MORPHOLOGY AND GENESIS OF NONCALCIC BROWN SOILS IN CALIFORNIA

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In North America, noncalcic brown soils occur almost exclusively in the interior valleys and foothill regions of northern California and in the coastal plain and valleys of southern California, excluding the desert region. This great soil group comprises approximately 17 per cent, or 4.5 million acres, of the 26 million acres of valley and foothill lands in the State which support intensive agricultural and range pasture programs.

An important concern is the fact that these noncalcic brown soils have inherent characteristics that are both beneficial and troublesome to agricultural use. Many of them are uniquely and consistently associated with management problems involving surface soil crusting, slow water penetration, and compaction of subsoil horizons.

The nature and severity of these problems depends upon whether they have been induced temporarily by improper management practices or whether they are pedologic in origin and too far advanced to be economically amended. In most cases, management difficulties are less severe when the noncalcic brown soils have some brunizemic or reddish brown lateritic characteristics. These and related aspects of noncalcic brown soils will be discussed in a subsequent report.

REGIONAL CHARACTERISTICS

The areal distribution of noncalcic brown soils in California is closely associated with a rather definite combination of soil-forming factors. For the purpose of orienting this great soil group into its unique regional environment, the pedogenic factors are described and evaluated.

Climate

An important feature of the climatic environment is that essentially a two-season cycle prevails. Spring and fall can be considered as mild transition periods between the two dominant seasons of hot dry summer and cool moist winter. This climatic pattern can be broadly classified as a mesothermal, semiarid to subhumid Mediterranean type.

The mean annual precipitation varies within the limits of 10 to 25 inches, with a dominant range between 12 and 20 inches. More than 90 per cent of the precipitation falls during the seven months of October through April. The mean January temperature varies between 45° and 52°F. with occasional periods of frost. About 230 or more days of the year are frost-free and seldom is more than an inch of the surface soil frozen. A July average temperature will vary between 62° and 82°F. with many days during July, August, and September having a maximum temperature as high as 103° or 110°F. The mean annual temperature is 56° to 63°F.

From extensive field observations and correlation of laboratory analyses, typical noncalcic brown soils, as defined in this report, only occur in regions having the climatic environment outlined. It seems reasonable to conclude therefore, that the genesis of a noncalcic brown soil is fundamentally dependent upon a unique two-season climatic pattern within prescribed limits of annual amounts of precipitation and degrees of temperature. Other opinions concerning the genetic role of this particular climate will be expressed when the chemical and physical data are discussed.

Soil material

A complex geologic pattern in California associated with numerous combinations of the other soil-forming factors has given rise to more than 600 soil series, which represent 26 or more great soil groups (5).

Noncalcic brown soils originate from many kinds of soil materials, with the exception of highly calcareous deposits and formations that are strongly acidic. Variations in the composition and fabric of soil material, in a given climatic

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environment, will be reflected proportionately in the chemical and physical properties of profiles about as expected.

From a practical consideration, the nature of soil material is important, because management problems are found to be more consistently associated with soils derived from sedimentary and metamorphic formations than with soils derived from igneous materials of plutonic or intrusive origin. The most troublesome problems of subsoil compaction and water penetration usually arise in soils that have a relatively high silt content and a low Ca/Mg ratio, often less than one, in the subsoil. These and other correlations are being studied in order to properly evaluate the cause and effect aspects.

Physiography

A diagrammatic cross-section of a large valley in California will show a slightly raised river flood plain near the center with a lower-lying flat basin on either side. Outward from the edge of the basin area gently sloping alluvial fans extend to the base of terrace deposits which, in turn, give way to rolling foothills and steeper mountains. Physiography or topography, as a factor of soil formation, includes the variables of degree, length, and shape of slope; compass exposure; and depth from land surface to permanent or intermittent water table.

Representative noncalcic brown soils occur predominantly in stabilized areas of well-drained alluvial fans, terrace deposits, and lower foothill regions. The slope gradient of these physiographic land forms will usually not be less than 2 per cent nor more than 25 or 30 per cent. When the relief is nearly level, and depending upon the presence or absence of groundwater influence, the soils are classified as intrazonal hydromorphic, halomorphic, or planosols. On relief steeper than 30 per cent, where erosion activity is favored, the soils become progressively shallower and have profile depths associated with azonal lithosols.

Vegetation

The dominant classes of native vegetation presently existing in the alluvial fan and terrace regions are grasses, forbs, and shrubs. At slightly higher elevations along the lower foothill region it is principally a grass-woodland vegetation with scattered blue oak and a few other deciduous trees. Most of the grass and small herbaceous plants mature during spring or early summer, leaving much of the land practically barren until the following winter rainy season.

It is difficult to sort out and satisfactorily demonstrate the influence of natural vegetation on soil properties. One of the complications is that under different climatic environments, vegetation can play a dual role as a dependent and an independent variable. In any event, the low organic matter content of noncalcic brown soils is consistent with their relatively sparce native vegetative cover. Other associated properties include weak surface soil structures, and pale, yellowish, or brown-colored surface horizons.

