DARK CLAY SOILS OF TROPICAL AND SUBTROPICAL REGIONS

edited by

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CONTENTS

INTRODUCTION

Clay soils having marked tendencies to shrink and swell with changes in moisture content are widespread in many parts of the world, especially in tropical and subtropical regions. Owing to their high clay activity, these soils are difficult to cultivate, especially with simple implements, and as a result large areas have remained unused or have not been used efficiently. With the present expansion of populations, however, it is becoming increasingly important to study the potentialities of soils which show favorable features for agricultural production.

It is the purpose of this monograph to present a summary of available knowledge on the nature and distribution of the dark clay soils, their present use, their origin and classification, and on various means for improving their management and increasing their output. It is hoped that this information will contribute to the effective transfer of experience and the results of research obtained in the use and management of these soils in one area to other areas with the same or similar soils. It should also be useful for the further study of these soils by increasing the understanding of their formation and thus providing a basis for improvements in their future utilization. Although this monograph is designed for the use of land planners, extension officers, administrators, farm management specialists and all those involved in the practical application of soil studies, it is hoped that the data compiled here will also contribute to the science of the dark clay soils.

The soils described here are known under many different names throughout the world. Some of the most common are Black Cotton soils (South Africa), Black Earths (Australia), Regurs (India), Tirs (Morocco), Grumusols and Vertisols (United States), Barros Pretos (Portugal) or Smonitzas (Yugoslavia). In the monograph, this group of soils will be called " dark clay soils " or " dark clays." These terms are short and descriptive and, although neither characterizes the group completely, they are used as a common denominator permitting easy reference in the text. Further discussion of nomenclature now in use or used in the past comprises a special section.

It should be pointed out that other soils with dark-colored surface layers occurring in the tropics and subtropics, such as Andosols, Humic Latosols, Humic Gley soils, Rubrozems and Rendzinas, are not considered here. Although these also have a dark surface color in common, they differ from the dark clays in a number of other important characteristics.

The monograph consists of three chapters: a first chapter on the general character and distribution of these soils and on the environments in which they occur; a second chapter on use, management and productivity, including a brief section on engineering problems related to dark clay soils; and a third chapter summarizing available information on their morphology, composition, genesis, nomenclature and classification. The latter chapter, which includes a series of profile descriptions and laboratory data, is a summary of the morphological and physico-chemical characteristics which provide a basis for the classification and correlation of dark clays in widely separated areas.

The monograph is mainly devoted to the dark clay soils of tropical and subtropical regions. However, some dark clays of warm-temperate climates are also included since they are essentially extensions of those in lower latitudes. Moreover, such soils are used for many of the same crops and require the same or very similar management for successful production. Dark clays are also known to occur in cool-temperate regions but these are not described in this monograph. Limiting the geographical coverage to the dark clays of tropical, subtropical and some warm-temperate regions permits the monograph to be focused on soils of the greatest interest for possible future development, and those with the greatest need for improved utilization.

1. GENERAL CHARACTERISTICS, DISTRIBUTION AND ENVIRONMENT OF DARK CLAY SOILS

General characteristics

The soils are mainly dark in color, fine in texture, low in organic matter, and alkaline or near-neutral in reaction; they expand and contract appreciably with changes in moisture and commonly lack distinct horizons in their profiles. Some of the major features of the dark clays are described briefly in the present chapter, a more complete account on their morphology and composition being given in Chapter 3 of the monograph.

The dark or very dark-colored surface layers of these soils are commonly between 1 and 3 feet thick. Despite their dark color, these soils are generally low in organic matter, both in the surface layer and in deeper parts of the profile.

Textures are commonly of the clay class throughout the profile. The high proportion of clay is reflected in the great plasticity and stickiness of the soils when they are wet and in their hardness and intractability when dry. An important and striking feature of the dark clays is their capacity to expand and contract with changes in moisture content; when it dries, the soil mass contracts or shrinks markedly. Cracks formed from the surface extend down into the soil, sometimes 1 meter or more. The process of contraction is reversed when the soil is again wetted after the end of the dry season.

As the dark clays shrink and crack on drying, some soil material commonly falls, or is washed down by rain, into the fissures and partially fills them. As the soil mass expands again when it becomes wet, it cannot reoccupy the cracks formed when it originally contracted so that some part of the soil mass is forced upward. This often gives rise to a characteristic microrelief of low hillocks and shallow depressions commonly called "gilgai." The contraction and expansion of the dark clays bring about a slow churning of the whole soil mass to the depth of the fissures. As a result of the falling of surface material into the cracks, the whole soil is gradually overturned to some depth. These dark clays have therefore been said to "plow themselves" or to be "self-swallowing" soils.

FIGURE 1. Profile of a dry brown-colored Grumusol developed from weathered shale (scale in feet). The profile is located one kilometer west of Altamont, Alameda County, California. (Courtesy W. M. Johnson, U.S. Soil Conservation Service, Berkeley, California, U.S.A.)

Pressures resulting from the force exerted by expansion cause the sliding of one mass of soil past another which produces polished and grooved surfaces called " slickensides."

The capacity to shrink and crack as they dry, to swell again slowly as they become wet and gradually to overturn, is distinctive of the dark clays and is responsible for their specific characteristics.

Distribution

The dark clays occur in all five continents and circle the world in the tropical, subtropical and warm-temperate zones. The general distribution of dark clays is shown in Figure 2. The map does not show the boundaries of the dark clays as such but indicates the regions of their major occurrence. Within these regions, dark clay soils often occur in association with other soils; for instance, with Saline soils in Chad, Tropical Ferruginous soils in Nigeria, Subarid Brown soils in Sudan, Red Loams in India, Hydromorphic soils in South Africa, Prairie soils in Argentina or Noncalcic Brown soils in Chile and California.

In Table 1 the distribution of dark clays is reviewed by country. The figures showing estimated coverage are strictly tentative but give an order of magnitude. The world coverage of dark clay regions is estimated at about 257 million hectares, an area nearly comparable to western Europe. Dark clays form a dominant component of the areas shown on the map but the figure of total coverage given would have to be reduced if the dark clays were delimited separately. On the other hand, the total figure for the extension of dark clay soils will probably increase substantially when the results of current and future field investigations are available and when the correlation of different nomenclatures is fully established. Indeed, dark clays may occur under names which, at first sight, do not indicate their presence; for example, compact Chernozems, clayey Prairie soils, dark Alluvial soils or black Mediterranean soils.

Major areas of these soils occur in Africa and Asia. They are widely distributed in Africa south of the Sahara, ranging from the margins of the great desert to the southern tip of the continent. They also occur to the east of the Sahara and in regions bordering the Mediterranean Sea. Dark clays are scattered from one end to the other of the southern half of Asia, with specially large areas in the Deccan plateau in India.

Important areas of these soils occur in Australia, North America and South America. In Australia, the dark clays occur both east and west of the great desert but the major areas lie to the east. In North America, they occur mainly in the south-central part although they are also found in small areas in the southwestern sections. These soils are widely

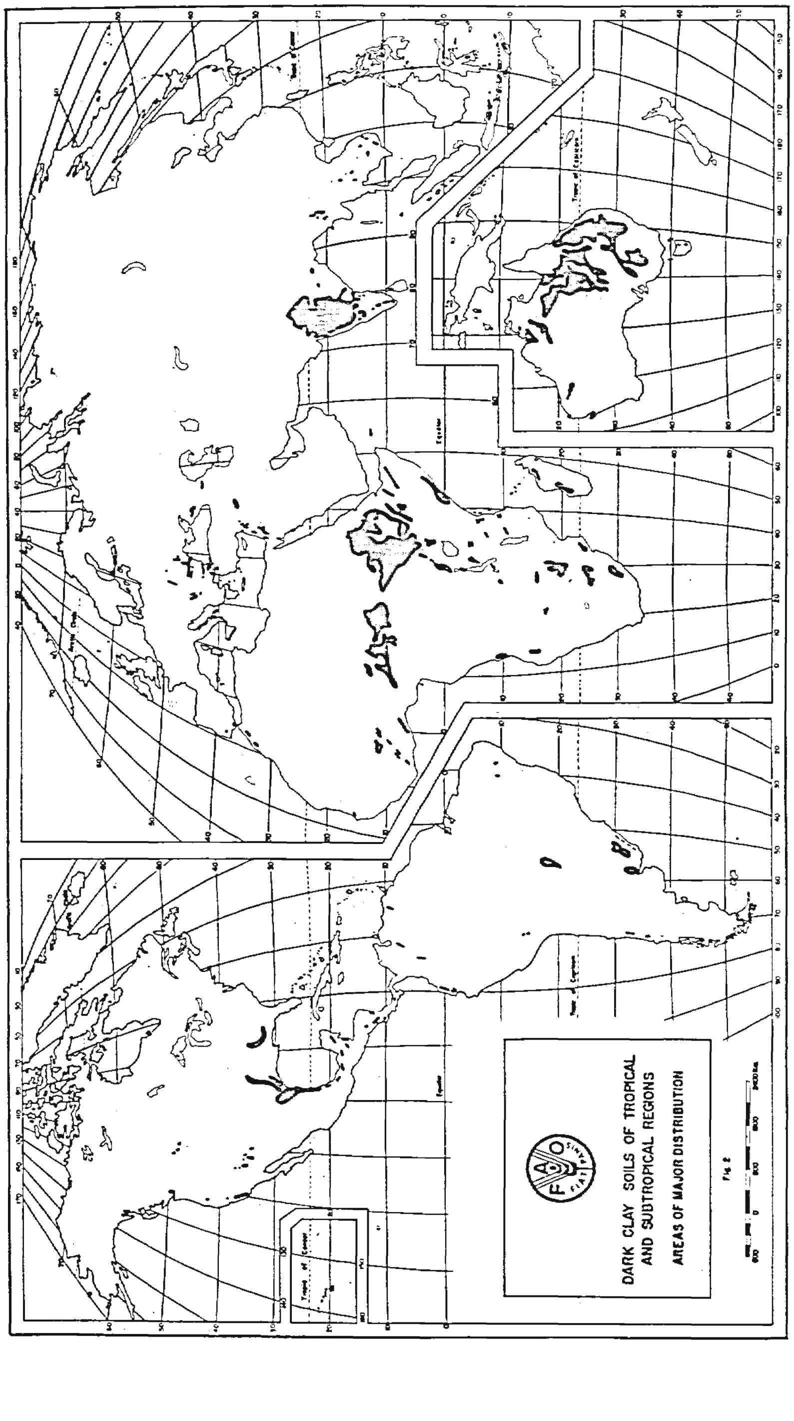


FIGURE 2. Dark clay soils of tropical and subtropical regions. Areas of major distribution.

TABLE 1. – DISTRIBUTION OF DARK CLAY SOILS

Country	Area	Estimated coverage in round figures (Million hectares)
Angola	Valleys of the Cunene and Cubango, region of Catete and southwestern part of the country	0.5
Argentina	Mainly in the northeastern part of the country in the province of Entre Rios, in the northeastern department of Buenos Aires, in south Corrientes, in Santa Fé and the Eastern Chaco	6.0
Australia	Mainly in Queensland (Darling Downs), northern New South Wales (Liverpool Plains), east-central part and coastal areas of the Northern Territories, patches in South Australia (near Adelaide), northwestern Australia and in Tasmania [1]	70.5
Basutoland	Drakensberg	2.3
Bechuanaland	West of Livingstone and Tuli; probably large areas around the Okovambo and Makarikari swamps	0.5
Bolivia	Mainly in the eastern part of the country, Gran Chaco and Santa Cruz plains; scattered patches in depressional areas	2.0
Brazil	Southwestern and western regions of Rio Grande do Sul (Bagé, Uruguaiana, Alegrese and D. Pedrito districts); in the western parts of the country bordering Uruguay, Paraguay and Bolivia; in limited areas of northeastern Brazil	4.5
Cameroon	Logone Chari basin and part of the Chad basin; peneplain of Kaélé and Marona region	1.2
Chad	Chad basin and scattered patches	16.5
Chile	Depressional areas associated with Non-calcic Brown soils in Santiago and O'Higgins provinces and also associated with Prairie and Chestnut soils in Magallanes Province	0.5

[1] The figures available for Australia are 33 million hectares of Black Earths and 75 million hectares of Gray and Brown soils of heavy texture. While Black Earths consist mainly of dark clay soils, it is believed that only a part of the Gray and Brown soils of heavy texture belongs to the dark clays. The proportion is not known; a figure of 50 percent of the total hectare coverage has been tentatively adopted here.

TABLE 1. – DISTRIBUTION OF DARK CLAY SOILS (*continued*)

Country	Area	Estimated coverage in round figures (Million hectares)
Congo	Ruzizi Plain, valleys of the Semliki and Lufira	0.3
Dahomey	Northern part of the country and in the region of Divo	0.1
Ecuador	Hilly lowland and valley bottoms in western part of the country (provinces of Guayas, Manabi, Esmeraldas)	1.0
Ethiopia	Rift valley and Ethiopian plateau	10.0
Ghana	Mainly Accra, Ho-Keta and Wineba Plains; scattered patches near Kpandu, Kwamen and Kwesi	0.2
India	Central and south-central Deccan plateau (parts of Bombay, Hyderabad and Madya Pradesh states)	60.0
Indonesia	Mainly in Central Java (Semarang, Demak, Bodjonegoro, Surabaya area), East Java and Lesser Sunda Islands (Lombok, Timor, Sumbawa and Flores)	1.8
Ivory Coast	In northern part of the country and in the region of Divo	0.2
Kenya	Athi Plains near Nairobi and other areas	2.0
Madagascar	Some valley depressions in the western part of the country and on uplands in the western and northwestern part	0.8
Malawi	Chyre valley and areas around Nyasa and Chilwa lakes	1.6
Mali	Niger valley, and a large area along the borders with Mauritania	0.7
Morocco	Mainly in the northwest (Gharb) and in the Doukkalas (south of Casablanca); scattered spots	0.2
Mozambique	Alluvial plains of the Limpopo and Inkomati rivers and surrounding uplands; Zambezi valley upstream of Tete; coastal area north of Mozambique city	1.1
Niger	Central Niger valley and several scattered patches	0.1

TABLE 1. – DISTRIBUTION OF DARK CLAY SOILS (*continued*)

Country	Area	Estimated coverage in round figures (Million hectares)
Nigeria	Northeast Bornu and Benoué river basin	4.0
Paraguay	Depressional areas in basaltic and limestone plateaus of the eastern region; in the Paraguay river basin and large areas in the Chaco region	1.5
Portugal	Depressional areas on diorite and limestone in Alentejo	0.1
Rhodesia, Southern	Part of the valley of the Zambezi; Livingstone area and southern part of the country	1.0
Senegal	Senegal valley, lowland of the northwest; on the Cape Verde peninsula	0.2
Somalia	In the plains extending between the Giuba and Scebeli rivers	0.8
South Africa	Bush Veld and Springbok Flats (Transvaal), Highveld (Orange Free State and Transvaal)	2.1
South West Africa	Probable occurrence in the Caprivi Strip along the Cubango river and around the " Etosha Pan "	0.7
Sudan	Region between the White and Blue Nile extending east of the Blue Nile into Ethiopia and covering an area west of the White Nile; widespread in South Sudan, Bahr el Gasal, Upper Nile and Equatoria Province	40.0
Swaziland	Mainly in the Middelveld, eastern Lowveld and Lebombo areas	0.2
Syria	Jezireh and basaltic plateaus south of Damascus	0.6
Tanzania	Valleys of the Mayowosi and Malagarasi, Great Ruaha valley areas near Tendigo swamps and Rukwa lake; scattered upland areas	7.0
Togo	In the northern part of the country and in the Mono valley	0.1
Uganda	Valley of the Semliki, areas near George, Albert and Edward Lakes, areas in the east and northeast of the country	1.7

TABLE 1. – DISTRIBUTION OF DARK CLAY SOILS (*concluded*)

Country	Area	Estimated coverage in round figures (Million hectares)
Union of Soviet Socialist Republics [1]	In the Caucasus between Krasnodar and Groznyy	0.8
United States of America	" Blackland " in Central Texas from the Red River bottomland on the north and northeast to the Rio Grande plain in the San Antonio area on the southwest; belt extending from Lowndes County in Missouri to Perry County in Alabama; basaltic plateaus in Arizona; scattered spots in California; islands of Oahu, Kanai and Molokai in Hawaii	5.6
Upper Volta	Souron Valley; poorly-drained basin deposits spread over the country	0.4
Uruguay	In the southwest, northwest and south-central part of the country and along the border with Brazil (Rio Grande do Sul, Bage area)	1.0
Zambia	Valleys of the Luangwa, Lukushashi and Zambezi; Kafue flats	0.9
Occurrence of dark clays has also been reported from:		
Albania, Algeria, Bulgaria, Burma, Cambodia, Ceylon, Colombia, Costa Rica, France, Greece, Honduras, Hungary, Iraq, Israel, Italy, Jordan, Mexico, New Caledonia, Nicaragua, Panama, Philippines, Principe, Romania, São Tomé, Spain, Thailand, Tunisia, Turkey, Venezuela, Viet-Nam, Yugoslavia	The extension of dark clay soils in the respective countries is relatively small and cannot be listed separately. The total surface occupied is estimated at	3.5
		257

[1] The compact Chernozems distinguished in the U.S.S.R. show distinct characteristics of dark clay soils (25). They are tentatively included here. However, a more precise correlation remains to be established.

distributed in South America although information on their distribution and extent in that continent is still limited.

In Europe the dark clays occur in several countries bordering the Mediterranean Sea and in the central part of the continent.

Small areas of these soils are scattered throughout Central America, Southeast Asia and the Pacific Islands.

Thus, the dark clays have a very wide geographical distribution which ranges from 45°S to 45°N latitude.

Environmental conditions

CLIMATE

In accordance with their extensive geographical distribution, the dark clay soils occur under a wide range of climatic conditions. They are found both in very hot and in cool climates, and under arid as well as under humid conditions. A study of the records of 140 meteorological stations, spread throughout the regions where dark clays occur, shows a great variety in the climatic data.

The average annual temperatures of the different stations have been grouped into classes, with intervals of 5½°C, and have been set out in a diagram (Fig. 3) against the number of stations. It shows that the average annual temperature generally ranges between 15.5-26.5°C and that only for a few stations, located in the northern part of the United States, Canada, and central Europe, the average annual temperature is below 10°C. In all cases the dark clay soils have high summer temperatures which are seldom lower than 20°C, and may even reach as high as 35°C as in Mali and central India. In some areas of North America, South America, North Africa, South Africa, India and Australia, the dark clays may suffer frost in the winter months, a factor which is very important for their agricultural utilization. The difference between the highest and the lowest mean monthly temperatures depends on the latitude at which these soils occur. Near the equator the difference is not more than 3°C, but in the higher latitudes it may be as much as 15°C.

The mean annual rainfall is dominantly between 500 and 1,000 millimeters (Fig. 4), the full range being from 150 millimeters in Sudan to 2,000 millimeters in Indonesia. In the drier areas precipitation may be supplemented by water from other sources such as floodwater, surface runoff from surrounding upland and seepage water.

The rainfall distribution is markedly seasonal (Fig. 5 and 6). The duration of the dry period varies from 0 to 12 months while the humid period ranges from 0 to 9 months. The data collected on the frequency

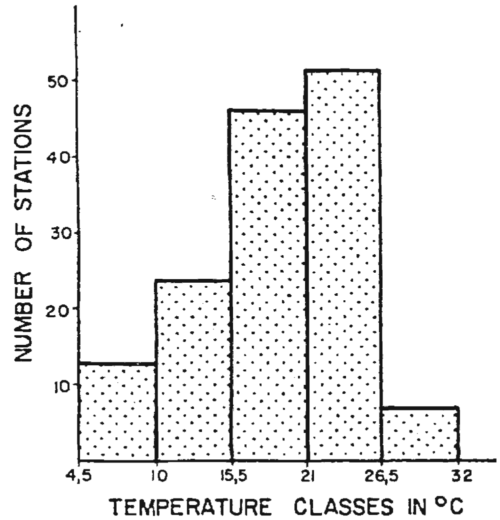


FIGURE 3. Mean annual temperature classes in dark clay soil regions.

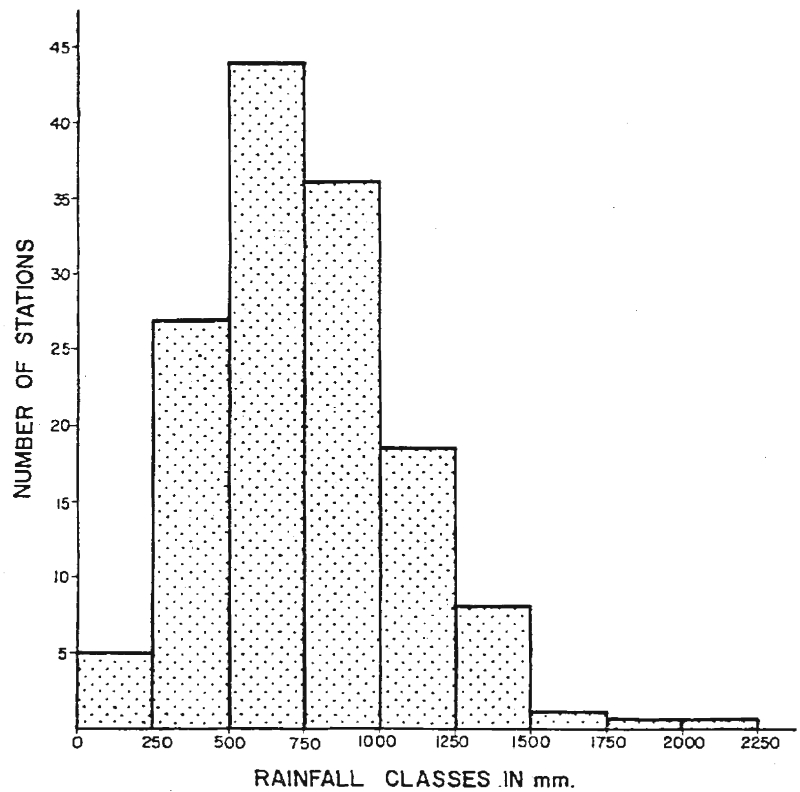


FIGURE 4. Mean annual rainfall classes in dark clay soil regions.

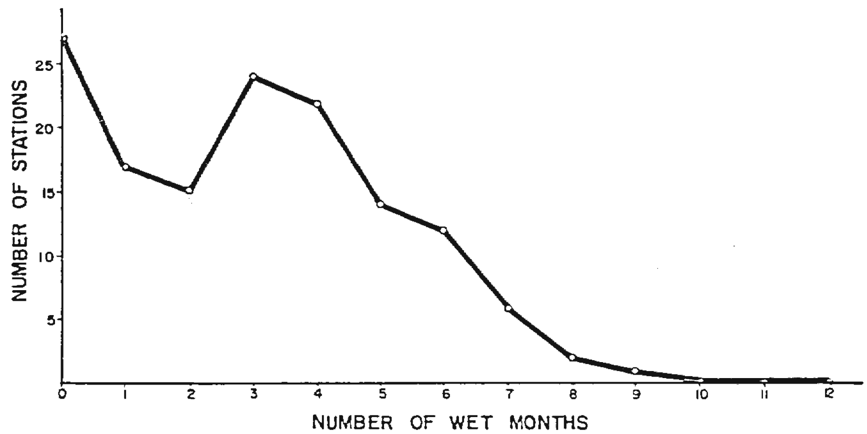


FIGURE 5. Number of wet months in dark clay soil regions.

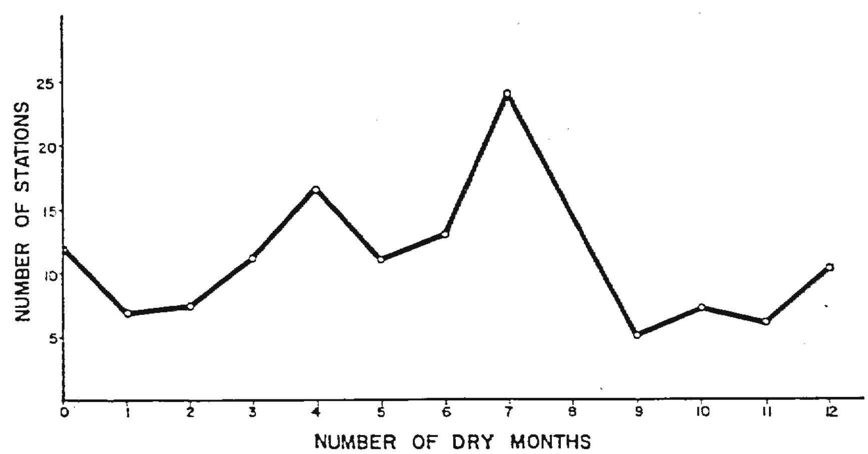


FIGURE 6. Number of dry months in dark clay soil regions.

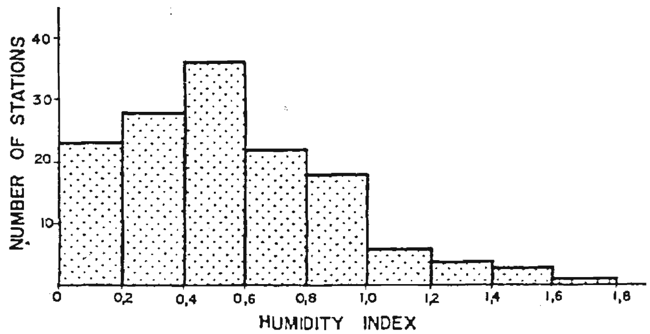


FIGURE 7. Humidity indexes in dark clay soil regions.

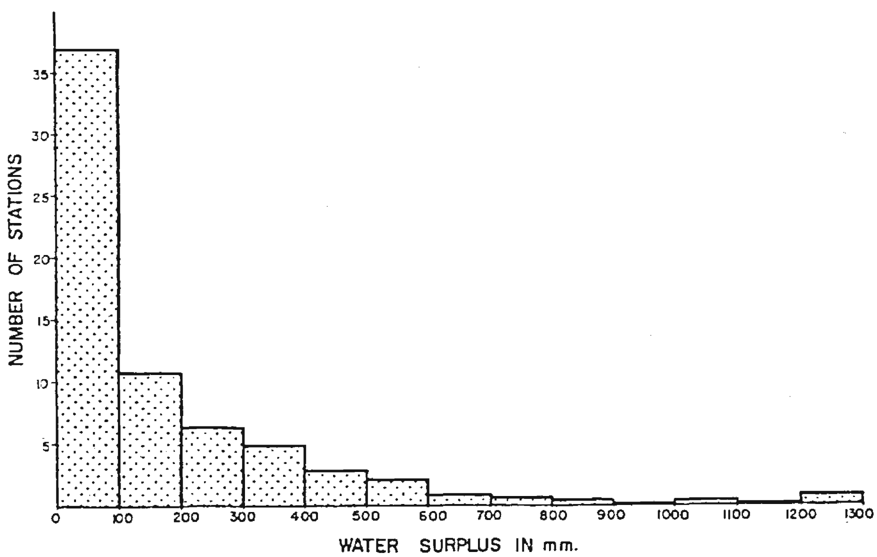


FIGURE 8. Water surplus classes in dark clay soil regions.

TABLE 2. – CHARACTERISTICS OF CLIMATIC PHASES DISTINGUISHED IN THE DARK CLAY SOIL REGIONS OF AUSTRALIA, INDIA AND SUDAN

Climatic phases	Desertic	Arid	Semiarid	Monsoon tropical	Monsoon equatorial	Semiarid temperate	Dry Medi-terranean	Subhumid temperate
Characteristic stations	Khartoum Sudan	Kassala Sudan	Scholapur India	Madras India	Nagpur India	Bourke Australia	Dubbo Australia	Hobart Australia
Number of dry months [1]	12	11	7	7	5	11	8	0
Number of nondry months	0	1	4	1	4	1	2	6
Number of humid months	0	0	1	4	3	0	2	6
Percentage of evapotranspiration covered by rainfall	4	10	27	53	72	16	37	104
Average annual rainfall (mm)	163	332	683	1 255	1 269	338	554	608
Average annual temperature (°C)	29.4	29.1	27.2	26.9	28.6	20.6	17.5	12.5
Maximum temperature (°C) Warmest month	41.7	41.1	40.6	42.8	38.3	37.2	33.9	21.7
Minimum temperature (°C) Coldest month	15.0	16.1	15.0	12.2	19.4	4.4	2.2	4.4

[1] According to J. Papadakis (171) a month is "dry" when available water (rainfall plus the water stored in the soil by previous rains) covers less than half of the evapotranspiration; it is "humid" when the rainfall exceeds evapotranspiration; when moisture conditions are intermediate they are considered as "nondry."

of dry months shows that dark clay soils only occur in climates with a pronounced dry season. A dry period from 4 to 8 months seems to be most common in dark clay soil regions. The wet season in these regions is very seldom longer than 7 months. In the driest areas the rainfall is often very erratic.

In the dark clay soil regions the humidity index — the ratio between the rainfall and the evapotranspiration — is usually between 0.1 and 1. Where the dry period is short the humidity index lies mainly between 0.7 and 0.9. It should be pointed out that the effectiveness of precipitation on dark clays is strongly influenced by the extreme characteristics of these soils. The tenacity with which water is held makes dark clays more arid and the slow permeability causes many of these soils to be more humid than the rainfall data would indicate.

Although the wide range of climatic conditions is not generally reflected in the morphological characteristics of dark clays, the differences in temperature and rainfall are of very great importance for the agricultural utilization of these soils. It has, therefore, been attempted to subdivide them into climatic phases. Each phase is characterized by a water balance which expresses the relationship between rainfall and evapotranspiration (Fig. 9).

For Australia, India and Sudan the following phases have been recognized: desertic,[1] arid, semiarid, monsoon tropical, monsoon equatorial, semiarid temperate, dry Mediterranean, and subhumid temperate. For each phase the climatic data of a representative station are shown in Table 2. The distribution of these phases is shown on a map (Fig. 10, 11, 12).

From the study of the data available and from the maps it appears that dark clay soils in these countries occur mainly in arid to semiarid zones with a high mean annual temperature, a rainfall ranging between 250 and 750 millimeters, and a dry period varying from 6 to 12 months.

In terms of agricultural potential the different climatic phases offer the following possibilities. Under desertic conditions all months are dry. No cropping is possible without irrigation. Where the soils are flooded, millet, sorghum, and in some cases, cotton can be grown. With irrigation very good yields of cotton, sugar cane and rice can be obtained. Many areas, e.g. all Sudan, are frostless; in west Australia and Queensland there are occasional frosts but the growing season is sufficiently long and

[1] Since the definition of arid climates varies from one author to another some clarification is given here with regard to the use of the term "desertic." This name covers a monsoon desert in which all months are dry, but where the rainfall covers more than 25 percent of the potential evapotranspiration during one or more months; the annual rainfall covers less than 22 percent of the potential evapotranspiration. In the "absolute desert" rainfall covers less than 25 percent of the evapotranspiration during all months of the year, and the annual rainfall covers less than 9 percent.

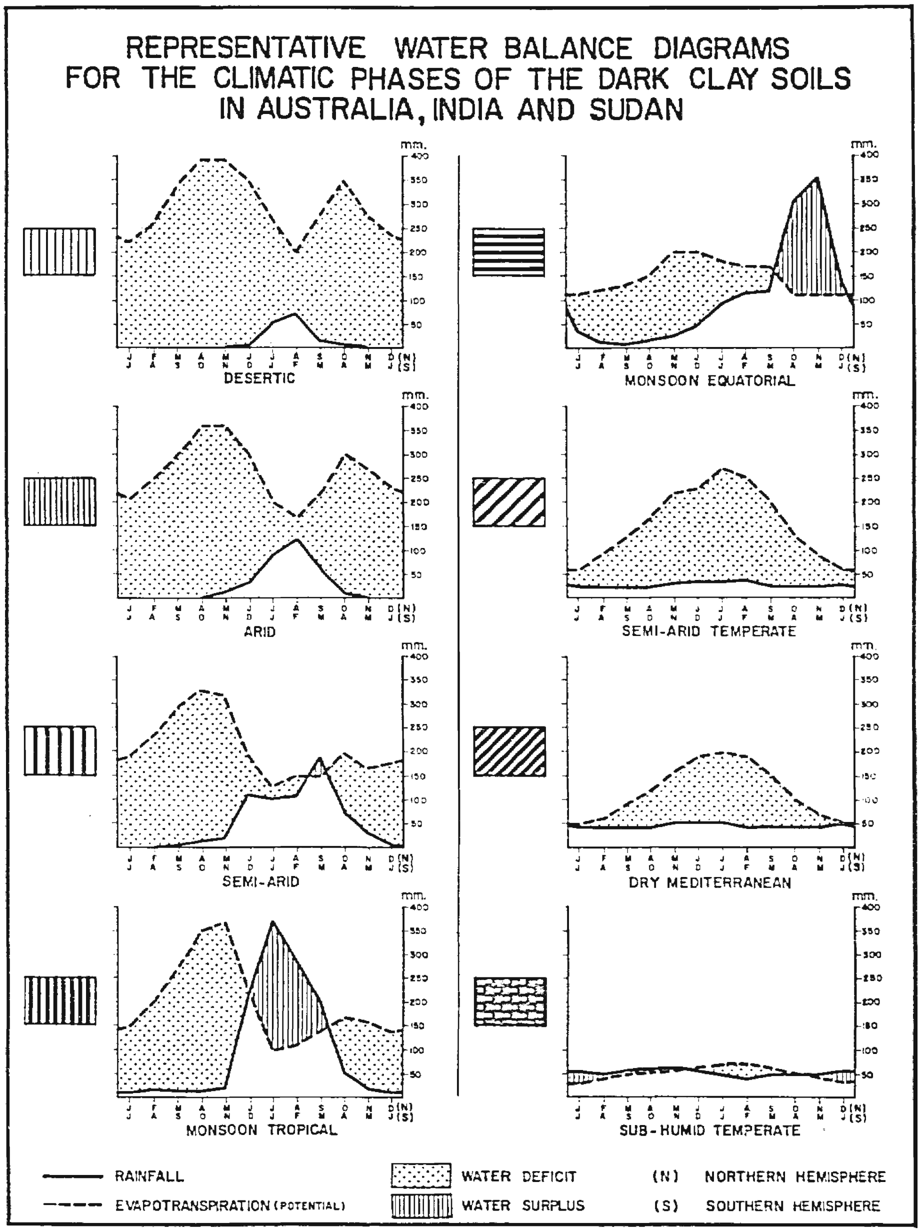


FIGURE 9. Representative water balance diagrams for the climatic phases of the dark clay soils in Australia, India and Sudan.

warm for sugar cane to be grown when irrigation is possible. In New South Wales the winter is too cold for this crop but wheat, various fruits, citrus and pasture crops can be grown with irrigation.

Under arid conditions one or more months are nondry, but no month is humid. Cropping is almost impossible without irrigation but grazing is provided during the short nondry season. Where floods occur the production of millet, sorghum and cotton becomes possible. With irrigation the possibilities are the same as those described for the desertic regions.

In the semiarid regions two to three months are humid, but the annual rainfall covers less than 44 percent of the annual potential evapotranspira-

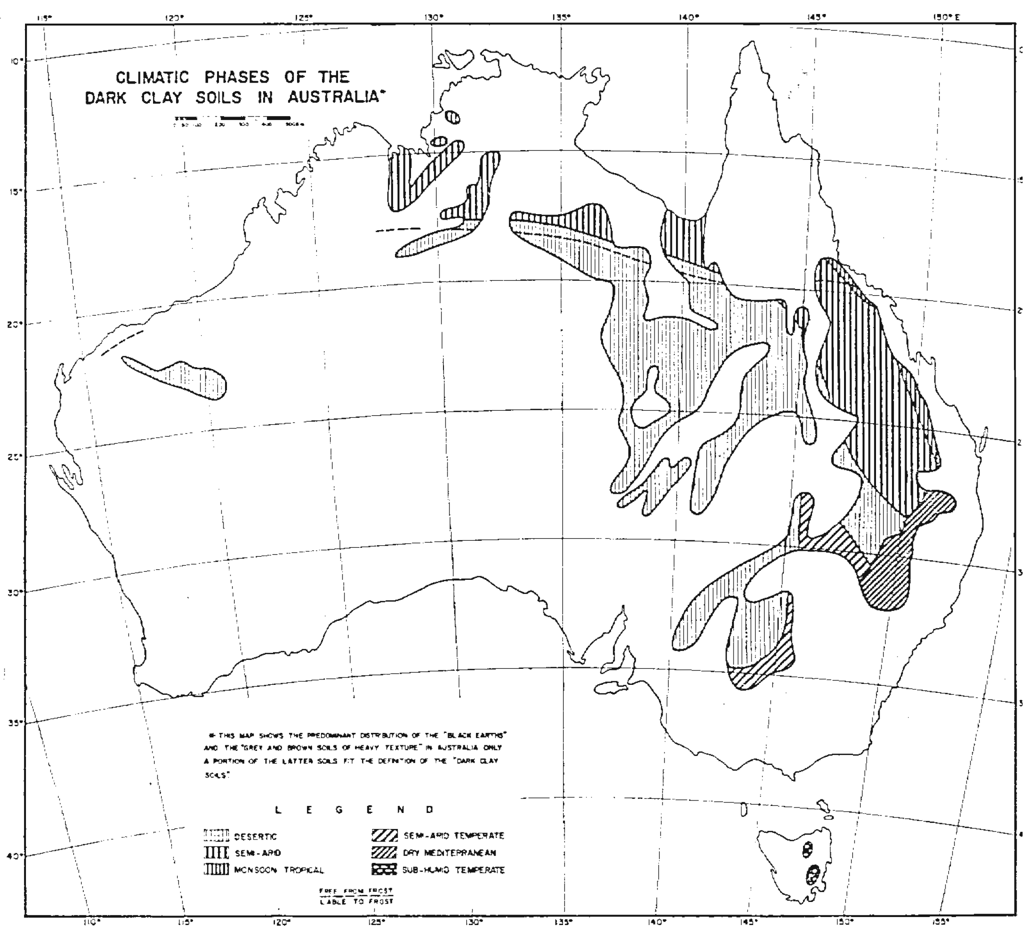


FIGURE 10. Climatic phases of the dark clay soils in Australia.

