SAT %	Al SAT %	EC 2.5 mS/cm
						cmol$_c$ kg^{-1}													
Ap	4.4	3.9	0.0	3.60	0.37	8.8	2.6	0.7	0.3	12.4	1.4	0.7	17.6	39	12.6	13.8	70	4	0.57
Bt	4.2	3.8	0.0	1.26	0.18	4.0	1.0	0.2	0.0	5.2	5.9	4.2	13.6	15	4.4	11.1	38	31	0.38
Btg1	4.1	3.7	0.0	0.67	0.11	0.2	0.0	0.1	0.2	0.5	10.2	7.5	13.6	15	2.3	10.7	4	55	0.13
Btg2	4.2	3.7	0.0	0.38	0.07	0.0	0.0	0.1	0.2	0.3	13.1	9.7	15.2	19	1.3	13.4	2	64	0.12
Btg3	4.3	3.6	0.0	0.39	0.04	0.0	0.3	0.1	0.0	0.4	16.2	12.3	17.2	23	1.4	16.6	2	72	0.08
2Cg	4.9	3.7	0.0	0.58	0.06	6.6	3.0	1.2	0.6	11.4	13.9	10.2	21.6	42	2.0	25.3	53	47	0.22
C	4.7	3.2	0.0	0.21	0.04	0.0	2.6	0.2	1.0	3.8	27.6	19.9	32.4	51	0.7	31.4	12	61	0.13

ELEMENTAL COMPOSITION OF TOTAL SOIL (in weight %) AND MOLAR RATIOS

Hor. no.	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	TiO2	MnO2	P2O5	IGN. LOSS	SiO2/ Al2O3	SiO2/ Fe2O3	SiO2/ R2O3	Al2O3/ Fe2O3
Ap	59.7	13.3	10.7	0.14	0.30	0.15	0.00	1.29	0.19	0.12	13.9	7.6	14.9	5.0	1.9
Bt	44.2	26.9	15.5	0.03	0.34	0.19	0.01	1.42	0.02	0.05	14.0	2.8	7.6	2.0	2.7
Btg1	45.0	27.5	15.5	0.00	0.32	0.25	0.00	1.46	0.01	0.05	12.9	2.8	7.7	2.0	2.8
Btg2	50.2	25.8	13.4	0.00	0.41	0.47	0.00	1.40	0.02	0.04	11.3	3.3	10.0	2.5	3.0
Btg3	48.0	25.0	12.9	0.00	0.49	0.49	0.00	1.40	0.02	0.03	10.7	3.3	9.9	2.5	3.0
2Cg	63.7	18.1	7.3	0.05	0.53	0.39	0.00	0.90	0.01	0.02	8.4	6.0	23.2	4.8	3.9
C	57.2	20.4	10.1	0.03	1.02	0.62	0.68	1.15	0.03	0.04	8.0	4.8	15.1	3.6	3.2

CLAY MINERALOGY (1 = very weak .. 8 = very strong) EXTRACTABLE Fe, Al, Si, Mn by amm. oxal.(o), Na dith(d) & pyroph.(p)

Hor.	MICA/ ILL	VERM	CHLOR	SMEC	KAOL	HALL	MIX	QUAR	FELD	GIBB	GOET	HEM	Fe(o)	Al(o)	Si(o)	Fe(d)	Al(d)	Fe(p)	Al(p)	Pret	pHNaF
Ap	0	0	0	0	8	0	3	3	2	0	3	0	-	-	-	4.9	-	-	-	-	-
Bt	0	0	0	0	8	0	3	1	2	0	4	0	-	-	-	7.7	-	-	-	-	-
Btg1	0	0	0	0	8	0	3	0	2	0	4	0	-	-	-	7.6	-	-	-	-	-
Btg2	0	0	0	0	8	0	4	0	1	0	3	0	-	-	-	7.0	-	-	-	-	-
Btg3	0	0	0	0	8	0	4	0	1	0	3	0	-	-	-	5.2	-	-	-	-	-
2Cg	0	0	0	5	8	0	3	1	1	0	3	0	-	-	-	2.9	-	-	-	-	-
C	0	0	0	7	5	0	3	1	1	0	0	0	-	-	-	2.4	-	-	-	-	-

remark sample 1 - 8: MIX=random smec-chlor

PSD: weight%. BULK DENS: g.cm^{-3}. pF: vol%. $CaCO_3$, org. C, tot. N: weight%. Exch. Bases, CEC: NH_4OAc pH7. Exch. ac.: 1*M* KCl.
Clay mineralogy: MICA/ILL mica/illite, SMEC smectite, KAOL kaolinite, MIX mixed layer silicates.