Time (age of soil material)

Time, or age of soil material, has long been recognized as an important factor in the development of distinctive soil profiles. In a key for the identification and classification of soils in California developed by Storie and Weir (6), five stages of profile development are defined. The alluvial soils are separated at the series level according to their degree of profile development and are placed into five profile groups ranging from undeveloped profiles to profiles containing a cemented hardpan. This scheme is particularly well adapted to the great variability in geologic age and physiographic position of land forms existing in the valleys and coastal plain areas of California (5).

Noncalcic brown soils are forming in a climatic environment which induces a very low and essentially uniform rate of leaching. The differences observed in profile development must therefore be related to age of deposition.

DESCRIPTION OF REPRESENTATIVE SOILS

Four representative soil series with profiles exhibiting different stages of development have been selected for a characterization of their morphology and associated environment. Horizon designations and descriptive terminology conform essentially with the nomenclature in the Soil Survey Manual (4). Some of their chemical and physical properties not included in the descriptions are presented in tables 1 and 2.

The stage or degree of profile development of the selected profiles is designated as minimal, medial, maximal, and maximal with a hardpan. These commonly used terms correspond to the terms young, immature, semimature, and mature as defined by Shaw (3), and to four of the profile groups defined by Storie and Weir (6).

Descriptions of other noncalcic brown soils are to be found in California soil survey reports of the Madera area (7), Merced area (1), and Stockton area (2). This report also includes data from unpublished manuscripts of the recently completed soil surveys of Tehama County by Ken Gowans, and Glenn County by Gene Begg.

Greenfield fine sandy loam—minimal development

Soils of the Greenfield series are forming on well-drained gently sloping alluvial fans at elevations usually less than 700 feet. The soil material is medium-coarse- to medium-textured granitic alluvium. Vegetation is mainly herbaceous plants, annual grasses, and occasional shrubs and oaks.

Annual rainfall varies from 12 to 17 inches during the moist half of the year, and an average January temperature is 48°F. The dry season has an average July temperature of from 70 to 80°F. and has many summer days with temperatures over 100°F. Usually about 200 or 250 days a year are frost-free and only during a few brief periods is the surface inch of soil frozen.

The profile described was obtained in the Salinas valley approximately 3 miles west of the town of Greenfield near where the series was established in 1925. At this site, beans, lettuce, peas, and other irrigated truck crops are grown annually.

Ap1 horizon, 0–10 inches

Brown (10YR 5/3, dry; 10YR 4/3, moist) fine sandy loam; rather massive and hard when dry; very weak fine granular and friable when moist; nonplastic, nonsticky; numerous roots. Gradual, smooth lower boundary.

A12 horizon, 10–20 inches

Yellowish brown (10YR 5/4, dry; 10YR 4/4, moist) fine sandy loam; very weak fine granular structure; slightly hard when dry, friable when moist; nonplastic, nonsticky; some medium and fine roots. Smooth lower boundary.

B2 horizon, 20–30 inches

Loam of same color as A12 horizon; weak medium subangular blocky; slightly hard, friable; nonplastic, nonsticky; thin patchy clay coatings. Clear, smooth lower boundary.

B3 horizon, 30–36 inches

Light yellowish brown (10YR 6/4, dry; 10YR 5/4, moist) fine sandy loam; weak medium subangular blocky; slightly hard, friable; nonplastic, nonsticky; few thin clay coatings. Gradual, smooth lower boundary.

C horizon, 36–60 inches

Sandy loam of same color as B3; often stratified with sandy loam or fine sandy loam; massive; soft when dry, very friable when moist; nonplastic, nonsticky. Essentially the same at lower depths with textural variations.

Tehama loam—medial development

The Tehama soils have formed on well-drained, medium-textured, valley-filling materials transported from sedimentary rock formations. They occur on stabilized lower terraces or older alluvial fans, with a nearly level relief at elevations ranging from 100 to 500 feet. Vegetation is mainly annual grasses with an open to very open stand of oaks.

Mean annual rainfall varies from 15 to 25 inches, with more than 75 per cent occurring during the winter months. An average January temperature is 45°F.; an average July temperature is 80°F. with prolonged hot spells over 105°F. during the summer months. About 270 days are frost-free and rarely is more than an inch of the surface soil frozen.

The selected profile was sampled in Tehama County, about 1 mile northwest of the railroad depot of Corning, which is 2 miles north of the type location for the Tehama series. At this site, barley is usually planted in the fall about 2 years out of 5 and dry-farmed.

Ap1 horizon, 0–8 inches

Pale brown (10YR 6/3, dry; 10YR 4/2, moist) loam; massive; hard when dry, friable when moist; slightly sticky and slightly plastic; many fine roots. Abrupt, smooth lower boundary.