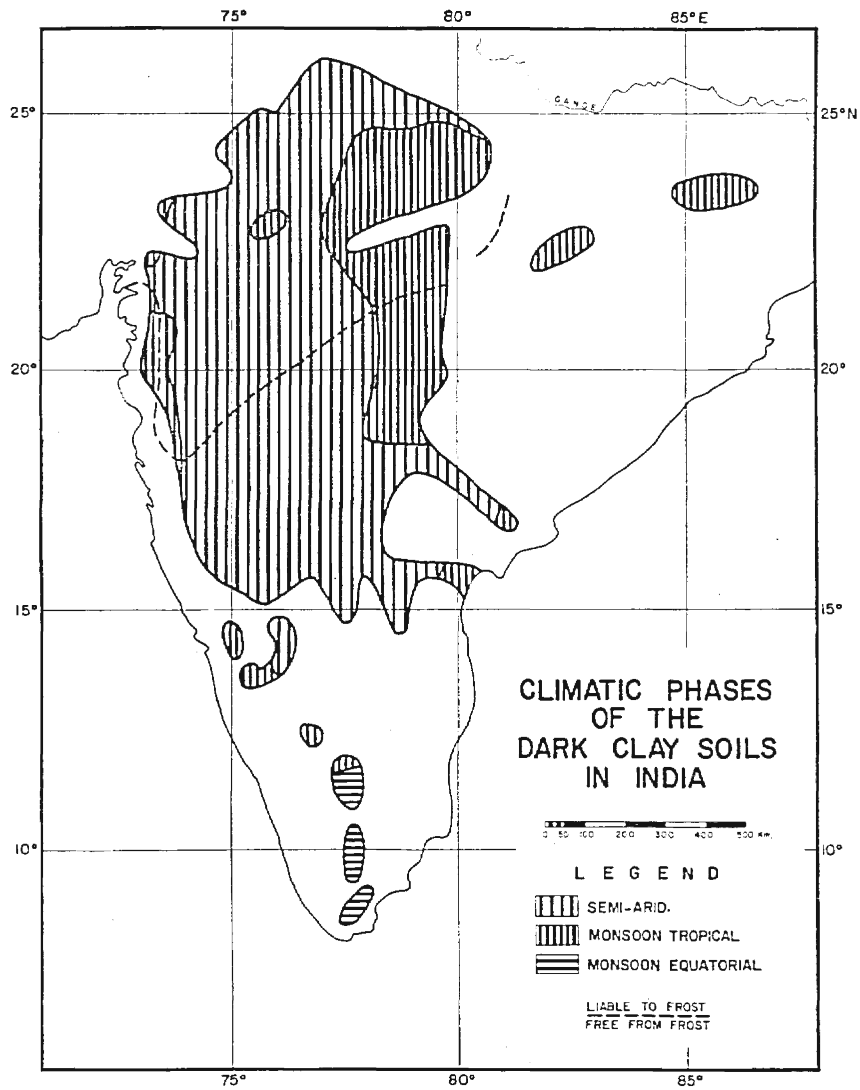


Fig. 11

FIGURE 11. Climatic phases of the dark clay soils in India.

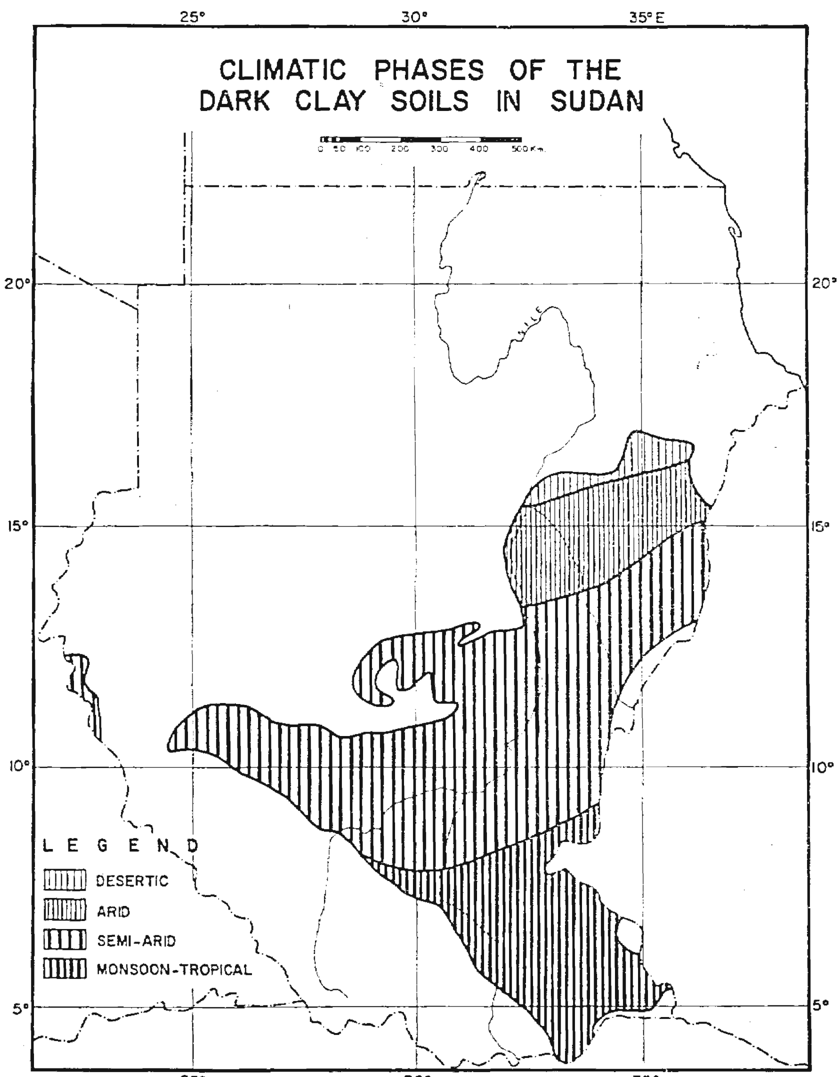


FIGURE 12. Climatic phases of the dark clay soils in Sudan.

tion and the dry period is very long. The production of millet, sorghum, even cotton, is possible, even without flooding. Grazing is provided during some months of the year; this period may be prolonged by flooding. Cotton, sugar cane, rice and forage crops yield highly where irrigation can be applied. Frost is observed only in northern India and southern Queensland, but owing to the long and warm growing season it does not impede the production of sugar cane; wheat and grams (chick-peas) are often sown as winter crops in northern India.

In monsoon tropical climatic conditions the rainfall covers more than 44 percent of annual potential evapotranspiration, but the water deficit is high and the dry season is long. The principal crops are millet, sorghum, cotton, rice and sugar cane. The latter two crops usually require irrigation. Maize is grown as a dry-land crop in the more humid parts, or with irrigation. In Sudan the region is frostless; in northern India and southern Queensland there are occasional frosts. Wheat and grams (chick-peas) are often grown as winter crops in northern India.

Under monsoon equatorial conditions the humid season is short (3-4 months), the dry season is not very long (4-5 months) and the average monthly minimum temperatures are above 19°C all the year round. The same crops are grown as in the monsoon tropical regions but better conditions prevail for sugar cane when irrigation can be applied. For cotton the control of pests and diseases becomes more difficult.

Under a semiarid temperate climate no month is humid but the winter is nondry and cool and grazing is provided during that season. This period is prolonged when floods occur. Wheat, deciduous fruits of temperate climates and pasture crops are grown with irrigation.

Under dry Mediterranean conditions some winter months are humid and winter crops can be grown without irrigation. Wheat and sheep are the dominant dry-land industries. Summer pasture and fruits can be grown with irrigation.

In a subhumid temperate climate the number of dry months does not exceed two, however, only the winter is humid. Winter crops (wheat, oats, peas, etc.), temperate-climate fruits (apples, pears, etc.) and pastures of cool environments are extensively grown. Sheep and fruits are the main industries.

This brief description shows that, except for the last two phases, cotton is the principal cash crop grown on dark clay soils. Sugar cane, sorghum and rice are also important crops. When flooded these soils provide grazing also during the dry season.

It must be emphasized that this separation in phases is tentative. More factors will have to be taken into account to assure a reliable transference of agricultural knowledge, but this first attempt may form a useful basis for further study.

PHYSIOGRAPHY, TOPOGRAPHY AND DRAINAGE

Dark clay soils occur at elevations running from sea level up to 2,200 meters with the majority occurring below 300 meters. However, important areas of these soils do occur above 300 meters; for example, the Regurs of India which lie mainly between 300 and 700 meters, the subtropical Black clays of South Africa which range up to 1,170 meters, some Grumusols in Arizona which are found at 1,800 meters and the dark clay soils of the Ethiopian highlands which occur up to 2,200 meters. The latter high elevations are uncommon on a world basis.

Dark clay soils are found in a large variety of landforms: on broad plateaus in India; on coastal plains in Texas; in broad continental basins in Sudan. Level and nearly level areas of dark clays occur chiefly in basins of various kinds, in alluvial plains, former floodplains, rift valleys, marine terraces and river terraces. More sloping areas may be found on the valley-sides in landscapes such as dissected plateaus or peneplains and on the lower slopes of volcanoes and monadnocks.

For the most part, dark clay regions have low relief, i.e., they are regions with limited local differences in elevation. Topography is most often undulating to level though it may be rolling in places. For example, land surfaces in the Deccan plateau of India and in the Blackland prairies of Texas consist of successions of low ridges with broad crests separated by wide shallow valleys. In such landscapes, dark clays virtually blanket the region. They occupy the ridge crests, upland slopes and valley floors. By way of contrast, dark clays commonly form only a part of the soil pattern in rolling to hilly landscapes, generally occupying the smoothest and lowest positions. At the other extreme, dark clays form large, virtually level areas, as in continental basins such as the Gezira Plain of Sudan.

Slopes are commonly between 0 and 8 percent in gradient. Dark clays have been observed with slopes up to 15 percent but such areas are unusual. The slope of the major proportion of the dark clays does not exceed 5 percent. Considering the group as a whole, it is characterized by gentle slopes and mild relief.

Many dark clays have a microrelief variously called gilgai, crab-hole, melon-hole, hog-wallow, puffs and shelves, and a number of other names. This microrelief consists of a pattern of low hillocks and shallow depressions. The irregularities in the land surface exhibit a variety of forms and sizes, expressed in several kinds of pattern such as lattice, network, striped, wavy and tank gilgai. The term "gilgai" will be used here as a collective name for these different forms of microrelief.

It should be recognized that gilgai microrelief does not exist in all areas of dark clays. It may occur in one region and be missing from another nearby. It is widespread in Australia and Texas but much less common in South Africa and India. The microrelief does have important effects on the morphology of soils wherever it occurs, influencing both the nature and sequence of horizons in soil profiles. Causes of gilgai microrelief are discussed in Chapter 3.

Gently sloping to strongly sloping dark clays commonly occur in regions with an extensive though often incomplete network of natural drainage-ways. Water moves readily over the surface into stream channels, most of which have an intermittent flow. Owing to their low permeability and the unstable structure of the surface layer, the soils are readily susceptible to erosion by water, even on very gentle slopes. Soil profiles that are relatively shallow may therefore be encountered on slopes with no more than a 5 percent gradient.

Broad, level or nearly level areas of dark clays often lack a network of drainage channels. In fact, such areas may lack stream channels except for those originating outside the dark clay area. As would be expected from the fine texture and swelling tendencies of the soils, movement of water through profiles is slow. After each rainy season, water may stand on the surface for considerable periods, especially in the small depressions if an area has gilgai microrelief. More generally, the land surface has a slight slope so that water will move away slowly into nearby permanent or seasonal marshes from which it is slowly lost by evaporation.

Parent materials

Dark clays are derived from a variety of parent materials ranging from hard rocks, such as basalts, shales or limestones, to various unconsolidated deposits such as lacustrine clays and marls. However, the variety of materials on which these soils have developed have important features in common. They are generally fine-textured owing to the original character of the deposits themselves or to weathering of hard rocks which provide high proportions of clay. Secondly, the parent materials are generally high or moderately high in alkaline earths (calcium, magnesium, etc.) in a form that is readily released with weathering.

The types of parent material from which dark clays have developed can be considered in two broad classes, according to origin, as follows:

1. Clayey materials of sedimentary origin

(*a*) River and marine alluvium
(*b*) Colluvial deposits (in depressions or piedmont areas)
(*c*) Lacustrine deposits
(*d*) Marls

FIGURE 13. Subtropical Black Clay soil or Black Turf soil developed from basalt near Codrington, South Africa. (Courtesy H. W. Weber)

2. Clayey materials weathered from hard or unconsolidated rocks

(*a*) Sedimentary rocks, such as limestone and shale
(*b*) Eruptive and metamorphic rocks, generally of basic nature, e.g., basalt, gabbro, norite, amphibolite, diabase, dolerite and serpentine
(*c*) Volcanic ash and tuff

The parent materials are generally basic in character, being relatively high in one or more of plagioclases, ferromagnesian minerals and calcium and magnesium carbonates. Where parent materials are not basic, alkaline earths can be added by seepage or by flood waters, as happens in many areas of low-lying dark clays. A high level of alkaline earths can thus be maintained in the soil under certain circumstances, even though initial supplies were low.

The fine texture of the dark clays, their low permeability and slow internal drainage limit the removal of alkaline earths by leaching, whether those originating from a breakdown of silicates or carbonates in place or those imported by seepage or flood waters. High levels of alkaline earths in the soils and parent materials are of great importance to the trend of the subsequent weathering and the horizon differentiation.

A fact which deserves emphasis is that parent materials for dark clays, whether of sedimentary, metamorphic or volcanic origin, share a number of important characteristics.

VEGETATION

Reliable information about the natural or seminatural vegetation of the dark clays is available for very few localities. Most published information on the floristic composition of savannas or steppes in tropical and subtropical regions is not accompanied by precise identification of the soils. Conversely, reports and maps providing accurate information on the nature and distribution of soils rarely carry full descriptions of the vegetation. Thus, over wide areas, it is not possible to obtain exact data on the plant communities occupying the uncultivated land on the dark clays; only general information, drawn in the main from studies of savannas, is therefore presented in this section.

Both in subtropical and tropical areas, the vegetation of uncultivated dark clay soils is mostly grassland. It seems possible, however, that the

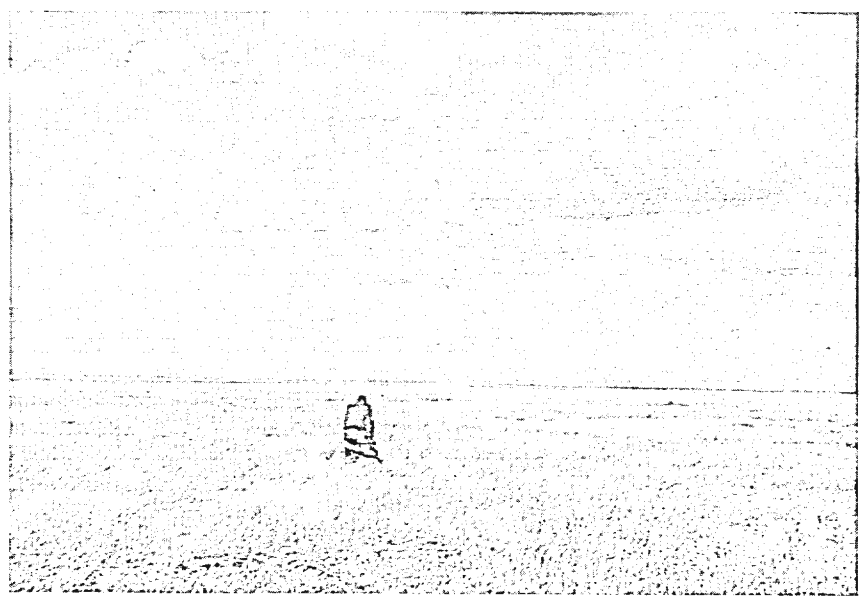


FIGURE 14. Dark clays on level relief: seasonally flooded plain of Usangu, Tanzania (80° 30' S; 34° 30' E).

(Courtesy B. Anderson, Southern Regional Research Centre, Department of Agriculture, Nachingwea, Southern Province, Tanzania) original climax vegetation in many areas was some form of forest. In general, the natural vegetation has been greatly disturbed by man's activities, such as fire and grazing. In several instances the presence of woodland on sites, which elsewhere carry savannas, implies that the savannas are secondary. Other evidence on this point is found locally when boundaries between woodland and savannas are clear-cut as a result of human influence.

The prevailing vegetation on uncultivated land is medium to tall grass savanna with scattered trees and shrubs of fire-resistant species. Such vegetation is by far the most extensive type in semiarid to subhumid regions. The proportion of trees to grass depends on both the intensity of burning and the rainfall. With increasing rainfall, trees tend to become more frequent in the savannas which may eventually be replaced by open semi-deciduous forest. Only in the most humid climates do dark clay soils bear tall closed forest.

The floristic composition of savannas varies with local conditions to a considerable degree. The range of variations is less for dark clays on level ground or in depressions than it is for those on slopes because the former commonly have poor surface drainage and are waterlogged during part of the year regardless of the climatic conditions.

Under semiarid conditions in tropical Africa the grass cover of the savanna includes species such as *Schoenfeldia gracilis*, *Ctenium elegans* (Central Africa); *Vetiveria fulvibarbis* and *Brachiaria falcifera* (Ghana); *Cymbopogon nervatus*, *Sorghum* and *Setaria* spp. (Sudan). Common trees are *Acacia seyal* which is sometimes dominant, *A. mollifera* and *A. arabica* in depressions. On dark clays transitional to saline soils, *Colophospermum mopane* may occur.

In Arizona, where climatic conditions range from semiarid to subhumid, the vegetation cover is dominated by grasses. In the drier, warmer environment of lower elevations, the major species are tobosa grass (*Hilaria mutica*), sand dropseed (*Sporobolus cryptandrus*), and ring muhly (*Muhlenbergia torreyi*). In the relatively cool and moister areas at higher elevations, the grasses are ring muhly, western wheatgrass (*Agropyron smithii*), and blue grama (*Bouteloua gracilis*). From a few to many juniper trees occupy the soils in all environments, but these are believed to have invaded the areas in fairly recent times, probably within the past two hundred years.

Under subhumid conditions in Africa the type of vegetation is a bush savanna with low trees and shrubs. The grasses mentioned for semiarid areas of tropical Africa are still dominant but are mixed with *Aristida*, *Pennisetum*, *Andropogon*, *Heteropogon* (Central Africa), *Schizachyrium* (Ghana), *Themeda* spp. (Congo), *Hyparrhenia* spp. (Sudan). In South Africa, *Sehinia gulpini*, *Aristida*, *Setaria* and *Cymbopogon plurinodis* form the grass cover. Trees are mainly *Acacia* spp. Others are *Bauhinia rufescens*, *B. reticulata*, *Pseudocedrella kotschii*, *Balanites aegyptiaca*, *Pterocarpus lucens*. Under similar conditions in Australia, *Ophiuros exalatus*, *Dichanthium superciliatum* (blue grass), *Astrebla* spp., *Bothriochloa* spp. and *Themeda* spp. have been reported as dominant grasses. In the subhumid areas of Nicaragua, the grasses are *Aristida ternipes*, *A. jorullensis* and *Bouteloua alamosana*; the most common savanna trees are *Crescentia alata* (Jicaro), *Guazuma ulmifolia* and *Acacia costaricensis*.

Under humid conditions in Africa the vegetation ranges from a bush savanna to a semideciduous forest. Grasses such as *Panicum*, *Pennisetum*, *Echinochloa*, *Paspalum*, *Hyparrhenia*, form the undergrowth. Trees reported from humid areas are *Acacia* spp., besides *Pseudocedrella kotschii*, *Terminalia macroptera*, *T. oblongata*, *Daniellia oliveri*, *Butyrospermum parkii*, *Combretum* spp., *Tabebuia pentaphylla* (Nicaragua).

In Bombay State, India, deciduous forest with teak, *Terminalia*, *Anogeissus*, *Boswellia* and *Lannea* have been reported. In monsoon forests on dark clays, e.g., in Indonesia, palms and bamboos are often common. These types of forests easily degrade to various types of savanna through grazing and burning.

Where dense tall woodland occurs (Australia) it is composed of *Casuarina lepidophloia*, *Geijera parviflora*, *Acacia harpophylla*, *A. pendula*.

2. USE, MANAGEMENT AND PRODUCTIVITY OF DARK CLAY SOILS

Owing to their broad geographical distribution, the dark clays occur under a correspondingly wide range of climatic conditions and are used by population groups with greatly differing levels of technology. Hence, there is a wide range in the use made of the dark clays, in the nature and intensity of their management and in their productivity. These subjects will be considered in this chapter; a short part will be devoted to the importance of the dark clay properties in relation to building and engineering.

Soil use

Some areas of dark clays have been farmed for centuries whereas others remain virtually untouched. The use of these soils is governed by a combination of physical, economic and social factors. Emphasis is laid here on the physical factors, economic and social factors being mentioned where pertinent information is available. Taking the group as a whole, present use includes grazing, pasture and the production of a variety of crops. The majority of the crops depend on rainfall; in some areas crops are grown under irrigation. A few tracts have been converted to productive forest reserves but their total extent is small.

In some instances the reasons for the present use or lack of use of the dark clays are evident. For example, most areas of dark clays used for grazing are in regions where cultivation is not feasible because of low rainfall. Other areas, although in humid regions, are also used for grazing owing to their distance from population centers. Difficulties in the control of insect pests discourage the growing of cotton and encourage the use of the dark clays for pasture in Alabama and Mississippi. In some places in Africa, the lack of use is due to the difficulty of tilling the soils with simple implements. Large development schemes are now in progress for some areas of dark clays in Australia and Ghana and similar developments should also be feasible elsewhere, although a careful study of each area is a prerequisite for successful development. It is thought that some, though by no means all dark clays now idle are suitable for agriculture and could be brought into production.

Although accurate information is not available, it seems that the larger proportion of the dark clay soils is used for grazing, although their value for grazing by livestock is generally low to moderate. The limitations seem to be more in carrying capacity than in the nutritional value of the

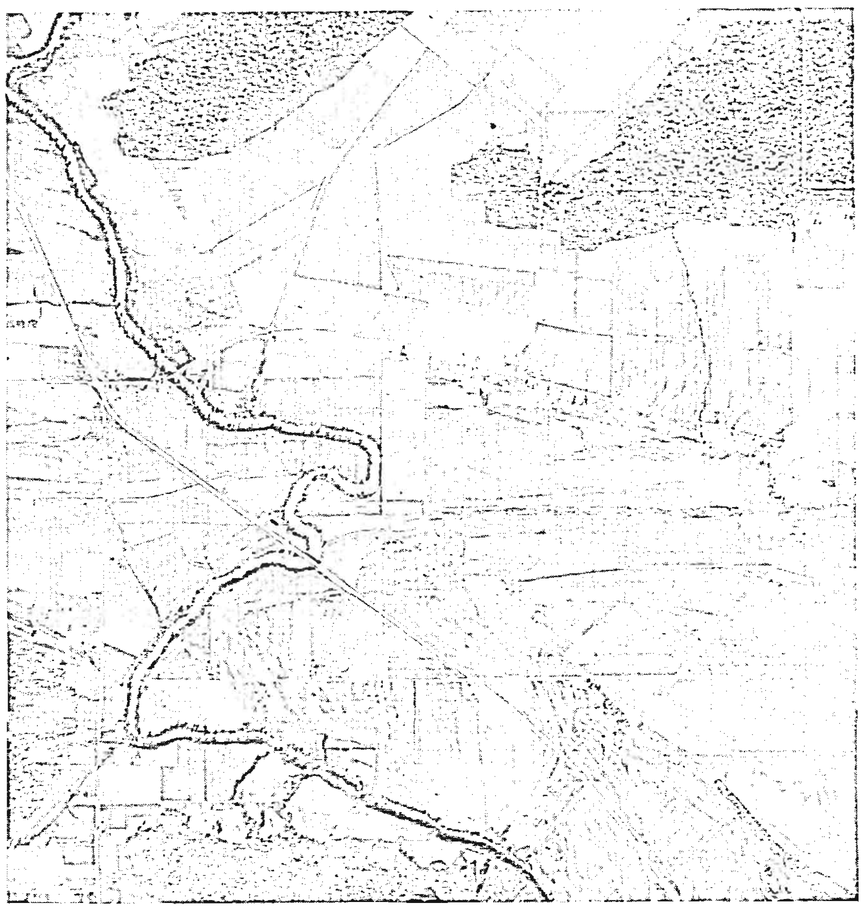


FIGURE 15. Pattern of land use in an area dominated by dark clays along the Mississippi River in the State of Mississippi, U.S.A. Originally forested, the area still has patches of forest on the wetter soils. The parallel strips in a number of the fields, especially near the top of the photograph, are low ridges made to improve drainage by bedding. The principal crops grown in this area are cotton and maize.

(Courtesy U.S. Department of Agriculture) forage which is usually adequate. During dry periods the carrying capacity of the soils drops substantially, the grasses become woody and tough, are less palatable and lose part of their food value. Although this seasonal shortage of forage is not specific to dark clays, the situation is more acute on these soils owing to their high wilting point and the damage to the root systems caused by the pronounced cracking of the soil on drying.

Where rainfall exceeds a certain minimum or when irrigation water is available, the use of the dark clays for grazing usually gives way to crop production except where low pressure on the land does not provide the incentive for more intensive use. In the driest regions, where the annual rainfall is not sufficient for continuous crop production, some form of " dry farming " is commonly practiced, the soils being kept fallow for the whole of one growing season to permit storage of extra moisture. A crop may be produced every other year or, sometimes, two crops may be grown for each year of fallow. In the semiarid belt in Sudan the system of dry farming is known as " terus " cultivation. On the slightly sloping clay plains, fields are laid out surrounded by low earth dams; rain water accumulates in the lower part of the field where sorghum, millet and sesame are grown. The same fields are cultivated every year. On the dark clays of humid and subhumid regions, the normal practice is to grow a crop every year. Only in a few regions can more than one crop per year be produced without irrigation.

Locally, dark clays are cultivated under irrigation. Individual irrigated tracts may be very small, as is generally the case in India. On the Deccan plateau, many of the fields irrigated from a well or reservoir are half a hectare or less in size. On the other hand, irrigated tracts may be very large, as in the Gezira of Sudan or the Nizamsagar scheme in the State of Hyderabad, India, where they may extend hundreds of hectares in size. Considering all dark clays throughout tropical and subtropical regions, the combined area of all tracts under irrigation is relatively large although it is much smaller than the area cultivated without irrigation.

The most important among the crops grown on the dark clays are sorghum, rice, millet, sugar cane and cotton; these are major crops in both irrigated and nonirrigated areas. Other widely grown crops occupying less important areas are wheat, corn, sunflowers, soybeans, tobacco and various oilseeds. Subsistence crops, such as cassava, groundnuts, vegetables and small fruits, are commonly grown in gardens around the homes of cultivators.

The distribution of these crops on dark clays, especially when grown without irrigation, depends greatly upon climate and particularly upon rainfall and temperature. With regard to rainfall, sugar cane and tobacco are grown in the more humid regions, whereas sorghum and wheat are grown in regions with lower rainfall; corn and millet are also produced more widely in less humid regions, though generally under higher rainfall than sorghum and wheat; cotton is grown over a wide range of rainfall, though it tends to be absent from semiarid regions except in irrigated areas. With regard to temperature, sugar cane tends to be restricted to the warmer regions of the dark clays; cotton is produced over the full range of temperature under which the soils occur; corn is less widely grown in the tropics than in the subtropics. When dark clays are placed under irrigation, the influence of rainfall is sharply reduced but temperature remains important.

The pattern of cropping, or the sequence of crops produced in one field over a period of years, differs from place to place. In most regions the dark clays are used for more than one crop, although systematic rotation of crops is not common practice. Sorghum is grown year after year on some of the soils of Sudan. Alternate crops of wheat and tobacco, or rice and soybeans, are grown on dark clay soils in parts of Java. A succession of wheat and leguminous crops is successfully grown in Portugal. In some instances cropping patterns include green manure crops. Mixed culture — growing several crops at the same time in the same field in mixed stands — is also practiced locally. In semiarid regions, the soils may be alternately fallowed, sometimes as often as every other year.

Possible cropping patterns are strongly influenced not only by the climate but also by the level of technology of the population. For instance,

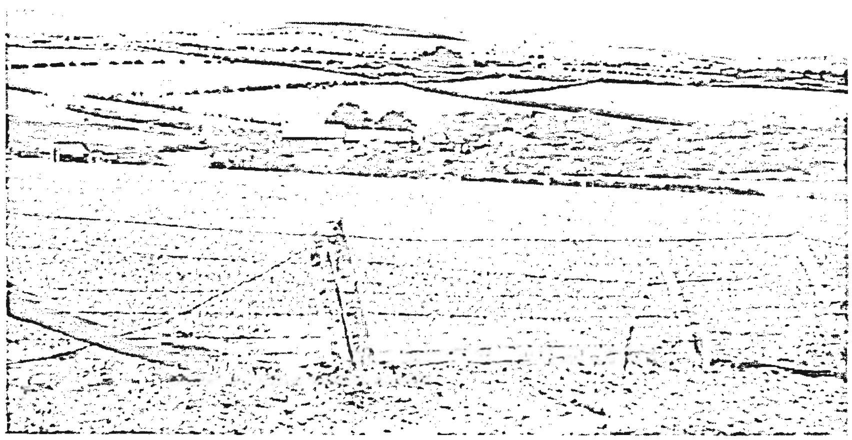


FIGURE 16. Black Earths on undulating relief near Sorell in Southern Tasmania, Australia. Soils devoted to wheat, oats, barley, fodder crops and grazing by sheep and dairy cattle. Rainfall 550 mm per annum, mainly from autumn to spring.

(Courtesy C. G. Stephens, Division of Soils, Commonwealth Scientific and Industrial Research Organization, Adelaide, Australia)

FIGURE 17. Regur soils developed from limestone near Raipur, India. Zebu cattle grazing on native vegetation consisting of grasses with scattered acacias. Irregularities of the land surface are related to gilgai microrelief.

(Courtesy Roy W. Simonson, U.S. Soil Conservation Service, Hyattsville, Maryland, U.S.A.)

where the dark clays support grass vegetation and people rely on hand tools for tillage, it has been found that the grasses cannot be controlled or eradicated with simple implements and that spontaneous vegetation reoccupies a cultivated patch within a matter of months after it is cleared. A new patch is then cleared by burning the grass shortly after the beginning of the rainy season. The time for burning is chosen when the grass is still dry but after weeds have germinated and begun to grow. Crops are planted immediately. The chances of obtaining good yields, one year with another, are poor but the cultivators lack the means to secure a more stable production.

Some of the dark clays in more humid regions remain under semideciduous forest, although the original forest stands have been changed in many areas. In monsoon climates, e.g., in Java, Indonesia, the original mixed forest has been converted to highly productive teak plantations. Even though growth is slow, the production from improved or converted forest stands on the dark clay soils compares favorably with the return from other kinds of use.

Soil management

As used in this monograph, management includes the whole range of practices used in production from the soil. It may consist of a succession of well-studied techniques which, in combination, lead to the sustained production of very valuable crops. On the other hand, management may be no more than the herding of sheep by nomads to produce meat and wool. Practices important in primary production are tillage, irrigation, drainage, weed control, fertilization, selective cutting, rotation of crops, controlled burning, rotation grazing and the planting of desirable tree species. This list is not meant to be complete, but suggests the number and variety of practices comprising management.

As an aid in choosing the most effective combinations of management practices, the elements of soil management used on the dark clays in various parts of the world are summarized in this chapter. The purpose of the discussions is to outline the major management practices used, what they require in the way of skills and equipment, and what their comparative advantages may be. Subsequent sections of the chapter are on tillage, moisture conservation and use, soil conservation, use of fertilizers, and crops and cropping systems.

Tillage

As a group, the dark clays offer many difficulties to successful tillage. Because they are high in active clay minerals they are very hard when dry, and for the same reason they are plastic and sticky when wet. If cultivated when they are wet, many of these soils puddle and become massive and hard. If tilled when too dry, many of these soils are turned up in large blocks or clods that will not slake down to a granular mass. The optimum range in moisture for tillage is rather narrow and the soils remain in that range for relatively brief periods. Many of them are therefore cultivated at moisture levels below the optimum, with resulting poor tilth. Moreover, power requirements for the tillage of the dark clays are very great when the soils are dry, whereas implements may clog because of the stickiness when the soils are wet.

Tillage problems are not uniform for all dark clays. The least difficult soils of the group are those of the so-called self-mulching clays, which have a natural tendency to granulate in the surface layer. This granular surface layer may be as little as 2 centimeters or as much as 30 centimeters thick. For the most part, the granular structure is formed by the gradual crumbling of large clods formed by tillage. As these large clods are soaked by rain and begin to dry, they crumble slowly down into granules of various sizes. A similar crumbling process gives rise to a thin granular surface layer in some dark clays even though they are not cultivated.

Tillage problems are most difficult on the dark clays without self-mulching characteristics. Many of them lack any natural tendency to form a granular surface layer, and some tend to form a crust as they dry. By crusting is meant the hardening of a surface layer 2 centimeters or more thick. The prevention of crusting and the promoting of a granular structure is a major purpose of tillage on these soils. The improvement of the physical condition of the dark clays is often a long-term process. After the initial ripping, a period of from two to three years may be required before the surface layer crumbles enough to permit the preparation of a good seed bed.

Methods of tilling of the dark clays of tropical and subtropical regions range very widely. The most primitive method is to use a stout stick, the only implement available to cultivators in some localities. The stick is forced into a crack in the dry soil and used as a lever to break out a large clod or block and overturn it completely or partially. The clod is left on the edge beside the hole formed by its removal and the crop,

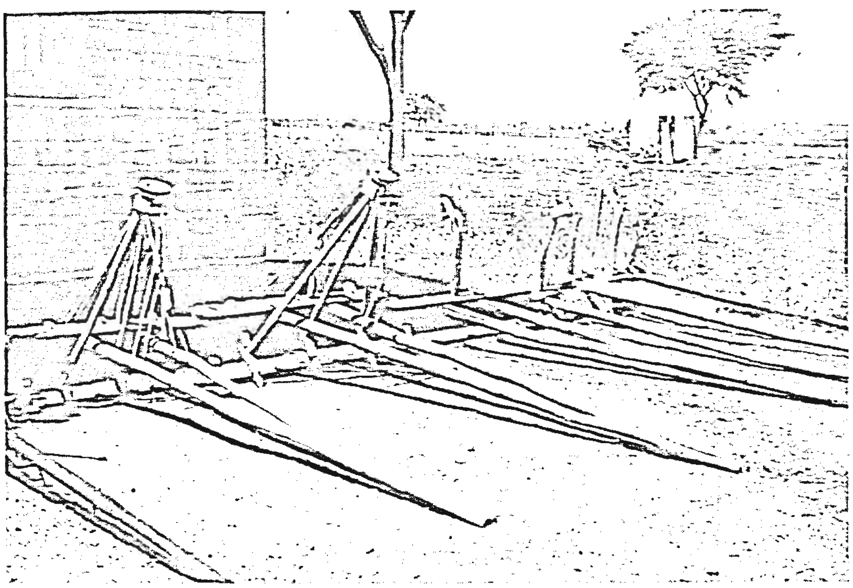


FIGURE 18. Improved implements developed on Malegaon Farm, an experiment station located on dark clay soils near Sholapur, Bombay, India. The first two implements on the left are four-row seeders, whereas the others are harrows or rod weeders.

(Courtesy Roy W. Simonson, U.S. Soil Conservation Service, Hyattsville, Maryland, U.S.A.)

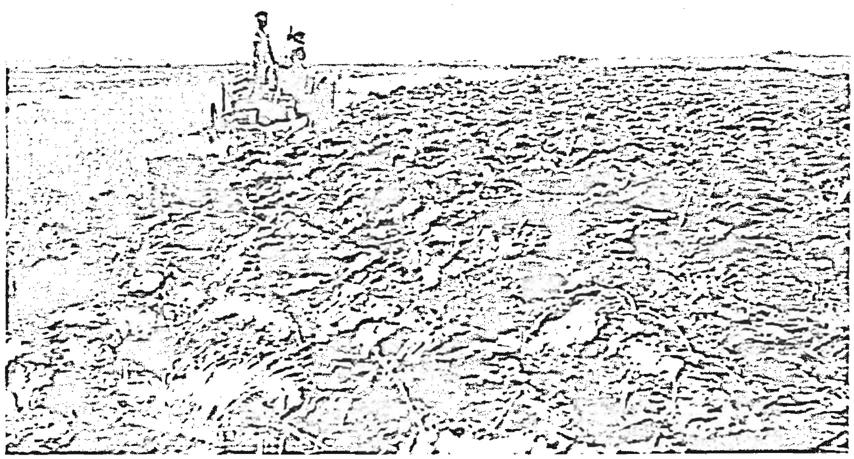


FIGURE 19. Ripping of Black Earths near Kpong, Accra Plains, Ghana. The soils are left in large clods to weather down to a more favorable structure.

(Courtesy S.V. Ady, Principal Agricultural Officer, Soil and Land-Use Survey Branch, Kumasi, Ghana)

e.g., corn or cassava, is planted in the bottom of the hole, which is then covered with sand or ashes to limit evaporation. Either seeds or cuttings may be used and planting is done during the latter part of the dry season, shortly before the beginning of the rains. When the rains come, the clod of soil slowly crumbles as it wets and dries and the loose material is then put into the hole over the seed, or around the young plant. The use of a stick does not permit the cultivation of soils when they are moist or wet, so that the cultivator must take advantage of the moisture stored in the subsoil for the germination and early growth of a crop before the rains begin.

In many places tillage with a hoe or mattock is general practice. This is an improvement on the stick, especially in controlling weeds. A better seed bed can also be prepared although tillage to considerable depths is impracticable for more than a small garden plot. The hoe or mattock thus has a limited value in promoting granular structure in a surface layer of appreciable thickness. It also has limited value in deepening the rooting zone for plants.

Many areas of dark clays are cultivated by wooden implements, sometimes steel-shod, drawn by animal power. They include various kinds of plows, harrows, planters and seeders pulled by bullocks, water buffaloes or other animals. The use of animal power and implements made entirely or largely of wood is general in the large areas of Regur soils in the Deccan plateau of India. Implements drawn by animal power permit tillage of a larger unit area than can be accomplished by human labor and the soil can be turned over to greater depths.

It is rarely possible for a cultivator dependent upon animal power to till all his fields while they are at optimum moisture levels. The average size of holding in the Deccan being about 6 hectares, not all the holding will necessarily be cultivated in any one season. With one pair of bullocks several weeks are required for tillage of the fields to be planted and only for a small part of this period are the soils at optimum moisture levels, and hence in good tillage condition.

Limitations of power and equipment reduce the possibilities for controlling perennial weeds, especially grasses, for the vigorous and repeated cultivation of intractable soils is not feasible with animal power or with human labor, except for very small holdings. The effective control of certain weeds is practically impossible as can be observed in the spread of "alang-alang" (*Imperata cylindrica*) on hilly dark clays in Java or in the difficulties of controlling "kans" grass (*Saccharum spontaneum*) on Regur soils in India.