Annex 2 Evaluation of Land Qualities of JM 4 using JAMPLES

LAND QUALITY		Availability (1)	vh	h	m	l	vl
		Hazard/Limitation (2)	n	w	m	s	vs

vh = very high, h = high, m = moderate, l = low, vl = very low

n = not present, w = weak, m = moderate, s = serious, vs = very serious

JM 4

			vh / n	h / w	m / m	l / s	vl / vs
CLIMATE							
Radiation regime	- total radiation	1					
	- day length	1					
Temperature regime		1		■			
Climatic hazards (hailstorm, wind, frost)		2					
Conditions for ripening		1					
Length growing season		1		■			
Drought hazard during growing season		2					
SOIL							
Potential total soil moisture		1				■	
Oxygen availability		1			■		
Nutrient availability		1				■	
Nutrient retention capacity		1			■		
Rooting conditions		1				■	
Conditions affecting germination		1		■			
Excess of salts	- salinity	2	■				
	- sodicity	2	■				
Soil toxicities (e.g. high Al sat.)		2					■
LAND MANAGEMENT							
Initial land preparation		2		■			
Workability		1		■			
Potential for mechanization		1		■			
Accessibility	- existing	1	■				
	- potential	1	■				
Erosion hazard	- wind	2	■				
	- water	2		■			
Flood hazard		2	■				
Pests and diseases		2	■				

COMMENTS

Limitations of JM 4 for maize. For evaluation of other land utilization types and explanation on JAMPLES, see Annex 3.

Annex 3 JAMPLES: Explanatory Notes and Tables

Table A-1 Agro-ecological limitations of reference soil JM 4 for selected crops under current conditions (soil ref. no. 89/84C/JM 4)

	land qualities													
	LT	HT	OX	RC	NR	NA	PH	CC	AL	SA	SO	WH	WM	Erosion
rice (irrig.)	0	0	0	0	1	2	1	0	2	0	0	0	0	a0
sugar cane	0	0	0	0	1	2	2	0	2	0	0	0	0	a0
maize	0	0	1	1	1	2	2	0	2	0	0	0	0	a0
pigeon pea	0	0	1	1	0	2	2	0	1	0	0	0	0	a0
red pea	0	0	1	1	0	2	2	0	2	0	0	0	0	a0
cassava	0	0	1	1	0	2	2	0	1	0	0	0	0	a0
yam	0	0	1	1	0	2	2	0	2	0	0	0	0	a0
tomato	0	0	1	1	1	2	2	0	2	0	0	0	0	a0
breadfruit	0	0	1	1	0	2	2	0	2	0	0	0	0	a0
citrus	0	0	1	1	0	2	2	0	2	0	0	0	0	a0
ackee	0	0	1	1	0	2	2	0	2	0	0	0	0	a0
mango	0	0	1	1	0	2	1	0	2	0	0	0	0	a0
forestry	0	0	0	0	0	2	1	0	2	0	0	0	0	a0
natural forest	0	0	0	0	0	1	0	0	1	0	0	0	0	a0
banana	0	0	1	1	1	2	2	0	2	0	0	0	0	a0
pineapple	0	0	1	1	0	1	1	0	1	0	0	0	0	a0
unimpr. pasture	0	0	0	0	0	1	1	0	1	0	0	0	0	a0
impr. pasture	0	0	0	0	0	2	2	0	1	0	0	0	0	a0

Table A-2 Suitability of reference soil JM 4 for selected crops produced within specific technical and socio-economic settings (MLU) in the Worthy Park area, Jamaica (soil ref. no. 89/84C/JM 4; planting/sowing May).

		Agro-ecological suitability class for:			
Crop	Slope (%)	MLU-A (rainfed)	MLU-B (rainfed)	MLU-C (rain/irr.)	MLU-D (irr./rain)
rice (irrig.)	0-2%	-	-	S2f	S2f
sugar cane	0-2%	N	S3fr	S2f	S2f
maize	0-2%	N	S3p	S3p	S2f
pigeon pea	0-2%	N	S3p	-	-
red pea	0-2%	N	S3pr	S3p	S2f
cassava	0-2%	N	S3p	-	-
yam	0-2%	N	S3pr	-	-
tomato	0-2%	N	S3p	S3p	S2f
breadfruit	0-2%	N	S3p	-	-
citrus	0-2%	N	S3p	S3p	S2f
ackee	0-2%	N	S3p	-	-
mango	0-2%	N	S3p	S3p	S2f
forestry	0-2%	N	S2f	-	-
natural forest	0-2%	S2f	-	-	-
banana	0-2%	N	S3pr	S3p	S2f
pineapple	0-2%	S3p	S2p	-	-
unimpr. pasture	0-2%	S3f	-	-	-
impr. pasture	0-2%	-	S2f	S1	S1

Climatic data: R75 = 1265; Rav = 1522; PET = 1441 (mm/yr); R75/PET = 0.87
Note: Irrigation is generally not needed considering annual R75/PET ratio (MLU-C/D).