A3 horizon, 8–19 inches

Pale brown (10YR 6/3, dry; 10YR 4/4, moist) loam; massive; hard when dry, friable when moist; slightly sticky and slightly plastic; few fine pores; some sand particles with dark coatings; few fine roots. Abrupt, smooth lower boundary.

B2 horizon, 19–31 inches

Brown (10YR 5/3, dry; 10YR 4/3, moist) clay loam; massive but breaks to angular blocks; extremely hard when dry, very sticky and very plastic; very few fine roots. Diffuse, irregular lower boundary.

B31 horizon, 31–42 inches

Light yellowish brown (10YR 6/4, dry; 10YR 5/4, moist) clay loam; massive; extremely hard when dry, very firm when moist; very sticky and very plastic; few dark coatings on sand particles; thin clay films in seams; very few fine roots. Clear, irregular lower boundary.

B32 horizon, 42–56 inches

Loam of same color as B31; massive; very hard when dry, firm when moist; sticky and plastic; few thin clay films between sand grains; very few fine roots. Gradual, irregular lower boundary between variable C1 horizon which may contain some lime.

Kimball loam—maximal development

The soils of the Kimball series are well drained and have formed in alluvium composed mainly of sedimentary rock materials mixed with lesser amounts of acid and basic igneous materials. They occur on very old terrace land forms with a smooth, very gently undulating topography at elevations ranging from 100 to 400 feet. Native vegetation consists of annual grasses and forbs. Trees and other deep-rooted plants cannot grow successfully because of the strongly developed clay pan condition in these soils.

The mean annual rainfall is about 18 inches during the moist half of the year and an average January temperature is 46°F. An average July temperature is 80°F. and, during the long, dry half of the year, there are prolonged hot spells with daytime temperatures of 105°F. and higher. The frost-free season is about 230 to 280 days and rarely is more than an inch of the surface soil frozen.

The profile chosen for illustration was sampled at the type location for the Kimball series which is near the west edge of the Western Pacific railroad right of way, 0.3 miles south of Central House Road about 2 miles northwest of Honcut in Butte County. At this site, the soil is used as range pasture and occasionally a dry-farmed barley crop is raised.

Ap1 horizon, 0–4 inches

Brown (7.5YR 4/5, dry; 7.5YR 3/5, moist) loam; massive; hard when dry, friable when moist; many very fine pores; abundant fine roots. Abrupt, slightly wavy lower boundary.

A3 horizon, 4–10 inches

Loam of same color as Ap1; massive; hard when dry, friable when moist; slightly sticky and slightly plastic; many very fine pores; many very fine roots. Clear, smooth lower boundary.

B1 horizon, 10–17 inches

Reddish brown (5YR 4/5, dry; 7.5YR 4/5, moist) loam; massive breaking to coarse angular blocks; very hard when dry, friable when moist; slightly sticky and slightly plastic; many very fine, few fine pores; thin, nearly continuous clay films in pores; many very fine roots. Abrupt, slightly wavy lower boundary.

B2 horizon, 17–34 inches

Reddish brown (5YR 4/5, dry; 5YR 4/4, moist) clay; moderate prismatic structure breaking to strong coarse angular blocks; extremely hard when dry, very firm when moist; sticky and very plastic; common very fine tubular pores; few fine shot; moderately thick, continuous clay films on ped faces, colloid mainly in bridges; many very fine roots along ped faces. Gradual, slightly wavy lower boundary.

B31 horizon 34–46 inches

Brown (7.5YR, dry; 5YR 4/4, moist) sandy clay loam; massive, breaking to irregular blocks; very hard when dry, firm when moist; slightly sticky and plastic; clay films moderately thick and nearly continuous in very fine pores; some black stains in pores; few very fine roots. Diffuse, irregular lower boundary.

B32 horizon, 46–64 inches

Sandy clay loam of same color as B31; massive; hard when dry, firm when moist; slightly sticky and plastic; common, thin discontinuous clay films in many very fine pores, mainly interstitial; very few fine roots. The depth of sola range from 36 inches to more than 60 inches.

San Joaquin loam—maximal development with a hardpan

The San Joaquin series comprises well-drained soils with hardpans that have formed in moderately coarse-textured alluvium that is dominantly granitic in composition. They occur at elevations between 50 and 500 feet on old terrace land forms that are very gently sloping or undulating and have a pronounced hummocky microrelief. Native vegetation is a moderate to thin stand of annual grasses and herbs. A dense clayey subsoil horizon overlying an indurated hardpan severely restricts the growth of trees and other plants that require deep rooting.

Mean annual precipitation varies from 10 to 20 inches during the moist season, and the average January temperature is 45°F. More than 250 days a year are frost-free and only occasionally is the surface soil frozen to a depth of one inch. The dry season has an average July temperature of 80°F. with many daytime temperatures of 105°F. and higher.

The selected profile was obtained about a mile south of Woodbridge in San Joaquin County, along old U.S. Highway 99 from Stockton to Sacramento. A pit was dug in the fenced-off and uncultivated edge of the right of way. From this site northward into Sacramento County, more than 180,000 acres of San Joaquin soils have been mapped.