Some areas of dark clays are cultivated by means of large steel implements pulled by tractors. The implements include plows, disks, disk harrows, harrows, listers, disk tillers and drills. Far more power per unit of soil is available in such areas and therefore opportunities of tilling at the appropriate time and for controlling weeds are correspondingly greater. Care should be taken in using heavy machinery when the soils are wet since this carries some danger of compaction and the consequent less favorable condition for moisture and root penetration.

The discussion of tillage has so far been centered largely on dry farming conditions and on irrigated farming in which the soils are not kept wet for long periods. The functions of tillage are not the same in the production of rice. The general objective is to promote better plant growth, but the soil requirements are not the same for paddy rice as for dry-land crops. Cultivation of the paddies is intended to puddle the clays rather than promote granular structure. As a second function, tillage may be done to control weeds, in conjunction with the alternating of rice with dry-land crops.

Methods for the tillage of soils in rice paddies range from use of a hoe or mattock to the use of tractor-drawn implements. If human labor or animal power is used, the paddies are commonly cultivated when wet, often when under water. Where tractors or some form of mechanical power is used, the paddies or fields are commonly drained and allowed to dry so that the soil will support the large machinery needed for plowing, harrowing, seeding, etc. Under these conditions, the paddies or fields are flooded again after the preparation of a seed bed and the planting of the seed. Machinery has now also been developed to cultivate the fields when flooded.

There is a slow but continuing shift toward greater mechanization of agriculture on the dark clays of the tropics and subtropics. On the Gezira project in Sudan, a machinery service is being provided by the Sudan Gezira Board. The Cotton and Tropical Textile Plants Research Institute of Togoland reports that the black clay earths are now being tilled by caterpillar and super-rooter in the dry season when plows cannot be used. Significantly, it is added that with the physical improvement of the soil by cover crops plowed under and by the use of manure and fertilizers, tillage problems become easier as the years go by. The University College of Ghana has developed the " broadland " system of tillage (see also under Moisture Conservation and Use) which, with technical help for engineering layout and a minimum of supplemental mechanized service, can be carried on by individual cultivators with plows and animal power. In India, farmers' co-operatives have provided machinery service to cultivators of small farms at a reasonable cost. Heavy equipment service provided by co-operatives is used for bunding, leveling and plowing massive dark clay soils that cannot be properly handled by bullock power. Tillage with heavy machines obviates this problem and leads to increases in yield of 50 percent or more.

With the increasing trend to mechanization, attention must be drawn to the danger of compaction caused by the use of heavy machinery. At the Blackland Experiment Station in Texas (212) soil measurements indicate a substantial difference in soil density between plots which were tilled by hand and others which were cultivated with heavy machinery. In the first case the bulk density was 1.59 while in mechanically-cultivated fields bulk densities of 1.9 to 2.1 were measured. The higher density is related to the formation of a " plow pan." No compact layers have been observed in the plots cultivated by hand; on the contrary, the soil showed a good aggregate porosity and wormholes. Biological activity is higher in the absence of compaction and favors soil looseness. Experiments have been made in shattering the dense layers by chiseling to about 25 to 30 centimeters. The best way to avoid pan formation is to secure timely tillage and reduce to a minimum the operations with heavy machinery. Timeliness in tillage remains a continuous problem. Not only should the upper layers have a suitable moisture content for efficient tillage; the moisture in the underlying layers should also be reduced to a level which ensures resistance to compaction.

Levels of crop production from the dark clays are closely related to methods of tillage the world over since these are themselves related to the level of technology in the areas where the soils are used. Where the soils are tilled with simple implements such as a mattock, other resources such as fertilizers or improved varieties of seed are seldom available to the cultivator and crop yields are generally low. Where the dark clays are cultivated with tractor-drawn implements, more resources in the way of fertilizers, insecticides, improved varieties and scientific knowledge are commonly available to farmers and the total production, whether per unit area or per man-day of work, is then correspondingly higher. More food and a better income for the cultivator and his family are possible.

Moisture conservation and use

The conservation and effective use of water are more difficult on the dark clays than on most soils. The low infiltration rates make irrigation troublesome in many instances while low permeabilities make the soils difficult to drain when they are too wet for satisfactory plant growth. The absence of leaching, slow drainage and strong evaporation may induce salinity. The retention of water by the dark clays is high but much of the water held is not available to plants. Thus, the effective utilization of water, whether from rainfall or from irrigation, meets with a number of problems.

During dry seasons or in regions where the total rainfall is low, management practices on dark clays need to be directed toward maximum infiltration and storage of moisture. On the other hand, drainage is essential for dark clays in high rainfall areas, or in level or depressed positions, where water from heavy rain, runoff or flooding may stand for hours or days and destroy all or part of the crop. Management for effective use of water in crop production on the dark clays will therefore differ from place to place.

Infiltration rate

The rate at which water enters a dark clay depends upon the condition of the surface, the presence or absence of shrinkage cracks and the amount of water already in the soil. Infiltration rates are higher in the self-mulching dark clays, i.e., those with a surface layer that crumbles and becomes granular upon drying, than in crusting dark clays. The intake of water can be very rapid for a time in a dark clay that is very dry and has a number of shrinkage cracks extending up to the surface. The intake of water may also be high if the rains come when the moisture content of the soil is low.

By and large, infiltration rates for the dark clays are low to moderate. The general range in such rates can be illustrated by data for three soils occurring in Texas and by the results of irrigation trials on a clay in the Gezira region, Sudan.

The amounts of water absorbed by three soils in Texas, all dark clays, were determined by trials with a rainfall simulator (83); the results of the trials are given in Table 3. Water was applied at the rate of 62 millimeters per hour for a period of three hours to plots which were free of vegetation but had been cultivated to shallow depths. Two experimental runs with the rainfall simulator were being made on each plot. The first run was made with the soil at a relatively low moisture content, whereas the second run was made 24 hours later while the soil was still wet. The moisture content of the soils was determined prior to each of the two runs.

Cumulative amounts of water absorbed by each soil, expressed in millimeters, are given in Table 3 along with the moisture content of the surface layers at the start of each run. For each interval of time given in the Table, the millimeters of water represent the total amount absorbed from the onset of the individual run. Thus, for example, the moderately eroded Houston clay absorbed 26 millimeters by the end of 15 minutes, 27 millimeters by the end of 30 minutes, 28 millimeters by the end of 60 minutes, and so on.

These results show that the infiltration rates for these dark clays drop sharply after the first 15 minutes of the first run and remain low for the remainder of that run. The formation of a thin crust or puddled layer at the surface, due to the impact of falling drops of water, seems to have been one factor in lowering infiltration rates after the first 15 minutes. This explanation is supported by the observation that a covering of straw on the surface of Houston Black clay maintains higher infiltration rates for a longer period of time.

TABLE 3. – INFILTRATION RATES, MEASURED WITH A RAIN SIMULATOR, FOR DARK CLAYS IN TEMPLE, TEXAS, U.S.A. (83)

Soil	% of H_2O in surface layer before run	Cumulative infiltration in mm				
		15 min	30 min	60 min	120 min	180 min
Houston clay, moderately eroded	(*a*) 32.4	26	27	28	29	30
	(*b*) 54.9	1	1	1	2	2
Houston Black clay, slightly eroded	(*a*) 38.5	15	18	20	22	23
	(*b*) 54.6	0.5	0.8	1	2	3
Houston Black clay, moderately eroded	(*a*) 28.0	22	24	26	28	29
	(*b*) 40.7	0.5	0.8	1	2	2

NOTE: Two runs are reported for each of these soils. The first run (*a*) was started with the soil at field moisture content as given, the second run (*b*) was made 24 hours later.

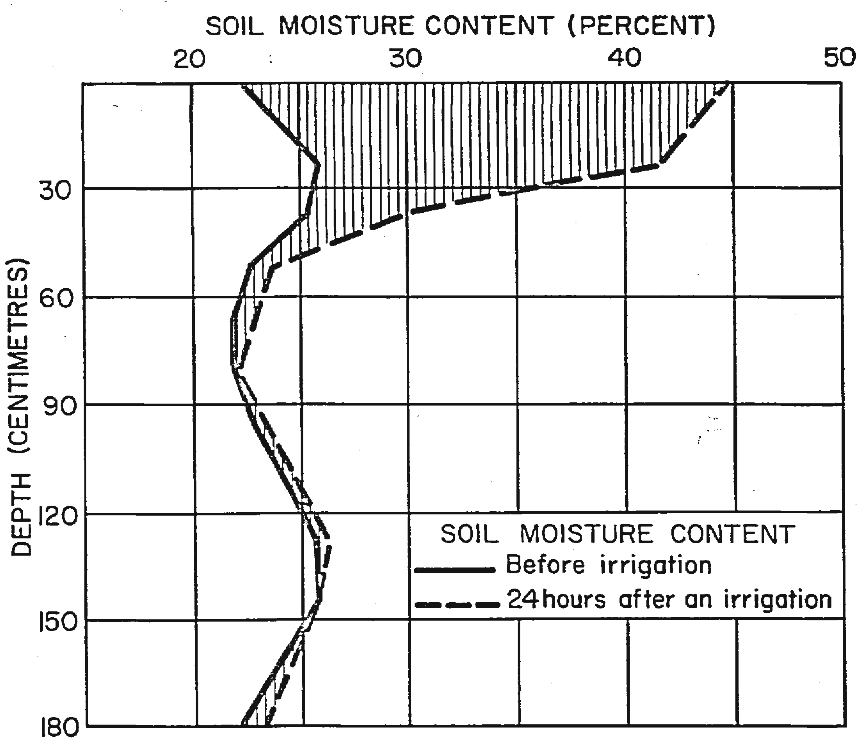


FIGURE 20. Soil moisture content.

A second factor of importance to the intake of rain or irrigation water is the original degree of saturation of the surface soil. As shown in Table 3, the infiltration rate dropped sharply when after the first 15 minutes the moisture content of the surface layer had been increased appreciably. The infiltration rate was low at the beginning of the second run, which followed the first by 24 hours and was made while the soil was still wet and the intake of water did not increase during the run.

Infiltration rates may be very high for a time in a dark clay with many shrinkage cracks extending to the surface, for water can enter such cracks in large amounts. For example, the initial infiltration rate in a dark clay near Pachuta, Mississippi, was 86 millimeters per hour where numerous shrinkage cracks were present, many of them extending to depths of 60 centimeters. A similar infiltration rate of 82 millimeters per hour was observed on Houston Black clay in Texas when the soil was dry. The effects of shrinkage cracks on the intake of water are also evident in the absence of runoff from experimental plots in oats on Houston Black clay after a rainfall of 48 millimeters in 28 minutes. Once the cracks have been closed and sealed, infiltration rates drop back to the order of magnitude indicated in the trials with the rain simulator.

Management of the dark clays can be designed to maintain or improve the intake of water. Infiltration is generally highest in soils having surface layers with a granular structure. The development and maintenance of a granular structure can be encouraged by proper tillage, by crop rotations, by additions of organic matter and by proper handling of crop residues. The growing of grasses and legumes seems to affect the soils favorably, partly through the influence of the roots on granulation and partly by adding organic matter.

The generally low infiltration rates of dark clays have an important bearing on the efficiency of irrigation practices to be applied on these soils. Problems common to all irrigation farming are more acute on dark clay soils: use of appropriate amounts of water so as to prevent damage to crops and waterlogging; sufficient wetting of the subsoil; proper timing of watering. Irrigation trials made on dark clays in the Gezira region, Sudan (90), showed that a total of 14 separate irrigations was required for each crop of cotton. In each irrigation, water was applied at a rate of approximately 95 millimeters. Roughly four fifths of the water applied in one irrigation was absorbed by the soil. The distribution of moisture in the soil profile prior to and 24 hours after an irrigation is shown in Table 3. About a quarter of the water absorbed penetrated beyond a depth of 30 centimeters in a 24-hour period following irrigation. Downward movement of water was evident at a depth of 60 centimeters and still detectable at 1 meter.

Permeability

Where dark clays occur in level or depressed topography, drainage problems may become very severe owing to the slow permeability of these soils; the excess water may originate from rainfall, flooding or even from irrigation. The first rains following the dry season are completely absorbed by the soil but, once the cracks are sealed, the downward flow through the soil becomes very slow and leads to the surface ponding of excess water.

The slow internal drainage and negligible lateral movement of water in these soils make subsurface drainage inefficient and practically unfeasible. Excess water must be removed by surface drainage either by ridge and furrow cultivation or by open drains. Examples of the latter can be found in dark clay areas of South Africa and Morocco where community systems of open drains provide outlets for farm drainage. In other countries ridge and furrow cultivation has been applied, e.g., the "broadland" technique which has been developed in Ghana (III). This consists of broad plow-made ridges laid out on a specific gradient. Their width depends on the crops, the rainfall and the implements to be used for planting and harvesting. The broadlands produce two main effects: the runoff water is shed from crest to furrow during heavy rainfall and infiltrating water moves slowly through the surface soil toward the open plow furrow which leads off the excess water. Similar methods have been applied in other countries such as the "hilling with furrows" in South Africa or the "bedding" in Argentina.

The systems mentioned above have proved very suitable for heavy-textured soils since they combine erosion control and effective drainage. Other methods of soil conservation, accentuating mainly the physical protection of the soil, often overlook the drainage requirements. This aspect is often neglected when effecting the improvements referred to above for increasing the infiltration rate in dark clay soils. Attention is often focused so much on the need to conserve and store water that waterlogging results. Thus, methods to improve water storage and irrigation practices should be devised in such a way that the soil holds water from one wetting to another while maintaining free drainage. An exception to this practice is the use of low ridges round rain-fed paddy fields on dark clays where advantage can be taken of the poor internal drainage to pond an amount of water sufficient to produce a good crop of rice. Whereas on other soils the water seeps through, dark clays can be maintained in a submerged condition for several weeks after the rains have stopped.

Salinity hazards

With regard to irrigation and drainage, the problem of salinity often interferes with improved management. Dark clays are high in bases and slowly permeable and occur under climatic conditions which induce strong evaporation during a part of the year. As a consequence of restricted drainage and a lack of leaching these soils may be subject to salinization. In several countries, dark clays occur in association with saline or alkali soils and transitional belts between them may cover large areas. The bulk of the dark clays are not saline. However, the question arises whether they may not become saline under irrigation.

Although there may be an appreciable amount of salts in dark clays derived from the weathering of primary minerals or from sedimentation, accumulation from these sources alone is unlikely to form a saline soil. Usually the salts will be brought from other locations, irrigation or ground water being the main carriers. The majority of dark clays do not have high ground-water levels and, even when they have, upward movement of water through the soil profile is negligible or nonexistent owing to their slow permeability. A thorough investigation was carried out in Sudan to ascertain whether subsoil salts move upward under the influence of irrigation (93). It was found that these soils have a natural reaction against the surface accumulation of salts owing to the occurrence of temporary vertical outwash through cracks and fissures. It appears that, under normal irrigation, the general tendency is for the salts to be evacuated from the surface layers, so that a natural equilibrium is reached whereby the salts accumulate in the subsoil but do not reach dangerous levels in the rooting zone. The depth at which salts accumulate is normally not less than 30 centimeters which corresponds to the depth of substantial infiltration.

The figures given in the section dealing with the composition of dark clays point to a relative accumulation of salts in the lower horizons and to a downward increase of Na in the sorptive complex. In Sudan, no adverse cumulative changes in physical properties of the soil have been detected in areas irrigated during a period of twenty years, nor has any significant decline in fertility been established (93). However, this does not exclude the possibility that an adverse change may prove to be disastrously rapid once it sets in. Several soils show a percentage of Na in the sorptive complex ranging from 5 to 10, which is still well below the 15 percent level indicative of alkalinization but well above the maximum level of 5 percent indicative of favorable physical properties.

The electric conductivity of the extract of saturated soil paste gives an indication of the salt content. It is generally accepted that no harmful effects to plants occur when conductivity remains below 2 mmhos per centimeter at 25°C. A conductivity of 16 mmhos is the limit beyond which profitable plant growth can hardly be expected. From certain areas, e.g., Northern Gezira, Sudan; Nira Right Bank canal, India; Dawhwenya area, Ghana, conductivity figures ranging from 2 to 6 mmhos have been measured in the upper layers of dark clays. Salt contents up to 2 percent have been reported at depths of 30 to 120 centimeters. Normally the salt content of dark clays does not exceed 0.2 percent. Most crops grown on dark clays, e.g., wheat, rice, sorghum, corn, oats and cotton, are moderately salt-tolerant. It appears that the best way to maintain production under irrigation on dark clays is to take preventive measures, i.e., to assure appropriate applications of irrigation water and the best possible drainage. On dark clays corrective measures are expensive and difficult to apply successfully.

Considering that dark clays occur in areas with relatively dry climates and that they occasionally border regions of saline soils, the water collected for irrigation may contain harmful amounts of salts and sodium. Water control should be carried out regularly and management practices must be adapted to the quality of water used. The presence of sodium in the exchange complex of dark clays justifies a careful consideration of irrigation rates in order to prevent total waterlogging. In the Congo, the Dikuluwe river of the Lufira basin has been found to have too high a salinity during the dry season. In India, several centuries of irrigation with water from the Pedda Hagari river, containing 80 to 130 ppm soluble salts, have caused a deterioration of the land, while areas irrigated with Tungabhadra water, containing 15 ppm soluble salts, have remained productive.

Soil conservation

The concentration of the rainfall over short periods in many dark clay regions, combined with low infiltration rates, slow permeability and often with the poor surface structure of these soils, makes them very susceptible to erosion, especially when cultivated. Besides tillage difficulties, erosion resulting from a high rate of runoff may be considered as a major problem in the management of dark clay soils, even on very gentle slopes. It appears that standard conservation practices do not suffice to protect these soils adequately; terracing, which proves useful on gentle slopes, becomes ineffective on steeper slopes owing to lateral sliding of the soil mass; contour banks often cause ponding which may lead to serious breaches; ridges thrown up every year can be dangerous on sloping land since they may not withstand strong surface water discharge during heavy rainfall. As mentioned above when discussing drainage problems, the application of techniques which reduce runoff entail a stagnation of water which may be more detrimental to plant growth than the advantages gained.

The Blackland Experiment Station of Temple, Texas, has conducted runoff, erosion and related measurements on dark clays for over twenty years. Some of the major conclusions reached were published in 1954 (232) and are reproduced below. It should be stressed that these conclusions are valid only in the climatic [1] and physiographic conditions prevailing at the Station. However, the general principles outlined may be adapted for other environments and other cropping patterns.

Extensive work on terrace construction has led to the standard use of terraces primarily designed to prevent concentration of runoff and

[1] Climatic data for the Station: mean annual rainfall 875 millimeters; average maximum temperature for July 35°C; average minimum temperature for January 15°C; average frost-free season of 249 days; evapotranspiration exceeds rainfall from mid-June until September.

FIGURE 21. Gully erosion on hilly Grumusols from volcanic tuffs in the Pati-Ajam hills, Central Java, Indonesia.

(Courtesy R. Dudal, Soil Correlator, FAO, Rome, Italy)

gully formation. Their effectiveness is greatest where supported by suitable cropping and regular maintenance.

It has been shown that, on land where the crops are cultivated in rows, water and soil losses on an annual basis are closely related to total rainfall, and especially to its intensity. The greatest losses have been caused by

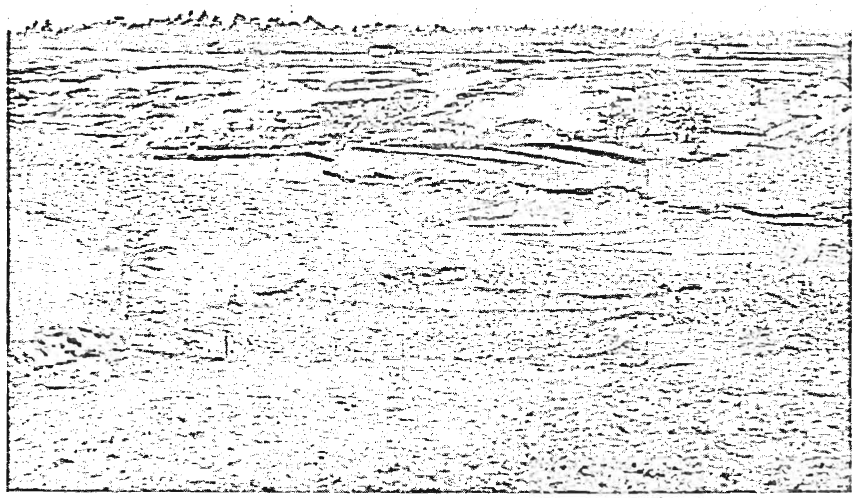


FIGURE 22. Strongly eroded landscape on Grumusols from tertiary marls. Terraces built to prevent erosion slide down the slope in the Kendeng hills, Central Java, Indonesia.
(Courtesy R. Dudal, Soil Correlator, FAO, Rome, Italy)

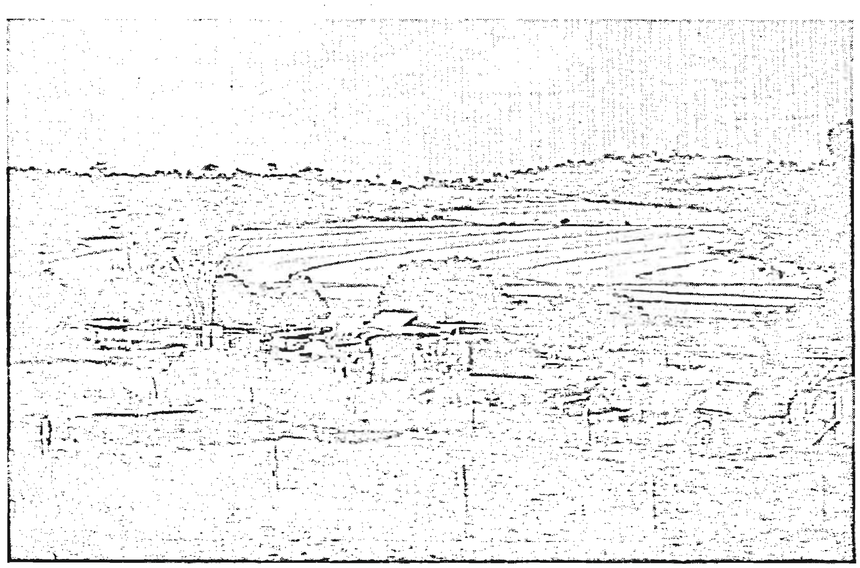


FIGURE 23. Soil conservation practices applied on dark clay soils near Pittsworth, 40 kilometers south west of Toowoomba, Queensland, Australia: pondage banks (above cultivated fields), graded banks, grassed waterways, and contour cultivation and cropping.
(Courtesy G. D. Hubble, Department of Agriculture and Stock, Brisbane, Australia)

rainfalls of more than 2.5 centimeters in 24 hours and by intensities of more than 2.5 centimeters per hour lasting for 30 minutes. It commonly requires rains of 5 centimeters or more in 24 hours to cause much runoff when the soil is dry and in a reasonable physical condition. A high percentage of runoff occurs from light rains of 1 centimeter or less when the soil profile is wet. The average of ten years' measurements on the Blackland Experiment Station shows a maximum loss of 15 quintals per hectare per month for a total rainfall of 265 millimeters. This maximum is reached during the month of May when the soils are saturated to their moisture-holding capacity. The minimum loss, reached in December, is about 2.5 quintals per hectare per month for a total rainfall of about 100 millimeters.

The percentage of the slope has little effect on the runoff but a big influence on erosion. Individual field-scale plots with slopes varying from 1.39 to 3.01 percent provide evidence, in general agreement with results from other locations, that erosion increases in the 1.4 power of slope percentage. The length of slopes seems to have a minor influence on sheet erosion. Runoff tends to be slightly less on long slopes because of the extra time for infiltration. However, the variations in treatment normally overshadow slope length effects.

The effect of crops on runoff and erosion depends primarily on the amount of cover provided during critical seasons. The effects of maize and cotton are not consistently different. Small grains, alone or in combination with sweet clover, have been effective because their heaviest growth gives maximum protection during March, April and May, the period of maximum rainfall. With the ordinary turning in of residues, one year of maize or cotton following small grains has caused the loss of as much soil and water as one year of row crops following another. The growing of sweet clover alone has resulted in good erosion control. However, the results of experiments have shown that the growing of small grain in combination with sweet clover has proved more favorable than growing either crop separately. Untrampled Bermuda grass in small plots has given the best results for water intake and erosion control. Observations indicate that, under pasture conditions, heavy runoff is to be expected when the wet soil is heavily trampled, even on dense sod.

As an example, a few figures are given in Table 4 on results from runoff and erosion measurements from small plots in different crop sequences at Temple. The slope was 3.5 to 4 percent and the rainfall 820 millimeters as an average for the rotation.

Cultivation on the contour has consistently shown reduced runoff and erosion in small plots. A 50 percent reduction in soil and water loss is obtained on slopes up to 4 percent. Strip cropping on field-scale plots with a three-year rotation of maize, cotton and oats reduced both water and soil losses. The effect was greater on 3 percent slopes than on 2 percent slopes. Even so, gully erosion was not stopped on the 3 percent slope thus emphasizing the important function of terraces. Subsoiling has shown little effect on runoff. Recently, shallow chiseling has been used to break up the dry soil enough to permit subsurface plowing. The surface residues from major crops can thus be handled effectively and the influence on water and soil conservation appears to be favorable.

TABLE 4. – RUNOFF AND SOIL LOSS UNDER DIFFERENT ROTATIONS, TEMPLE, TEXAS, U.S.A. (212)

Cropping pattern	Runoff (mm)	Total soil loss (metric tons per ha)
Continuous maize	127	26.6
Bermuda grass (ungrazed)	5	trace
Cotton, oats and alfalfa (in rotation)	36	7.5
Continuous cotton (rows on contour)	71	23.9

It should be stressed that high crop yields are an essential aspect of conservation and that measures taken to increase them are simultaneously protecting the soil against erosion.

On the basis of observations made at the Blackland Experiment Station four classes of land capability have been established with regard to the erosion control practices to be applied:

Class I Land, with slopes from 0-1 percent, which can be used for two crops each year without severe damage by erosion. However, improved practices are to be introduced to prevent soil deterioration under continuous row cropping

Class II Land, with slopes from 1-3 percent, which can be improved by one year of small grain with sweet clover or equivalent, alternating with one year of row crops

Class III Land, with slopes from 3-5 percent, which can continue to grow one year of row crops for every two years of protection and improvement with small grain and sweet clover, or grass with clover

Class IV Land, with slopes from 5-8 percent which should seldom, if ever, be used for row crops. It is profitably used for Johnson grass (*Sorghum halepense*) and sweet clover, continuous small grain with sweet clover, or permanent grasses and legumes

As mentioned under the section on Moisture Conservation and Use, the " broadland " system of cultivation developed in Ghana (111) offers excellent protection against erosion while also securing adequate drainage. The system has the advantage that it can be achieved by tillage with standard agricultural equipment and that it provides for compact workable units which can accommodate both rain-fed and overhead irrigated crops.

It thus appears that the efficient conservation of dark clay soils requires a combination of practices adapted to soil properties, slope, rainfall distribution and intensity, implements available to the farmer and economic cropping patterns.

Use of fertilizers

As used here, the term " fertility " refers to the capacity of the soil to provide nutrients in the proper amount and combinations for growing plants. In some countries, dark clay soils have produced crops for a very long time without the use of fertilizers, and therefore have often been considered as very fertile. However, the actual fertility level of these soils is not particularly high; absolute amounts of essential nutrients may be limited or, when certain elements are more plentiful, the ratio between the different nutrients may become unbalanced. The low but sustained production obtained on these soils without fertilizers demonstrates their stability under extensive use rather than a high degree of fertility. This stability may well be due to the so-called self-mulching which many of these soils show, i.e., upon cracking the surface soil is mixed into the subsoil and fresh material appears at the surface. This turnover replenishes the nutrient content of the upper layers and assures a more even distribution of organic matter throughout the profile.

Although the level of fertility of dark clays may vary widely, e.g., in relation to the kind of parent material on which they have developed, it is found that their nutrient status shows several features in common. In general, dark clays are relatively low or even deficient in phosphorus and nitrogen. The shortage of nitrogen is often related to poor drainage and to the relatively low content in organic matter. However, both these factors can be influenced by management. With phosphorus the problem is more often one of unavailability rather than of total amount, the phosphate being present as tricalcium phosphate in an alkaline medium. Potassium may be present at a moderate level but is sometimes unavailable owing to potassium fixation. Calcium and magnesium are present in high amounts. Sodium may form a substantial percentage of the adsorbed bases, especially in the lower layers. Secondary elements, such as sulfur, and the trace elements such as iron and molybdenum, are often lacking. The content of organic matter is relatively low but is distributed to a depth ranging from 30 to 90 centimeters, its total amount thus being higher than in many other soils formed under similar climatic conditions.

Yields on dark clays can be substantially increased by an efficient use of fertilizers in those cases where other handicaps, e.g., deficient moisture supply or poor physical conditions, can be overcome. On the other hand it is reported from India that the benefit to be obtained from other costly improved practices, such as irrigation, good seeds and better tillage, depends very much on an adequate use of fertilizers.

It is generally accepted that different soils react differently to the application of fertilizers, or in other words, that fertilizer use must be adapted to the characteristics of the soils if it is to be efficient. The dark clays, with their high sorptive capacity, heavy texture, low permeability, high pH, high base saturation and a rather unbalanced nutrient content, provide a striking example of how specific soil properties must be taken into account when determining the kind and amount of fertilizer to be used and the timing of its application.

The pH of most dark clays ranges from slightly acid to alkaline. Under alkaline conditions the availability of phosphorus and of several trace elements is decreased. The high pH in these soils is associated with a high percentage of calcium and magnesium. These elements may interact with other nutrients; for example, it is known that high calcium and magnesium contents reduce the availability of potassium. It has also been reported that high calcium content induces manganese deficiencies for oats and iron deficiencies for sorghum. This relative imbalance between different elements must be taken into account in determining the amount and kind of fertilizers to be applied. Because of the low levels of both nitrogen and phosphorus the application of one of these elements may result in a relative shortage of the other. Occasionally the one-sided application of fertilizers on dark clays may bring a reduction in yields because of the accentuation of existing conditions of imbalance. On these soils with high pH, the use of acid fertilizers may be recommended. It has been reported that the use of acid nitrogenous fertilizer has made phosphorus available, so that a smaller application of the latter element was needed.

Owing to the heavy texture and slow permeability, fertilizers applied on dark clays do not penetrate deeply into the soil and are available only in the surface layers, at least during the current vegetation period. Furthermore, the strong runoff on these soils may remove a substantial amount of the fertilizers applied. In this case it may be desirable to apply fertilizers repeatedly but in small amounts.

Since dark clays have rather unfavorable physical properties, the maintenance of the organic-matter content deserves careful attention. The humus content may be increased by the use of manures and composts and by the introduction of leguminous crops and grasses in the rotations. At Blackland Experiment Station, Temple, Texas, the following differences in organic-matter content were noted in relation to different cropping patterns; plots in continuous maize — plow layer 2.05 percent; all plots in crop rotations — plow layer 2.28 percent; continuous Bermuda grass for 20 years — upper 7.5 centimeters, 3.94 percent. Soil organic matter can effectively be maintained by increasing plant residues through higher yields obtained from the use of fertilizers. Organic-matter levels and trends provide one of the best indices of soil improvement.

Besides soil characteristics, the kind of crops, cropping patterns, management systems and climate have a strong influence on the use of fertilizers on dark clays. For sugar cane it was reported from India that 250 kilograms of nitrogen per hectare was the economic limit for the Pindia variety, while for the POJ 2878 variety this limit had not been reached at 335 kilograms of nitrogen per hectare. The cropping sequence used in the Blacklands (Texas) has proved to be important from the point of view of fertilizer use; crops grown in rotation with phosphate-fertilized sweet clover do not respond to the addition of nitrogen and phosphorous fertilizers since they benefit from the soil-improving qualities of the legume.

Soil management may alter soil properties to the extent that neighboring fields may call for different treatment; a striking example is the difference in fertilizer requirements on dry land and adjacent irrigated land. Reduction, induced by stagnating water, leads to the formation of sulfides which harm root development. In soils containing a sufficient amount of iron the hydrogen sulfide may be neutralized, but in soils poor in iron — which is the case for many dark clays — it seems advisable to avoid the use of sulfatic fertilizers. Interruption of the reducing stage and restoration of surface structure by proper rotation is to be recommended (75).

A few examples of fertilizer application on dark clays for different crops are given below. These are merely illustrations and should in no way be considered as guidelines for fertilizer use on dark clays since, as outlined above, responses, type and amount of fertilizers, and method of application depend largely on management, climate and the original fertility status of the soil.

In Java, yields of irrigated rice have been increased by 37 percent with the application of 100 kilograms of double superphosphate per hectare. The same amount of fertilizer yielded an increase of 44 percent on dry land. With the application of 100 kilograms of double superphosphate and 100 kilograms of ammonium sulfate, the yield increases reached 55 and 75 percent respectively. The check-plots produced 1,830 kilograms of stalk paddy on irrigated land and 810 kilograms on dry land. The high responses on dry land can be explained by the fact that the dark clays in Java are favored by an annual rainfall of 1,250 to 1,500 millimeters, which approaches the highest rainfall — up to 2,000 millimeters — under which these soils occur.

In the Congo, irrigated rice on an experimental plot produced 5,695 kilograms per hectare with a fertilizer application of 300 kilograms of ammonium sulfate and 200 kilograms of superphosphate; without fertilizers, production was 3,600 kilograms. In Nicaragua rice yields are doubled to 60 quintals per hectare with the application of 100 kilograms of urea and 100 kilograms of an NPK mixture.

Green manure is locally used for the production of rice, for example, sunn hemp (*Crotalaria juncea*) in Indonesia or "turgbos" (*Sesbania mosambicensis*), which grows luxuriantly as a weed on irrigated dark clays in South Africa, and is reported to increase yields of the main crop substantially.

On sugar cane in India a normal application of fertilizers is 100 to 450 kilograms of N, 40 to 100 kilograms of P_2O_5, and 80 to 160 kilograms of K_2O per hectare. It was found that under irrigation the combination of organic and inorganic nitrogen gave better results than inorganic nitrogen alone.

Cotton yields in India have been increased by 70 kilograms with an application of 35 kilograms of N per hectare. A basic dressing of bulky organic manure is found to increase the effectiveness of inorganic fertilizers. In the United States, response has been obtained from a combined nitrogen and phosphorus application.

In India a 20 percent increase of sorghum production was obtained with the application of 17 kilograms of N per hectare.

In South Africa 50 kilograms of ammonium sulfate, 40 kilograms of superphosphate and 60 kilograms of potassium sulfate per hectare are applied to flue-cured or cigar tobacco. In Indonesia, flue-cured tobacco is given 30 kilograms of N, 60 to 90 kilograms of K_2O, 30 kilograms of P_2O_5 and 180 grams of boron per hectare.

In South Africa, wheat is given 140 to 200 kilograms of superphosphate per hectare. In Australia, 100 kilograms of superphosphate per hectare are applied. In India, excellent results have been obtained under irrigation by the application of 10 to 35 kilograms of N per hectare. In the same country, a residual effect on wheat was obtained with the application of 170 kilograms of superphosphate per hectare applied to the preceding tobacco crop.

In South Africa, maize is given 100 to 200 kilograms of superphosphate per hectare. In Indonesia, the application of 20 kilograms of N per hectare has been reported to double maize yields.

A 100 percent increase in yields of soybeans was obtained in Indonesia with an application of 80 kilograms of K_2O per hectare.

There is still great scope for experimental work in the field of fertilizer application on dark clays; several reports on fertilizer experimentation, however, contain so little soils information that it is difficult even to ascertain on which kind of soil the trials were carried out let alone to extend the results obtained to other areas in similar environments. Specific information on fertilizer responses on dark clays is therefore rather limited.

All in all, it may be said that responses of dark clays to fertilizers, as a part of good over-all management, have been encouraging, though possibly smaller than for other widely distributed soils in the tropics such as Alluvial soils or Latosols.

Crops and cropping systems

Crops and cropping systems are most important factors in soil management since the income derived from them pays for labor and equipment, provides a living and produces a profit.

Certain characteristics of the dark clays limit plant growth: their strong swelling and shrinking, poor soil-water relationships, very heavy texture, firm consistence and unstable surface structure. These limitations may be overcome by proper management including adapted crop rotations. Thus, the range of crops and their rotations vary not only with climatic conditions but also with management practices, availability of irrigation water and mechanical equipment.

A number of major crops grown on dark clays are listed below with brief comments on their general distribution and the cultural practices specific for these soils.

Rice

Rice is generally grown on dark clays under either gravity or pumping irrigation. In some areas advantage is taken of the impermeability of dark clays to pond rain water by putting up a low ridge around the field so that no additional irrigation is needed. In Indonesia, where many dark clay soils are tilled by hand, the soil is flooded before cultivation. Use is made of a special hoe with a long blade fixed at a sharp angle so that the surface soil can be sliced off instead of being turned over. On dark clays rice is grown on level land since terracing is limited by the instability of the soil.

As mentioned in the section on fertility, prolonged stagnation of water causes the reduction of the upper layers and the consequent formation of sulfides which harm root development, especially in the dark clays which generally contain too little iron to neutralize the hydrogen sulfide formed. There are also indications that these soils deteriorate physically when kept permanently moist. In several countries it has been shown that yields are higher when rice alternates with dry crops or is preceded by green manure crops. In both cases the aeration provided by rooting systems and tillage favors the following rice crop by interrupting the reducing conditions and improving the physical properties of the soil.

Rice can be grown year after year, alternating with fallow during the dry season. In some areas, where enough water and varieties of rice adapted to the prevailing daylight conditions are available, even two crops a year can be grown, for example in some parts of Java. Rice may be grown in rotation with such crops as tobacco and sugar cane (over a two-year period) or subsistence crops such as cassava, groundnuts, maize and beans of various kinds.

Rice on dark clays is grown mainly in Australia (New South Wales, Northern Territory), Ghana, India, Indonesia, Philippines and southern United States, and to some extent in Cameroon, Congo, Dahomey, southern France, Thailand and Togo.

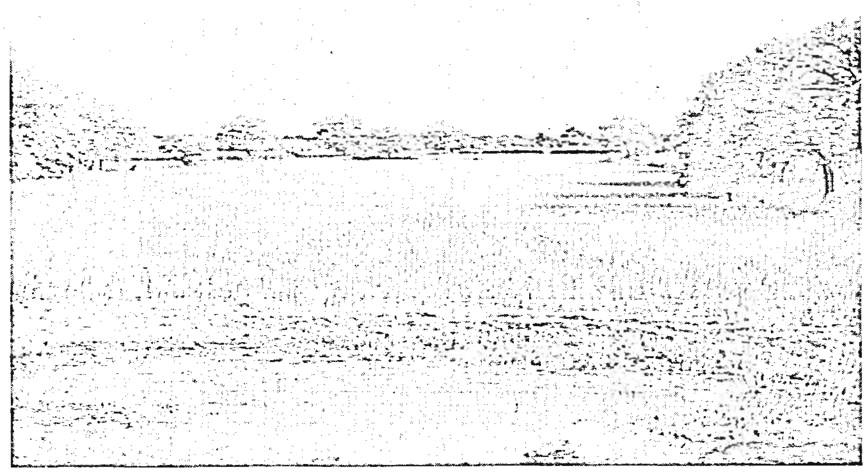


FIGURE 24. Paddy rice grown on Regur soils from limestone west of Raipur, India. The low trees around the rice field are acacias, which were part of the native vegetation.