A) Land and Land Use

Land utilization types (LUTs) are defined as management systems which produce a particular crop in a defined technical and socio-economic setting. This setting is described under the general heading "Major Kind of Land Use (MLU)", (SSU 1990).

Table A-3 Land qualities and associated land characteristics as considered in JAMPLES

Land qualities	Land characteristics
Moisture availability	Monthly rainfall: monthly PET, available water capacity of soil
Temperature regime	Air temperature
Nutrient retention capacity	Effective Cation Exchange Capacity (ECEC) in upper 30 cm
Soil reaction	pH-H_2O (1:2.5) in upper 50 cm
Nutrient availability	Exchangeable Ca, Mg and K (1M NH_4OAC at pH 7); organic matter content; available P (Truog) in upper 30 cm; (also: pH, salinity, sodicity, $CaCO_3$ and Al)
Calcium carbonate toxicity	$CaCO_3$ content in upper 50 cm
Aluminium toxicity	Percentage of ECEC saturated with exchangeable aluminium in upper 50 cm
Excess of salts	Electrical conductivity in saturated paste; depth of occurrence of salts within 100 cm from surface
Sodicity hazard	Exchangeable sodium percentage (ESP) in upper 50 cm
Availability of oxygen	Soil drainage class
Ease of rooting	Soil depth to physical root limiting layer; drainage class; stoniness/rockiness; porosity; vertic properties
Erosion hazard	Soil texture, soil structure, organic matter content; slope angle and length; rainfall erosivity; present vegetation cover
Ease of cultivation/reps. mechanisation	Soil consistence; stoniness and/or rockiness; soil depth; slope angle; ESP
Ease of irrigability	Available water capacity; soil permeability; slope angle; monthly rainfall

Four MLUs are considered in this land evaluation:

MLU-A: Mixed non-commercial (subsistence) rainfed farming based on low technology and capital intensity
MLU-B: Mixed, commercial (rural market oriented) rainfed farming using intermediate technology and capital intensity
MLU-C: Mixed, commercial (rural/urban market oriented) rainfed farming with supplementary irrigation under intermediate technology and capital intensity
MLU-D: Commercial (urban/export market oriented) rainfed/irrigated farming based on high technology and capital intensity

B) Matching Module (MATHMOD)

Land qualities of a given soil map unit are matched with the requirements of selected annual and perennial crops using MATHMOD. Results of the matching process are presented in tables showing the degree of limitation of the land qualities for specific crops (see Table A2). Land qualities are given the following code:

PH	Adequacy of soil pH for pH	(0-30 cm, 30-50 cm)
OX	Availability of oxygen for crops in rootable zone	(0-100 cm)
RC	Adequacy of rooting conditions for crops	
SA	Soil salinity	(0 - 100 cm)
SO	Sodium toxicity	(0 - 50 cm)
CC	Occurrence of toxic levels of finely divided lime	(0 - 50 cm)
Al	Occurrence of toxic levels of exchangeable Aluminium	(0 - 50 cm)
NR	Nutrient retention (ECEC)	(0 - 30 cm)
NA	Available nutrients (OM%, avail. P, exch. Ca, Mg and K)	(0 - 30 cm)
WH/WM	Workability manual resp. mechanised	
MR	Adequacy of soil moisture for crops	
TR	Thermal limitations for crops at highest (HT) resp. lowest (LS) point of land unit	
E	Long-term erosion 'hazard', which is shown for slope classes, viz.: a(0-2%), b(2-5%), c(5-8%), d(8-16%), e(16-30%), f(30-50%) ad g(>50%).	

The degree to which a land quality is limiting for a specific crop is indicated by a number, viz.:

0: no limitations	(e.g. Al0, exch. Aluminium is not limiting)
1: slight limitations	(e.g. RC1, rooting conditions are slightly limiting)
2: strong limitations	(e.g. SA2, salinity is strongly limiting)
	(e.g. Ed2, strong erosion on 'd' slopes)

The final suitability of a land unit for a particular use (crop/management system) is determined using the LANDEV module, which amounts for the fact that identical land units may have different suitability for a particular crop when it is produced under different level of management.