A1 horizon, 0–6 inches

Brown (7.5YR 5/3, dry; 7.5YR 4/4, moist) loam; massive to weak fine granular; hard when dry and friable when moist; nonsticky and nonplastic; many fine pores; abundant grass roots. Clear, smooth lower boundary.

A3 horizon, 6–15 inches

Yellowish brown (10YR 5/4, dry; 10YR 4/3, moist) loam; weak fine blocky structure; hard when dry and friable when moist; nonsticky and nonplastic; many fine pores; abundant grass roots. Clear, smooth lower boundary.

B1 horizon, 15–24 inches

Reddish yellow (7.5YR 6/6, dry; 7.5YR 4/4, moist) loam; moderate fine blocky structure; very hard when dry and friable when moist; nonsticky and nonplastic; thin clay films on ped faces and in the fine pores, with some clay bridging between sand grains; many fine roots. Clear, smooth lower boundary.

B2 horizon, 24–30 inches

Reddish brown (5YR 4/4, dry; 5YR 3/3, moist) clay loam; strong fine and medium blocky structure; extremely hard when dry and firm when moist; slightly sticky and slightly plastic; continuous clay films on ped faces; few fine pores; very few roots. Abrupt, slightly wavy lower boundary.

Cm horizon, 30–38 inches

Strong brown (7.5YR 5/6, dry; 7.5YR 4/4, moist) indurated iron-silica hardpan; smooth on upper surface and very dense, with a few manganese stains in fissures; lower portion is less strongly cemented and occasionally contains a few lime seams. Abrupt, smooth lower boundary.

C horizon, 38–72 inches

Light yellowish brown (10YR 6/4, dry; 10YR 4/4, moist) gritty loam; massive; very weakly consolidated; hard when dry and firm when moist, becoming softer with increasing depth; nonsticky and nonplastic. This horizon is quite variable as to firmness or degree of consolidation.

FIELD AND ANALYTICAL PROCEDURES

The information presented in this paper was obtained from the regions of California where noncalcic brown soils predominate. In some of the regions, cooperative soil surveys by the University of California and the United States Department of Agriculture, either recently completed or in progress, provided an appreciable amount of data. This was supplemented in other regions with field examinations from auger borings, pits, and bank cuts. The intensity of field investigation varied from just looking around in a reconnaissance manner to detailed mapping procedures.

From more than 200 sites, 86 profiles representing 31 soil series were chosen for a detailed examination of their genesis, morphology, field environment, and chemical and physical properties. Figures 1–4 show the trend and variation with depth of four selected properties of these 86 profiles. For practical reasons, only four of the many profiles examined could be described in detail in this report and some of their important properties are presented in tables 1 and 2.

All laboratory measurements were made according to the standard methods and procedures as outlined in numerous articles of scientific journals. Descriptions of these standard methods will be omitted in order to conserve space and reading time.

Most of the analyses were made in the University of California Soil Morphology Laboratories either at Berkeley or Davis. Selected data for about 10 profiles were extracted from analyses made in the U. S. Dep. Agr. Soil Survey Laboratory at Riverside, California.

DISCUSSION

As previously indicated, noncalcic brown soils in California have characteristic properties that are largely the result of a definite range of annual precipitation and temperature, which is distributed in accordance with a prevailing two-season climatic pattern. The summer half of the year is hot and dry and the winter half is cool; annual precipitation is between 10 and 25 inches.

In regions of California where the summer season is cool or the winter season humid and cold, the soils have properties that are characteristic of other zonal great soil groups. For example, soils with brunizemic characteristics usually occur in regions where the precipitation during the moist season is greater than 25 inches and the dry summers are relatively cool. Reddish brown lateritic soils are commonly found in regions with a moist season of 35 inches or more precipitation and summers which are warm to hot and winters not extremely cold. Intrazonal and azonal soils, however, can be expected to occur in any of the zonal soil climatic environments, because their origin is largely dependent upon such factors as drainage conditions, topography, and composition of soil material.

Only the noncalcic brown great soil group seems to be confined essentially to a moist-dry two seasonal climate with a prescribed annual minimum and maximum range of precipitation and temperature. In contrast, all the other great soil groups in California are found in other parts of the United States and elsewhere under a variety of climatic patterns. Their specific requirement as to annual precipitation and temperature is not dependent upon any particular seasonal distribution.

The chemical and physical data in tables 1 and 2 will point up the dominating influence of a contrasting two-season annual climate on the genesis and morphology of noncalcic brown soils. Table 1 shows that, in the A horizons of all four selected profiles, the organic carbon content is less than 1.5 per cent, and it decreases rapidly with depth. The low organic matter content, as indicated by the organic percentages, must be attributed to the limited amount of grass and shrub vegetation that can grow during the warmer months of the moist season. This inherent or consequent low organic matter content is considered to be largely responsible for the massive or very weak surface soil structures that are characteristic of noncalcic brown soils.