(Courtesy Roy W. Simonson, U.S. Soil Conservation Service, Hyattsville, Maryland, U.S.A.)

Wheat, oats and barley

Wheat is extensively grown on dark clays both under dry and under irrigated conditions. With dry cultivation, wheat normally alternates with fallow (as in Australia) or with pulses (as in some parts of India). When irrigated, the rotation is more diversified. Wheat may alternate with tobacco and legumes (for instance in South Africa) or with cotton or linseed and gram (as in India). Oats are grown extensively in rotation with cotton in the United States. Barley has been grown under irrigation in Chile.

Wheat is grown on dark clays mainly in Australia, India, South Africa, Portugal and Uruguay and to a lesser extent in Brazil, Chile, southern France and Turkey. The cultivation of wheat under irrigation has recently started in Sudan.

Sorghum, maize and millet

Being very resistant to drought these cereals are extensively grown on dark clays in dry-land conditions; in subarid areas maize may receive supplementary watering. Sorghum may be grown continuously (Sudan), alternating with fallow (Australia) or in rotation with cotton (United States, Sudan and India). Maize may also be grown continuously or alternate with fallow, cotton, rice or soybeans. It may be grown in combination with other crops such as cotton, chilies, soybeans and groundnuts. A cotton-maize-legume-fallow rotation has been applied successfully in Ghana. Millet may be grown in association with sorghum or in rotation with cotton (India).

Sorghum is grown on dark clays mainly in Australia, India, Mali, Senegal, Sudan, Uruguay and the United States.

Maize is grown on dark clays in South Africa, Indonesia, Uruguay and the United States; millet mainly in India and several African countries such as Cameroon, Chad, Senegal and Sudan.

Sugar cane

With suitable climatic conditions and management, dark clays appear to be very suitable for the production of sugar cane. However, the dark clays are difficult to work and this calls for the careful planning of cultural operations. A suitable timing in tilling the land, planting and first growth, topping and ripening is most important.

On the dark clays sugar cane is grown as a row crop. Drainage is provided by a closely-spaced system of open field channels or, when planted

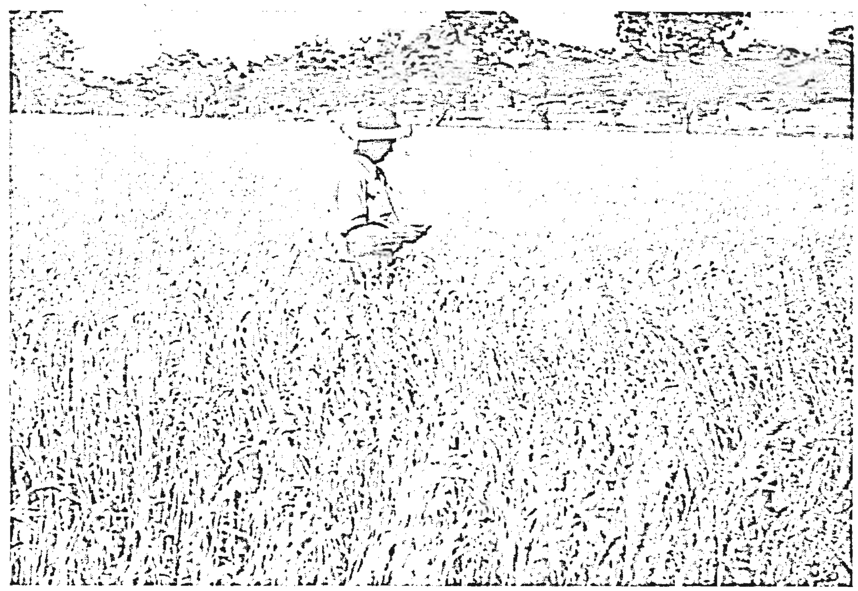


FIGURE 25. Wheat crop on Black Earth on Darling Downs in southern Queensland, Australia. (Courtesy C. G. Stephens, Division of Soils, Commonwealth Scientific and Industrial Research Organization, Adelaide, Australia)

on cambered beds, by deep open field drains separating the beds. In the first case, the furrows serve concurrently to drain and irrigate, while with the second method irrigation water is provided through shallow furrows made on the beds. In either case the cane is planted in the furrows which, at a later stage, are filled up and made into ridges by opening up the original beds. These operations may be performed by hand or mechanically.

Sugar cane is produced both as chewing cane and as a commercial product. It may be grown continuously including production of a first and second ratoon before replanting, or in rotation with paddy rice and dry subsistence crops. The latter rotation is spread over a period of three years and requires replanting for each cane crop (as in Indonesia). The cane may be preceded by a green manure crop such as sunn hemp (as in India).

Sugar cane is grown on dark clays mainly in Brazil, Cuba, El Salvador, India, Indonesia, Nicaragua and the Philippines. Cultivation of sugar cane has been started in Sudan and in Ghana.

FIGURE 26. Cultivation in beds, favoring surface drainage, on dark clays in East Java, Indonesia.

(Courtesy R. Dudal, Soil Correlator, FAO, Rome, Italy)

Cotton and other fiber crops

For cotton, soils must be sufficiently water-holding to supply the necessary moisture to the plant during the dry spell required for boll formation. Dark clays appear to meet these requirements.

Cotton is grown as a row crop on dark clays both under dry and under irrigated conditions. When irrigation is practiced, water is only applied when signs of wilting appear, which in the dark clays is before the soil starts cracking.

On the dark clays cotton may be grown on farms ranging from a few hectares to thousands of hectares, managed by hand and animal labor, as in India, semimechanized as in Sudan or as a highly-mechanized enterprise as in the United States. On tropical dark clays cotton may alternate with fallow (for example in India) or, in subhumid to humid areas, it may be grown in rotation with rice. In the latter case, the rice is grown during the wet season and the cotton planted immediately after or just before the rice harvest, taking advantage of the water stored in the soil for germination and growth. The rotation established in Sudan is: cotton, sorghum, a legume (*Dolichos lablab*) and fallow. In that country, cotton also alternates with natural grassland under the so-called " hariq " system in which the savanna is protected from fire during the dry season, and

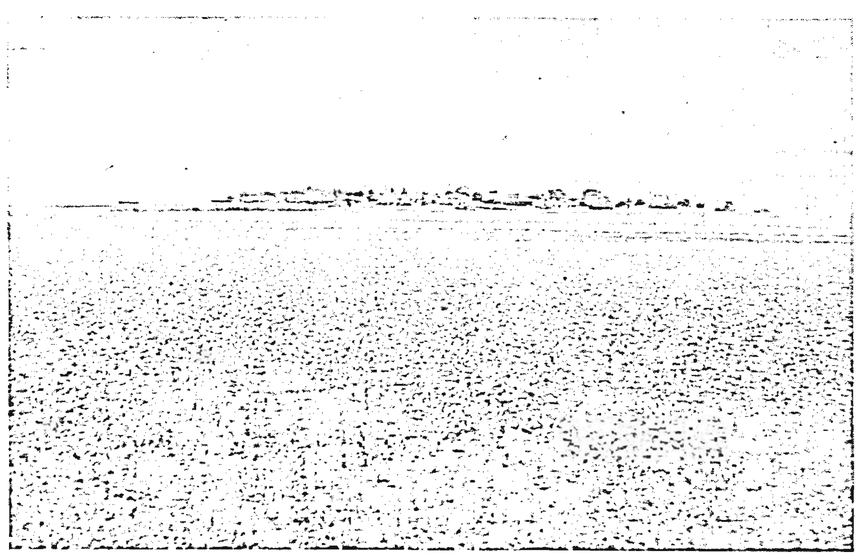


FIGURE 27. Cotton on Houston Black Clay at Blackland Experiment Station, Temple, Texas, U.S.A.

(Courtesy Dr. R. M. Smith, Superintendent, Blackland Experiment Station, Temple, Texas, U.S.A.)

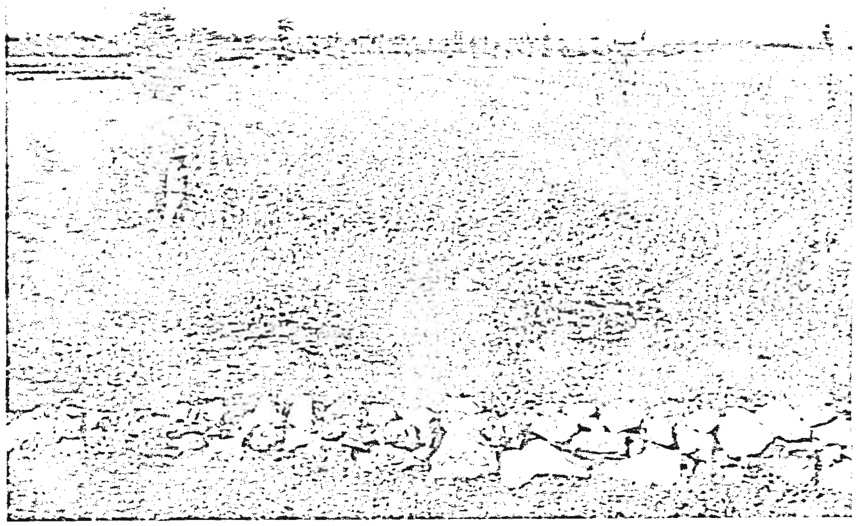


FIGURE 28. Cotton in bloom on Regur soils from trap rock near Betul, India. Boulders formed in the weathering of the trap rock are stacked in the fence in the foreground. A few rows of sunn hemp (*Crotolaria*) are growing at the edge of the cotton field. Occasional rows of tur (*Cajanus inducus*) and scattered jowar or sorghum plants are interspersed among the rows of cotton. The even sky line in the distance indicates the dominantly level topography of the region.

(Courtesy Roy W. Simonson, U.S. Soil Conservation Service, Hyattsville, Maryland, U.S.A.)

the dead grass is burnt off during a convenient dry spell in the wet season. The fire also destroys weeds and leaves a clean seed bed for the cotton crop. In the United States, cotton is rotated with maize, sorghum, or small grains. When rotated with legumes, it has been found that the latter exhaust too much of the moisture stored in the soil. Cotton may be grown continuously, provided fertilizers are used.

Cotton is cultivated extensively on dark clays in India, Sudan and the United States, and to a lesser extent in Cameroon, Indonesia, Mali, Thailand and Togo.

Besides cotton, a few other fiber crops have been reported growing on dark clays: flax in Uruguay and kapok in Indonesia. The possibilities of growing cotton and jute in Ghana are being investigated.

Pasture and fodder crops

Pasture land is probably the dominant land use on dark clays. The greater part of this land, however, only provides rough grazing and sown, improved, or irrigated pasture land is seldom reported. Large areas of natural grassland are still ungrazed owing to lack of water in the dry season.

Dark clays are seldom suitable for the development of a cattle industry along progressive lines. In the dry season there may be an acute shortage of food and water which makes a seasonal shift of stock necessary and although the shortage is not specific for dark clays, it is more pronounced on these soils because of the drought hazard. The nutritive value of the fodder is generally high and animals grazing on dark clays do better than those grazing on adjacent soils of different composition. With adequate management these soils can be turned into high-class grazing land: sprinkling irrigation on pastures in California and southern France has given excellent results; with the use of fertilizers in Ghana, where pilot grazing and cattle improvement schemes have been introduced, more economic grasses showed a marked tendency to dominate the sod. In Central America the highly productive Elephant grass, Pangola grass and Japanese King grass are grown mainly on dark clays.

Grassland on dark clays is generally permanent, but its composition may be strongly influenced by man, for example by overgrazing, or by regularly burning the grass cover. In some countries grassland has been introduced in the rotation, for example with wheat in Australia. In the United States, Johnson grass (*Sorghum halepense*), Bermuda grass (*Crynodon dactylon*) and tall native grasses are used for the improvement of permanent grasslands; Sudan grass (*Sorghum sudanense*) is found to be one of the best crops for grazing all the year and is especially valuable during the hot dry weather when other grazing is scarce. Yellow bluestem (*Andropogon ischaemum*) is recommended in combination with clover on shallow severely eroded or steeply sloping soils. In Sudan, cotton is rotated with natural grassland in the "hariq" system described above. In Indonesia, rice paddies often alternate with a grass fallow which is grazed by cattle and buffaloes. There is usually no other grazing land and a supplement of fodder is cut along the roadsides and in waste patches.

The systematic production of fodder crops on dark clays is undertaken only in countries with a highly developed agriculture. In experimental work in the United States (232) a combination of oats, barley and wheat with sweet clover, using phosphate fertilizer, has become the mainstay of soil conservation and cattle-raising. These crops serve a dual purpose: in cool weather the small grains constitute the main grazing; by early March the cattle are removed from areas where maximum grain production

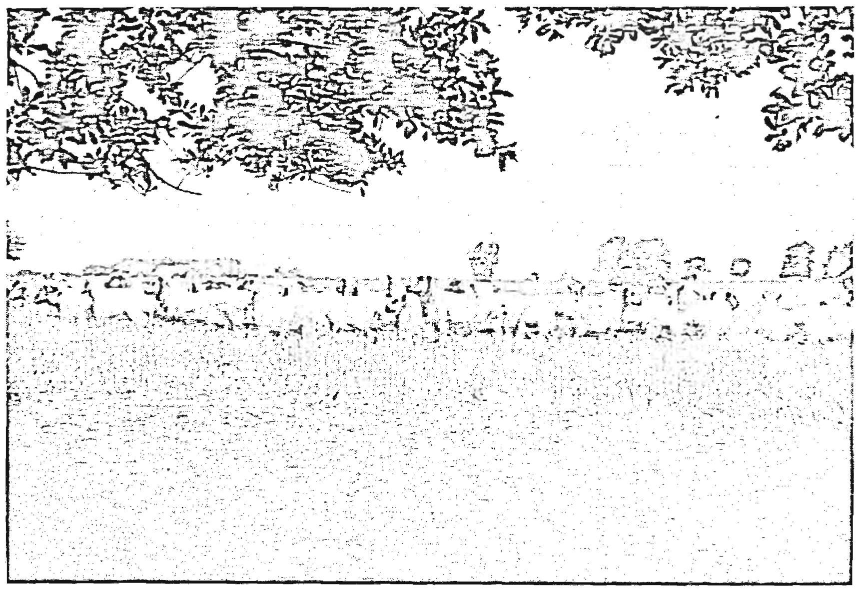


FIGURE 29. White clover (*Trifolium repens*) and Dallisgrass (*Paspalum dilatatum*) pastures growing on dark clay soils in the Black Belt region of Alabama, U.S.A. These soils are well adapted to forage production for beef and dairy cattle and sheep.

(Courtesy Auburn University Agricultural Experiment Station, Alabama, U.S.A.)

or a heavy hay yield is expected; other fields are used for continuous grazing. The high meat returns obtained with this combination show the value of these crops for cattle-raising and for soil protection and water conservation. On land classes III and IV (see the section on Soil conservation) a combination of small grains and sweet clover compares favorably with row crops as an economic proposition.

In Sudan a legume (*Dolichos lablab*) is introduced in rotation with cotton. The crop receives five to eight waterings and is cut for fodder and stacked or baled. A second cut may be taken or the crop may be left to seed.

In many countries animal husbandry could play a more important role in the development of dark clay soils. Pasture land could be improved and leguminous fodder crops more commonly introduced in rotations. Legumes have not yet come to occupy the place they deserve for soil improvement, pasturage and fodder production. Research and extension in this field are still needed for tropical and subtropical countries.

Dark clays are extensively used as pasture land in almost all the countries where they occur; large areas are grazed in South Africa, Argentina, Australia, Chile, India, Sudan, Uruguay and the United States.

Forest products

Since the vegetation on the majority of dark clays is a grass savanna, little data are available on the exploitation of forest products in dark clay regions. Where they are under forest, it is usually a clear open stand producing firewood and light timber.

Areas of dark clays in Argentina are reported to have once supported good stands of quebracho (*Schinopsis balansae*) which have recently been depleted by exhaustive logging, and reproduction is not good. In monsoonal climates forests have been locally changed from the original mixed cover to more productive stands. In Java dark clays are known to produce high quality teak (*Tectona grandis*), the development of which is improved by selective clearing and by planting. In Ghana the successful introduction of teak, nim (*Azadinacta indica*), *Cassia siamea*, *Dalbergia sissoo*, *Anogeissus leiocarpus* and *Casuarina equisetifolia* has been reported.

FIGURE 30. Wild grazing on shallow Grumusols from marls in the Kendeng hills, Central Java, Indonesia. The condition of the cattle shows the poor quality of the grazing land. Attempts to reforest with teak and *Pinus merkusii* have not been successful owing to trampling by cattle.

(Courtesy R. Dudal, Soil Correlator, FAO, Rome, Italy)

Miscellaneous crops

Several other crops have been reported to grow on dark clays. They are not dealt with separately since specific data on cultural practices as affected by soil properties are not available. Also these crops cover too small an area to be considered as representative for crop production on dark clay soils. They are mentioned here to complete this section: cacao (Ivory Coast); cassava (Ghana and Indonesia); groundnuts (Indonesia); linseed and castor (India); sesame (India and Sudan); soybeans (Indonesia); sugar beet (Uruguay); sunflowers (South Africa, Chile, Sudan and Uruguay); tobacco (Ghana); and various kinds of peas and beans (spread throughout the dark clay regions).

Farming experience and productivity

The capacity to produce crops depends on a large number of factors such as soil, climate, management, cropping systems, varieties of crops, control of pests and diseases, etc. The influence of the soil on production is very marked with dark clays: their high density and churning phenomena slow down root development; the heavy texture and stickiness make tillage and seedbed preparation difficult; the often high pH and a relative imbalance of absorbed bases limit the availability of nutrients; their slow permeability presents special problems of drainage and irrigation; the shallowness, and sometimes the instability of the structured surface layer make these soils subject to erosion.

Although progressive scientific and technological methods have succeeded in removing obstacles to intensive use, the properties of the soil still remain a very important factor. With regard to the economic feasibility of farming practices, a satisfactory yield may be obtained on a good soil with relatively simple techniques, while on a poor soil a similar yield can only be obtained by a high investment in labor, machinery and other industrial aids. It must be stressed that, if soil improvement is too complex and expensive, the farmer's profit may be reduced or production may even be uneconomic.

In addition to soil characteristics, climate also strongly affects yields. It governs the natural water supply and its distribution over the year, the length of the day and the length of the dry and wet seasons. Yields vary markedly on the same soil according to the variation of the rainfall from one year to another. For instance, it has been reported from Texas (232) that average yields of 2,000 kilograms of maize per hectare may reach 3,000 kilograms when rainfall exceeds the average. On the other hand, concentrated rains may damage some crops, like tobacco, considerably and severely reduce yields.

FIGURE 31. Kapok and maize on level Grumusols developed on old alluvial sediments in East Java, Indonesia.
(Courtesy R. Dudal, Soil Correlator, FAO, Rome, Italy)

Management practices are known to have a strong influence on productivity. On a similar soil, yields vary depending on whether the soil is cultivated under dry or irrigated conditions, whether it is fertilized or not, and whether tilled with a hoe or with a plow. There is a wide range between primitive management conditions and the conscious application of modern technology. In some dark clay regions maize, wheat and cotton yields have increased by 200 percent with irrigation; yields of rice have been reported to increase by 55 percent with the use of fertilizers under irrigation conditions. An increase of 225 kilograms per hectare of seed cotton was obtained in Texas by spacing cotton plants at 5- to 10-centimeter intervals in 100-centimeter rows instead of spacing them at 20 to 30 centimeters. A substantial increase in cotton yields was also obtained when the crop was rotated with small grains and grass instead of being grown continuously.

The variety of production systems in dark clay regions under different sets of conditions is illustrated below by a few examples showing how, in different countries, farm management practices have been adapted to the physical potential of the soils.

1. A farm management study published by the Government of India for the year 1954/55 covered a group of over 400 farm units in Bombay State. These farms averaged 9 hectares in area with 60 percent of them being less than 8 hectares. Of the average total investment of 6,000 rupees [2] per farm, 80 percent was in land and the remainder in buildings, implements, tools and livestock. Of these farms 61 percent were owner-operated and most of the remainder were partly owned and partly rented. Most of them had a minor percentage of the land irrigated from wells. Cultivation was mainly carried out with bullock-drawn wooden implements, hand tools and a few improved iron plows. Farming schemes included wheat, coarse grains, fodder, lucerne, vegetables, and small amounts of livestock products. The average over-all gross farm income was less than 1,000 rupees with a net income of about 240 rupees. Distances of farms from the nearest motorable road varied from 2 to 15 kilometers. The extensive use of manual labor and the lack of power and modern equipment characterize these farms which only provide for a family's subsistence.

2. A different pattern is seen in reports issued by the Department of Agriculture and Stock, Brisbane, Australia, on dark clay soils farming in (*a*) the intensively farmed southern Queensland area, and (*b*) the larger, newer and less intensive region of central Queensland. For both areas the reported high living standard is borne out in the following statistics: farm size, 80 to 120 hectares in the south, up to 2,000 hectares in the central area; total farm investment, up to £22,000;[3] gross income £5,000-£10,000; farm expenses, £4,000-£5,000. Major crops with average yields per hectare for the southern area are: wheat 2,000 kilograms, barley 2,250 kilograms, linseed 750 kilograms, canary seed 270 kilograms, grain sorghums 110 kilograms, cowpeas 325 kilograms. In the central area, emphasis is on livestock with grain sorghums as the major crop. Unimproved pastures carry 1 sheep to 1.2 hectares. Labor in both areas is furnished mainly by the family. Farm operations are mechanized. Tenure is a mixture of freehold and perpetual and specific leaseholds. The major problems which remain to be solved are the lack of permanent pastures and of standard cropping systems.

3. From Portugal a report on the utilization of the " Black Barros of Beja " indicates that these soils form one of the prosperous agricultural

[2] 1 Indian rupee = 0.20 U.S. dollars.
[3] 1 Australian £ = 2.23 U.S. dollars.

districts in that country. Farms vary in size from 50 to 300 hectares. They are operated by owners or cash tenants. Farming operations are performed with mechanized equipment and the entire farming system exemplifies profitable and permanent agriculture. The crop rotation includes chick-peas (*Cicer arietinum*), spring and winter wheat and horse beans. Nitrogen and phosphorous fertilizers are used. Productivity is normally indicated by wheat yields of 1,200 to 1,600 kilograms per hectare, and up to 3,500 kilograms under favorable conditions, chick-peas 550-750 liters per hectare and horse beans 800-950 liters per hectare.

4. A report from Uruguay describes varying patterns of use and management on the dark clay soils of that country.

In the northern regions large grazing enterprises predominate, with cultivated pastures to supply supplementary fodder for cattle. Farm units average 2,500 hectares with a total investment of about 500 pesos [4] per hectare, under management of both owners and tenants. Permanent hired labor is used. Average gross income is 100 pesos and expenditure 25 pesos per hectare. The farm living standard is quite adequate.

Large mechanized farms averaging 1,000 hectares prevail in the western region of the black soil area of Uruguay. Average farm investment is 700 pesos per hectare; gross income is at 600 pesos and expenditure at 300 pesos per hectare. Family labor is supplemented by hired labor. The cropping system includes wheat, which yields 1,200 to 1,300 kilograms per hectare, flax and pasture. The living standard of the farmers is satisfactory. This development scheme has only been in operation for the last 25 to 30 years.

On family farms, averaging 30 hectares, in the south-central region dark clay soils in Uruguay, the major enterprises are vegetables, fruits and dairying. Here the farm living standard is reported to be low. The present system of cultivation dates back about 100 years; ownership is less usual and there are many tenant farms. Farm operations are carried out with hand tools and animal power. The reported average yields per hectare are 25,000 kilograms for tomatoes, 15,000 kilograms for peaches and 10,000 kilograms for grapefruit.

5. In Nicaragua, dark clay soils are mainly devoted to grazing, although recently a start has been made by the large operators to cultivate crops with heavy equipment; small farmers cannot afford the cost of such equipment. Dark clays are not extensively cultivated in Nicaragua. In areas of dense population, farmers cultivate the soils of coarser textures and

[4] 1 Uruguayan peso = 0.21 U.S. dollars.

leave the heavy clays in pasture; in thinly populated areas livestock operations predominate.

On the few farms that are cultivated, combinations of cotton, rice, sorghum and sugar cane are grown both on irrigated and unirrigated land; nitrogen and phosphorous fertilizers are used. Farms are large, ranging from 35 to 280 hectares. Fair yields have been obtained and can be increased as management problems are solved by experience; tillage costs are high.

Engineering problems

Although this paper deals mainly with the agricultural use and problems of dark clay soils, it is felt that the significance of some of the soil characteristics for engineering construction also deserves mention.

The swelling of the clay fraction in dark clay soils, their heavy expansion and shrinking with changing moisture conditions, their high density and firm consistence are all factors which greatly affect construction and engineering works. Only some general features are mentioned here since a specialized study of the problems of soil mechanics would reach beyond the scope of this paper.

Although dark clays have a high bearing capacity on account of their density, heavy cracking and soil movement endanger the stability of constructions. Several characteristics of dark clays, such as shiny ped surfaces, slickensides, tonguing of surface horizons into the subsoil and gilgai topography, clearly indicate that the soil undergoes strong pressure, is subject to churning and that it rises and settles during wet and dry weather respectively. Changes in volume may be as great as 50 percent and seem to be at least 25 percent in most dark clays. For example, soil movement relative to concrete bench marks showed a total vertical movement of 25 millimeters during the year for a bench mark sunk to 1.5 meters and 38 millimeters for a 1-meter bench mark. Bench marks sunk to 2.5 meters, 3 meters and 4.5 meters moved less than 5 millimeters (126). As a result of contraction and expansion of the soil, mainly in the upper 1.5 meters, brick and even concrete structures frequently crack, and may in the worst cases be ruptured or twisted out of shape. When building on dark clays, it is desirable to dig foundation trenches through the layer of heavy texture and varying moisture content, i.e., through the entire solum. With regard to the soil swelling pressure, it is recommended that designs of foundation loadings should be based on data from laboratory and field plate-bearing tests.

Road construction on dark clays raises several problems. Since road foundations can hardly be laid at great depth owing to the high cost, the construction must provide for adequate drainage to prevent excessive swelling and churning. The same applies to airfield runways on dark clays, taking into account, however, that sufficient moisture should be available to maintain adequate grass cover between the runways.

On slopes there is a danger of landslides; owing to an excess of water the soil mass may become so heavy that the entire hillside gives way and moves downward. Structures built in such locations risk total rupture and roads passing through hilly country in dark clay areas often break down over large sections. Road verges also subside and block the traffic. The downward movement may not take the form of a slide but of a slow progression downhill; poles, fences and often trees, lean and point downhill and downward slipping of this sort can be active on very gentle slopes. In the construction of roads and terraces it is imperative that the permissible angle of slope should be established, so as to ensure the stability of the structure.

Dark clays can only be used to a limited extent for building dams owing to their high plasticity. They erode very easily and care should be taken to minimize cracking and the formation of runnels in the banks. Dark clays can be used safely only if mixed with less plastic or nonplastic material, the amount of which is in turn limited by the resulting infiltration capacity of the mixture.

It is reported from Burma that the banks of the Shwebo and Ye U irrigation canals, running through the dark clay area of central Burma, are still unstable even though 50 years have elapsed since their construction. The instability seems to result more from shallow surface slumping than from deep-seated circular slips. It is suggested that the cause of bank failure is probably the low permeability rate of the clay, which leaves a high enough residual pressure for slumping after the drawing down of the water level in the canal; even a lowering of the level at the rate of only 30 centimeters per week does not seem to prevent failure. Furthermore, breaches in the walls sometimes occur when the canals are refilled. Washout and piping occur through the cracks, which develop during the dry season, until the soil swells again after an addition of moisture.

Dark clays are usually unsuitable for brick-making on account of their high plasticity and often of the presence of lime nodules or concretions. The clay can be used if mixed with coarser "opening" material, such as grog, coal, ash or sand, to prevent shrinkage during drying. Bricks manufactured from dark clays are generally irregular in shape, highly porous and with poor crushing strength. An improved method consists in using calcined clay, instead of ash, to mix with the basic material; the product thus obtained is denser and stronger.

In general, engineering work is hampered by the difficulty of moving machinery on dark clays when wet. Roads and tracks become slippery and very muddy and even the use of animals as draft power does not solve the problem since the clay sticks to their feet and limits freedom of movement. Unmetaled country roads in dark clay regions are often unusable during the wet season.

Agricultural potential

While the difficulties of farming in the dark clay soil regions are real enough and deserve attention, their favorable features in relation to agricultural production should be given equal emphasis. Compared with other soils in the same climatic zones, the dark clays generally have a high content of nutrients. In many cases, they develop a good surface structure, have a high water-holding capacity and strong biological activity, and show a certain stability with regard to their fertility status and salinity hazards owing to the self-mulching process.

Increased agricultural production on these soils can be obtained in two ways: by increasing present yields through improved management and by opening up new land. The margin for increasing production on these soils is very great; for example, in Indonesia 500 to 700 kilograms of rice (husked paddy) per hectare are obtained on dry land; an average of 1,800 kilograms is obtained with irrigation while 2,800 kilograms are currently obtained with an additional application of 200 kilograms of fertilizers (nitrogen and phosphorus in a relation of 1:1); yields of irrigated cottonseed vary from 500 to 2,000 kilograms per hectare, of irrigated sugar cane from 270 to 1,100 quintals per hectare, of dry land sorghum from 400 to 4,000 kilograms per hectare, of dry land wheat from 500 to 3,000 kilograms per hectare. These differences may be ascribed partly to climatic conditions but to a large extent the higher yields are the result of improved management practices such as irrigation, drainage, application of fertilizers, the use of selected seed, pesticides and better tillage implements, the introduction of erosion control and adequate crop rotations.

The few examples mentioned above are clear evidence that the potential production of dark clay soils is high and that there is much scope for increasing their yield. It should be stressed that a greater benefit is to be expected from a combination of management practices — tillage at optimum moisture levels, proper choice of crops, efficient use of fertilizers, etc. — than from any of these practices used alone. Each improvement enhances and increases the effect of the others.

Improvements such as fertilization, surface drainage, pest control, mechanization and crop rotation can normally be achieved by the individual farmer. However, the choice of improved soil management practices must be made with due regard to the skill and resources of the farmers and to the scientific and industrial support available in the country or which can economically be made available to it from outside sources. It is obvious that the alternatives open to the farmer who tills his land with a wooden stick by turning over clods of soil are very different from those offered to the farmer who uses a tractor and large steel implements and is thereby supported by a technically developed society. Flood control in lowland areas, irrigation works or the organization of co-operatives call for government support.

With reference to opening up new land, dark clays occupy an important place among the soil resources available for development. Large areas still lie idle and, since they are generally covered with grass or open grassy woodlands, clearing for cultivation is relatively easy. Wide experience in the exploitation of these soils is available from the developed countries and can be used in regions with the same environmental conditions. Farming practices developed in one locality may be carried out successfully in other areas with similar soils and climate, provided the prevailing economic and social conditions are taken into account. Advantage can be taken of the results obtained at experimental stations located in other dark clay soil regions, such as Temple (Texas), Kpong (Ghana), Wad Medani (Sudan), Debra Zeit (Ethiopia), Nagpur (India) and Ord River (Western Australia). Cultivation should not be extended to areas susceptible to erosion; on the contrary they should be reforested where rainfall is adequate. Although reforestation on these soils is difficult and the growth of timber generally slow, the production from forests on such soils compares favorably with the returns from other uses.

The wide range of climates under which dark clays occur has already been pointed out. It should be stressed again that the climatic factor is of great importance when selecting suitable crop rotations and management practices to be applied.

3. NATURE, ORIGIN AND CLASSIFICATION OF DARK CLAY SOILS

Morphology

The dark clay soils as a group show a high degree of uniformity in many properties throughout the profile. As compared with other soil groups they lack distinct or prominent horizons. They have a characteristic darkened surface layer or A_1 horizon [1] which grades progressively into the C horizon and may be quite thick. As a group, these soils are high in clay, plastic and sticky when wet, mostly dark in color with low chromas, subject to marked swelling and shrinking with changes in moisture content, and lack textural distinctions due to soil-forming processes. Many of the dark clays are calcareous, often with concretions. Most of them have a high pH although a few are acid. They generally have moderately deep to deep profiles. The range of variability in textural class, consistence, coefficients of expansion and contraction and clay accumulation is limited, whereas wider ranges occur in a number of other characteristics.

Horizon sequences in profiles of dark clays

The dominant sequence consists of A_1, AC and C horizons. In addition, horizons of carbonate accumulation, D horizons and gleyed horizons may occur in some profiles.

The A_1 horizon is characterized by an accumulation of organic matter, which is reflected in a darker color and more friable consistence. It should, however, be pointed out that the color results more from the formation of a complex between clay and organic matter rather than from high amounts of organic matter; indeed the content of the latter in dark clay

[1] Concepts of soil horizons, and the terminology for properties of these horizons, used in this publication are taken from the *Soil survey manual*, published by the U.S. Department of Agriculture (244).

soils is relatively low. The majority of dark clays have A_1 horizons consisting of two or three subhorizons, differing slightly in one or more aspects — color, structure or consistence.

The AC horizon is transitional from the surface layer, with its accumulation of organic matter, to the underlying parent material or C horizon. Its characteristics are commonly gradational between the horizons above and below. In a few profiles the AC horizon consists of interdigitating tongues from the A and C horizons, or it may be absent from some profiles which show an abrupt or clear boundary between the A and C horizons.

The intermediate or transitional horizon in profiles of dark clays has sometimes been identified as a B horizon and sometimes as an A_3 horizon. The available profile descriptions indicate that it would not qualify as a B horizon according to the definitions given in the *Soil survey manual* (244). The horizon in question is not a layer of accumulation of silicate clay minerals, organic matter or sesquioxides; neither is it a layer of prismatic or blocky structure combined with a stronger color or consistence than the A and C horizons. Nor does the identification of the intermediate layer as an A_3 horizon seem desirable. As defined in the *Soil survey manual*, the A_3 horizon is transitional from the A to the B horizon but more like the former than the latter. Consequently, the AC horizon notation seems more appropriate for the intermediate layers in dark clays and it will be used here.

The C horizon may consist of any one of a variety of disintegrated and partially weathered rock materials. The C horizon may be saprolite, i.e., disintegrated and partially weathered rock in place, or it may consist of weathered rock materials transported by water, wind or gravity. As indicated in the earlier section on parent materials, the dark clays have been formed both from unconsolidated deposits and from saprolite weathered in place from hard rock.

In the deeper profile a number of dark clays have C_{ca} horizons consisting of calcium carbonate accumulated in finely divided or concretionary forms. It should be noted that carbonates are present in one or both forms in all horizons of most dark clays. However, the subscript " ca " is intended for horizons with marked accumulations. The dark clays derived from hard rocks are more likely to have C_{ca} horizons than are those from unconsolidated sediments since in the latter cracking and churning with consequent mixing of materials throughout the profile extend to great depths. This mixing of materials tends to preclude the accumulation of appreciable quantities of carbonates in any one layer. In the dark clays derived from hard rocks, saprolite commonly forms the C horizon and, having a low clay content, it does not crack and churn with the soil material above it. Carbonates moving downward in solution can therefore be precipitated and gradually accumulate in the saprolite.

Some dark clays have D horizons below or replacing part of the C horizon. Such soils have been formed from fine-textured sediments, ranging from 50 centimeters to 2 meters in thickness, over unrelated materials. Examples of sediments in which soils with D horizons might form are river alluvium and lacustrine clays.

A few dark clays have incipient A_2 and B horizons, indicating that the soil is an intergrade to some other group in which those horizons normally appear. Such soils comprise a small minority of the group of dark clays, but their existence should be noted so that they may be identified when they are encountered.

Character of major horizons

The principal features of the characteristic horizons of dark clay profiles are summarized in the following paragraphs. Most attention is given to the A_1 horizon because of its importance in the genesis and behavior of these soils. Given an A_1-AC-C horizon sequence, the uppermost horizon is the principal one owing to soil-forming processes and is often the major part of the entire profile as well. By way of contrast, the A_1 horizon is only one among others in the profiles of Podzolic soils. Such soils have A_2, B_1, B_2 and B_3 horizons in addition to A_1 and C horizons. Examples of horizon sequences are given in the detailed profile descriptions at the end of this chapter.

The A_1 horizon

In these soils the A_1 horizons are typically dark, which is the reason for calling the group *dark* clays. By far the most common colors of moist A_1 horizons are very dark gray and very dark grayish-brown. Colors are most frequently of 2.5Y and 10YR hues[2] though they range from 5Y to 2.5YR for the group as a whole. Values and chromas are characteristically low, regardless of hue.

Colors of the A_1 horizons of 39 profiles were tabulated to determine dominant values and chromas, the profiles being chosen to represent the dark clays occurring in five continents and in several island groups. Among the group of 39 profiles, 27 have A_1 horizons with values of 2 or 3, the latter being twice as common as the former. The remaining five A_1 horizons have values of 4. These values are all for moist conditions.

[2] The color designations are taken from the *Munsell soil color charts*, the use of which is described in the *Soil survey manual* (244).

When the soils are dry, the values are generally 1 unit higher and only in a few cases as much as 2 units higher.

Chromas are also low, all but one profile having A_1 horizons with chromas of 1 or 2. A single A_1 horizon has a chroma of 4. The low chromas reinforce the impression of dark colors given by the comparatively low values common to these soils.

In summary, the A_1 horizons of the dark clays have generally dark and rather drab colors. The full range in color is not wide so that distinctions from one soil to another may be small despite important differences in character of soil-parent materials, drainage conditions, thickness of profile, reaction and the like.

There is a tendency to restrict the term dark clay soils to those with hues ranging from 10YR to 5Y which appear " black "; hence the many names implying the name " black " in the nomenclature. It should be stressed, however, that characteristic dark clays may have hues as red as 2.5YR although, on the basis of their color, they previously have often been excluded from the group.

Some general relationships between the color of the A_1 horizon and other characteristics or qualities of dark clays may be noted. The color of the A_1 horizon is somewhat related to the depth of the profile and to drainage conditions. By and large, the darkest A_1 horizons are found in the soils that either have deep profiles or are poorly drained. Low values, i.e. dark colors, prevail among the deeper soils in the group, most of which are formed from unconsolidated sediments such as alluvium or colluvium. This relationship is not found true in all cases, however, as is indicated by Regurs from alluvium in India with values of 4 in the A_1 horizon. Conversely, some dark clays without particularly deep profiles have black A_1 horizons.