NOTE: The MATMOD and LANDEV modules of JAMPLES are only validated for use in Jamaica!

Four land suitability classes are recognized in JAMPLES. Classes within orders are indicated with numerals and reflect the respective degree of suitability.

S1 - highly suitable (app. 80-100 % of targeted yield)
S2 - moderately suitable (app. 40-80 % of targeted yield)
S3 - marginally suitable (app. 20-40 % of targeted yield)
N - not suitable

The class "not relevant" (--) is used when a particular land use is not pertinent within the socio-economic context of the survey area.

Suitability subclasses are indicated in the suitability symbol with common letters, where the land suitability of a specified use is either S2 or S3. Each letter reflects the nature of a major limitation of the envisaged land use. Where relevant, subclasses are indicated in the output tables using small letters:

t: air temperature is limiting for the crop under consideration
w: high rainfall is a constraint for satisfactory production
r: rainfall is low and highly variable thereby limiting growth of the specified crop (MLU-A and MLU-B)
f/p: soil/terrain conditions are unfavourable after land improvement. Only the most stringent condition is indicated:
f for limiting soil fertility
p for soil physical and topographic constraints
e: soil erosion is a risk under sustained application of the indicated use

Annex 4 Units, Glossary, Class ratings and Acronyms

UNITS

Weights and measures

	Imperial	**SI equivalent**
	1 acre (ac)	0.405 hectare (ha)
	1 pound (lb)	0.45 kilo (kg)
	1 pounds/acre	0.184 kg.ha^{-1}

Other units

	cmol$_c$ kg^{-1}	centimol charge per kilogram (formerly meq/100 g; 1 meq/100 g = 1 cmol$_c$ kg^{-1})
	mS cm^{-1}	milliSiemens per cm at 25°C (formerly mmho cm^{-1})

GLOSSARY

Air capacity	Amount of pore space filled with air 2 or 3 days after soil has been wetted. It is calculated from the difference between amount of water under almost saturated conditions (pF 0.0) and moisture retained at "field capacity" (pF 2.0), and expressed as volume percentage.
Al saturation	Ratio of exchangeable aluminium to the CEC, expressed as percentage.
Available soil	Amount of moisture retained between "field capacity" (pF 2.0) and "wilting point" (pF 4.2), moistureexpressed as volume percentage (also called "available water capacity"), which is indicative of the amount of moisture in the soil available for plants.
Base saturation	Ratio of the sum of bases to the CEC, expressed as percentage.
Bulk density	Weight of an undisturbed soil sample divided by its volume, expressed as g.cm^{-3}.
CEC	Cation exchange capacity, indicative of the potential nutrient retention capacity of the soil, expressed in cmol$_c$ kg^{-1}.
Clay mineralogy	Type of clay-sized ($< 2\mu m$) particles.
kaolinite	Clay mineral with a low nutrient retention capacity, common in soils from (sub)tropical regions.
smectite	Silica-rich clay mineral with a high nutrient retention capacity and the ability to absorb water, resulting in swelling of the clay particles.
illite	Potassium-rich clay mineral with a moderately high nutrient retention capacity, common in soils from temperate regions and in alluvial soils.
vermiculite	Clay mineral with a high nutrient retention capacity and strong potassium-fixation.
chlorite	Aluminium-rich clay mineral with a moderately high nutrient retention capacity, occurring in variable quantities in soils rich in aluminium.
halloysite	Clay mineral with a moderately high nutrient retention capacity, common in soils derived from volcanic ashes.
quartz	Residual silica, resistant to weathering.
feldspar	Residual primary mineral, unstable in soil environments and, if present, indicative of a slight to moderate degree of weathering.
hematite	Reddish coloured iron oxide, common in well drained soils of tropical regions.
goethite	Yellowish coloured hydrated iron oxide, common in soils of temperate regions.
gibbsite	Aluminium hydroxide, indicative of a high degree of weathering.
Cockpit karst	a series of cone-shaped hills separated from each other by multi-sided, closed depressions ("cockpits") producing a hummocky landscape (see photos 1 and 4).
Cone-karst	See cockpit karst.
Consistence	Refers to the degree and kind of cohesion and adhesion of the soil material, or to the resistance to deformation or rupture.
Doline	A conical depression in the limestone which may be several metres in diameter.
ECEC	Effective cation exchange capacity. It is calculated by addition of the sum of bases and exchangeable acidity, and reflects the actual nutrient retention capacity of the soil, expressed in cmol$_c$ kg^{-1}.
ESP	Exchangeable sodium percentage, ratio of exchangeable sodium to the CEC, expressed as percentage.
Exchangeable acidity	Sum of exchangeable hydrogen and aluminium.
Horizon	Layer of soil or soil material approximately parallel to the earth's surface.
Karst	Landscape shaped by chemical solution of the underlying rock rather than by erosional or sedimentary processes.
Land characteristic	Measurable property of land (e.g. texture).
Land quality	Set of interacting land characteristics which have a distinct influence on land suitability for a specified use (e.g. erosion hazard, which is a.o. influenced by slope, rainfall intensity, soil cover, infiltration rate, soil surface characteristics, texture).
Leaching	Downward or lateral movement of soil materials in solution or suspension.
Mottle	Spot or blotch differing in colour from its surroundings, usually indicative of poor soil drainage.
Organic carbon	Content of organic carbon as determined in the laboratory (% org. C x 1.72 = % org. matter)