Other data in table 1 show that, regardless of age or stage of profile development, the per cent of base saturation is high in all parts of the profile, and usually highest in the lower subsoil horizons. These values are fairly consistent with the reaction trend in the profiles at all stages of development. Surface horizons have pH values ranging from near neutral to slightly acid, which remain relatively uniform or increase about 1 pH unit to neutral or slightly basic in the lower subsoil horizons. Under the prevailing climate, the soils are leached with respect to carbonates and soluble salts. Yet even after a long period of time, the overall leaching effectiveness can be considered only as moderate in the upper horizons and slight in the lower horizons.

The cation-exchange capacity (table 1) for loam or fine sandy loam textured surface horizons is in the order of 12 me. per 100 g. for young soils and 8 me. for very old soils. The maximum cation-exchange capacity is about 30 in the finer-textured surface horizons of young soils. In any given profile, the textural B2 horizon usually will have the highest cation-exchange capacity. The magnitude of difference between the surface and the B2 horizon is greatest in profiles with maximal development. Calcium and magnesium are by far the dominant exchange cations and they increase in content with profile depth. The exchange calcium content varies from 2 or less me. per 100 g. in surface horizons to about 15 me. in lower subsoil horizons. Ca/Mg ratios are greater than one, but quite variable in surface horizons, and narrower or with magnesium in excess of calcium in the subsoils of older profiles.

Considering all members of the noncalcic brown group of soils, there is a rather wide range in cation-exchange capacity and content of exchange calcium and magnesium. This variance is initiated by the nature of their soil materials, which are developed through progressive stages of weathering in a unique climate and are characterized by the composition of their clay mineral fraction.

Young soils derived from basic igneous materials are usually finer-textured; they have the highest cation-exchange capacity and the highest content of exchange calcium and magnesium. Coarse-textured soils formed from acid igneous materials have the lowest cation-exchange capacity at all stages of profile development, while soils derived from sedimentary and metamorphic materials have a wide intermediate range.

From the limited number of x-ray analyses at hand, it is indicated that the clay fractions of young soils are predominantly 2:1 lattice clays

TABLE 1

Chemical properties of representative noncalcic brown soils

Horizon	Depth	pH of Soil Paste	Extractable Cations				Cation-Exchange Capacity	Base Saturation	Organic Carbon
			Ca	Mg	Na	K			
	in.		*me./100 g. soil*					%	%
GREENFIELD fine sandy loam—Minimal development									
Ap1	0–10	6.5	7.4	1.7	0.16	0.69	13.0	77	1.36
A12	10–20	6.4	6.6	2.2	0.19	0.24	11.0	85	0.57
B2	20–30	6.3	8.9	3.9	0.24	0.16	15.3	87	0.13
B3	30–36	7.0	8.2	4.8	0.21	0.11	14.3	94	0.23
C	36–60	7.2	6.0	3.9	0.18	0.09	11.2	91	0.11
TEHAMA loam—Medial development									
Ap1	0–8	5.5	3.8	2.3	0.1	0.1	9.5	66	0.86
A3	8–19	5.9	5.3	4.4	0.1	0.1	13.4	74	0.33
B2	19–31	6.5	6.8	11.9	0.1	0.2	23.0	83	0.25
B31	31–42	7.0	6.1	10.7	0.1	0.2	23.0	74	0.12
B32	42–56	7.1	6.2	10.6	0.1	0.1	23.5	72	0.14
KIMBALL loam—Maximal development									
Ap1	0–4	6.4	6.0	2.7	0.1	0.3	11.4	80	1.01
A3	4–10	6.0	3.7	2.2	0.1	0.2	8.7	71	0.38
B1	10–17	6.1	4.6	3.4	0.1	0.1	11.8	69	0.20
B2	17–34	6.6	11.2	8.6	0.2	0.2	22.0	92	0.19
B31	34–46	7.1	11.6	8.4	0.2	0.2	21.0	97	0.09
B32	46–64	7.0	10.6	7.0	0.2	0.1	18.8	95	0.07
SAN JOAQUIN loam—Maximal development with hardpan									
A1	0–6	5.6	3.6	1.6	0.08	0.54	8.3	70	1.41
A3	6–15	5.7	3.3	1.6	0.36	0.35	6.7	84	1.02
B1	15–24	6.1	3.6	2.4	0.14	0.16	7.3	86	0.76
B2	24–30	6.0	4.0	11.6	0.45	0.18	16.5	99	0.25
Cm	30–38	—	—	*	*	*	—	—	—
C	38–72	6.8	8.1	4.3	0.20	0.20	13.7	93	0.22

* Iron-silica-cemented hardpan.

and that montmorillonite is the dominant clay mineral. In some of the strongly weathered soils with hardpans, up to 60 per cent of the clay is kaolinite and 40 per cent an assortment of 2:1 lattice clay minerals. Most of the clays analyzed, however, had a range in the order of 25 to 30 per cent kaolinite in young soils and about 45 per cent in old soils.