Dark colors are also characteristic of the poorly drained soils although again there are some exceptions. The chroma of the A_1 horizon is also commonly lower in the wetter dark clays, which tend to have chromas of 1 or are neutral in color. The association of low chromas with wetness is a general relationship which exists in most instances, but not all.

The hues of A_1 horizons can be a helpful guide if used with caution. Yellowish hues are frequently, but not invariably, associated with wetness. The more poorly drained dark clays commonly have A_1 horizons of 5Y and 2.5Y hues, especially in that part of the horizon not disturbed by tillage. Accurate identification of hue is difficult when values and chromas are low.

In addition to having low chromas, the A_1 horizons of poorly drained dark clays are often mottled in the deeper part. Mottling serves as evidence of poor drainage, especially when it occurs in conjunction with low chromas of 2.5Y or 5Y hue or with neutral colors.

The A_1 horizons of dark clays are usually thick. For the group of profiles given in this chapter the average thickness is 60 centimeters and about two thirds of the profiles have A horizons between 30 to 90 centimeters in thickness. The maximum thickness is slightly less than 110 centimeters in a profile of Houston Black clay in Texas, and the minimum thickness about 20 centimeters in a Margalite or Regur soil of Indonesia.

The thickness of the A_1 horizon at any given spot depends on the churning of the soil. In areas with gilgai microrelief, thickness of the A_1 horizon may differ markedly over short distances. On top of a hillock or low ridge, the A_1 horizon may be less than 30 centimeters thick, while in an adjacent small basin or depression the corresponding horizon may be as much as 1 meter thick.

The majority of the dark clays have A_1 horizons high in the clay fraction, which is a reason for calling them clays. A few of the soils in the group are marginal in texture to the clay class, being clay loams, sandy clays, silty clays or silty clay loams.

The A_1 horizons commonly have a granular or blocky structure though a few are massive. Generally only the upper part of the horizon is granular; the lower part being more often blocky or massive. The A_{11} horizons in 12 of the 39 profiles, for which color data were tabulated, have granular structure, and 14 have a blocky structure. The remainder are massive or show a mixed granular and blocky structure. The deeper parts of the A_1 horizon (A_{12} and A_{13}) are blocky in nearly all instances. Grades of structure, i.e., the degree to which the structure is expressed, range from very weak to strong. Sizes of the individual structural units also have a considerable range, extending from fine granular (1 to 2 millimeters in diameter) to coarse blocky (20 to 50 millimeters in diameter).

With regard to the consistence of the soils for which descriptions are available, they are either plastic and sticky or very plastic and very sticky, according to the classes of consistence given in the *Soil survey manual* (244). When dry, the A_1 horizons are hard to extremely hard; when moist, many of them are firm, a few very firm or extremely firm. Considering their place among all the soils of the world, the dark clays tend to be concentrated at one end of the range in consistence as they are in texture.

The AC horizon

A majority of the profiles of dark clays have a transitional horizon between the two main horizons in the profile, the A and the C; reasons for calling this an AC horizon rather than an A_3 or B horizon have been given above.

The colors of the AC horizons show a wider range and a greater scatter than do those of A_1 horizons; both the values and the chromas are low on the whole, but not as low as for the A_1 horizons. Among the 39 profiles for which data were tabulated, 21 had AC horizons and the remainder did not. For these 21 profiles, values range from 2 to 6, two of them being above 4; chromas range from 1 to 6 with two above 2. Chromas of 1 are twice as numerous as chromas of 2. The hues range from 5Y to 5YR. The colors of the AC horizons, as compared with those of the A_1 horizons of the same profiles, are slightly lighter and more intense.

Some AC horizons have mottled color patterns due to interdigitating tongues and masses from the adjoining A_1 and C horizons, or to gleying because of poor drainage. The original character of the parent material remains more evident in the AC horizons than in the A_1 horizons and is also expressed to some degree in the color pattern.

The average thickness of the AC horizons is approximately half that of the A_1 horizons, the average thickness being 30 centimeters for the 21 profiles described hereafter. The range in thickness extends from 12 centimeters to 60 centimeters but for two thirds of the profiles it is between 20 and 40 centimeters. Variations in the thickness of horizons are to be expected owing to the churning of the soil.

The texture of the AC horizon is usually identical with that of the A_1 horizon of the same profile.

Structure of the AC horizon is generally of weaker grade than it is in the A_1 horizon and may be entirely lacking since a considerable number of AC horizons are massive. Slightly more than half the AC horizons in the group of 21 profiles have blocky structure of weak or moderate grade. The range in size of the structural units is comparable to that of the A_1 horizons, extending from medium granular (2 to 5 millimeters) to coarse blocky (20 to 50 millimeters).

The consistence of the AC horizon is also usually similar to that of the A_1 horizon. Friability is slightly lower on the whole because of the lower levels of organic matter; plasticity and stickiness may be slightly greater but the difference is small.

The C horizon

The color of the C horizon depends upon the nature of the original material and its history of weathering and extends over the full range of hues, values and chromas. Mottled color patterns may be a reflection of wetness or poor drainage, variations in parent materials, or a mixing of materials from differing horizons.

The range in thickness of the C horizon need not be discussed since the lower boundary is determined arbitrarily in most cases. As a matter of convenience it is normally set at some depth within the disintegrated and partially decomposed rock materials and is rarely a reflection of soil formation.

Like the colors, the textures of the C horizons also range widely from sandy loam to loam, sandy clay loam, sandy clay, silty clay and clay. The sandier C horizons are saprolites derived from crystalline rocks such as basalt or gneiss, while the finer textured C horizons are derived from limestone or consist of unconsolidated deposits. By and large, sedimentary deposits are finer textured than those formed by weathering in place.

Structure is usually lacking in the C horizon, though some C horizons may have a blocky structure, which is however weakly expressed. A few have a moderate or strong platy structure inherited from the original rock or sediment.

Consistence shows a wider range in C horizons than in the other parts of the dark clay profile. The sandier C horizons are very friable when moist and although they do not become plastic or sticky when wet they may be hard when dry. At the other extreme, the C horizons of clay texture, i.e. those consisting of lacustrine deposits, river alluvia, or residuum from limestone, are like the A_1 and AC horizons in consistence.

The character of C horizons in profiles of dark clays strongly reflects the original nature of the material from which they are developed.

FEATURES RELATED TO SHRINKING AND SWELLING

The morphology of the dark clays is strongly affected by the expansion and contraction of the soil mass with changes in moisture content. Features closely related to the shrinking and swelling of the soil are: the thickness of horizons, especially the A_1 horizon; the topography of horizon boundaries; the distribution of concretions, pebbles, etc., in the profile; the shapes and nature of structural peds; the formation of a microrelief.

Thickness of horizons

The range of thickness of the A_1 horizon has already been dealt with in a previous section of this chapter and will not be discussed further here.

Horizon boundaries

The boundary between the A_1 and AC horizons is wavy in many of the dark clay soils. The amplitude between the crests of waves and the bottoms of intervening troughs is commonly below 10 centimeters but may be as much as 60 centimeters. The distances from one crest to another may be from 1 to 3 meters or more. Wavy boundaries, i.e., those with undulating topography, are widespread among dark clays with gilgai microrelief. Boundaries with uneven topography may also be due to the downward extension of tongues or cores from the A_1 horizon into the AC and C horizons. They are commonly from 4 to 8 centimeters in diameter horizontally, though some are 30 centimeters or more wide. These tongues or cores may extend 30 to 60 centimeters below the general lower boundary of the A_1 horizon. They commonly occur at horizontal intervals of several meters but may also be 30 to 60 centimeters apart. Where the tongues occur fairly near one another, they are commonly smaller than those spaced at wide intervals.

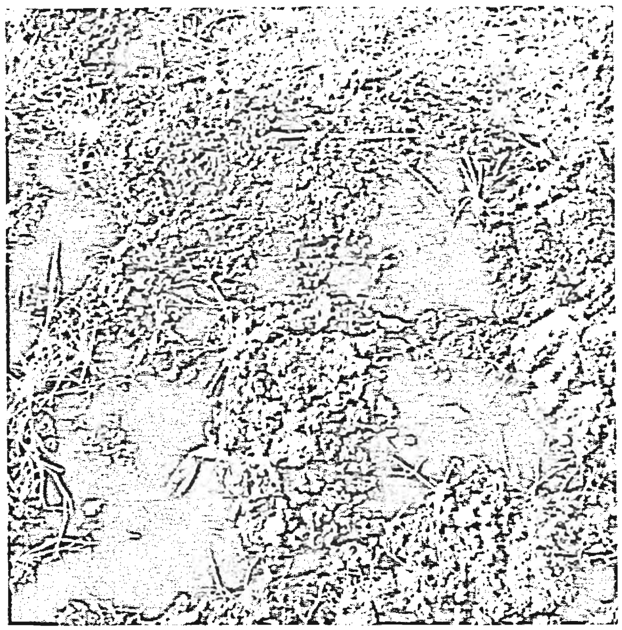
Distribution of concretions, pebbles and stones

The distribution of concretions and pebbles in profiles of dark clays may be uniform throughout the profile, especially in the A_1 and AC horizons, or localized in patches, probably as a result of the churning of the soil mass.

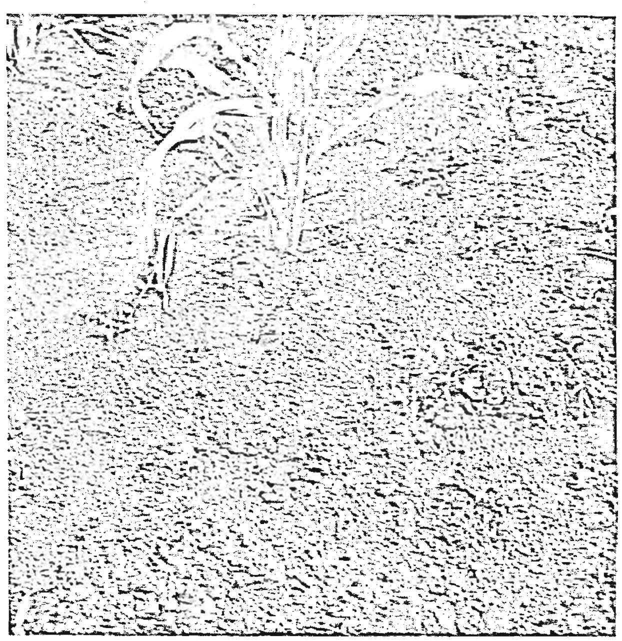
The location of carbonate concretions in the profiles of Regur soils in India illustrates the different distribution patterns. In many of the Regurs, concretions are concentrated in a layer, known as Kankar or Kunkar, occurring especially at the contact between clay and saprolite. In other Regur soils, the carbonate concretions are concentrated in strips or pockets near the surface and may be completely lacking in the deeper profile. Another distribution pattern is the concentration of concretions in roughly vertical bands extending from the soil surface to a depth of 1 meter or more. As exposed in the side of a pit, these bands may be as little as 15 centimeters or as much as 1 meter or more in width.

Distribution patterns of iron oxide concretions and pebbles in dark clay soils resemble those of carbonate concretions, the latter being, however, more widespread.

Where dark clays develop over stony material — for instance, igneous rocks — boulders and rock fragments are often brought to the surface by the churning of the soil mass. The land may thus become very stony although the solum itself does not necessarily contain a high percentage of stones. The stoniness of the surface layers often constitutes a serious handicap to tillage.



FIGURES 32 and 33. Clods of Grumusols progressively developing a granular structure in the surface layer under the influence of successive wetting and drying, Central Java, Indonesia. (Courtesy Soil Research Institute, Bogor, Indonesia)



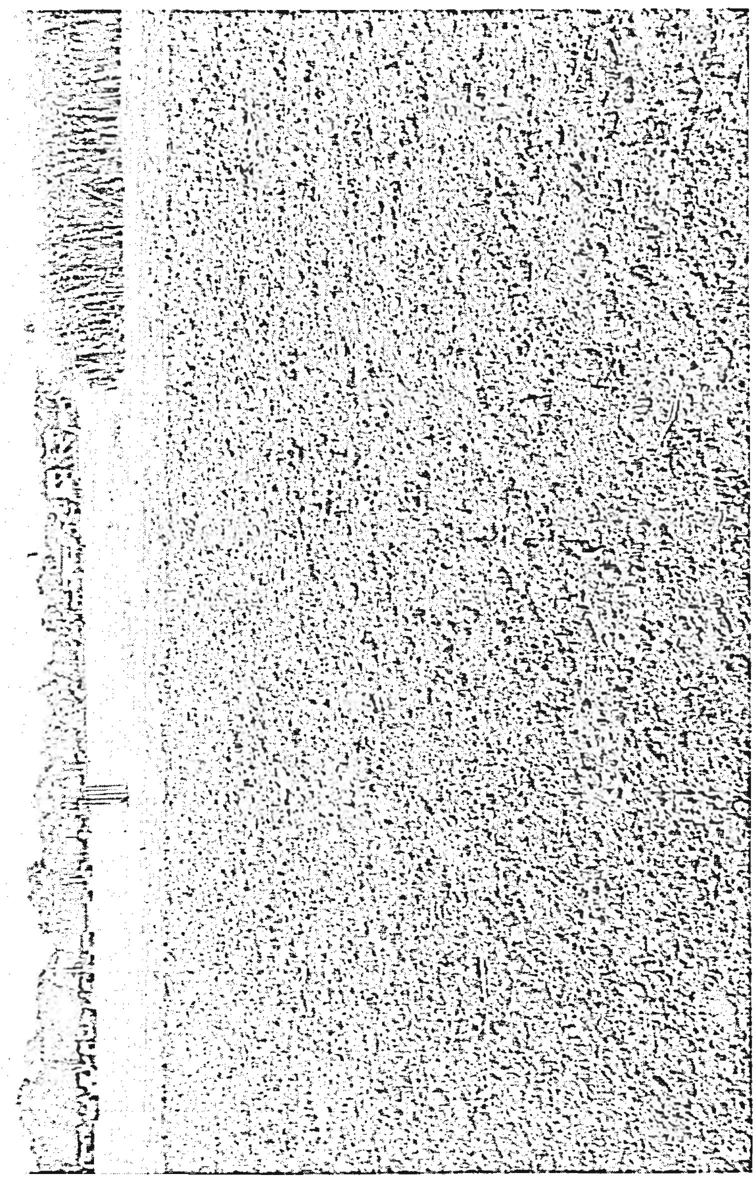


FIGURE 34. Plowed field showing crumbling of the surface layer of a Regur soil developed from trap rock on the farm of the Agricultural Research Institute, Nagpur, India. Beyond the plowed area there is pasture and a field of sunn hemp (*Crotalaria*). (Courtesy Roy W. Simonson, U.S. Soil Conservation Service, Hyattsville, Maryland, U.S.A)

Structure

The structure of the lower A_1 and the AC horizons, and in places the upper C horizon, exhibits certain characteristics due to swelling, shrinking and mass movement. In many dark clays, ped surfaces show slickensides. Commonly applied to rocks, this term was originally used in geology; applied to soils it refers to surfaces marked by shallow grooves parallel to the direction of mass movement or the sliding of one face over another (246). Slickensides appear as slightly shiny surfaces, inclined to the horizontal plane at angles ranging from 20° to 60°, but most commonly about 45°. The block-like structure of the lower A_1 and the AC horizons in many dark clay soils is due to intersecting slickensides.

Peds in the lower A_1 and AC horizons commonly have shiny surfaces when moist, even though slickensides are not always evident. These are referred to as "pressure faces," and are formed as the soil mass swells when it becomes wet without expanding enough to cause the movement of one mass over another. At first glance, these pressure faces have much the same appearance as ped faces covered by clay films, but they do not show ripple marks or other evidence of translocation of silicate clay minerals. Furthermore, adjacent ped faces which come together as the soil mass expands are mirror images. Pressure faces are most common on block-like peds but they also occur on the vertical faces of prisms.

Peds formed by intersecting slickensides in the deeper horizons of dark clays assume a characteristic shape which deviates from the typical block-like form. These peds have been compared in shape to lentils and described as "lenticular" in Black Earths in Queensland, Australia and in the Grumusols of Arizona. The similarity of shapes observed in the soils of three continents indicates the widespread occurrence of a characteristic structure in the deeper horizons of dark clays, reflecting active expansion and contraction and movement within the soil mass.

Formation of a microrelief

The cracking and swelling of dark clays may give rise to a characteristic microrelief, variously called gilgai, crabhole, or hog wallow. As described above, the cracks formed during the dry season fill up with loose soil material falling in from the surface. On swelling the soil mass cannot reoccupy its original volume so that part of the soil is forced upward and gives rise to the formation of hummocks and hollows at the surface. The depressions or lower portions of the soil surface are called "shelves" while the raised parts are termed "puffs." Besides this small-scale undulation, sinkholes may appear where the surface soil has broken and fallen in.

FIGURE 35. Dry weather cracks in a wheat strip in the Blacklands of Texas, U.S.A. The cracks, having an average depth of 75 cm and a width of 12 cm, help to prevent runoff of the first rains and thus promote moisture conservation.
(Courtesy J. W. O'Dannion Farm, Garland, Texas, U.S.A.)

It was recently suggested (66) that gilgai relief only develops in materials deposited in very wet conditions such as lake, sea or swamp bottoms. The first irreversible desiccation of the mud, known as "ripening," is considered as an essential stage in the formation of gilgai relief. In this stage, huge cracks are formed at relatively large distances apart. Where the structure of the clay is more favorable, the blocks between the cracks are small, the width of the cracks is also relatively small and no gilgai topography is formed. It is assumed that where gilgai is found outside former lake, sea or swamp bottoms, its presence is caused by colluvial transportation during which the original clay soil reverts to a mud.

There is a considerable difference in the magnitude and form of the gilgai undulations. In Australia the following types are distinguished (101): normal or round gilgai in which the puffs and shelves are nearly circular; wavy gilgai found on gentle slopes in which puffs and shelves are continuous and form regular lines more or less at right angles to the contour; lattice gilgai which is comparable to the wavy type but in which the puffs and/or shelves are discontinuous; tank gilgai in which puffs and shelves form a large rectangular pattern; stony gilgai which takes the form of one of the above-mentioned types but in which the puffs are covered by stones of varying size; melon-hole gilgai which consists of mounds and depressions with sinkholes of varying shapes and sizes.

Physical properties and chemical composition

Not enough comparable data are available for a systematic study of the physical properties and chemical composition of dark clays. The information given below has been collected from very different sources and the analyses carried out in the various laboratories were generally not done by the same methods. Furthermore, the data reported from any one country cover only a limited number of profiles and are not necessarily representative of all the dark clays. However, these data show clearly that, despite the great diversity of environmental conditions and the wide range of distribution of these soils, they have a set of characteristics in common.

The following properties are commented upon below: texture, pH, bulk density, organic matter, basic exchange capacity, nutrient content, salts, mineralogy.

The physical properties, such as color, structure and consistence, have been dealt with in the section on morphology. Too little data were available to comment on porosity, permeability, specific surface and critical moisture values.

FIGURE 36. Marked gilgai microrelief on Regur soil from limestone west of Raipur, India. This land lies immediately across the road from the rice field shown in Figure 24 and supports grass vegetation with scattered acacia trees. (Courtesy Roy W. Simonson, U.S. Soil Conservation Service, Hyattsville, Maryland, U.S.A.)

Texture

The texture of dark clay soils is generally clay but occasionally silty clay or loam, the clay content of most of the profiles studied ranging between 40 and 60 percent. The clay contents may however, reach 80 percent or be as low as 30 percent. In most of the profiles, the clay content remains uniformly high throughout the profile to a depth of at least 1 meter. In some cases, there is a gradual increase with depth, while in others a decrease with depth has been reported. These differences may be due to variations in the parent material rather than to soil formation and no strict relation has been established between environment and clay content. In Ghana, however, increasing clay content is associated with increasing rainfall; in Central Africa, the clay content was reported higher in lowland soils than in upland soils in the same area.

The silt proportion in dark clays amounts to 10 to 40 percent of the total soil. The sand fraction is generally low, and coarse sand is virtually absent in most of these soils although in Morocco " tirs " have been reported containing only 20 percent of clay and a much higher amount of sand (12). No detailed descriptions are available to ascertain whether these soils would fit the dark clay concept.

Gravel may occur locally, in the form of calcareous or iron-manganese concretions.

pH

The pH values in the surface layers of dark clays usually range between 6 and 7.5, but where the $CaCO_3$ content is high the pH of the surface layer ranges from 7.2 to 8.5; surface layers can also be more acid and pHs of 5 to 5.8 have been recorded. There is generally an increase of pH values with depth corresponding to an increase of $CaCO_3$ and other salts, and the pH in the lower part of the soil generally ranges between 7.8 and 8.6; where signs of alkalization are observed, a pH of 9 to 9.5 may occur. Occasionally profiles have been described where the pH is neutral at the surface and becomes slightly acid below to a depth of about 2 meters.

The pH levels are related to the composition of the parent material and to climatic and topographic conditions. Other environmental factors being similar, dark clays developed from limestone show a higher pH range than soils on igneous rocks. From Ghana and Sudan, it is reported that the pH decreases with increasing rainfall. It also appears that dark clays are often more acid where they occur in major depressions subject to seasonal flooding and a subsequent stronger leaching.

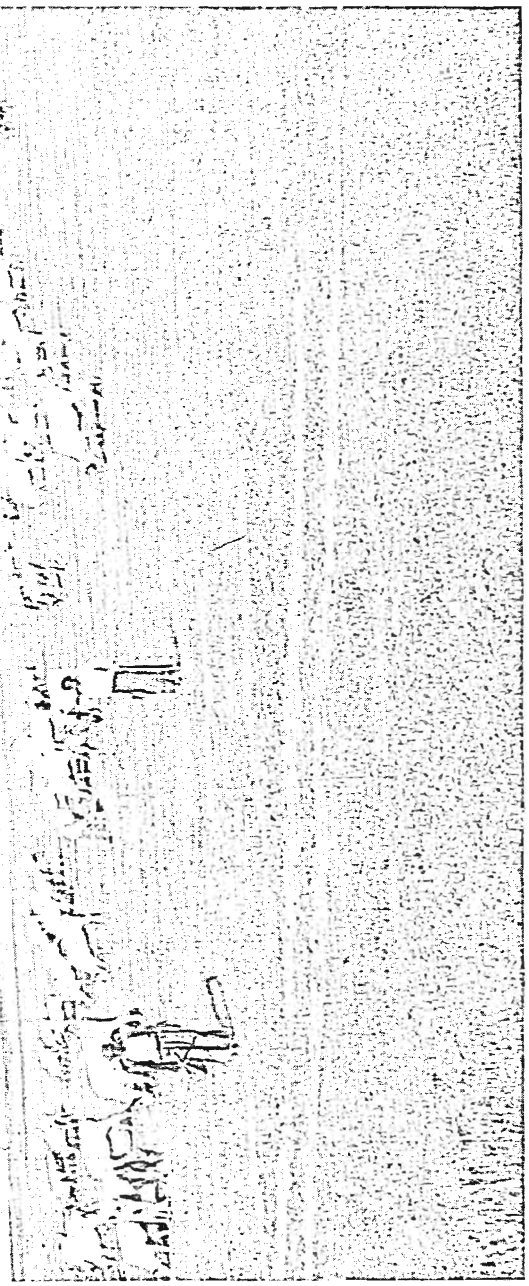


FIGURE 37. A wavy gilgai microrelief on native pasture land in a gently sloping Grumusol area north of Tekirdag, Thrace, Turkey. (Courtesy H. Oakes, *The soils of Turkey* [168])

Bulk density

Dark clays are characterized by a high bulk density.

Undisturbed cores of Houston clays in Arkansas showed a density of the order of 1.81 and values of 2.08 were found in Mississippi profiles by the dry clod method. In Texas, a value of 2.1 was measured in a field cultivated mechanically while on soils tilled by hand a value of 1.59 was obtained. Grumusols from Arizona have bulk densities ranging from 1.74 to 1.98, the values below 1.8 being always in the weakly granular horizon immediately below the surface.

Organic matter

The organic-matter content in dark clays is relatively low, but a rather large variation is noted on comparing figures from different countries.

In India, the organic-matter content of the surface soil ranges from 0.5 to 1.5 percent with a mean value of 1 percent remaining practically unaltered to a depth of about 1 to 2 meters where there is a slight falling off to 0.8 percent.

In the United States (Alabama, Arkansas, Mississippi) organic-matter content of the A_{1p} horizon ranges from 2.3 to 4.4 percent, these values decreasing with soil depth in all cases. In the subsoil the value is about 1 percent decreasing further 0.7 or 0.4 percent in the C horizon.

In Central Africa, organic-matter contents in the surface horizons reach about 1.5 percent; in Australia about 2 percent; in Ghana between 1 and 3 percent. In the central plains of Sudan, figures as low as 0.5 percent have been recorded while contents up to 1 percent have been reported from the southern plains. Higher percentages have been reported from areas which are regularly flooded, e.g., 5 percent in Australia, 2 percent in Sudan, 5 percent in Ghana, 2 percent in Central Africa.

The C/N ratio normally varies between 10 and 14 but sometimes reaches 16 in seasonally waterlogged soils or in arid areas. The C/N ratio for Australian soils varies from 13.5 to 18.5 at the surface, the range widening somewhat in the subsurface horizon. For dark clays in India, the range is from 8.3 to 21.3 with a mean value of 14.1. The trend of the C/N ratio varies with depth; in Australia and India there seems to be a slight increase while some profiles in Ghana show a slight decrease.

The organic-matter content seems to be strongly related to cropping history or natural vegetation. At the Blackland Experiment Station in Texas, differences were noted between plots in continuous maize, plots in crop rotation and plots under continuous Bermuda grass for twenty years, the plow layers containing 2.05 percent, 2.28 percent and 3.94 percent of organic matter respectively. In Alabama values of 3.4 to 4.4 percent were found under pasture. The difference between the low levels of organic matter (as in India) and the high levels (as in Australia) has been ascribed to the fact that the Indian soils have been cultivated for centuries whereas the Australian samples were mostly taken in uncultivated country under grass cover. In Ghana, where dark clays occur both under grassland and under forest, the organic-matter content under tree vegetation was substantially higher, the difference being related not only to the vegetation but to a more humid environment.

Base exchange capacity [3]

For the surface horizons the base exchange capacity ranges from 24 to 34 milliequivalents/100 grams for dark clays in Arkansas and Mississippi; from 31 to 62 milliequivalents/100 grams in Arizona; from 56 to 66 milliequivalents/100 grams for Alabama profiles; from 60 to 80 milliequivalents/100 grams in Ghana; from 40 to 60 milliequivalents/100 grams in India; from 25 to 35 milliequivalents/100 grams for lowland dark clays in Central Africa and from 25 to 80 milliequivalents/100 grams for upland dark clays in the same areas; from 35 to 45 milliequivalents/100 grams for dark magnesium clays in Hawaii; and from 20 to 25 milliequivalents/100 grams in the Congo. For profiles in Mississippi the base exchange capacity of the different fractions is as follows: for the silt fraction (20 to 50 microns) values range from 4 to 25 milliequivalents/100 grams; for the coarse clay (0.2 to 2 microns) the values are of the order of 27 to 57 milliequivalents/100 grams while the fine clay fractions ($<$ 0.2 micron) have an exchange capacity of the order of 80 to 90 milliequivalents/100 grams.

In the surface layers the base exchange capacity may be influenced by the organic-matter content; however, there is seldom a consistent change in sorptive capacity with depth, which suggests that the major role is played by the mineral soil components. From Arizona (125) it was even reported that in some cases when two horizons have the same clay content the one with more organic matter has the lower exchange capacity, a condition which has also been observed in other soils containing combinations of organic matter and montmorillonite as, for example, in some Brunizems in Iowa and Nebraska.

[3] The base exchange capacity is expressed in milliequivalents per 100 grams of soil.

Nutrient content

Besides their physical properties and their dark color, a most important characteristic of the dark clays lies in the high degree of base saturation, a value of 50 percent or higher being reached in almost all profiles; generally base saturation increases with depth. Ca and Mg prevail in the composition of the sorptive complex. In India, for example, Ca saturates 60 to 80 percent of the absorptive complex and Mg 10 to 30 percent. In Arizona Ca is reported to occupy 60 to 70 percent of the exchange capacity. The Ca/Mg ratio generally ranges between 3/1 and 1/1. This relation reaches values of 5/1 to 7/1 on dolerites in the Logone Valley in Chad. Since, in general, Ca decreases while Mg increases in the lower horizons, the ratio tends to decrease with depth.

In some profiles reported from the United States, the ratio reaches as high as 1000/1, Mg contents being exceedingly low (of the order of 0.04 milliequivalents/100 grams) while Ca contents range between 30 and 50 milliequivalents/100 grams of clay. The Grumusols described in Arizona have an exchangeable calcium content ranging from 16 to 39 milliequivalents/100 grams with a calcium-magnesium ratio of 3 to 4. It appears that magnesium is relatively more abundant in profiles from the cooler and more humid areas.

In some cases the exchangeable Ca exceeds the exchange capacity, owing to the presence of soluble Ca compounds such as $CaCO_3$. Reserve ratios are, however, reported from Australia and Hawaii where Mg may dominate the Ca. An extreme case is reported from New Caledonia where some dark clays are saturated with Mg up to 80 percent of the saturation complex (231). These high contents in Mg are related to hyperbasic parent materials such as peridotite and serpentine.

The following figures are examples of Ca and Mg contents in dark clays: in the Congo 9.17 milliequivalents/100 grams of Ca; in Australia 20 to 60 milliequivalents/100 grams of Ca and 15 to 50 milliequivalents/100 grams of Mg; in Ghana 20 to 30 milliequivalents/100 grams of Ca and 10 to 25 milliequivalents/100 grams of Mg; in India 40 to 60 milliequivalents/100 grams of Ca and 8 to 35 milliequivalents/100 grams of Mg; in South Africa up to 60 milliequivalents/100 grams of Ca and 7 to 10 milliequivalents/100 grams of Mg; in the United States from 33 to 50 milliequivalents/100 grams of Ca and 0.04 to 2.2 milliequivalents/100 grams of Mg; in Hawaii 11.7 to 18 milliequivalents/100 grams of Ca and 12.8 to 20 milliequivalents/100 grams of Mg.

Potassium and sodium are present in the sorptive complex in variable amounts. Potassium is generally present in small quantities; for example, 0.1 to 0.3 milliequivalents/100 grams in profiles from Central Africa; 0.2 to 0.5 milliequivalents/100 grams in the United States; 0.05 to 0.4

milliequivalents/100 grams in Ghana; 0.05 to 0.13 milliequivalents/100 grams in a profile from the Congo. Higher levels of 1 and 0.7 milliequivalents/100 grams have been reported from Sudan and North Cameroon respectively. The saturation of the sorptive complex with K does not generally exceed 2 percent.

Sodium is also present in small amounts, for example, 0.2 milliequivalents/100 grams in dark clays of Central Africa. In certain areas, however, the Na content may reach higher values in the lower horizons as in Ghana for instance (1.5 milliequivalents/100 grams); in the Congo (6 milliequivalents/100 grams); in the Gezira, Sudan (3 to 10 milliequivalents/100 grams). Saturation with Na normally remains below 5 percent but may reach about 10 percent in the lower horizons. High percentages of K and Na often occur in horizons in which Mg dominates the Ca saturation or is about equal to it.

Manganese is present in small amounts: for example, 0.09 to 0.53 milliequivalents/100 grams in India and 0.05 to 0.15 milliequivalents/100 grams in profiles from Ghana. Manganese is relatively high in soils formed on traprock or basalt and low in soils formed from limestone; it often occurs as iron-manganese concretions.

Available phosphorus is generally low; in India it seldom attains 10 ppm; figures from the United States show a phosphorous content ranging from traces to a maximum of 17 ppm, with a mean value around 4 ppm; in upland soils in Central Africa the content of P_2O_5 in available form may reach 0.02 to 0.03 percent, which corresponds approximately to 80 ppm. Hydrochloric acid extracts for Australian soils indicate a total P_2O_5 percentage of 0.02 to 0.5 percent with mean values around 0.2 percent; in India figures of 0.05 to 0.15 percent total P_2O_5 with a mean value of 0.08 percent have been recorded. Where figures are given for the various horizons of a profile, available phosphorus seems to decrease with soil depth.

The nitrogen content is closely related to the organic-matter content. In Sudan, the Niger Valley and Upper Volta, figures of 0.04 to 0.06 percent have been recorded, and from 0.18 to 0.2 percent in Ivory Coast. The available figures for surface horizons of dark clays in Ghana indicate contents of 0.08 to 0.2 percent, in the Congo 0.15 to 0.3 percent, in South Africa 0.1 to 0.15 percent. In Australian soils, the nitrogen content in the surface layers varies from 0.05 to 0.2 percent. Most of the values range between 0.08 and 0.18 percent. The values for subsurface layers are somewhat lower, ranging from 0.04 to 0.18 percent. In India, the dark clays contain nitrogen between narrow limits such as 0.028 and 0.054 percent with a mean value of about 0.04 percent with only a slight decrease in content with depth to about 1.2 meters, the mean value being about 0.03 percent.

Sulfur content has been determined for a few profiles in the United States, and was found to reach 8 to 40 ppm.

SALTS

Although the presence of $CaCO_3$ is not an absolute characteristic of dark clays, it occurs in many of these soils throughout the world. The content varies widely; for example, in India it ranges from 0.5 to 8 percent with extremes of 0.1 to 20 percent, in the Black Earths of Australia from 5 to 15 percent, in the Margallitic soils of Java from 5 to 60 percent. The $CaCO_3$ may be present either as concretions or in a finely distributed form.

Substantial amounts of $CaSO_4$ and $MgSO_4$ often occur in dark clay, as in some areas of Sudan; arid conditions during a considerable part of the year favor their accumulation. Calcium sulfate may occur in a fine divided state, in concentrated layers or as gypsum crystals. High contents of $MgCO_3$ in the form of concretions have been reported in the " hypermagnesian dark clays " of New Caledonia (231).

The content of soluble salts of dark clays has been commented upon in the section on Moisture Use and Conservation.

MINERALOGY

In most areas where dark clays have been studied mineralogically, montmorillonite and " mixed layer " clays have been reported to form an important part of the clay fraction. This concurs with the high cation exchange capacity, the swelling properties, the plasticity and the stickiness of these soils.

In Ghana, the profiles analyzed show a definite dominance of montmorillonite, somewhat diluted with a proportion of other clay minerals supposed to be illite. In the Congo the " black compact soils " of the Ruzizi Valley contain 65 percent montmorillonite mixed with poorly crystallized kaolinite; in similar soils of the Lufira Valley, illite was the dominant clay mineral with, as a secondary component, " mixed layers " having swelling properties.

In India the clay fraction has been subdivided into coarse clay (1.4 to 0.1 microns), fine clay (0.1 to 0.06 microns) and superfine clay (<0.06 microns). The finest fraction contained pure montmorillonite; the fine clay was found to contain 70 percent montmorillonite, 10 percent kaolinite, 15 percent mica and 5 percent quartz; while the coarse clay contains only 25 to 35 percent montmorillonite, the other components being mainly quartz and kaolinite.

In profiles from the United States, the fine clay fraction (<0.2 microns) is predominantly composed of montmorillonite with kaolinite, illite, vermiculite and halloysite as secondary components. In some profiles the silt fraction is characterized by illite mixed with small quantities of quartz and kaolinite while in others this fraction is dominated by kaolinite. The coarse clay fraction (2 to 0.2 microns) may be composed mainly of kaolinite — montmorillonite, illite, vermiculite and halloysite occurring in lesser amounts — or of montmorillonite with some kaolinite and illite.

From Morocco and Niger, dark clays were reported to be composed mainly of kaolinite, with some illite and silica gels. The physical properties are ascribed to the silica gels and to a complex of magnesium and organic matter (12).

Little data are available on the composition of the heavy minerals in the fine sand fraction. In general, dark clays seem to develop readily from rocks rich in amphiboles and pyroxenes having much hornblende and plagioclase.

Variations related to microrelief

It is interesting to note that the properties listed above not only vary with parent material, degree of soil development, climatic conditions and cropping history but that they also show considerable variation within very short distances where a gilgai microrelief has developed.

A " microcatena " was studied in the Lufira Valley, Congo (253) where the difference in elevation between puffs and shelves is about 30 to 40 centimeters. On the puffs, the organic carbon content of the surface horizon is 0.5 percent while in the shelves it is 2 percent. The clay content in the higher-lying profile shows an average of 47 percent while in the lower parts of the gilgai topography it is about 60 percent. These data can be explained by a transfer of fine components to the depression and by a less rapid decomposition of organic matter under poor drainage conditions. As a consequence of water stagnation it also appears that the shelves undergo a stronger leaching. The pH on the puffs and in the shelves ranges from 6.5 to 7.6 and from 5.6 to 7 respectively. A gypsum layer occurs at a depth of 1.60 meters in the shelves while it reaches the surface in profiles located on the puffs.

Genesis

The formation and specific features of the dark clays are closely related to the contraction and expansion of the soil mass and the churning of the soil materials. These phenomena are caused by a heavy texture, a dominance of swelling clays in the fine fraction and by marked changes in moisture content. Factors which favor the formation of clays of the expanding type and conditions which permit successive wetting and drying govern the genesis of dark clays.

Swelling clays may be present in the original parent material of the soil or may be formed by synthesis during the weathering process of the rock. The former alternative seems limited to lacustrine sediments deposited in alkaline and strongly magnesian media and it is likely that large stretches of dark clays in Africa which are situated in basins have inherited montmorillonitic clays from sediments deposited under salty lacustrine conditions. The stability of these clays depends, however, on the absence of substantial leaching or on a continuous supply of alkaline earths from outside sources. If acid conditions follow sedimentation, a new equilibrium tends to be established by the transformation of the montmorillonite into illites and kaolinites.

As for the clay minerals formed by the weathering of rocks in place, present knowledge indicates that the synthesis of expanding clay minerals is favored by an adequate level of alkaline earths in the weathering zone. The magnesium plays a role in the synthesis of montmorillonite while the calcium maintains a favorable level of pH for its formation. The supply of alkaline earths is provided by the weathering of basic rocks, for example, those relatively high in plagioclase, ferromagnesian minerals or calcium and magnesium carbonates, or by secondary enrichment from floodwaters or seepage in flats and depressions. Clay synthesis can take place only when these elements, once released, remain in the weathering zone for a sufficient length of time. The retention of these mobile elements is favored by climatic conditions which, though permitting intermittent weathering, do not give rise to rapid leaching. Thus, dark clays generally form in climates showing an alternation of wet and dry conditions. The downward movement of soluble compounds, whether originating from the breakdown of silicates and carbonates or imported from outside, is also impeded by the slow permeability and poor internal drainage of the heavy-textured materials.