Parent material	The unconsolidated mineral or organic material from which the soil is presumed to have been developed by pedogenetic processes.
pF value	Measure for soil moisture tension, being the loagartithmic value of cm H_2O pressure or suction (16000 cm H_2O is pF 4.2).
Soil reaction (pH)	Expression of the degree of acidity or alkalinity of the soil.
Soil structure	Aggregates of primary soil particles (sand, silt, clay) called peds, described according to grade, size and type.
Sum of bases	Total of exchangeable calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^+) and sodium (Na^+), expressed in $cmol_c\ kg^{-1}$.
Texture	Refers to the particle-size distribution in a soil mass. The field description gives an estimate of the textural class (e.g. sandy loam, silty clay loam, clay); the analytical data represent the percentages sand, silt and clay measured in the laboratory.
Water soluble salts	Salts more soluble in water than gypsum.

CLASS RATINGS OF SOME ANALYTICAL SOIL PROPERTIES

Organic Carbon - C (%)

< 0.3	very low
0.3 - 1.0	low
1.0 - 2.0	medium
2.0 - 5.0	high
> 5.0	very high

Acidity pH-H_2O

< 4.0	extremely acid
4.0 - 5.0	strongly acid
5.0 - 5.5	acid
5.5 - 6.0	slightly acid
6.0 - 7.5	neutral
7.5 - 8.0	slightly alkaline
8.0 - 9.0	alkaline
> 9.0	strongly alkaline

Available phosphorus (mg kg^{-1})	Olsen	Bray
low	< 5	< 15
medium	5 - 15	15 - 50
high	> 15	> 50

CEC [pH7] ($cmol_c\ kg^{-1}$ soil)

< 4	very low
4 - 10	low
10 - 20	medium
20 - 40	high
> 40	very high

Sum of bases ($cmol_c\ kg^{-1}$ soil)

< 1	very low
1 - 4	low
4 - 8	medium
8 - 16	high
> 16	very high

Base saturation - BS [CEC pH7] (%)

< 10	very low
10 - 20	low
20 - 50	medium
50 - 80	high
> 80	very high

Aluminium saturation (%)

< 5	very low
5 - 30	low
30 - 60	moderate
60 - 85	high
> 85	very high

Exchangeable sodium percentage - ESP (%)

Soil structure		*Crops*
< 5	very low	< 2
5 - 10	low	02 - 20
10 - 15	medium	20 - 40
15 - 25	high	40 - 60
> 25	very high	> 60

Bulk density (kg dm^{-3})

< 0.9	very low
0.9 - 1.1	low
1.1 - 1.5	medium
1.5 - 1.7	high
> 1.7	very high

ACRONYMS

FAO	Food and Agriculture Organization of the United Nations
ISIS	ISRIC Soil Information System
ISRIC	International Soil Reference and Information Centre
NASREC	National Soil Reference Collections and Databases project
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United States Department of Agriculture

Country Reports

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No.	Country	No. of soils*
1	Cuba	22
2	P.R. of China	51
3	Turkey	15
4	Côte d'Ivoire	7
5	Thailand	13
6	Colombia	18
7	Indonesia	48
8	Ecuador	in prep.
9	Brazil	28
10	Peru	21
11	Nicaragua	11
12	Costa Rica	12
13	Zambia	11
14	Uruguay	10
15	Gabon	6
16	Ghana	in prep.
17	Philippines	6
18	Zimbabwe	13
19	Spain	20
20	Italy	17
21	Greece	in prep.
22	India	in prep.
23	Kenya	in prep.
24	Mali	in prep.
25	Nigeria	in prep.
26	Mozambique	in prep.
27	Botswana	in prep.

* State of reference collections as of January 1995