The production of clay and the solution of mineral materials is very slow in noncalcic brown soils. Chemical weathering processes and microbial activity are confined essentially to the few late spring months when the soils are warming up and still moist. Effective leaching occurs only during the winter season when there is sufficient rainfall from a concentrated storm to penetrate the deep subsoil horizons. Nevertheless, the physical data in table 2 show that increasingly dense B2 horizons and iron-silica-cemented hardpans eventually can be formed.

At all stages of profile development, the proportion of clay relative to silt plus clay (table 2),

TABLE 2

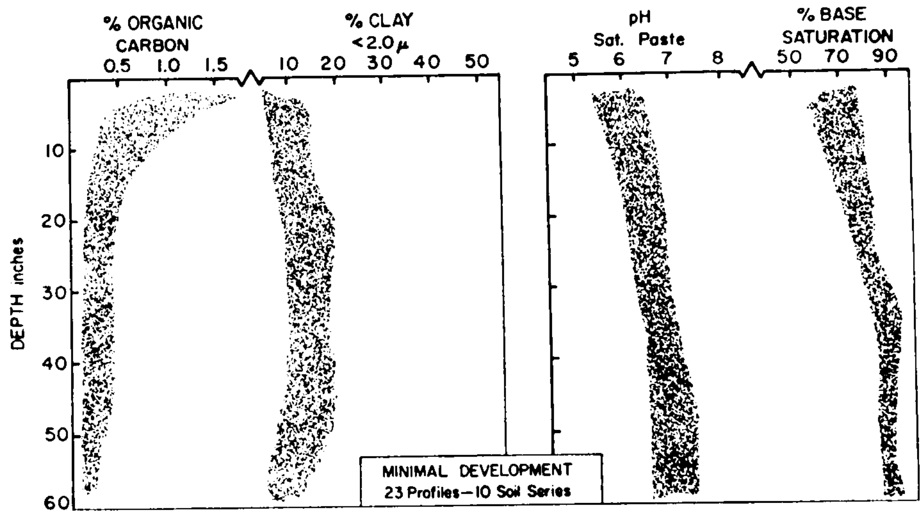
Physical properties of representative noncalcic brown soils

Horizon	Depth	Particle Size Distribution				Bulk Density	Moisture Tensions		
		Sand 50μ	Silt 50-2μ	Clay			Moisture equivalent	1/3 atm.	1/15 atm.
				Total 2.0μ	Fine 1.0μ				
	in.	%				*g./cc.*	%		
GREENFIELD fine sandy loam—Minimal development									
Apl	0–10	60.9	28.8	10.3	8.7	1.5	13.3	13.4	5.8
A12	10–20	63.0	26.7	10.3	9.1	1.5	11.6	11.8	4.7
B2	20–30	56.6	26.8	16.6	12.8	1.7	13.8	14.4	5.6
B3	30–36	63.9	23.7	12.4	10.7	1.6	12.2	12.2	5.2
C	36–60	77.6	14.1	8.3	7.7	1.5	8.4	8.2	3.9
TEHAMA loam—Medial development									
Apl	0–8	33.9	52.1	14.0	10.1	1.5	19.5	23.7	5.0
A3	8–19	32.4	51.1	16.5	12.6	1.7	17.8	20.1	6.2
B2	19–31	22.7	46.9	30.4	25.7	2.0	21.8	23.1	11.3
B31	31–42	27.5	44.4	28.1	24.0	2.0	20.8	23.6	10.0
B32	42–56	32.2	43.7	24.1	21.8	1.8	20.3	23.5	9.4
KIMBALL loam—Maximal development									
Apl	0–4	46.3	35.1	18.6	14.5	1.7	17.9	19.8	7.4
A3	4–10	44.3	37.9	17.8	14.4	1.7	15.6	17.4	6.5
B1	10–17	39.1	37.1	23.8	19.8	1.8	17.6	19.7	8.6
B2	17–34	32.1	30.1	37.8	34.2	2.0	26.1	29.6	16.6
B31	34–46	46.0	25.0	29.0	25.2	1.8	23.7	26.1	13.4
B32	46–64	51.2	23.0	25.8	22.4	1.8	22.2	25.0	12.1
SAN JOAQUIN loam—Maximal development with hardpan									
A1	0–6	46.5	39.8	13.7	11.5	1.3	18.5	—	5.9
A3	6–15	38.0	45.4	16.6	13.7	1.6	15.6	—	5.1
B1	15–24	45.6	37.0	17.4	14.2	1.6	15.5	—	5.6
B2	24–30	34.3	32.6	33.1	30.1	1.8	21.2	—	11.8
Cm	30–38	—	—	*	*	*	—	—	—
C	38–72	47.5	35.8	16.7	12.8	1.6	19.9	—	10.2

* Iron-silica-cemented hardpan.

increases with depth and the ratio becomes progressively wider for older soils. In addition to the four profiles in table 2, analyses for a number of representative profiles show that young soils have an actual clay increase in B2 horizons ranging from about 5 to 10 per cent. Soils with maximal development have an actual clay increase in B2 horizons ranging from 20 to 40 per cent.