The terms "lithomorphic" and "topomorphic" have been proposed (56) to emphasize the dominant role played by the parent rock or by the topography in the formation of dark clays. This distinction may be satisfactory in theory but in practice it seems difficult to determine the part played by either factor. Indeed, the roles played by parent material in undulating and level topography situations overlap substantially.

From what precedes it appears that dark clays form in media adequately supplied with magnesium and calcium where the climate is sufficiently warm and humid to permit weathering, but at times sufficiently dry to cause wide cracking. These conditions are generally met where soils develop from basic materials under climates with high average temperatures, medium to low rainfall and a marked dry season; for instance, in tropical subtropical or warm temperate climates with a marked alternation of wet and dry periods. However, dark clays may also develop under high rainfall where leaching is reduced by the impermeability of the parent material and by high evaporation. They may also develop in arid areas where floodwaters replace the high rainfall of a wet season.

With regard to parent material, dark clays may also form from acid parent rocks where the lack of bases is compensated by alkaline earths imported by seepage from adjacent uplands. Dark clays may thus be formed from a great variety of parent materials and under a wide range of climatic conditions. They constitute a striking example of how soil-forming factors may compensate for one another and how different combinations of environmental conditions may lead to the same end product.

The effects of swelling and shrinking and of self-mulching have already been dealt with. It need only be repeated that these phenomena play an important and unique role in the formation of dark clays. They are largely responsible for the deep and irregular penetration of organic matter into the soil and thus for the thickness and often wavy lower boundary of the A_1 horizon; the shapes and nature of structural peds; the distribution and location of concretions and pebbles in the soil mass; the formation locally of a special microrelief; the maintenance of a certain fertility level and a high base saturation; the resistence to salinization in the upper horizons; the lack of distinct horizons apart from the A_1 horizon and the absence of substantial clay migration.

The color of the dark clays has been the subject of many elaborate investigations. It soon appeared that the dark color was not due to the total amount of organic matter present, since the humus content of dark clays is relatively low. Several studies suggested that metallic oxides, or other mineral constituents, were responsible for the specific coloration but it has been shown more recently that the dark color is due to the formation of a clay/organic-matter complex (208); indeed, the organic matter may be adsorbed on the clay surfaces and it may even be chemically bound to the clay. As one would expect, montmorillonitic clays are the most active in this respect while kaolinite is nearly inert. X-ray diffraction examinations of Grumusols in Arizona (125) showed that the montmorillonite is well crystallized and gives sharp X-ray reflections in all horizons except in most of the 0- to 2.5-centimeter surface horizons. In these, the reflections are low and broadened, indicating that the clay is finer sized or somewhat disordered. With glycol solution, spacings are commonyl found to be 19 to 21.1 Å rather than 17.9 to 18.1 Å typical for this mineral. The wider spacings may be an indication that the clay is complexed with organic matter.

It has been suggested (145) that the formation of a clay/organic-matter complex would be favored by anaerobic conditions prevailing during the wet season and that a certain hydromorphism is an essential factor in the formation of dark clays. The organic matter thus fixed on the clay becomes very resistant to decomposition and its stability is enhanced by the presence of calcium. Additional factors which may induce a dark color are the presence of iron sulfides and manganese oxides. As mentioned above, the thickness of the dark-colored layer is due to a mechanical homogenization rather than to an accumulation in depth or a downward percolation of organic matter. Indeed, in these heavy-textured soils, the humification process is very much limited to the surface layers of the soil and the very slow internal drainage precludes the migration of coloring substances. The factors which govern the variation of color within the dark clays have not yet been satisfactorily elucidated but it appears that those soils with poor drainage are, in general, darker than those which allow an adequate removal of excess water or which develop in drier climatic conditions. The recognition of dark clays with hues redder than 10YR (up to 2.5YR) is fairly recent and no systematic studies are available on the factors which cause these differences in color. It may be concluded that drainage, duration and severity of the dry season, composition of parent material and age of the soil all play a role, but no precise relationships have so far been established.

Nomenclature

Many different names have been applied to the dark clays in various parts of the world. Most names refer to their dark color or to their heavy texture; a few reflect their capacity for shrinking and swelling or the microrelief associated with these phenomena. Some names have been taken from the vernacular of the country of their origin while others have been coined. A number of names given to dark clays are listed in Table 5.

The range of properties among soils known under certain names varies widely. Thus, the name Grumusol, as used in the United States, apparently includes the group of Black Earths and many of the Gray and Brown Soils of Heavy Texture in Australia, and most, if not all, of the Regur soils of India and the Black Cotton soils in Africa. On the other hand, some of the soils called Tirs in North Africa would probably fall outside the range of the Grumusols while brown and reddish-brown Grumusols would not be included in the Black Cotton soils, on the basis of color. These few examples illustrate that some of the names are meant to cover a large range of dark soils in the tropics or subtropics, whereas others have more restricted meanings.

Among the forty names in Table 5, six are widely used at the present time: Black Cotton soils, Black Earths, Gray and Brown Soils of Heavy Texture, Grumusols, Regurs and (Sub)tropical Black clays. The name Vertisol, which has recently been coined (246), is gaining in popularity.

Some of the names given to dark clays in the past are now disappearing from scientific literature, for example, Adobes, Black Turf soils, Margalite soils, Rendzinas and Tropical Chernozems. The term "Black Turf soils" has given way to "Subtropical Black clays" in South Africa (151). Adopted in Indonesia a few years ago, the term Margalite soils (51) has recently been dropped in favor of Regurs (63) to show their relationship to the extensive dark clays of India; the term "margalitic" has, however, appeared again in soil literature in the U.S.S.R. (142). Dark clays in Africa and India have been called Tropical Chernozems in the past, but the name has fallen into disuse in face of the cumulative evidence of many important distinctions between these soils of low latitudes and the typical Chernozems of higher latitudes. The name Rendzina was formerly used for dark clays in parts of North America but has been superseded by the term "Grumusol."

Several of the names listed in Table 5 are those used locally by cultivators. Examples are Badobes, Barros Pretos, Firki, Kahamba, Karail, Mbuga, Morogan, Mourcis, Regur, Smolnitza, Sols de Paluds, Tirs and Vlei. Most of these names, with the exception of Regur and Smolnitza, have had only a limited use in scientific literature.

The large number of names used for dark clays complicates the transfer of knowledge from one part of the world to another; their profusion tends to obscure similarities among the soils while a difference in name often suggests that some difference also exists in the nature of the soils.

Attempts have been made to evaluate the degree of similarity among dark clays with different names in various parts of the world. Fifty years ago Hilgard (109) concluded, largely on the basis of analytical data, that the Adobes of California and the Regurs of India were very similar and might be identical. Hosking (113) analyzed samples of Black Earths from Australia and of Regurs from India and concluded that the dark clays of the two continents were members of the same broad group. Oakes and Thorp (169) summarized information from a number of sources on dark clays of warm regions variously known as Regurs, Black Cotton soils, Rendzinas and Tirs, together with personal observations on the dark clays formerly known as Rendzinas in the United States. They concluded that many, though perhaps not all, the soils covered by these names should be placed in one broad group for which the name Grumusol was proposed. Simonson (206, 207) offered descriptions of Regurs from India, together with a partial summary of published analytical data, as evidence of the identity of dark clays in that country with those of the southern United

States. Brammer (32) reported both field and laboratory data on dark clays of the Accra plain in Ghana and of the Springbok Flats in Transvaal and concluded that those soils were sufficiently similar to permit the direct transfer of experience in agricultural development from the one place to the other.

Attempts to compare dark clays in different countries have tended in recent years to move away from exclusive reliance on laboratory data to the use of a combination of field observations and laboratory analysis. Even so, relatively few complete profile descriptions of dark clays, expressed according to published standards, are available. This lack of morphological data restricts the effective comparison of soils of separate regions.

TABLE 5. – NAMES FOR DARK CLAY SOILS AND REGIONS OF USE

GROUP I. *Names including the word "black"*	
Barros Pretos	Portugal
Black clays	South Africa, Australia
Black Cotton soils	Africa, India
Black cracking clays	Uganda
Black Earths	Australia, Africa
Black Turf soils	South Africa
Subtropical Black clays	Africa
Sols noirs tropicaux	Africa
Terra Nera	Italy
Terras Negras Tropicais	Mozambique
Tropical Black clays	Africa
Tropical Black Earths	Angola, Ghana
Tropical Black soils	Africa, India
GROUP II. *Names reflecting the black color*	
Karail	India
Melanites	Ghana
Teen Suda	Sudan
Tropical Chernozems	Africa, India
GROUP III. *Names taken from the vernacular*	
Adobe soils	United States
Badobes	Sudan
Gilgai soils	Australia
Firki	Nigeria
Mbuga	Tanganyika
Kahamba	Congo
Morogan	Romania
Mourcis	Mali
Regur	India, Indonesia

TABLE 5. – NAMES FOR DARK CLAY SOILS AND REGIONS OF USE (*concluded*)

Rendzina	United States
Smolnitza	Bulgaria, Romania
Smonitza	Austria, Yugoslavia
Sols de paluds	France
Tirs	North Africa
Vlei soils	South Africa
Sonsocuite	Nicaragua
GROUP IV. *Coined names*	
Densinigra soils	Angola
Gravinigra soils	Angola
Grumusols	United States
Margalite soils	Indonesia
Vertisols	United States

Classification and correlation

In most soil-classification systems, dark clay soils have been recognized at a high level of generalization. Their place in each system and their further subdivision are determined by the different concepts used in the classification of soils, i.e., soil genesis, soil geography or soil morphology.

In the French classification scheme proposed in 1954 (10), the dark clay soils were listed in the order of developed soils (sols évolués sur place) and in the suborder of Hydromorphic soils. This subdivision is based on the seasonal water saturation of these soils, which is considered an essential factor in their formation. In the scheme presented in 1956 (11), more emphasis being given to the presence of alkaline earths, the dark clays appeared in the class of Calcimorphic soils, subclass of Hydromorphic soils. Recently the dark clays have become an independent class under the name of Vertisols and Para-Vertisols which is subdivided at the subclass level into Vertisols with humid pedoclimate (topomorphic soils) and Vertisols with temporarily humid pedoclimate (lithomorphic soils). At the group level, both subclasses are subdivided on the basis of the formation of a thin granular structure in the surface layers (more than 20 centimeters). The concept at the basis of the French classification is soil genesis, with special attention to parent material and drainage conditions.

In the classification used for the Soil Map of Asia (142) the dark clays fall in the Soils of the tropical and equatorial belt, facies of Soils formed under climatic conditions with a moderately marked dry season. These soils are further subdivided into Regurs, characterized by a granular surface horizon, and Margalitic soils which do not granulate. Soil genesis is also the basic concept for this classification, special emphasis being placed on the climatic factor and the zonality concept of soil formation. From a compilation of the U.S.S.R. literature (25), it appears that the Compact Chernozems mapped in the Caucasus show great similarities to dark clay soils. Indeed, they have a clay texture, blocky structure, high density, low organic-matter content and show wide cracking when dry. Their yields are reported to be distinctly lower than those of the Typical Chernozems. It thus appears that a part of the Compact Chernozems in the U.S.S.R. may fit the definition of dark clays.

In Australia, dark clay soils are found in the great groups of the Black Earths and of the Gray and Brown Soils of Heavy Texture (216). Both belong to the order of the Pedocals, the former being part of the suborder of the Soils with dark-colored solum, slightly acid to neutral, with eluvial horizons and calcareous illuvial horizons; the latter are part of the suborder of the soils with neutral to alkaline weakly developed eluvial horizons and calcareous and/or gypseous illuvial horizons. The Black Earths are reported to occur in the summer rainfall zone while the Gray and Brown Soils of Heavy Texture occur mostly in semiarid to arid regions; this subdivision is based on morphological characteristics and concurrently on differences in climatic conditions. It should be pointed out that probably only part of the Gray and Brown Soils of Heavy Texture fals within the definition of dark clays.

In an early U. S. classification (243), dark clay soils were known under the great soil group name of Rendzinas. Within the order of intrazonal soils, they belonged to the suborder of the calcimorphic soils. Since the name Rendzina was used for other soils in Europe, it was subsequently changed to Grumusol (169). Recently (246) these soils were classified as an independent order under the name of Vertisols, subdivided into two suborders, the Aquerts and the Usterts. The first have chromas of 1.5 or less throughout the upper 30 centimeters or have distinct or prominent mottling within the upper 75 centimeters or both. The Aquerts are saturated with water at some season and show gley phenomena. The Usterts are Vertisols with chromas of more than 1.5 throughout the upper 30 centimeters and lack distinct or prominent mottling within the surface 75 centimeters. The hues are often redder than 10YR. Generally the Usterts are restricted to the drier part of the climatic range of the Vertisols. Both suborders may be further subdivided into great groups, according to granulation and self-mulching (Grumaquerts and Grumusterts), or the formation of crusty surface horizons with low self-mulching (Mazaquerts and Mazusterts). All these units are defined in terms of morphological characteristics.

It thus appears that dark clays have been classified in the different schemes at a comparable level of generalization. It should be pointed out, however, that even at this level the various classification units do not fully match. In the U.S. classification, for instance, Vertisols must have a minimum clay content of 30 percent, while the French classification extends its Vertisols and Para-Vertisols to soils which may be less high in clay. It should be noted that the Vertisols include soils with an exchangeable sodium percentage exceeding 15 — e.g., Natraqualfic Mazaquerts, Natrustalfic Mazusterts — which in other classification systems may be considered as alkali soils. With regard to Australian soils, it appears that only part of the Gray and Brown Soils of Heavy Texture belongs to the Vertisols; other members of this group probably correspond to the Aridisols of the U.S. classification. In the U.S.S.R. classification, the dark clay concept is restricted to soils occurring in tropical and equatorial regions with a moderately marked dry season. It appears, however, that dark clays also occur outside the tropical and equatorial belt.

Subdivision of the dark clays at lower levels of classification has been made on the basis of different criteria in the various classification schemes. To a certain extent, however, a correlation seems possible; for instance, the lithomorphic Vertisols of Africa seem to correspond largely to the Usterts; the Regur soils as defined on the Soil Map of Asia seem to correspond to Grumaquerts; while Margalitic soils of Asia as referred to above seem to correspond to the Aquerts with surface crusting. A more precise definition of the units will be necessary to establish an accurate comparative table. It is hoped that through the exchange of information adjustments can be made in the currently used systems of classification so as to obtain a matching parallelism.

Profile description and laboratory data

The profile descriptions of dark clay soils given in the following pages illustrate the dominant horizon sequences and the nature of the different horizons. They indicate the ranges in characteristics of the horizons and their relationship to drainage and parent materials.

The descriptions have been made according to the guides outlined in the *Soil survey manual* of the U.S. Soil Conservation Service (244). Colors are given mainly for moist conditions, but where colors for the dry condition are available they are also indicated.

Conventions are given in the *Soil survey manual* for the use of the terms " soft " and " hard " for consistence of soil when dry, " friable " and " firm " for consistence of soil when moist, and " plastic " and " sticky " for consistence of soil when wet. The terms for the full range of consistence of dry soil are: loose, soft, slightly hard, hard, very hard and extremely hard. The similar range for moist soil is loose, very friable, friable, firm, very firm and extremely firm. For wet conditions, two sets of terms are used, one referring to plasticity and the other to stickiness. These terms are slightly plastic, plastic and very plastic; and slightly sticky, sticky and very sticky. In the specimen profile descriptions that follow, all the above terms will be used without indication of moisture conditions as long as the usage conforms to the conventions in the *Soil survey manual.*

Guides are not included in the *Soil survey manual* for describing concretions of various kinds. The size classes used here correspond to those applied to granular peds, viz., very fine ($<$ 1 millimeter), fine (1-2 millimeters), medium (2-5 millimeters), coarse (5-10 millimeters), and very coarse ($>$ 10 millimeters). Abundance is indicated in three classes by the comparative terms, few, common and many.

In assembling the profile descriptions below, an attempt has been made to place them all on a comparable basis with regard to the designation and description of horizons. In a number of instances, horizon designations have had to be added since they were not included in the original description. In other instances, some modification of the original horizon designations has been made in order to obtain uniformity. These modifications are based on interpretations of the original descriptions and on laboratory data when available. The descriptions of individual horizons have all been arranged according to one pattern so that the comparison of one horizon with another in the same profile and with corresponding horizons in other profiles is simplified.

Profile descriptions are listed in two groups. The first consists of descriptions of profiles that have distinct indications of wetness or poor drainage, while the second comprises descriptions of profiles that, although not necessarily well drained, lack evidence of poor drainage.

Profile descriptions of poorly drained dark clays

Indications of poor drainage may assume several forms, all being evidence of reducing conditions in the soil for some part of the year. Examples of such evidence are very low chromas, neutral or gley colors, yellowish hues and mottling at moderate depths; for most profiles, more than one form of evidence is available. These morphological features may be supplemented by the topographic position of the soil or by external evidence of flooding or overflow. In the main, these soils occur in humid regions or occupy concave positions in the landscapes of semiarid and subhumid regions.

1. Houston Black clay (Grumusol) - United States (Ellis County, Texas)

(*a*) *Setting*: The profile site is plane with a slope gradient of 1 percent in an upland area with very gently undulating topography. Slopes are commonly long and relief is mild. Differences in level are generally less than 1 meter. Original vegetation was tall prairie grass.

(*b*) *Profile description:*

A_{11}	0-45 cm	Very dark gray (2.5Y 3/1) clay, dark gray (2.5Y 4/1) when dry; moderate fine to medium granular structure; very hard, friable, very plastic and very sticky; strongly calcareous; gradual boundary.
A_{12}	45-95 cm	Very dark gray (2.5Y 3/1) clay, dark gray (2.5Y 4/1) when dry; weak, very coarse, blocky structure; extremely hard, extremely firm, very plastic and very sticky; strongly calcareous; clear boundary.
AC	95-135 cm	Black (2.5Y 2/1) clay mottled with light olive-brown (2.5Y 5/4), dark gray (2.5Y 4/1) mottled with light yellowish-brown (2.5Y 6/4) when dry; massive; extremely hard, extremely firm, very plastic and very sticky; very strongly calcareous with many $CaCO_3$ concretions; clear boundary.
C	135-210 cm	Yellowish-brown (10YR 5/6) clay mottled with grayish-brown (2.5Y 5/2), brownish-yellow (10YR 6/6) mottled with light brownish-gray (2.5Y 6/2) when dry; weakly laminated or shaly in appearance; very strongly calcareous.

(*c*) *Additional notes:* Colors are given for both moist and dry conditions with the former listed first. Surface drainage is moderate to slow but water does not stand on the surface. Soil is very slowly permeable. Underlying formation providing parent materials for the soil is a marl. The profile description is from H. Oakes and J. Thorp.

2. Houston Black clay (Grumusol) - United States (Collin County, Texas)

(*a*) *Setting*: The profile site is a microdepression with less than 1 percent slope on a nearly level divide in an upland area with gently undulating topography. Differences in level are generally less than 1 meter. Original vegetation was tall prairie grass.

(*b*) *Profile description*:

A_{1p}	0-15 cm	Black (10YR 2/1) clay, very dark gray (10YR 3/1) when dry; moderate fine granular structure; friable; very plastic and very sticky; weakly calcareous; clear boundary.

A_{12}	15-60 cm	Black (10YR 2/1) clay, very dark gray (10YR 3/1) when dry; moderate fine irregular blocky structure; extremely hard, very firm, very plastic and very sticky; moderately alkaline; gradual boundary.
A_{13}	60-80 cm	Black (10YR 2/1) clay, very dark gray (10YR 3/1) when dry; moderate coarse blocky structure breaking to moderate and strong fine irregular blocky peds; extremely hard, very firm, very plastic and very sticky; few soft $CaCO_3$ lumps in lower part; weakly calcareous; gradual boundary.
AC_1	80-100 cm	Very dark gray (10YR 3/1) clay, dark gray (10YR 4/1) when dry; moderate coarse blocky structure breaking to moderate and strong fine irregular blocky peds; very hard, very firm, very plastic and very sticky; many soft $CaCO_3$ lumps of medium granular size; strongly calcareous; gradual boundary.
AC_2	100-112 cm	Black (2.5Y 2/2) clay, very dark grayish-brown (2.5Y 3/2) when dry; weak coarse blocky structure with shiny faces on peds; hard, firm, plastic and sticky; distinct slickensides; many soft $CaCO_3$ lumps of medium granular size; strongly calcareous; clear boundary.
C	112-125 cm	Mottled pale olive (5Y 6/3) and olive yellow (2.5Y 6/6) chalky earth, probably of clay texture; soft, friable; strongly calcareous; many soft lumps of $CaCO_3$ up to 5 centimeters in diameter.
D_r	125-175 cm	Pale yellow (2.5Y 8/3) weakly indurated chalk, (2.5Y 8/2) when dry; thinly bedded with very dark gray stains on parting planes.

(c) *Additional notes*: Colors are given for both moist and dry conditions with the former listed first. Color of the A_1 horizon ranges from black to very dark grayish-brown and depth to the C horizon ranges from 90 to 112 centimeters on the walls of the sample pit. Surface drainage is slow and permeability is very slow. Parent material for the soil was derived from the underlying chalk. The profile description is from H. Oakes.

3. Beaumont clay (Grumusol) - United States (about 8 kilometers west of Rosenberg, Fort Bend County, Texas)

(a) *Setting*: Profile site was a microdepression in an essentially level upland with distinct gilgai microrelief. The general area is less than 30 meters above sea level. Immediate area is a native meadow with brown *Paspalum*, *Panicum*, and *Andropogons* as the main grasses. The average annual rainfall is 1,075 millimeters and mean monthly temperatures are 13°C in January and 28°C in July.

(*b*) *Profile description*:

A_{11}	0-30 cm	Very dark gray (10YR 3/1) clay mottled with yellowish-brown, gray (10YR 5/1) mottled with light yellowish-brown when dry; moderate medium subangular blocky breaking readily to moderate fine subangular blocky structure; very hard, very firm, very plastic and sticky; many grass roots; few small brown concretions; pH 5.5; gradual boundary.
A_{12g}	30-62 cm	Dark gray (10YR 4/1) clay mottled with yellowish-brown, gray (10YR 5/1) mottled with light yellowish-brown when dry; moderate medium blocky structure; very hard, very firm, very plastic and very sticky; grass roots common; few brown concretions; pH 5.5; gradual boundary.
A_{13g}	62-125 cm	Gray (10YR 5/1) clay with common dark yellowish-brown and occasional strong brown mottles; weak medium blocky structure; very hard, very firm, very plastic and very sticky; few grass roots; few brown and black medium concretions; gradual boundary.
AC_g	125-165 cm	Gray (2.5Y 5/1) clay mottled with light olive-brown, light gray (2.5Y 6/1) when dry; weak coarse blocky structure; very hard, very firm, very plastic and very sticky; few black fine concretions; pH 7.0; gradual boundary.
C_{ca}	165-225 cm	Light yellowish-brown (2.5Y 6/4) clay mottled with light gray and pinkish gray; pale yellow (2.5Y 7/4) with faint mottles when dry; massive; very hard, very firm, plastic; dark gray clay in some crevices; small lumps and concretions of $CaCO_3$ common; strongly calcareous; gradual boundary.
C	225-285 cm	Yellowish-red (5YR 4/8) clay with few distinct gray mottles, yellowish-red (5YR 5/8) when dry; massive; hard, firm, plastic; few $CaCO_3$ concretions.

(*c*) *Additional notes*: Colors are given for both moist and dry conditions with the former listed first. The profile description is from H. Oakes.

4. Victoria clay (Grumusol) - United States (near Robstown, Neuces County, Texas)

(*a*) *Setting*: The soil occurs in a flat plain comprising a coastal terrace near the Gulf of Mexico and less than 30 meters above sea level. The profile was described and sampled in a field which had recently been plowed. Average annual rainfall in the locality is 700 millimeters and the mean temperatures are 13°C in January and 28°C in July.

(*b*) *Profile description*:

A_{1p}	0-12 cm	Very dark gray (N 3/) clay, dark gray (N 4/) when dry; massive when wet; moderate medium and fine granular structure when dry; very hard, friable, very plastic and very sticky; strongly calcareous; clear smooth boundary.
A_{12}	12-48 cm	Very dark gray (N 3/) clay, dark gray (N 4/) when dry; moderate fine and very fine irregular blocky structure when dry; weak coarse blocky structure to massive when wet; extremely hard, firm, very plastic and very sticky; strongly calcareous; gradual boundary.
A_{13}	48-70 cm	Very dark gray (N 3/) clay, dark gray (N 4/) when dry; moderate medium angular blocky and subangular blocky structure; very hard, very firm, very plastic and very sticky; few fine pores; few roots between and in peds; many slickensides; ped faces shiny; strongly calcareous; gradual boundary.
AC	70-120 cm	Mottled very dark gray (N 3/) and dark gray (2.5Y 4/1) clay, dark gray (N 4/) and gray (2.5Y 5/1) when dry; mottles are common, coarse, and faint; weak coarse subangular blocky structure; very hard, firm, plastic and sticky; few very fine roots; many slickensides; strongly calcareous; gradual boundary.
C_1	100-128 cm	Light yellowish-brown (2.5Y 6/3) clay, pale yellow (2.5Y 7/3) when dry; massive; slightly hard, friable; few vertical tongues or veins of dark gray clay; many slickensides; many small pockets of gypsum crystals; gradual boundary.
C_2	128-168 cm	Light yellowish-brown (2.5Y 6/3) clay, pale yellow (2.5Y 7/3) with yellow mottles when dry; mottles are few, fine, and faint; massive; slightly hard, friable; few slickensides; small nests or pockets of gypsum crystals common; strongly calcareous.

(*c*) *Additional notes*: Colors are given for both moist and dry conditions with the former listed first. The profile description is from H. Oakes.

5. Dark gray Grumusol from lake bed sediments - United States (Coconino County, Arizona)

(*a*) *Setting*: The profile was described in the bed of a small intermittent lake on a rolling basalt plateau at an elevation of approximately 2,190 meters above sea level. The lake bed itself is smooth and level and is largely barren of vegetation. Average annual rainfall is estimated to be 550 millimeters.

(*b*) *Profile description*:

A_1	0-18 cm	Black (10YR 2/1) clay, very dark gray (10YR 3/1) when moist; moderate very coarse prismatic structure breaking readily to moderate coarse and medium subangular blocky structure; extremely hard, very firm, very plastic and very sticky; clear wavy boundary.
AC_g	18-58 cm	Very dark gray (2.5Y 3/1) clay mottled with dark yellowish-brown (10YR 3/4), dark gray (2.5Y 4/1) mottled with reddish-yellow (7.5YR 5/6) when dry; mottles are common, fine and medium, distinct; very coarse irregular platy and coarse irregular blocky structure due to intersecting slickensides; large peds breaking readily to moderate fine blocky structure; extremely hard, extremely firm, very plastic and very sticky; roots common; few fine to coarse black and reddish-brown concretions; gradual wavy boundary.
C_{1g}	58-85 cm	Dark gray (5Y 4/1) clay with few distinct medium and fine mottles of dark yellowish-brown, same color when moist; very coarse irregular platy and coarse irregular blocky structure due to intersecting slickensides; large peds breaking to weak medium and fine blocks; extremely hard, very firm, very plastic and very sticky; few fine to coarse black concretions; gradual wavy boundary.
C_{2g}	85-122 cm	Dark gray (5Y 4/1) clay with many fine and medium distinct mottles of dark yellowish-brown, same color when moist; very coarse irregular platy and coarse irregular blocky structure due to intersecting slickensides; extremely hard, very firm, very plastic and very sticky; few fine to coarse black concretions; clear irregular lower boundary.
C_{3g}	122-138 cm	Dark yellowish-brown clay with dark gray mottles, brown with gray mottles when dry; mottles are common, fine and medium, faint; massive when wet with slickensides common when dry, mostly at angles of 30 to 45 degrees with the vertical; extremely hard, very firm, very plastic and very sticky; common medium and fine black concretions; few irregular $CaCO_3$ concretions.

(*c*) *Additional notes*: A surface layer 6 millimeters thick is a distinct crust and below it is a somewhat thicker layer with strong very fine granular structure. Vertical cracks down from the surface form a pattern of crude polygons 1-2 meters in diameter. The cracks are 5 to 10 centimeters wide at the surface and extend downward 105 centimeters. The soil is poorly drained with no runoff and very slow permeability. The site is under water at times, occasionally for as long as six to eight months. Parent materials are sediments washed from brown Grumusols derived from basalt in surrounding uplands. The profile description is from W. M. Johnson, J. Cady and M. James.

6. Subtropical Black clay - South Africa (Bath-Avon profile, Springbok Flats)

(*a*) *Setting*: The soil occurs on a plateau with an elevation of 1,050 meters. Surface drainage is moderately good. Soils of this kind are used mainly for maize, sunflower and fodder production under dry land farming and for winter wheat and tobacco under irrigation. Average annual rainfall is 610 millimeters.

(*b*) *Profile description*:

A_{11}	0-30 cm	Black (5YR 2/1) heavy clay; strong medium to coarse blocky structure; very hard, very firm, very plastic and very sticky; many grass roots; pH 6.8; gradual boundary.
A_{12}	30-85 cm	Black (5YR 2/1) heavy clay; moderate medium to coarse blocky structure; very hard, very firm, very plastic and very sticky; some grass roots; few $CaCO_3$ concretions; pH 7.4; gradual boundary.
AC	85-100 cm	Very dark gray (10YR 3/1) heavy clay; weak coarse blocky structure; very hard, very firm, very plastic and very sticky; few very fine roots; pH 8.1; clear boundary.
C	100-108 cm	Grayish-brown (2.5Y 5/2) clay; massive; hard, firm, plastic and sticky; very few roots; small pieces of basalt common; many small $CaCO_3$ concretions; pH 8.2; clear boundary.
D_r	108-150 cm	Gray decomposing basalt.

(*c*) *Additional notes*: Colors given in the above description are for dry conditions. When it dries, this soil contracts so that cracks extend well down into the AC horizon. The profile description is from C.R. van der Merwe.

7. Subtropical Black clay - South Africa (Hartebeestpoort profile, Brits District)

(*a*) *Setting*: This soil occurs on a plateau with an elevation of 1,150 meters and with an annual rainfall of 680 millimeters. Surface drainage is moderately good. Soils of this kind are used mainly for maize, sunflower and fodder under dry land farming and for wheat and tobacco under irrigation.

PROFILE No. 6. – SUBTROPICAL BLACK CLAY – SOUTH AFRICA (BATH-AVON PROFILE, SPRINGBOK FLATS)

Horizon	Depth cm	Stones >2 mm	Sand 2-.05 mm	Silt .05-.002 mm	Clay <.002 mm	Soluble material %	pH	Resists 60°F	Clay minerals
A_{11}	0–30	0.0	20.7	17.4	62.4	0.0	6.8	180	Montmorillonite
A_{12}	30–85	0.0	19.0	17.5	64.4	1.7	7.4	180	Montmorillonite
AC	85–100	0.0	22.4	22.8	54.8	40.0	8.1	330	Montmorillonite
C	100–108	5.2	79.8	7.0	13.1	4.4	8.2	350	Montmorillonite

Horizon	Depth cm	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	Mn_3O_4	CaO	MgO	Na_2O	K_2O	P_2O_5	Ignition loss
A_{11}	0–30	64.1	6.4	22.1	1.2	0.14	2.1	3.1	0.46	0.89	0.09	11.9
A_{12}	30–85	64.6	5.9	19.9	1.2	0.14	2.4	3.2	0.42	0.81	0.07	11.7
AC	100–108	62.0	5.4	20.6	1.1	0.16	5.6	3.6	0.49	0.84	0.08	12.1
C	108–150	59.4	6.7	20.9	1.0	0.16	3.6	4.8	0.56	0.80	0.10	12.2

Horizon	Depth cm	Base exchange (me per 100 g moisture-free soil)						Carbon %	Nitrogen %	Molecular ratios		
		Ca	Mg	Na	K	S-values	T-values			$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$
A_{11}	0–30	36.8	14.0	0.39	0.86	52.0	53.8	1.48	0.100	4.14	4.91	26.6
A_{12}	30–85	39.8	14.3	0.65	0.89	55.7	55.3	1.12	0.090	4.63	5.51	29.0
AC	100–108	25.8	11.5	0.58	0.64	38.5	33.8			4.37	5.10	30.6

PROFILE NO. 7. – SUBTROPICAL BLACK CLAY – SOUTH AFRICA (HARTEBEESTPOORT PROFILE, BRITS DISTRICT)

Horizon	Depth cm	Stones >2 mm	Sand 2-.05 mm	Silt .05-.002 mm	Clay <.002 mm	Soluble material %	pH	Resists 60°F	Clay minerals
A_{11}	0–22	0.0	21.9	17.6	60.1	4.3	8.1	290	Montmorillonite
A_{12}	22–50	0.0	19.5	15.5	64.2	6.4	8.1	290	
	50–65	0.0	18.9	16.2	65.6	6.4	8.2	330	Montmorillonite
A_{13}	65–95	0.0	18.2	16.2	66.2	6.1	8.3	350	
	95–110	0.0	16.6	16.6	66.5	7.6	8.4	320	
C_{ca}	110–115	0.0	39.6	17.9	43.4	15.0	8.4	470	
C	115–135	0.0	73.6	14.5	12.6	4.8	8.2	590	Montmorillonite

Horizon	Depth cm	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	Mn_3O_4	CaO	MgO	Na_2O	K_2O	P_2O_5	Ignition loss
A_{11}	0–22	55.9	5.6	25.4	1.0	0.17	7.9	3.2	0.08	0.37	0.07	16.8
A_{12}	22–50	57.1	5.7	24.3	1.0	0.13	7.5	3.3	0.17	0.34	0.05	16.2
	50–65	57.2	6.0	22.8	1.0	0.10	7.6	3.4	0.27	0.47	0.05	15.1
A_{13}	65–95	57.2	8.2	22.9	0.9	0.10	7.3	3.6	0.18	0.34	0.06	15.5
	95–110	56.8	7.7	22.9	0.9	0.12	7.3	4.0	0.21	0.38	0.08	16.3
C_{ca}	110–115	56.4	9.1	22.5	1.1	0.17	7.1	3.9	0.25	0.36	0.08	15.5
C	115–135	56.6	9.8	22.4	1.0	0.20	5.3	4.6	0.28	0.33	0.05	13.2

Horizon	Depth cm	Base exchange (me per 100 g moisture-free soil)						Carbon %	Nitrogen %	Molecular ratios		
		Ca	Mg	Na	K	S-values	T-values			$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$
A_{11}	0–22	58.8	7.6	0.90	0.96	68.2	66.3	1.60	0.132	3.27	3.73	26.5
A_{12}	22–50	58.2	6.8	0.90	0.43	66.3	67.1	1.25	0.078	3.45	3.98	26.5
	50–65	55.0	8.4	0.96	0.33	64.6	63.9	1.17	0.076	3.63	4.25	25.2
A_{13}	65–95	57.2	8.9	1.56	0.46	68.0	66.1	1.11	0.067	3.44	4.22	18.6
	95–110	59.4	9.5	1.66	0.55	71.1	69.0	1.16	0.076	3.46	4.22	19.6

(*b*) *Profile description*:

A_{11}	0-22 cm	Black (5YR 2/1) heavy clay; strong medium to coarse blocky structure breaking into strong coarse granules; hard, firm, very plastic and very sticky; many grass roots; few $CaCO_3$ concretions; pH 8.1; gradual boundary.
A_{12}	22-65 cm	Black (5YR 2/1) heavy clay; moderate medium to coarse blocky structure when moist, strong coarse granular structure when dry; very hard, very firm, very plastic and very sticky; grass roots common; few $CaCO_3$ concretions; pH 8.1; gradual boundary.
A_{13}	65-110 cm	Black (5YR 2/1) heavy clay; moderate medium to coarse blocky structure when moist, strong coarse granular structure when dry; very hard, very firm, very plastic and very sticky; few grass roots; $CaCO_3$ concretions common; pH 8.2; clear boundary.
C_{ca}	110-115 cm	White (5YR 8/1) clay, strongly calcareous with both finely divided and concretionary carbonates; pH 8.4; clear boundary.
C	115-135 cm	Light brown gravelly loam, sandy loam (partly decomposed norite); few tongues of very dark brown clay; few veins of $CaCO_3$ concretions; few nests or pockets of gypsum crystals.

(*c*) *Additional notes*: Colors given in the above description are for dry conditions. As it dries, this soil contracts so that cracks extend down through the A_{13} horizon. The profile description is from C.R. van der Merwe.

8. Tropical Black Earth (slightly leached) - Ghana (Kpong Irrigation Research Station)

(*a*) *Setting*: The profile was described on the middle of a slope in a gently undulating landscape. Slope gradient is about 2 percent and surface drainage is slow. This is part of a coastal plain in which rainfall ranges between 875 and 1,125 millimeters. Vegetation consists of tussocky medium grasses with scattered trees.

(*b*) *Profile description*:

A_{11}	0-12 cm	Very dark gray (10YR 3/1) clay; weak medium to coarse subangular blocky structure breaking under firm pressure to moderate coarse granules; very hard, very plastic and very sticky; many grass roots; pH 6.4; gradual boundary.

PROFILE NO. 8. – TROPICAL BLACK EARTH (SLIGHTLY LEACHED) – GHANA (KPONG IRRIGATION RESEARCH STATION)

Horizon	Depth cm	Mechanical analysis (international) %						Organic matter %				Moisture
		Gross				Fine earth						
		Stones	Coarse gravel	Fine gravel	Fine earth	Silt	Clay	C	N	C/N	OM	Air-dry soil %
A_{11}	0–12	Nil	Nil	Nil	100.0	7.3	32.2	1.74	0.103	16.9	3.0	5.95
A_{12}	12–38	Nil	0.1	0.4	99.5	7.0	36.8	0.84	0.058	14.5	1.4	6.59
A_{13}	38–60	Nil	0.5	3.5	96.0	8.9	42.0	0.63	0.044	14.3	1.1	7.43
	60–75	2.4	1.0	3.8	92.8	9.0	46.1	0.45	0.032	14.1	0.8	7.99
C_{ca}	75–105	30.6	18.9	3.5	47.0	7.6	39.7	0.17	0.014	12.1	0.3	7.27
	105–120	1.7	12.4	2.8	83.1	10.6	40.9	0.09	N.D.	N.D.	0.1	7.35
D_{ca}	120–142	Nil	1.1	0.8	98.1	11.0	27.2	N.D.	N.D.	N.D.	N.D.	5.92
D	142–180	16.1	1.4	0.5	82.0	10.4	13.8	N.D.	N.D.	N.D.	N.D.	3.82

Horizon	Depth cm	pH	$CaCO_3$	Exchange capacity[1]	Exchange complex me/100 g fine earth					Total bases	Conductivity 25°C mmho × 10^3	Phosphorus	
					Ca	Mg	Mn	K	Na			Total	Truog
A_{11}	0–12	6.4	0.05	39.80	21.49	12.66	0.13	0.21	0.60	35.09	56	306	3.2
A_{12}	12–38	7.0	0.09	39.21	20.80	11.40	N.D.	0.17	1.00	33.37	53	257	N.D.
A_{13}	38–60	8.2	2.20	41.70	26.20	13.10	N.D.	0.20	2.20	41.70	195	264	N.D.
	60–75	8.3	5.00	42.90	26.09	16.90	N.D.	0.21	3.10	46.30	222	283	N.D.
C_{ca}	75–105	8.4	18.80	40.46	22.80	12.60	N.D.	0.13	3.10	38.63	246	409	N.D.
	105–120	8.4	12.10	41.89	22.10	15.00	N.D.	0.20	3.20	40.50	246	880	N.D.
D_{ca}	120–142	8.4	2.00	34.00	19.60	14.00	N.D.	0.20	2.80	36.60	229	1 535	N.D.
D	142–180	8.6	0.65	22.15	11.88	10.27	N.D.	0.17	1.71	24.03	170	1 508	N.D.

[1] Horizons 1 and 2: Barium acetate, pH 8.2. Horizons 3, 4, 7, 8: Ammonium acetate, pH 7.0. Horizons 5 and 6: Sodium acetate, pH 8.2.
N.D. = no data.

A_{12}	12-38 cm	Dark gray (10YR 4/1) clay; weak coarse subangular blocky structure; very hard, very plastic and very sticky; few coarse quartz grains; few small solution-pitted $CaCO_3$ concretions; pH 7.0; gradual boundary.
A_{13}	38-75 cm	Dark gray (10YR 4/1) clay; weak very coarse subangular blocky structure; very hard, very plastic and very sticky; few small MnO_2 concretions; few small ironstone concretions; few small solution-pitted $CaCO_3$ concretions; pH 8.2; gradual boundary.
C_{ca}	75-120 cm	Gray (5Y 5/1) clay; weak very coarse subangular blocky structure; very hard, very plastic and very sticky; some coarse quartz grains; few small ironstone concretions; many $CaCO_3$ concretions; band of well-rounded quartz pebbles up to 5 centimeters in diameter at base; pH 8.4; clear boundary.
D_{ca}	120-142 cm	Grayish-brown (2.5YR 5/2) sandy clay faintly stained with yellowish-red and black (massive but soft decomposing garnet-hornblende gneiss); many $CaCO_3$ concretions; pH 8.4.
D	142-180 cm	Grayish-brown (2.5YR 5/2) sandy loam (decomposing garnet-hornblende gneiss); pH 8.6.

(*c*) *Additional notes*: Moisture conditions under which colors were identified are not known but it is presumed that the soil was dry. Internal drainage of the soil is very poor, downward movement through the profile being virtually nil. Under natural conditions the soil is compact to the surface and cracks vertically when dry. Large polygonal blocks are thus formed which break down into irregular small blocks some centimeters in diameter. The profile description is from H. Brammer with horizon designations added.

9. Normal Black Vleisol - Ghana (Dechidaw Valley, about 2 kilometers north of Dawhwenya, Post 25 on Accra-Lagos road)

(*a*) *Setting*: This profile was described in a valley bottom which is level. Water may stand on such sites for several hours after rains. Vegetation consists of tussocky medium grasses.

(*b*) *Profile description*:

A_{11}	0-10 cm	Very dark gray (10YR 3/1) clay; weak coarse subangular blocky structure; very hard, very plastic and very sticky; wide vertical cracks; few very small soft ironstone pieces; pH 6.0; gradual boundary.
A_{12}	10-25 cm	Very dark gray (10YR 3/1) clay; weak very coarse subangular blocky structure; very hard, very plastic

PROFILE No. 9. – NORMAL BLACK VLEISOL – GHANA (DECHIDAW VALLEY, ABOUT 2 KILOMETERS NORTH OF DAWHWENYA, POST 25 ON ACCRA-LAGOS ROAD)

Horizon	Depth cm	Mechanical analysis (international) %						Organic matter %				Moisture
		Gross (% air-dry)				Fine earth (% oven-dry)						
		Stones >20 mm	Coarse gravel 20-6.25 mm	Fine gravel 6.25-2 mm	Fine earth <2 mm	Sand 2-0.02 mm	Silt and clay <0.02 mm	C	N	C/N	OM	Air-dry soil %
A_{11}	0–10	<0.1	<0.1	<0.1	100.0	17.3	77.6	2.97	0.229	12.97	5.11	9.91
A_{12}	10–25	<0.1	<0.1	<0.1	100.0	20.9	77.0	1.18	0.076	15.53	2.03	11.50
A_{13}	25–88	<0.1	<0.1	<0.1	100.0	20.5	77.4	1.26	0.059	21.36	2.17	11.45
C_{1g}	88–170	<0.1	<0.1	<0.1	100.0	43.6	56.4	0.34	0.038	8.95	0.58	8.07
C_g	170–220	<0.1	<0.1	<0.1	100.0	77.9	22.1	N.D.	N.D.	N.D.		2.81

Horizon	Depth cm	pH	$CaCO_3$	Exchange capacity [1]	Exchange complex me/100 g fine earth [2]					Na% in ex-change complex	Total bases	Ca/Mg	Mg/K
					Ca	Mg	Mn	K	Na				
A_{11}	0–10	6.0	0.02	56.55	26.07	22.40	0.10	0.83	1.62	3.1	51.62	1.16	26.99
A_{12}	10–25	6.1	0.03	57.62	28.67	22.64	0.33	0.22	2.20	4.1	54.06	1.27	102.91
A_{13}	25–88	6.8	0.02	59.59	29.55	22.75	0.12	0.17	4.33	7.6	56.92	1.30	133.82
C_{1g}	88–170	6.9	0.01	37.35	18.12	16.08	0.04	0.09	3.74	9.8	38.07	1.13	178.67
C_g	170–220	7.4	<0.002	11.45	5.51	5.13	0.02	0.06	1.44	11.6	12.16	1.07	85.50

Horizon	Depth cm	Water soluble anions and cations combined to salts % oven-dry weight									Phosphorus (ppm)	
		$CaSO_4$	$CaCl_2$	$MgSO_4$	$MgCl_2$	KCl	Na_2SO_4	NaCl	$NaHCO_3$	Total	Total	Truog
A_{11}	0–10	0.0095	<0.01	0.0048	<0.01	0.0052	0.0178	0.0263	0.0143	0.0779	796	29.3
A_{12}	10–25	0.0116	<0.01	0.0042	<0.01	0.0015	0.0050	0.0321	0.0286	0.0830	262	4.0
A_{13}	25–88	0.0088	<0.01	0.0072	<0.01	0.0007	0.0092	0.0672	0.0395	0.1326	203	3.6
C_{1g}	88–170	0.0150	<0.01	0.0144	<0.01	0.0022	0.0291	0.1618	0.0042	0.2267	169	N.D.
C_g	170–220	0.0082	<0.01	N.D.	<0.01	0.0030	0.0249	0.0678	0.0017	0.1056	N.D.	N.D.

[1] Ammonium acetate: pH 7.0.
[2] All exchangeable cations corrected for salts.
N.D. = no data.

		and very sticky; wide vertical cracks; few very small soft ironstone pieces; pH 6.1; gradual boundary.
A_{13}	25-88 cm	Very dark gray (10YR 3/1) clay with faint mottles; weak very coarse subangular blocky structure; very hard, very plastic and very sticky; vertical cracks; few MnO_2 concretions; pH 6.8; gradual boundary.
C_{1g}	88-170 cm	Dark grayish-brown (10YR 4/2) clay loam with faint brown mottles; weak very coarse subangular blocky structure; very hard, very plastic and very sticky; some very small very soft ironstone pieces; some very small MnO_2 concretions; pH 6.9; clear boundary.
C_g	170-220 cm	Brown (10YR 5/3) sandy loam faintly mottled with gray and yellowish-red; massive in place but single-grained when removed; hard, very friable; pH 7.4.

(*c*) *Additional notes*: Colors given are for dry conditions. Internal drainage of the soil is very poor. Presence of wide cracks down through the A_{13} horizon are indicated in the description; they narrow with depth but are continuous from the surface down to the C_{1g} horizon. The profile description is from H. Brammer with horizon designations added.

10. Grumusol from calcareous clay or marl - Turkey (south of Highway 1 about 18 kilometers northwest of Corlu)

(*a*) *Setting*: The profile was described in gently undulating upland with dominantly convex slopes having gradients of less than 3 percent. Surface drainage is slow to moderate. Rainfall of the region is mainly between 500 and 750 millimeters. The soils of the vicinity are practically all in cultivation, being used mainly for wheat, oats and sunflowers.

(*b*) *Profile description*:

A_{1p}	0-25 cm	Very dark gray (10YR 3/1) clay, dark gray (10YR 4/1) when dry; moderate medium and coarse granular structure; hard, friable, plastic and sticky; mildly alkaline; gradual boundary.
A_{12}	25-55 cm	Very dark gray (10YR 3/1) clay, dark gray (10YR 4/1) when dry; weak medium subangular blocky structure breaking to moderate medium granules; very hard, very firm, very plastic and very sticky; weakly calcareous in lower part; gradual boundary.
AC	55-115 cm	Dark gray (10YR 4/1) clay, gray (10YR 5/1) when dry; massive; very hard, very firm, very plastic and very sticky; weakly calcareous with few soft lumps and concretions of $CaCO_3$; gradual boundary.

C_1	115-145 cm	Mottled gray (10YR 5/1) and light olive-brown (2.5Y 5/4) clay; massive and dense; very hard; strongly calcareous with many soft lumps of $CaCO_3$; clear boundary.
C_2	145-190 cm	Light olive-brown (2.5Y 5/4) clay; massive; strongly calcareous with many soft lumps and specks of $CaCO_3$.

(*c*) *Additional notes*: Colors are given for both moist and dry conditions, with the former placed first. Cracks which are 7 to 10 centimeters across and 1 to 2 meters deep form in such soils during extremely dry periods. A few small $CaCO_3$ concretions may occur on the surface and in any horizons of the profile. The profile description is from H. Oakes.

11. Deep Regur soil from limestone - India (about 500 meters northwest of buildings on the Labhandi Experimental Farm, Raipur, Madhya Pradesh)

(*a*) *Setting*: Known as the Chatisgarh plain, the region around Raipur is nearly level with local relief measurable in centimeters. The broad level crests of the low ridges grade into long slopes leading down into very shallow valleys. The gradient of these long slopes is often as low as 1 percent. The Regur soils occupy the shallow valleys and the lower portions of the long slopes. They are marked by gilgai microrelief of low mounds and shallow depressions, 1.5 to 5 meters in diameter and some termite mounds about 1 meter high. The soils on the ridge crests seem to be latosolic in character, and many of them are highly concretionary.

(*b*) *Profile description*:

A_{11}	0-30 cm	Very dark gray (5Y 3/1) clay; weak medium granular structure; extremely hard, very firm, very plastic and very sticky; fine roots common; fine black and brownish-black concretions common; gradual boundary.
A_{12}	30-70 cm	Olive-gray (5Y 4/2) to dark olive-gray (5Y 3/2) clay; strong medium blocky peds that break down to weak fine and medium granular peds; extremely hard, extremely firm, very plastic and very sticky; faces of the blocky peds show slickensides; fine roots common; few fine black concretions; gradual boundary.
AC	70-150 cm	Olive-gray (5Y 4/2) clay; strong medium to coarse blocky structure; extremely hard, extremely firm, very plastic and very sticky; most peds show slickensides; few fine black concretions; few fine roots; some variegation of olive-gray (5Y 4/2) and olive

		(5Y 4/3) colors make this layer seem brighter than the one immediately above; gradual boundary.
C	150-200 cm	Olive-gray (5Y 4/2 to 5/2) clay with faint, fine common mottles of light olive-brown (2.5Y 5/4); massive in place but breaking down into very weak coarse blocky peds when removed; few roots; very coarse $CaCO_3$ concretions (hard) and $CaCO_3$ accretions (soft) common.

(*c*) *Additional notes*: All horizons of the profile are neutral to mildly alkaline in reaction, but $CaCO_3$ concretions are absent above the C horizon. Fine plant roots are common in the A_{11} and A_{12} horizons, but the numbers drop off sharply in the AC horizon. From its appearance in the field, the soil seems extremely intractable and difficult to cultivate, except when it is used for paddy rice. Many fields are badly infested with " kans grass, " probably because of the difficulties of tillage and consequent weed control. In the classification used in tax assessment for rural lands, this soil has the local name of Kanhar. Colors are for moist soil conditions. The profile description is from R. W. Simonson.

12. Deep Regur soil from traprock - India (near machinery shelters on Agriculture Research Institute Farm, Nagpur)

(*a*) *Setting*: The soil occurs in a broad plain with very gently undulating topography. Slopes are long and local relief is measurable in meters. Occasional small buttes stand up several meters above the general level. Average annual rainfall is 1,025 millimeters and the mean annual temperature is 27°C. Most of the land is in cultivation, with cotton and sorghum as major crops.

(*b*) *Profile description*:

A_{1p}	0-22 cm	Very dark grayish-brown (2.5Y 3/2) clay; moderate fine granular structure; hard, friable, plastic and sticky; fine $CaCO_3$ concretions common; clear boundary.
A_{12}	22-55 cm	Olive-gray (5Y 4/2) clay; strong medium blocky breaking readily to moderate fine granular structure; ped faces shiny; gradual boundary.
AC_g	55-70 cm	Olive-gray (5Y 4/2) clay mottled with olive-brown and yellowish-brown; mottles are few, medium, and faint; strong medium blocky crushing readily to moderate fine granular structure; very hard, very firm, very plastic, and very sticky; ped faces shiny; gradual boundary.
C_{1g}	70-125 cm	Mottled olive-gray (5Y 4/2) and brown (10YR 5/3) clay, mottles are many, medium and faint; strong

		medium to coarse blocky breaking with difficulty to moderate medium and fine granular structure; very hard, extremely firm, very plastic and very sticky; ped faces shiny; gradual boundary.
C_{2g}	125-200 cm	Light olive-brown (2.5Y 5/4) clay mottled with yellowish-brown and brown, mottles are common, fine and medium, faint; massive to very weak coarse irregular blocky structure; extremely hard, extremely firm, very plastic and very sticky; large slickensides common; coarse $CaCO_3$ concretions common; basalt pieces of fine gravel and coarse sand size with black coatings common; crushed soil mass is lighter in color than broken faces by less than one unit of value.

(*c*) *Additional notes*: Colors are given for moist conditions. The whole profile is calcareous although concretions seem to be distributed erratically and are absent from some horizons. Some cracks are evident in the plow layer even though the soil is moist. The profile description is from R. W. Simonson.

13. Medium Black soil - India (about 29 kilometers from Chhindwara City on the Chhindwara-Narsingpur Road)

(*a*) *Setting*: The profile was described at the bottom of a small hillock in an essentially flat area supporting grass vegetation. So far as could be determined, the area has not been cultivated nor received any fertilizer.

(*b*) *Profile description*:

A_1	0-90 cm	Black (N 2/) clay; weak coarse irregular blocky structure; very hard; shiny faces on blocks or clods; few coarse roots; calcareous.
C	90-180 cm	Yellowish-brown (10YR 5/4) sandy loam; friable; few small well-weathered rock fragments.
D_r	180 cm plus	Yellowish-brown (10YR 5/4) saprolite weathered from basalt and containing some hard pieces of basalt.

(*c*) *Additional notes:* Colors given are for moist conditions. When the soil is dry, vertical cracks extend down through the A_1 horizon. The profile description is from G. C. Padole.

14. Grumusol from marly clay - Indonesia (Bodjong Petjung, along Tjidjulang River in western Java)

(*a*) *Setting*: The profile was described in a level area at an elevation of approximately 460 meters above sea level. Rainfall is about 2,500 millimeters with a dry season from May until August. The site is used alternately for rice and maize.

(*b*) *Profile description*:

A_{1p}	0-15 cm	Very dark gray (10YR 3/1 to 4/1) clay; moderate medium subangular blocky structure; firm; pH 6.0; diffuse smooth boundary.
A_{12}	15-60 cm	Very dark gray (10YR 3/1) clay; strong coarse angular blocky structure; very hard, very firm; some dark grayish-brown (2.5Y 4/2) irregular $CaCO_3$ concretions; pH 7.1; diffuse smooth boundary.
A_{13}	60-105 cm	Very dark gray (10YR 3/1) clay; moderate medium angular blocky structure; very hard, firm to very firm; pH 7.2; gradual smooth boundary.
AC	105-130 cm	Dark gray (10YR 4/1) clay; strong medium angular blocky structure; very hard, very firm; pH 7.2; gradual smooth boundary.
C	130 cm plus	Dark gray (10YR 4/1) to dark grayish-brown (2.5Y 4/2) clay; strong coarse angular blocky structure; very firm; pH 7.7.

(*c*) *Additional notes*: Colors given are for moist conditions, the soil being approximately at field capacity. Effervescence with HCl was not noted anywhere in the profile except for the concretions in the A_{12} horizon. The profile description is from the Soil Research Institute, Bogor, Indonesia.

PROFILE NO. 14. – GRUMUSOL FROM MARLY CLAY – INDONESIA
(BONDJONG PETJUNG, ALONG TJIDJULANG RIVER IN WESTERN JAVA)

Horizon	Depth cm	pH	$CaCO_3$ %	Clay < 0.002 mm	Silt 0.002-0.05 mm	Sand > 0.05 mm	Organic matter %
A_{1p}	0–15	6.0	—	64.9	26.7	8.4	1.45
A_{12}	15–60	7.1	0.77	71.2	22.4	5.9	0.64
A_{13}	60–105	7.2	1.54	73.1	19.4	6.5	0.57
AC	105–130	7.2	0.03	73.3	19.7	7.0	0.40
C	+130	7.7	0.37	68.7	24.4	6.9	0.25

15. Grumusol from volcanic tuffs - Indonesia (Patihajam hills, south of Muria volcano, Central Java)

(*a*) *Setting*: The profile was described in a cut exposed by a landslide on a 15 percent slope at an elevation of approximately 150 meters above sea level in the Patihajam hills. This strongly dissected landscape is covered by a series of tuff-breccias from the Muria volcano. Mean annual temperature is 26°C and average annual rainfall is 1,700 millimeters.

The dry season lasts four months. Formerly forested, the area is now mostly unused and is covered with weeds and grasses among which " Alang-alang " (*Imperata cylindrica*) is dominant. A small part of the area has been planted in teak.

(*b*) *Profile description*:

A_{1p}	0-3 cm	Very dark brown (10YR 2/2) clay to clay loam; moderate medium granular structure; hard, friable; many roots; medium acid; clear boundary.
A_{12}	3-50 cm	Very dark brown (10YR 2/2) to very dark grayish-brown (10YR 3/2) clay to clay loam; moderate medium prismatic structure breaking down under some pressure to strong medium angular blocky structure; slightly hard, firm, plastic; many roots mainly between prismatic peds; slickensides; medium acid; gradual boundary.
A_{13}	50-95 cm	Very dark grayish-brown (10YR 3/2) with many distinct medium mottles of dark brown (7.5YR 3/2 - 3/4); moderate fine angular blocky structure; slightly hard, firm, plastic; gray (5Y 5/1) vertical veins and streaks common; slickensides; medium acid; clear boundary.
AC	95-200 cm	Mottled clay loam, both brown (7.5YR 3/2 - 3/4) and gray (5Y 5/1) colors continuous; weak fine subangular blocky structure; many rounded very dark brown concretions; gray (5Y 5/1) veins evident along cracks; medium acid; clear boundary.
C	200 cm plus	Light brownish-gray (10YR 6/2) tuffaceous material; massive; very hard, gray (5Y 5/1) veins originating in upper profile extend downward through cracks in this layer; medium acid.

(*c*) *Additional notes*: Colors given are for moist conditions. No $CaCO_3$ is evident in the profile. Wetness is indicated by prominent mottling, the presence of tongues and veins of gray to neutral colors in the deeper profile, and the many landslides in the vicinity. The shiny ped faces and the deep penetration of veins and tongues in the deeper profile indicate cracking and churning of the soil during dry seasons. The profile description is from the Soil Research Institute, Bogor, Indonesia.

16. Coberinga clay (poorly drained Black Earth) - Australia (near Coberinga Siding, southeast of Home Hill, Queensland)

(*a*) *Setting*: The profile was described in a level plain 3 to 5 meters above sea level on the coast, at 19°S latitude. The site has well-developed gilgai microrelief with centers of depressions about 3 meters apart and the high spots about 25 centimeters above the low spots. Rainfall is 1,000 millimeters, with wet summers and dry winters. Tall grasses are dominant in the vegetation.

(*b*) *Profile description*:

A_{11}	0-20 cm	Very dark gray (5Y 3/1 to N 3/) heavy clay, dark gray (5Y 4/1 to N 4/) when dry; compound structure of coarse irregular blocks breaking down by stages to fine angular blocks; many large cracks; pH 7.2.
A_{12}	20-90 cm	Dark gray (5Y 4/1) heavy clay; strong mixed very coarse to coarse irregular blocky structure with ped faces due to intersecting slickensides; very plastic; few very coarse $CaCO_3$ concretions; pH 8.4.
AC_g	90-105 cm	Mottled gray and brown clay; few $CaCO_3$ concretions; pH 6 to 8.8.
C	105-150 cm	Brown (7.5YR 5/4) clay; plastic; few sharply angular $CaCO_3$ concretions; pH 8.6.

(*c*) *Additional notes*: Although not indicated in the description, the soil seems to have been dry at the time the profile was described. Many large cracks extend down through the A_{11} into the A_{12} horizon. The profile description is from J. Thorp with horizon designations added.

17. Sorell clay (Black Earth) - Australia (Sorell Township, Tasmania)

(*a*) *Setting*: The soil occurs on convex slopes below 8 percent in undulating uplands underlain by basalt. Average annual rainfall is about 625 millimeters per year. Vegetation is mainly grass with scattered eucalyptus.

(*b*) *Profile description*:

A_{11}	0-15 cm	Black (10YR 2/1) light clay; weak coarse blocky structure breaking to granules under moderate pressure; friable; pH 6.3; gradual boundary.
A_{12}	15-40 cm	Black (10YR 2/1) clay; weak coarse prismatic structure; hard, firm, plastic and sticky; pH 6.6; gradual boundary.
AC	40-60 cm	Very dark grayish-brown (2.5Y 3/2) to dark olive-gray (5Y 3/2) clay with few faint mottles; massive; very hard, very firm, plastic; some basalt gravels and stones; pH 7.0 to 7.5; gradual boundary.
C	60 cm plus	Light olive-brown to grayish-brown, sandy loam (decomposing basalt) with some basalt fragments; few fragments have $CaCO_3$ coatings.

(*c*) *Additional notes*: Although moisture conditions of the soil when described are not indicated, it is believed that the profile was moist. Depth to the C horizon in this soil type ranges from 45-75 centimeters. Basalt pieces are usually present on the surface and throughout the profile. Vertical cracking occurs from the surface down to the C horizon during dry seasons. The profile description is from J. Loveday.

18. Gray soil of heavy texture - Australia (west of Goondwini, southeastern Queensland)

(*a*) *Setting*: The profile was described in a broad plain near the junction of the McIntyre and Weir Rivers. Gilgai microrelief is common. Average annual rainfall is about 500 millimeters. Vegetation is an open forest with grass as ground cover.

(*b*) *Profile description*:

A_{11}	0-30 cm	Very dark gray (10YR 3/1) light clay, dark gray (10YR 4/1) when dry; weak fine subangular blocky structure (dry); plastic.
A_{12}	30-50 cm	Dark gray (2.5Y 4/1) clay, gray (2.5Y 5/1) when dry; massive or nearly so; plastic.
AC_{ca}	50-110 cm	Very dark gray (5Y 3/1) silty clay, dark gray (5Y 4/1) when dry; massive, extremely hard; many coarse $CaCO_3$ concretions; few medium black concretions.
C_{ca}	110-175 cm	Dark olive-gray (5Y 3/2) silty clay, dark olive-gray (5Y 4/2) when dry; weak fine blocky structure; extremely hard; many coarse $CaCO_3$ concretions.
D	175 cm plus	Very dark grayish-brown (10YR 3/2) silty clay loam, dark grayish-brown (10YR 4/2) when dry; weak fine blocky structure; friable.

(*c*) *Additional notes*: Colors given first are for moist conditions; those listed second are for dry conditions. Deep cracks are formed in the soil as it dries. The profile description is from J. Thorp with the addition of horizon designations.

19. Lualualei clay (dark magnesium clay) - United States (near Waianae, Oahu, Hawaii)

(*a*) *Setting*: The profile site is a gently sloping smooth valley floor at an elevation of about 15 meters, approximately 2 kilometers inland from the ocean. The average annual rainfall is 50 millimeters and the mean temperatures 22°C in January and 26°C in July. The site had been used for cotton but was now mainly in truck crops.

(*b*) *Profile description*:

A_{1p}	0-10 cm	Very dark gray (10YR 3/1) clay, dark gray (10YR 4/1) when dry; weak fine platy breaking to weak very fine granular structure; very hard, firm, very plastic and very sticky; abrupt smooth boundary.
A_{12}	10-22 cm	Very dark gray (10YR 3/1) clay, dark gray (10YR 4/1) when dry; weak very coarse irregular prismatic breaking to weak fine granular structure; extremely hard, very firm, very plastic and very sticky; slickensides common; clear wavy boundary.
A_{13}	22-60 cm	Very dark gray (10YR 3/1) clay, dark gray (10YR 4/1) when dry; weak very coarse irregular prismatic breaking to weak coarse irregular blocky structure; extremely hard, firm, very plastic and very sticky; many slickensides; ped faces shiny; clear wavy boundary.
D_{cs}	60-92 cm	Dark gray (10YR 4/1) sandy clay loam with some gravel and cobbles; very weak coarse prismatic breaking to weak medium granular structure; slightly hard, firm, plastic and sticky; many streaks and pockets of white gypsum crystals; few patchy clay films; clear wavy boundary.
A_b	92-110 cm	Very dark gray (10YR 3/1) sandy clay loam; moderate medium and coarse prismatic breaking to moderate medium blocky structure; hard, friable, plastic and sticky; coarse gypsum crystals common; clear boundary.
B_b	110-135 cm	Very dark gray (7.5Y 3/1) clay; strong medium and coarse angular blocky structure; very hard, very firm, very plastic and very sticky; many slickensides; ped faces shiny; coarse gypsum crystals common.

(*c*) *Additional notes*: Colors are given for moist conditions unless otherwise indicated. The soil is moderately well to somewhat poorly drained with very slow permeability. When dry the surface layer has many cracks that are 2 to 5 centimeters wide but when wet it seals over. Parent material is stratified alluvium. Sediments have come from basic igneous rocks but the soil does not seem to have been formed in residuum from such rocks. The profile description is from M. Johnson.

20. Gomensoro silty clay loam (Grumusol) - Uruguay (along Route 30 about 500 meters east of Masoller, near the Brazilian border)

(*a*) *Setting*: The profile occurs in level to very gently sloping uplands where surface drainage is slow. Vegetation consisted of prairie grass.

(*b*) *Profile description*:

A_{11}	0-18 cm	Black (10YR 2/1) silty clay loam; moderate fine granular structure; friable; clear boundary.
A_{12}	18-40 cm	Black (10YR 2/1) silty clay; moderate medium subangular blocky structure; very hard, very firm, very plastic; gradual boundary.
A_{13}	40-80 cm	Black (10YR 2/1) silty clay; moderate medium blocky structure; very hard, very firm, very plastic; some slickensides; gradual boundary.
AC	80-95 cm	Black (10YR 2/1) silty clay; moderate medium blocky structure; very firm, very plastic; some basalt fragments; abrupt boundary.
D_r	95 cm plus	Hard and massive basalt.

(*c*) *Additional notes*: Colors are for moist conditions. Internal drainage of the soil is very slow. The profile description is from F. F. Riecken.

21. San Vincente clay (Grumusol) - Chile (about 3 kilometers northeast of San Vincente, O'Higgins Province)

(*a*) *Setting*: The profile was described in a nearly level basin, approximately 200 meters above sea level. Average rainfall is believed to be slightly below 350 millimeters. The site was in grain stubble when the description was prepared.

(*b*) *Profile description:*

A_{1p}	0-18 cm	Very dark brown (10YR 2/2) clay, mottled with brown (7.5YR 4/4) along root channels, very dark grayish-brown (10YR 3/2) when dry; weak fine angular blocky structure; very hard, firm, plastic and sticky; roots common; pH 7.4; gradual boundary.
A_{12}	18-50 cm	Very dark brown (10YR 2/2) clay, very dark gray (10YR 3/1) when dry; moderate to weak fine angular blocky structure; very hard, firm, very plastic and very sticky; some small shiny black concretions; few pebbles; roots common; pH 7.6; gradual boundary.
AC	50-70 cm	Black (10YR 2/1) clay, very dark gray (10YR 3/1) when dry; moderate to strong fine angular blocky structure; very hard, firm, very plastic and very sticky; many small shiny black concretions; few roots; pH 7.8; gradual boundary.

C	70 cm plus	Black (10YR 2/1) clay, very dark gray (10YR 3/1) when dry; moderate to weak fine angular blocky structure; very hard, firm, very plastic and very sticky; pebbles common to many; pH 7.9.

(*c*) *Additional notes*: Colors are given for both moist and dry soil conditions, with the former listed first. The color and structure of the A_{1p} horizon are believed to have been affected by additions of silt from irrigation water. The profile description is from R. C. Roberts.

22. Grumusol from Pampeano loess - Argentina (northeast part of Entre Rios Province)

(*a*) *Setting*: The soil occurs in an extensive plain at an elevation of approximately 40 meters above sea level. Relief is mild, and dominant slopes in the locality are between 1 and 6 percent in gradient. Striped gilgai microrelief is common. Rainfall in the area is 1,200 millimeters. Natural vegetation is prairie grass.

(*b*) *Profile description*:

A_{11}	0-20 cm	Black (10YR 2/1) clay; moderate medium granular to moderate fine subangular blocky structure; very hard, firm, very plastic; pH 6.5; smooth gradual boundary.
A_{12}	20-50 cm	Black (10YR 2/1) clay; moderate medium to coarse subangular blocky structure; very hard, firm, plastic and sticky; pH 7.0; smooth gradual boundary.
A_{13}	50-75 cm	Black (10YR 2/1) clay; moderate medium to coarse angular blocky structure; very hard, very firm, plastic and sticky; slickensides common; pH 7.6; smooth clear boundary.
C_{ca}	75-100 cm	Black (10YR 2/1) clay; massive; very hard, firm to very firm; many $CaCO_3$ concretions, strongly calcareous; smooth clear boundary.
C	100-200 cm	Brown (7.5YR 5/2) clay; massive; hard, firm; few $CaCO_3$ concretions, moderately to strongly calcareous.

(*c*) *Additional notes*: Colors given are for moist conditions. Thickness of the A horizon ranges from 20 to 75 centimeters depending upon position of the soil with reference to ridges and depressions in the gilgai microrelief. Depth to carbonates ranges from 20 to 100 centimeters with carbonates nearest the surface on the ridges. The soil is moderately well to somewhat poorly drained with slow to very slow permeability. The profile description is from L. Farstad.

23. Grumusol from clay - Argentina (eastern part of Chaco Province)

(*a*) *Setting*: The soil occurs in a nearly level plain with an altitude of less than 150 meters above sea level. The Grumusols occur mainly on concave slopes with gradients of 1 percent or less. The average annual rainfall is 1,100 millimeters with distribution being rather uniform. Present vegetation is mainly coarse bunch grasses with some palms, though the area seems to have been forested originally.

(*b*) *Profile description*:

A_{11}	0-25 cm	Very dark gray (10YR 3/1) clay, gray (10YR 5/1) when dry; moderate fine and medium subangular blocky structure; hard, firm, very plastic and very sticky; pH 5.5; clear boundary.
A_{12}	25-42 cm	Very dark gray (10YR 3/1) to black (10YR 2/1) clay, very dark grayish-brown (10YR 3/2) when moist; moderate coarse angular blocky structure; very hard, very firm, very plastic and very sticky; slickensides evident; pH 6.5; clear boundary.
A_{13}	42-65 cm	Very dark gray (10YR 3/1) to very dark grayish-brown (10YR 3/2) clay, dark gray (10YR 4/1) when dry; moderate coarse angular blocky structure; extremely hard, very firm, very plastic and very sticky; slickensides common; pH 7.8; clear boundary.
C_{ca}	65-92 cm	Very dark gray (10YR 3/1) clay, dark gray (10YR 4/1) when moist; moderate coarse angular blocky structure; very hard, very firm, very plastic and very sticky; many $CaCO_3$ concretions; pH 8.0; clear boundary.
C	92-150 cm	Light brownish gray (10YR 6/2) silty clay to clay; massive; hard, firm, plastic and sticky; few $CaCO_3$ concretions; pH 8.0.

(*c*) *Additional notes*: Colors are given for both moist and dry conditions with the former listed first. If only one color is indicated, it applies to both moist and dry conditions. The soil is poorly to somewhat poorly drained with slow to very slow permeability. The profile description is from L. Farstad.

PROFILE DESCRIPTIONS OF LESS WET DARK CLAYS

The soils in this subdivision of the broad group of dark clays are mainly somewhat poorly drained or moderately well drained. So far as is known, none of the dark clays is well drained, because of the slow movement of water through the soil mass. The less wet dark clays lack evidence of wetness in the form of very low chromas, neutral or gley colors, mottling and the like. In the main, these soils occupy convex positions in landscapes of semiarid and subhumid regions. Few of them are found in humid regions.

24. Grumusol from shale - United States (near Altamont, Alameda County, California)

(*a*) *Setting*: The profile was described in a hilly upland approximately 215 meters above sea level. Local relief is measurable in meters. The profile site was a convex slope to the southeast with a gradient of 8 percent. The region has a Mediterranean climate with dry summers and moist winters. Average annual rainfall is approximately 350 millimeters.

(*b*) *Profile description*:

A_{11}	0-10 cm	Very dark grayish-brown (10YR 3/2) clay, dark grayish-brown (10YR 4/2) when dry; strong to moderate fine granular structure; very hard, firm, very plastic and sticky; clear smooth boundary.
A_{12}	10-38 cm	Very dark grayish-brown (10YR 3/2) clay, dark grayish-brown (10YR 4/2) when dry; moderate very coarse prismatic breaking to weak coarse subangular blocky structure; extremely hard, very firm, very plastic and very sticky; gradual wavy boundary.
A_{13}	38-60 cm	Very dark grayish-brown (10YR 3/2) clay, dark grayish-brown (10YR 4/2) when dry; moderate very coarse prismatic structure; extremely hard, very firm, very plastic and very sticky; few small $CaCO_3$ concretions, moderately calcareous; gradual wavy boundary.
AC	60-80 cm	Mottled very dark grayish-brown (10YR 3/2) and brown (10YR 4/3) clay, mottled dark grayish-brown (10YR 4/2) and brown (10YR 5/3) when dry; moderate very coarse prismatic structure; extremely hard, firm, very plastic and very sticky; calcareous; gradual wavy boundary.
AC_{ca}	80-100 cm	Dark yellowish-brown (10YR 4/4) clay, pale brown (10YR 6/3) when dry; dark streaks and pockets extend down into this horizon from one above; moderate very coarse prismatic structure; extremely hard, firm, very plastic and very sticky; many concretions and pockets of $CaCO_3$, strongly calcareous; gradual wavy boundary.
C_{ca}	100-125 cm	Grayish-brown (2.5Y 5/2) clay with many faint, medium, and coarse mottles of brown and yellowish-brown, light brownish-gray (2.5Y 5/2) mottled with pale brown and light yellowish-brown when dry; massive; many soft white pockets and few small concretions of $CaCO_3$; gradual wavy boundary.

D_r	125-175 cm	Olive-brown (2.5Y 4/3) weathered and fractured shale, light brownish-gray (2.5Y 6/2) when dry; $CaCO_3$ films along cracks, on rock fragment faces, and in pockets.

(*c*) *Additional notes*: Colors given are for both moist and dry conditions with the former listed first. At the time the soil was examined, it was not completely dry but had cracks 2 to 4 centimeters wide extending to depths of 30 to 45 centimeters. The soil is well drained, has rapid runoff, and has very slow permeability. The profile description is from W. M. Johnson.

25. Houston clay (Grumusol) - United States (Hunt County, Texas)

(*a*) *Setting*: This soil occurs in gently undulating erosional uplands, with local relief generally measurable in meters. Slopes, chiefly between 4 and 8 percent, are long and gilgai microrelief is common, especially on the lower parts of those slopes. Original vegetation was tall prairie grasses.

(*b*) *Profile description*:

A_{11}	0-25 cm	Black (5Y 2/2) clay, dark olive-gray (5Y 3/2) when dry; mixed subangular blocky and medium granular structure; hard, friable, plastic and very sticky; strongly calcareous; gradual wavy boundary.
A_{12}	25-66 cm	Dark olive (5Y 3/3) clay, olive (5Y 4/3) when dry; mixed weak medium granular and moderate fine blocky structure; very hard, very firm, very plastic and very sticky; few small $CaCO_3$ concretions, strongly calcareous; gradual smooth boundary.
AC	66-96 cm	Olive (5Y 4/3) clay with few to common medium distinct mottles of yellow (5Y 7/6), olive (5Y 5/3) with yellow (5Y 7/6) mottles when dry; weak coarse irregular blocky structure; very hard, very firm, very plastic and very sticky; large slickensides evident when slightly moist; few small $CaCO_3$ concretions, strongly calcareous; gradual smooth boundary.
C	96-132 cm	Pale olive (5Y 6/3) clay with many medium distinct mottles of light olive-gray (5Y 6/2); massive; very hard, very firm, plastic and sticky; large slickensides apparent when slightly moist; many small $CaCO_3$ concretions, strongly calcareous.

(*c*) *Additional notes*: Colors are given for both moist and dry conditions, with the former listed first, except for the C horizon where only dry color is given. The soil is moderately well drained with rapid runoff and slow to very slow permeability. The profile is commonly underlain at depths of 2 to 3 meters by strongly calcareous, almost impervious, gray and olive-gray clay which represents the parent material of the soil. The profile description is from H. Oakes and E. H. Templin.

26. Diablo clay (Grumusol) - United States (Alameda County, California)

(*a*) *Setting*: The profile was described in a hilly landscape about 255 meters above sea level. The site was on a plane slope facing to the north with a gradient of 25 percent. Present vegetation consists of annual grasses and weeds. The region has a Mediterranean climate with dry summers and moist winters, average annual rainfall being near 375 millimeters.