This characteristic range of clay increase in B2 horizons is believed to be largely due to inherent differences in the many kinds of soil materials from which noncalcic brown soils are formed. Variations in the matrix of soil materials associated with fabric, mafic mineral content, and the proportion of stable and unstable minerals must surely be reflected in weathered soil profiles. There is also the effect of stratification during the deposition of soil materials. Yet one cannot always be certain about the existence of stratification particularly when a finer-textured layer



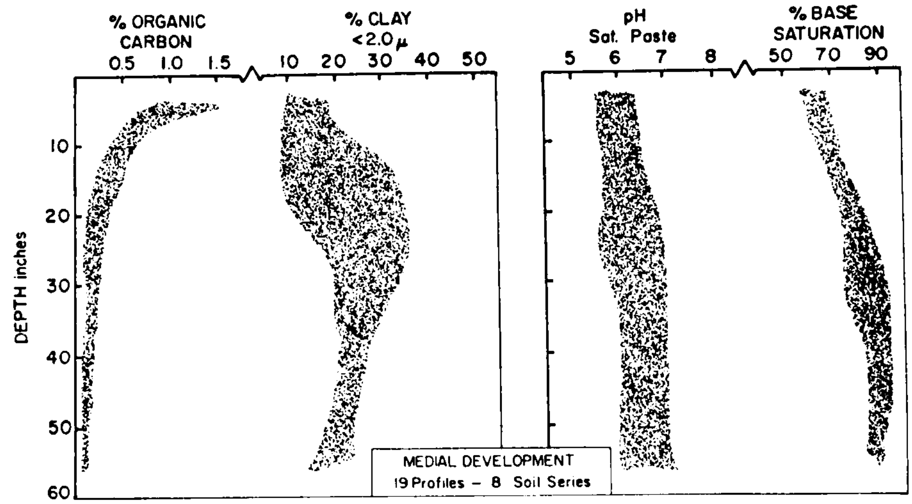


FIG. 1 (*Upper*). Range of per cent organic carbon, clay content, pH, and per cent base saturation with profile depth in 10 soil series having minimal noncalcic brown characteristics.

FIG. 2 (*Lower*). Range of per cent organic carbon, clay content, pH, and per cent base saturation with profile depth in eight soil series having medial noncalcic brown characteristics.

happens to have been deposited at a depth from the surface, and of a thickness which coincides with pedogenic B2 horizons of the region.

The genesis of iron-silica cemented hardpans in noncalcic brown soils is a debatable subject and several explanations have been proposed. This perhaps can be expected because a long period of time is involved and certain environmental assumptions are necessary. The most reasonable explanations, in the writer's opinion, are oriented around a thesis that these hardpans have formed under present climatic conditions.

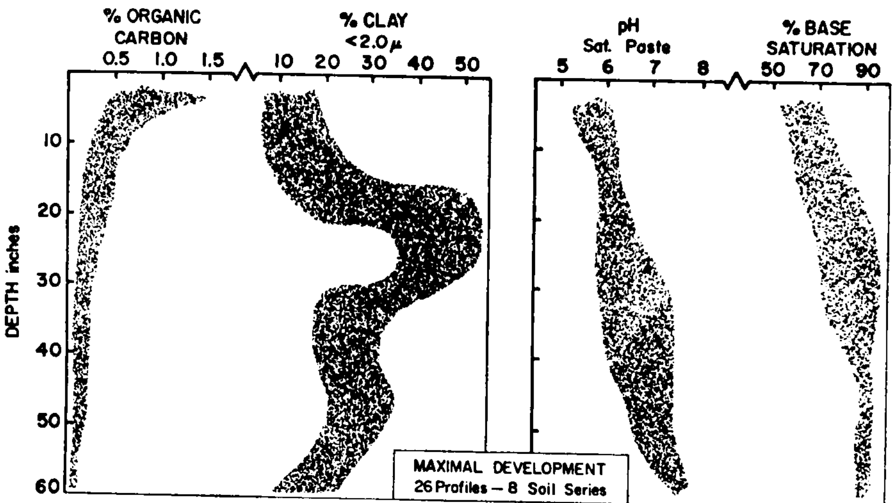
During the early spring months chemical and biological activity is favored by a warming soil and the moisture from late rains. This promotes the release of bases, the solution of silica and sesquioxides, and their general movement downward in the profile. As the soil is rapidly dried during late spring, iron and silica are irreversibly precipitated and a small increment of the less permeable subsoil gradually becomes cemented. Quite frequently, subsoil stratification induces a perched moisture condition and thereby determines the depth of hardpan formation.