(*b*) *Profile description*:

A_{11}	0-18 cm	Very dark gray (5Y 3/1) clay, dark gray (5Y 4/1) when dry; mixed strong coarse prismatic and strong coarse and medium blocky structure; very hard, very firm, very plastic and very sticky; clear smooth boundary.
A_{12}	18-42 cm	Very dark gray (5Y 3/1) silty clay, dark gray (5Y 4/1) when dry; mixed moderate coarse prismatic and moderate coarse and medium blocky structure; very hard, very firm, very plastic and very sticky; few slickensides; few fine $CaCO_3$ concretions; clear smooth boundary.
A_{13}	42-70 cm	Mottled very dark gray (5Y 3/1) and dark olive-gray (5Y 3/2) silty clay, mottled dark gray (5Y 4/1) and olive-gray (5Y 4/2) when dry; mottles are fine, faint and many; mixed moderate coarse prismatic and moderate coarse blocky structure; very hard, very firm, plastic and sticky; few slickensides; few fine concretions and mycelial films of $CaCO_3$ in lower part, slightly calcareous; clear wavy boundary.
C_{ca}	70-120 cm	Greenish-gray (5GY 5/1) heavy silty clay loam, greenish-gray (5GY 6/1) when dry; tongues and pockets of darker silty clay extend down from horizon above; weak medium and fine subangular blocky structure; hard, firm, plastic and sticky; few slickensides; few fine concretions and many mycelial films of $CaCO_3$; moderately calcareous; abrupt smooth lower boundary.
D_r	120 cm plus	Greenish-gray (5GY 5/1) disintegrated rock fragments with light gray to white films on fracture faces, greenish-gray (5GY 6/1) when dry; $CaCO_3$

coatings on faces of many rock fragments, interiors of which are also weakly calcareous.

(*c*) *Additional notes*: Colors are given for both moist and dry conditions with the former given first. The surface layer, about 3 centimeters thick, dries into an evident crust which is light gray (5Y 6/1) in color. Parent materials for the soil are calcareous interbedded shales and fine sandstones. The soil is well drained with slow surface runoff and rapid percolation when it is dry and deeply cracked but with rapid surface runoff and very slow permeability after it becomes wet enough for the cracks to close. The profile description is from R. Ulrich.

27. Springerville stony silty clay (Grumusol) - United States (Coconino County, Arizona)

(*a*) *Setting*: The profile was described near the crest of a low ridge on a rolling basalt plateau at an elevation of approximately 2,200 meters. The site was a convex slope of 1.5 percent facing south; it supports a sparse cover of grasses and weeds and a few stunted junipers. Average rainfall is estimated to be 550 millimeters.

(*b*) *Profile description*:

A_{11}	0-7 cm	Dark brown (7.5YR 3/2) stony silty clay, brown (7.5YR 4/2) when dry; moderate medium and coarse prismatic structure breaking first to moderate coarse and medium subangular blocky and finally to strong fine granular structure; very hard, very firm, very plastic and very sticky; many roots; few fine and medium black concretions; common fine and very fine tubular pores; clear wavy boundary.
A_{12}	7-23 cm	Dark brown (7.5YR 3/2) silty clay or clay, brown (7.5YR 4/2) when dry; strong very coarse prismatic structure breaking first to moderate coarse and medium subangular blocky structure and finally to weak fine and very fine granular structure; extremely hard, very firm, very plastic and very sticky; roots common; few fine and medium black concretions; gradual wavy boundary.
C_1	23-65 cm	Dark brown (7.5YR 3/2) silty clay or clay, brown (7.5YR 4/2) when dry; moderate to weak coarse prismatic structure breaking to moderate coarse and medium irregular blocky structure; many slickensides oriented at angles of 25° to 45° to the horizontal; few roots; few to common fine black concretions; few coarse $CaCO_3$ concretions; few fine and very fine tubular pores; gradual wavy boundary.
C_{ca}	65-88 cm	Dark brown (7.5YR 3/2) silty clay mottled with white, brown (7.5YR 4/2) mottled when dry; white mottles are broken lumps and concretions

		of $CaCO_3$; very coarse irregular platy structure due to many intersecting slickensides; large peds breaking to weak coarse and medium irregular blocks; very hard, firm, plastic and sticky; coarse to very coarse lumps and concretions of $CaCO_3$ common; few fine black concretions; moderately calcareous; abrupt irregular boundary.
D_r	88 cm plus	Weathered dark gray olivine basalt that is slightly magnetic.

(c) *Additional notes*: Colors are given for both moist and dry conditions with the former listed first. A surface layer about 3 to 6 millimeters thick is a faint crust, below which is a slightly thicker layer with strong very fine granular structure. The soil surface is stony to very stony, the stones being subrounded fragments of basalt 2 to 35 centimeters in diameter. Hard pieces of basalt ranging in size from 3 millimeters to 5 centimeters in diameter and showing signs of weathering are scattered throughout the profile. Carbonate concretions may occur erratically on the surface. The soil is well drained with medium runoff and very slow permeability. The profile description is from W. M. Johnson, J. Cady and M. James.

28. Normal Tropical Black Earth - Ghana (near Post 29, Accra-Lagos Road)

(a) *Setting*: The profile was described on the middle of a slope in very gently undulating upland. Slope gradient is less than 1 percent, and surface drainage is slow. The region is part of the coastal plain in which average annual rainfall ranges from 625 to 875 millimeters. Vegetation consists of tussocky medium grasses without trees.

(b) *Profile description*:

A_{11}	0-10 cm	Dark grayish-brown (2.5Y 4/2) clay; weak medium subangular blocky structure; very hard, very plastic and very sticky; few coarse quartz grains; many grass roots; few irregular $CaCO_3$ concretions; pH 8.0; gradual boundary.
A_{12}	10-33 cm	Dark grayish-brown (10YR 4/2) clay; weak very coarse subangular blocky structure; very hard, very plastic and very sticky; occasional coarse quartz grains; occasional ironstone concretions; few grass roots; many small $CaCO_3$ concretions; pH 8.1; gradual boundary.
A_{13}	33-72 cm	Dark grayish-brown (2.5Y 4/2) clay; weak very coarse subangular blocky structure; very hard, very plastic and very sticky; occasional coarse

PROFILE NO. 28. – NORMAL TROPICAL BLACK EARTH – GHANA (NEAR POST 29, ACCRA-LAGOS ROAD)

Horizon	Depth cm	Mechanical analysis (international) %						Organic matter %				Moisture
		Gross				Fine earth		C	N	C/N	OM	Air-dry soil %
		Stones	Coarse gravel	Fine gravel	Fine earth	Silt	Clay					
A_{11}	0–10	Nil	4.1	1.1	94.8	9.09	45.29	0.959	0.085	11.28	1.65	9.78
A_{12}	10–33	Nil	1.9	1.1	97.0	9.20	49.06	0.789	0.062	12.73	1.36	10.00
A_{13}	33–72	Nil	8.4	1.4	90.2	9.35	49.67	0.489	0.041	11.93	0.84	10.25
C_{1ca}	72–90	Nil	20.8	Nil	79.2	8.70	46.77	0.410	0.031	13.23	0.71	9.91
C_{2ca}	90–122	Nil	23.2	0.2	76.6	10.70	21.88	0.097	0.010	9.70	0.17	6.40
C_3	122–165	24.6	3.7	0.3	71.4	10.92	12.17	N.D.	N.D.	N.D.	N.D.	5.05

Horizon	Depth cm	pH	$CaCO_3$ %	Exchange capacity[1]	Exchange complex me/100 g oven-dry soil					Total bases	Conductivity 25° mmho × 10^6	Phosphorus	
					Ca	Mg	Mn	K	Na			Total	Truog
A_{11}	0–10	8.0	1.50	52.79	34.39[2]	17.04	N.D.	0.24	0.55	52.48	170.8	261	24
A_{12}	10–33	8.1	2.80	53.11	N.D.	N.D.	N.D.	0.26	0.91	N.D.	214.9	226	21
A_{13}	33–72	8.2	3.60	50.36	N.D.	N.D.	N.D.	0.15	1.67	N.D.	230.0	213	24
C_{1ca}	72–90	8.3	17.8	52.62	N.D.	N.D.	N.D.	0.20	2.75	N.D.	341.5	233	N.D.
C_{2ca}	90–122	8.6	1.02	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	208.2	1 107	N.D.
C_3	122–165	8.8	0.75	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	237.9	1 565	N.D.

[1] Ammonium acetate: pH 7.0.
[2] Includes 0.26 me Strontium.
N.D. = no data.

		quartz grains; occasional ironstone concretions; many small irregular $CaCO_3$ concretions; pH 8.2; gradual boundary.
C_{1ca}	72-90 cm	Grayish-brown (2.5Y 5/2) light clay; massive in place but becoming granular on exposure; very hard, friable; few ironstone concretions; much $CaCO_3$ in finely divided and concretionary forms; pH 8.3; clear boundary.
C_{2ca}	90-122 cm	Light brownish-gray (2.5Y 6/2) light clay; massive; much powdery and concretionary $CaCO_3$; pH 8.6.
C_3	122-165 cm	Multicolored loamy weathered garnet-hornblende gneiss; pH 8.8.

(c) *Additional notes*: Moisture conditions at which colors were identified are not known but it is presumed that the soil was dry. The profiles of these soils tend to be uniform down to the saprolite or weathered rock material. When dry, the soil cracks, apparently down to the saprolite, to form very coarse prisms about 30 to 45 centimeters in diameter. At the surface, these prisms are usually granular in structure to a depth of less than 3 centimeters. The profile description is from H. Brammer and horizon designations have been added.

29. Argile noire tropicale - Congo (near Limama INEAC Experiment Station, Lufira Valley, Katanga)

(a) *Setting*: Soils of this kind occur in the alluvial plains of rift valleys and in basins or depressions, under an average annual rainfall of about 900 millimeters. The dry season, lasting four or five months, is very pronounced. This profile is located in flat topography at an elevation of 850 meters.

(b) *Profile description*:

A_{11}	0-10 cm	Black (2.5Y 2/2) heavy clay with faint yellowish-red mottles; strong fine angular blocky structure; many roots; gradual boundary.
A_{12}	10-40 cm	Very dark grayish-brown (2.5Y 3/2) heavy clay; strong medium prismatic structure; very hard, very firm, very plastic; many roots; gradual boundary.
AC	40-80 cm	Dark grayish-brown (2.5Y 4/2) heavy clay; massive when wet, moderate coarse prismatic structure when dry; prominent slickensides within prisms; very hard, very firm, very plastic; few gypsum crystals, few $CaCO_3$ concretions.
C	80-150 cm	Dark yellowish-brown (10YR 4/4) heavy clay; massive when wet, prominent slickensides when dry; hard, very firm, very plastic; some gypsum and carbonates.

(*c*) *Additional notes*: Although moisture conditions are not stated, colors seem to have been identified when the soil was moist. Slickensides in the soil mass are faces that are roughly planed, commonly marked by slight grooves and have been formed by the sliding of one face past another during the contraction and expansion of the soil with changing moisture content. The profile description is from C. Sys.

30. Typical Regur soil from traprock - India (State Experimental Farm at Achalpur, Madhya Pradesh)

(*a*) *Setting*: The farm lies near the edge of the very gently undulating plain that comprises the extensive cotton-growing section of western Madhya Pradesh. Hills rising about 100 meters above the level of the plain are within sight to the north and northeast. Occasional belts or groups of lower hillocks, usually a few meters above the general level, occur locally in the plain itself between Achalpur and Amraoti. For the most part, however, local relief is measurable in meters and the slopes are long and gentle. The profile pit was on a very gentle slope with a gradient of about 2 percent. By far the greatest part of the land is in cultivation.

(*b*) *Profile description*:

A_{1p}	0-20 cm	Very dark grayish-brown (10YR 3/2) clay; moderate medium granular structure; slightly hard, friable, plastic and sticky; few fine roots; common to few medium and coarse $CaCO_3$ concretions; few fine traprock pebbles; clear boundary.
A_{12}	20-75 cm	Very dark grayish-brown (10YR 3/2) clay; compound structure of moderate fine blocks crushing under some pressure to moderate medium granules; hard, friable, plastic and sticky; few fine roots; few medium $CaCO_3$ concretions; few fine traprock pebbles; gradual boundary.
AC	75-95 cm	Dark grayish-brown (10YR 4/2) to brown (10YR 4/3) clay; weak fine to medium blocky structure; slightly hard, friable, plastic and sticky; few fine roots; few medium $CaCO_3$ concretions; few fine traprock pebbles; gradual transition from the solum to the saprolite.
C_{ca}	95-130 cm	Mottled light yellowish-brown (10YR 6/4), light brownish-gray (10YR 6/2) and pale brown (10YR 7/2) loam; mottles are fine to medium, distinct and numerous; massive in place but weak fine granular when removed; soft, friable, slightly plastic; light-colored patches seem to be mainly lime accretions; few roots; few traprock pebbles; apparently saprolite with $CaCO_3$ accumulation.

PROFILE NO. 29. – ARGILE NOIRE TROPICALE – CONGO
(NEAR LIMAMA INEAC EXPERIMENT STATION, LUFIRA VALLEY, KATANGA)

Horizon	Depth cm	Organic matter %		pH	Sorptive complex in me/100 g			Soluble salts micromhs	$CaCO_3$ %	$CaSO_4$ %
					Test HCl N/20		Tc a			
		C	N		Ca	K				
A_{11}	0–10	3.20	0.290	5.4	8.6	0.13	19.1	89	Nil	0.10
A_{12}	10–40	1.68	0.167	5.9	7.7	0.07	18.2	63	0.8	0.09
AC	40–80	0.74	0.087	6.6	4.6	0.05	19.6	654	1.0	0.37
C	80–150			7.6	17.0	0.06	40.4	3291	1.4	2.37

C 130-200 cm Dark yellowish-brown (10YR 4/4) loam flecked and mottled with light brownish-gray (10YR 6/2); mottles are distinct, fine to medium and common; essentially massive in place but weak fine granular when removed; soft, friable, slightly plastic; few traprock pebbles.

(*c*) *Additional notes*: The colors are for moist soil conditions. The C_{ca} horizon (upper part of the saprolite) is prominent on two sides of the pit but not on the other two. It is faint or barely evident at the bottom of the solum in a nearby pit in the same soil type. Checking or cracking marks the solum on all sides of this day-old pit. The cracks are 2 to 4 centimeters apart and tend to form squares, which suggest that checking operates in the formation of blocky structure in this soil. In the classification used in tax assessment for rural lands this soil has the local name of Morand I. The profile description is from R. W. Simonson.

31. Regur soil of medium depth from traprock - India (State Experimental Farm, 8 kilometers east of Betul, Madhya Pradesh)

(*a*) *Setting*: The farm lies on an extensive plateau in the northern part of the State which is some meters above the level of the general plain in western and central Madhya Pradesh. The surface of the plateau consists of low broad ridges separated by shallow valleys. Slopes are long and gentle and local relief is measurable in meters. The profile pit was on the upper part of a slope facing southeast with a gradient of about 3 percent. Over much of this plateau the Regur soils seem to be restricted to lower slopes and concave surfaces. Most of the land is under cultivation.

(*b*) *Profile description*:

A_{11} 0-25 cm Very dark grayish-brown (10YR 3/2) clay; mixed moderate medium granular and very fine blocky structure; slightly hard, friable, plastic and sticky; few medium and coarse $CaCO_3$ concretions; few medium black concretions; gradual boundary.

A_{12} 25-65 cm Dark grayish-brown (2.5Y 4/2) clay; compound structure of strong fine blocky peds that crush readily to moderate medium granular peds; hard, firm, plastic and sticky; few blocky peds show slickensides; few very fine $CaCO_3$ concretions; few medium black concretions; gradual boundary.

AC 65-110 cm Olive-gray (5Y 4/2) clay; strong fine to medium blocky peds crushing with difficulty to moderate medium granular peds; hard, firm, very plastic and very sticky; slickensides are common on the blocky peds; wavy boundary.

C	110-180 cm	Variegated light olive-brown (2.5Y 5/4) and olive-gray (5Y 4/2) clay which becomes more uniformly light olive-brown in color with increasing depth; weak fine blocks crushing under moderate pressure to mixture of weak very fine blocky and moderate medium granular peds; hard, firm, plastic and sticky; few very coarse $CaCO_3$ concretions of irregular form.

(*c*) *Additional notes*: Colors are for moist soil conditions. A few traprock pebbles are present in all horizons, and have dark coatings which make them look like concretions until they are broken. The profile is calcareous throughout, though $CaCO_3$ concretions are absent from the C_1 horizon. On one side of the pit, partial involution of dark and light-colored soil materials has occurred at a depth of 1 meter. In a nearby second pit, cores of darker material, each about the size and shape of a former insect channel, extend down into the C horizon. This profile represents a soil known locally as Morand II in the classification used for tax assessment. The profile description is from R. W. Simonson.

32. Shallow Regur soil from traprock - India (near buildings on Malegaon Farm Dry-Farming Research Station, Sholapur, Bombay State)

(*a*) *Setting:* This farm lies in an extensive plain which consists of broad gently-rounded ridges separated by shallow valleys. Slopes are commonly long and gentle with gradients below 5 percent and local relief is of the order of a few meters. The profile pit was on a very gentle slope of approximately 1 percent. Most of the land is under cultivation, with sorghum as the principal crop.

(*b*) *Profile description*:

A_{1p}	0-23 cm	Very dark grayish-brown (10YR 3/2) clay which becomes very dark gray (10YR 3/1) when it first begins to dry and then changes to dark gray (10YR 4/1) when fully dry; weak fine granular structure; very hard, friable, plastic and sticky; few coarse to medium $CaCO_3$ concretions; gradual boundary.
A_{12}	23-45 cm	Very dark grayish-brown (10YR 3/2) clay which becomes very dark gray (10YR 3/1) when it first starts to dry and then changes to dark gray (10YR 4/1) when fully dry; compound structure of moderate fine blocky peds with evident slickensides that crush readily to mixed weak and moderate medium granular peds; very hard, firm, very plastic and very sticky; few coarse to medium $CaCO_3$ concretions; gradual boundary.
AC	45-58 cm	Very dark gray (10YR 3/1) clay, leaning toward very dark grayish-brown (10YR 3/2); compound structure of strong medium to fine blocky peds

that crush under considerable pressure to weak fine granular peds; very hard, firm, very plastic and very sticky; slickensides are evident on the upper and lower surfaces of the blocky peds which are slightly elongated horizontally; few coarse $CaCO_3$ concretions; gradual wavy boundary.

C_{ca} 58-75 cm The saprolite or weathered rock with marked accumulation of carbonate is especially in upper part. Now largely loose, this is a loam with a variegated color pattern of yellowish-brown, pale brown and light gray.

(*c*) *Additional notes*: Colors are for moist soil conditions. Effervescence is general throughout the profile but is strong only in the C_{ca} horizon which is the upper part of the saprolite. The calcium carbonate is finely disseminated for the most part, though a few concretions are distributed through the solum. This profile represents Type A in the classification of Basu and Sirur (22). The profile description is from R. W. Simonson.

33. Deep Regur soil from alluvium - India (Powarkheda Experimental Farm, 8 kilometers south of Hosangabad, Madhya Pradesh)

(*a*) *Setting*: This is part of a nearly level landscape along the Narbada River. The surface is essentially level at the profile pit, and the local relief is generally measurable in centimeters. The level landscape, which parallels the river, seems to be a former flood-plain. The experimental farm is about 8 kilometers south of the river channel and about as far north of the dissected margins of the Betul plateau. Low sandstone mountains lie north of the river and the same rocks outcrop locally in a few low hills within the flood-plain south of the river.

(*b*) *Profile description*:

A_{1p} 0-25 cm Dark grayish-brown (2.5Y 4/2) heavy clay; weak medium granular structure; hard, firm, very plastic and very sticky; few medium black concretions; medium $CaCO_3$ concretions common; clear boundary.

A_{12} 25-105 cm Dark olive-gray (5Y 3/2) heavy clay which becomes olive-gray (5Y 4/2) when crushed; compound structure of moderate medium blocky peds crushing with difficulty to a mixture of moderate coarse granular and weak fine blocky peds; very hard, firm, very plastic and very sticky; blocky peds have slickensides in deeper part of the horizon; few medium black concretions; few medium $CaCO_3$ concretions; gradual boundary.

C	105-190 cm	Dark olive-gray (5Y 3/2) heavy clay which becomes olive-gray (5Y 4/2 to 4/1) when crushed; compound structure of weak medium to coarse blocky peds that crush with moderate pressure to a mixture of weak medium granular and weak medium blocky peds; hard, firm, very plastic and very sticky; few medium $CaCO_3$ concretions.

(*c*) *Additional notes*: Colors are for moist soil conditions. The alluvial nature of the sediments is indicated by the lenses and pockets of sandy clay loam and sandy clay in the sides of two of the four pits on the experimental farm and by the common occurrence of basalt and sandstone pebbles in the clay. Some of the pebbles also consist of unidentified rock species. In the bottom corner of one pit was a pocket of olive-gray (5Y 4/2) clay containing many very coarse black concretions. A few roots extend the full depth of each pit, but numbers are small below the A_{1p} horizon. In the classification for tax assessment, this soil is known as Mariyar. The profile description is from R. W. Simonson.

34. Regur soil from colluvium - India (Rudrur Experimental Farm, about 24 kilometers southwest of Nizambad, Hyderabad State)

(*a*) *Setting*: The experimental farm lies in a broad plain with mixed relief, local differences in elevation being measurable in meters and in tens of meters. Low hills and ridges, usually tens of meters higher than the general level, rise above the plain in places as though they were erosional remnants. The site of the profile pit is the level floor of a valley or trough about 3 kilometers wide between granitic ridges that rise some tens of meters above it. The Regur soils commonly occur in these troughs or valleys and in other parts of the plain where the land surface is smooth or concave. They do not seem to run up on the slopes of hills and ridges.

(*b*) *Profile description*:

A_{1p}	0-20 cm	Dark grayish-brown (2.5Y 4/2) clay; weak fine to medium granular structure; hard, friable to firm, plastic and sticky; few fine roots; fine quartz pebbles common; few medium lime concretions; gradual boundary.
A_{12}	20-60 cm	Dark grayish-brown (2.5Y 4/2) to olive (5Y 4/3) clay; almost massive in place but with very weak medium granular structure; very hard, firm, very plastic, very sticky; few quartz pebbles; some pockets of sand; few medium $CaCO_3$ concretions; gradual boundary.
AC	60-90 cm	Olive-gray (5Y 4/2) clay; weak coarse to medium blocky structure tending toward being platy in

the lower part; very hard, very firm, very plastic and very sticky; blocky peds have slickensides, some small pockets of sandy loam; few fine quartz pebbles; few medium $CaCO_3$ concretions.

(*c*) *Additional notes*: Colors are given for moist conditions. This profile was described at approximately the same site as profile No. 7 among those studied by Desai (55) and by Nagelschmidt, Desai and Muir (165). As noted in those earlier studies, the soil is mildly alkaline throughout but contains concretions rather than finely divided $CaCO_3$. Pockets of sandy material, discontinuous within the individual horizons, and a number of rock species among the pebbles present indicate that sediments came from several sources. The experimental farm lies near the margin between regions of granite and basalt. The profile description is from R. W. Simonson.

35. Irving clay, linear gilgai complex (Black Earth) - Australia (Hodgson Parish, Aubigny Country, Queensland)

(*a*) *Setting*: The profile was described on colluvial material covering a concave slope with a gradient of about 3 percent. The site is about 430 meters above sea level and has gilgai microrelief. Parent materials are clays transported after having been weathered from basalt. Natural vegetation is grass and the land is used for grazing cattle.

(*b*) *Profile description*:

A_{11}	0-8 cm	Very dark gray (10YR 3/1) heavy clay; mixed strong medium granular and strong medium to coarse irregular blocky structure; very hard, very firm, plastic; few quartz gravels; pH 7.4.
A_{12}	8-40 cm	Very dark grayish-brown (10YR 3/2) heavy clay; strong medium to coarse irregular blocky structure; very hard, firm to very firm, plastic; few basalt gravels; pH 7.9.
A_{13}	40-68 cm	Very dark grayish-brown (10YR 3/2) to very dark brown (10YR 2/2) heavy clay; moderate very coarse irregular blocky structure; very hard, firm to very firm, plastic; traces of $CaCO_3$ as smears and concretions; pH 8.5.
AC	68-85 cm	Dark brown (7.5YR 4/3) heavy clay with fine mottles; massive to weak coarse irregular blocky structure; very hard, firm to very firm, plastic; few $CaCO_3$ concretions; pH 8.6.
C_1	85-145 cm	Reddish-brown (5YR 4/3) clay with faint mottles; moderate medium to coarse blocky structure; very hard, firm, plastic; ped faces are shiny; few coarse $CaCO_3$ concretions; pH 8.7.

PROFILE NO. 35. – IRVING CLAY, LINEAR GILGAI COMPLEX (BLACK EARTH) – AUSTRALIA
(HODGSON PARISH, AUBIGNY COUNTRY, QUEENSLAND)

Horizon	Depth cm	pH	Moist	Ignition	$CaCO_3$	C	N	P	TSS	NaCl	Exchangeable cations (me %)				
											Ca	Mg	K	Na	H
A_{11}	0–8	7.4	10.3	11.8		2.8	0.19	0.12	0.05	0.02	32.7	29.2	1.9	1.2	7.4
A_{12}	8–40	7.9	10.4	10.4	0.05	2.3	0.14		0.05	0.02					
A_{13}	40–68	8.5	8.0	9.9	0.14	1.3		0.13	0.13	0.06	27.9	31.7	0.67	5.5	
AC	68–85	8.6	7.8	8.7	2.1	0.6			0.29	0.13					
C_1	85–145	8.7	10.0	10.7	8.5	0.2			0.33	0.15	18.6	27.0	0.74	4.8	
C_2	145–270	8.8	10.0	9.3	5.1	0.04		0.09	0.34	0.13					

Horizon	Depth cm	Mechanical analysis				
		Gravel	Coarse sand	Fine sand	Sand	Clay
A_{11}	0–8	6	<1	8	17	69
A_{12}	8–40	<0.2	<1	9	18	71
A_{13}	40–68	<0.2	<1	9	20	68
AC	68–85	<0.2	<1	10	30	55
C_1	85–145	2.2	1	9	14	69
C_2	145–270	4.7	<1	10	4	81

C_2	145-270 cm	Reddish-brown (5YR 4/3) clay with few pockets that are light reddish-brown; moderate fine to medium blocky structure; very hard, firm, plastic; ped faces are shiny; few basalt gravels; few coarse $CaCO_3$ concretions; pH 8.8.

(c) *Additional notes*: Moisture conditions under which colors were identified are not known, but it seems probable that the soil was fairly dry. Internal drainage is slow and external drainage good. The profile description was provided by J. K. Taylor with the horizon designations added.

36. Black Earth - Australia (on the outskirts of Hobart, Tasmania)

(a) *Setting*: The profile site is at an elevation of 100 meters above sea level with a slope of 17 percent to the north. This is on one side of a ridge running up to 330 meters. The land surface is smooth except for a few dolerite boulders. The immediate locality is being occupied by suburban homes.

(b) *Profile description*:

A_{11}	0-12 cm	Black (10YR 2/1) light clay; moderate medium irregular blocky structure breaking to moderate medium granules; firm to friable; some dolerite pieces; pH 6.8.
A_{12}	12-25 cm	Black (10YR 2/1) clay; weak very coarse blocky structure; very hard, firm, very plastic; pH 7.2.
AC	25-48 cm	Very dark grayish-brown (2.5Y 3/2) clay with some white specks; weak very coarse blocky structure; very hard, firm, plastic; some dolerite fragments of medium blocky size; pH 7.7.
C_1	48-60 cm	Light olive-brown (2.5Y 5/6) clay with white specks; massive; hard, friable, plastic; some weathered dolerite grains and stones; few $CaCO_3$ concretions; pH 8.4.
C_2	60-108 cm	Yellow (2.5Y 7/6) clay with veins and pockets of $CaCO_3$; friable to very friable; pH 8.8.

(c) *Additional notes*: Colors are for moist conditions, except perhaps for the deepest horizons, which may have been dry. External drainage of the soil is good and internal drainage slow. The profile description is from J. K. Taylor and horizon designations have been added.

PROFILE NO. 36. – BLACK EARTH – AUSTRALIA (ON THE OUTSKIRTS OF HOBART, TASMANIA)

Horizon	Depth cm	pH	Moist	Ignition	$CaCO_3$	C	N	P	NaCl	Exchangeable cations					
										Ca	Mg	K	Na	H	Total
A_{11}	0–12	6.8	11.2	15.4		4.3	0.38	0.01	0.02						
A_{12}	12–25	7.2	11.2	10.3		2.0	0.20	0.01	0.02	33.1	18.4	0.16	1.4	7.4	60.4
AC	25–48	7.7	12.6	7.7	<0.01	0.9	0.10		0.02	27.6	23.2	0.09	1.8	3.9	56.6
C_1	48–60	8.4	12.2	7.1	0.01	0.4	0.04		0.03						
C_2	60–78	8.8	13.6	7.3	0.23	0.2			0.08						
C_3	78–108	8.7	10.7	6.7	3.22	0.2			0.17						

Horizon	Depth cm	Mechanical analysis				
		Gravel	Coarse sand	Fine sand	Sand	Clay
A_{11}	0–12	1	7.4	34.3	15.0	40.0
A_{12}	12–25	2	5.4	28.8	10.5	50.0
AC	25–48		9.3	25.0	11.0	54.0
C_1	48–60		9.2	19.9	7.0	42.0
C_2	60–78		23.4	22.4	23.0	29.9
C_3	78–108		27.9	20.0	11.0	17.0

37. Janiember clay (Gray Soil of Heavy Texture) - Australia (six kilometers west of the village of Prairie, northern Victoria)

(*a*) *Setting*: The profile was described in the center of a broad plain with gilgai microrelief. This is a body of clayey alluvium, considered to be a riverine deposit, south of the Murray River. Now in pasture, the area supports savanna vegetation with many trees.

(*b*) *Profile description*:

A_{11}	0-8 cm	Dark grayish-brown (2.5Y 4/2) clay, grayish-brown (2.5Y 5/2) when dry; moderate medium to fine blocky structure; few $CaCO_3$ concretions.
A_{12}	8-25 cm	Olive-gray (5Y 4/2) heavy clay, olive-gray (5Y 5/2) when dry; moderate medium blocky structure; few $CaCO_3$ concretions.
A_{13}	25-40 cm	Olive-gray (5Y 5/2) heavy clay, light olive-gray (5Y 6/2) when dry; moderate medium to fine blocky structure; few $CaCO_3$ concretions.
C	40-180 cm	Pale olive (2.5Y 6/3) clay; weak medium blocky structure; few $CaCO_3$ concretions.

(*c*) *Additional notes*: Colors are given for both moist and dry conditions, with the former listed first. The profile description is from J. Thorp and horizon designations have been added.

38. Tala silty clay (Grumusol) - Uruguay (Molinelli Colonia, San Jacinto, Canelones Department, southwestern Uruguay)

(*a*) *Setting*: The profile occurs in gently undulating uplands with most slopes convex and with gradients between 1 and 5 percent. These areas often have gilgai microrelief. Annual rainfall in the region ranges from 875 to 1,250 millimeters per year. Vegetation was mainly tall grass prairie.

(*b*) *Profile description*:

A_{1p}	0-15 cm	Black (10YR 2/1) silty clay; moderate medium granular structure; firm; pH 6.6; gradual boundary.
A_{12}	15-45 cm	Black (10YR 2/1) silty clay; moderate medium subangular blocky structure; firm to very firm; pH 6.6; gradual boundary.
A_{13}	45-80 cm	Black (10YR 2/1) silty clay; weak very fine blocky structure; very firm to extremely firm; a few medium black concretions; some slickensides; pH 6.6; clear boundary.

AC	80-90 cm	Dark reddish-brown (5YR 3/2) silty clay; moderate fine blocky structure; very firm; pH 6.8; clear boundary.
C_{ca}	90-100 cm	Dark reddish-gray (5YR 4/2) heavy silty clay loam with some gray (5Y 5/1) mottlings; moderate medium subangular blocky structure; firm; strongly calcareous; many medium to coarse $CaCO_3$ concretions; clear boundary.
C	100-150 cm	Mottled reddish-gray (5YR 5/2) and reddish-brown (5YR 5/3) silty clay loam; massive; firm; moderately calcareous.

(*c*) *Additional notes*: Colors are for moist conditions. Internal drainage of the soil is fair to slow, but surface drainage is good. The profile description is from F. F. Riecken.

39. Gezira Clay soil - Sudan (Wad Medani, Gezira Research Station)

(*a*) *Setting*: The profile is located in level topography on an uncultivated plot of the Research Station. The climate is semiarid with an annual rainfall of 400 millimeters, mainly in July and August, but also some in June and September. The mean yearly maximum temperature is 37.1°C with a mean yearly minimum of 19.9°C. The vegetation consists of a tall grass savanna, with *Cymbopogon nervatus* (dominant), *Sorghum* spp., *Sporobolus helveolous*, and a few scrub, 1-2 meters high, of *Acacia nubica* and *A. seyal.*

(*b*) *Profile description*:

A_{11}	0-0.4 cm	Brown (10YR 4/3 moist; 5/3 dry) clay; dry; structureless, massive; soft; a thin, brittle surface crust, finely stratified; many dark gray concretions (nodules), 1-10 centimeters diameter; these consist largely of calcium carbonate. In addition: fine white concretions (granules) of calcium carbonate, 1-2 millimeters diameter.
A_{12}	0.4-2 cm	Dark yellowish-brown (10YR 3/4 dry and moist) clay; dry; a fine and medium granular surface mulch; peds slightly hard nodules and granules as above; abrupt boundary to
A_{13}	2-15 cm	Dark brown (10YR 3/3.5 moist; 3/3 dry) clay; dry; compound subangular blocky and moderate medium platy; largest structural units are prism-like blocks separated by wide cracks from the surface; nodules and granules as above; gradual boundary to
A_{14}	15-40 cm	Dark brown (10YR 3/3.5 moist; 3/3 dry) clay; dry; structure as above; very hard; frequent dark

		gray nodules and white granules, few very fine, white soft concretions of calcium carbonate, the latter sparse, vertically arranged; cracks narrower; gradual boundary to
A_{31}	40-60 cm	Dark brown (7.5YR 3/2 moist; 10YR 3/3 dry) clay; dry; compound moderate fine angular blocky and moderate medium platy; very hard; few dark gray nodules and sparse, vertically arranged, fine white soft concretions of calcium carbonate; narrow cracks; gradual boundary to
A_{32}	60-90 cm	Dark brown (7.5YR 3.5/2 moist; 4/2 dry) clay; almost dry; compound moderate angular blocky and moderate medium platy; very hard; many vertical tongues, 2 to 4 centimeters wide, of dark grayish-brown (10YR 4/1.5 dry and moist) clay; few dark gray nodules, mainly confined to the dark brown clay; frequent very fine white soft concretions of calcium carbonate, mainly confined to the tongues of dark grayish-brown clay (i.e., vertically arranged); narrow cracks; clear boundary to
AC_1	90-130 cm	Dark grayish-brown (10YR 4/1.5 dry and moist) clay; almost dry; compound weak angular blocky and moderate medium and thick platy; structural aggregates have shiny faces; very hard; many fine vertical tongues of dark brown (7.5YR 3.5/2 moist, 4/2 dry) clay, decreasing in size and frequency with depth; few dark gray nodules, medium cream-coloured soft concretions of calcium carbonate, the latter almost absent in the dark brown clay; accumulation of gypsum in nests (3.5 millimeters diameter) of fine crystals (absent in the dark brown clay); gypsum accumulation mainly in upper part of the horizon, soft concretions of calcium carbonate mainly in lower part; gradual boundary to
AC_2	130-165 cm	Brown (10YR 5/3 moist; 4.5/3 dry) clay; slightly moist; weak fine and medium angular blocky, wedge-shape not distinct; peds have distinct metallic-like bluish coatings in spots; slickensides; extremely firm; much gypsum accumulation, coarse lenticular crystals (2-5 millimeters long) single or in clumps; frequent both soft and hard cream-coloured concretions and dark gray nodules of calcium carbonate (1-3 centimeters diameter); gradual boundary to
AC_3	165-185 cm	Yellowish-brown (10YR 5/3.5 moist; 5/3 dry) clay; as above, except for heterogeneous color in appearance, due to metallic-bluish manganese and reddish iron coatings and gypsum accumulation abundant; gradual boundary to

PROFILE No. 39. – GEZIRA CLAY SOIL (WAD MEDANI, GEZIRA RESEARCH STATION)

Depth cm	Coarse fragments [1] %	Mechanical composition [2]				Soluble salts [3] %	Sodium value [4]	$CaCo_3$ [5] %	pH [6]
		2-0.2 mm %	0.2-0.02 mm %	20-2mμ %	<2 mμ %				
0–2	3	7	21	14	58	0.04	8	2.2	9.2
2–40	2	6	17	15	62	0.06	16	2.5	9.4
40–60	2	6	18	14	62	0.06	19	2.1	9.6
60–90	1	5	18	16	61	0.08	22	1.8	9.6
90–130	1	4	15	17	64	0.29	27	2.2	8.5
130–165	1	4	13	21	62	0.33	25	3.9	8.2
165–185	1	3	14	20	63	0.32	25	4.9	8.2
185–220	1	3	14	19	64	0.30	27	4.5	8.3
220–250	1	2	13	20	65	0.17	25	3.1	9.1

[1] Mainly dark gray nodules of calcium carbonate.
[2] There is no pretreatment for destruction of organic matter; soluble salts, gypsum and carbonate are not removed.
[3] From conductivity data in a 1 : 5 soil/water suspension.
[4] Milliequivalents of soluble plus exchangeable sodium per 100 grams of oven-dry clay.
[5] Measured in the 'fine soil' (under 1 mm).
[6] Measured in a 1 : 5 soil/water suspension.

C_{cs}	185-220 cm	Yellowish-brown (10YR 5/4 moist; 5/3 dry) clay; as above, but gypsum accumulation decreasing in abundance with depth; clear boundary to
C	220-250 cm	As above, but there is no accumulation of gypsum.

(*c*) *Additional notes*: Colors are given for moist and dry conditions. The surface of this soil shows an irregular polygonal pattern of cracks with a diameter ranging from 40 to 200 centimeters, the width of the cracks is from 5 to 14 centimeters. It is to be noted that this profile has a thin flaky surface crust. A few shell fragments are scattered throughout the profile and fine roots penetrate to a depth of 90 centimeters. Termite tunnels are frequent to a depth of 250 centimeters, but are not apparent in the upper 60 centimeters of the profile. The profile description is from W. A. Blokhuis and L. H. J. Ochtman.

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