The variation and trend with profile depth of per cent organic carbon, clay content, reaction, and per cent base saturation is illustrated in figures 1–4. This is a composite image of 86 representative profiles comprising 31 soil series. Only occasionaly will the limits of range indicated be exceeded in a profile that is considered to be a typical noncalcic brown soil at a designated stage of profile development.

One of the distinguishing characteristics of these soils is their low per cent of organic carbon as shown in figures 1–4. Maximum values of 1.5 per cent in surface horizons were usually obtained in profiles taken at uncultivated sites. The organic matter content, as indicated by the organic carbon values, decreases rapidly with depth in older soils, which are the least suitable for plant growth.

The distribution of clay with depth (figs. 1–4) clearly indicates the justification for a minimal, medial, and maximal separation of noncalcic brown soils on the basis of their stage of profile development. The range of clay content, particularly in the B2 horizons of these soils, is considered to be normal in view of the fact that their soil matrices are quite variable.

There is a consistent increase in pH values with depth (figs. 1–4) and this is another distinguishing



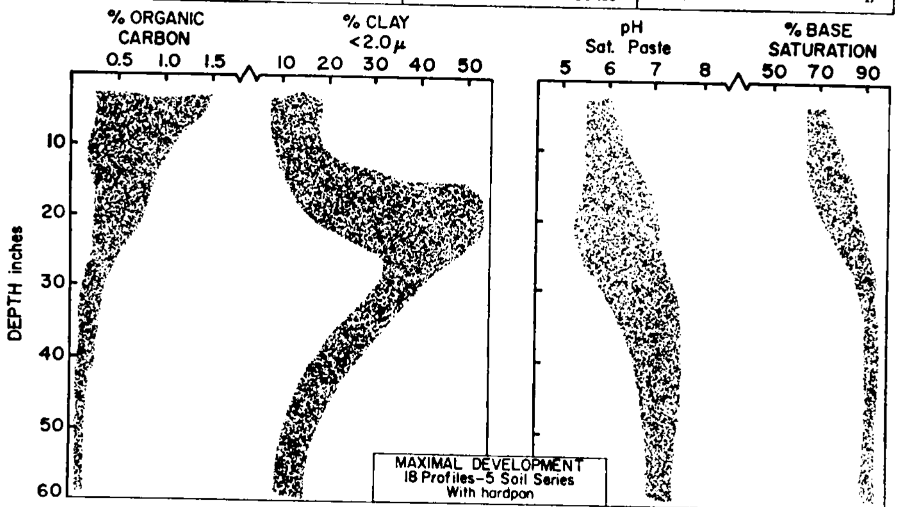


FIG. 3 (*Upper*). Range of per cent organic carbon, clay content, pH, and per cent base saturation with profile depth in eight soil series having maximal noncalcic brown characteristics.

FIG. 4 (*Lower*). Range of per cent organic carbon, clay content, pH, and per cent base saturation with profile depth in five soil series having maximal with hardpan noncalcic brown characteristics.

characteristic of noncalcic brown soils. The increase is usually less in young soils regardless of whether the reaction at the surface is near neutral or slightly acid. The oldest soils, being the most leached, generally have surface horizon pH values between 5.5 and 6 and near neutral to slightly basic in the deep subsoil.

The per cent of base saturation, as indicated in figures 1–4, is high in all soils, being consistently higher than 50 per cent in surface horizons and increasing with depth to values higher than 80 or 90 per cent. There is also a fairly consistent and proportional increase of pH values accompanying the accumulation of bases in subsoil horizons. Leaching has been slow over the years and it has taken a long time to impress its mild to moderate effectiveness.

A discussion of the morphology and genesis of noncalcic brown soils would seem incomplete without the important role of climate being mentioned again. Previous statements have implied that noncalcic brown soils, as defined in this report, can originate and develop only in regions where essentially a two-season climate prevails. The annual rainfall is limited to a range between 15 and 25 inches and most of it falls during a cool winter season. After a transition period, there follows a long dry and hot season. Under this mesothermal, semiarid to subhumid Mediterranean type of climate, soil distinctions at the series classification level are primarily the result of differences in the nature of soil materials and degree of profile development with time.

SUMMARY

The distinguishing characteristics of noncalcic brown soils are:

1. Very weak surface soil structures when moist, or essentially massive and hard to very hard when dry.

2. Low organic carbon content with maximum values of 1.5 per cent in surface horizons, decreasing rapidly to amounts less than 0.5 per cent in subsoils.

3. The color of soils will vary in accordance with the mafic mineral content of their soil material. As a general range, surface soils (moist and dry) are between 7.5YR and 10YR in hue, 4 to 6 in value, and 3 to 6 in chroma, with little change in the subsoils of young soils. In older soils, the subsoils become browner, yellowish red, or redder with age.

4. At all stages of profile development, the proportion of clay relative to silt plus clay increases with depth, and the ratio becomes progressively wider the older the soils.

5. pH values increase with profile depth. Surface soil reactions are near neutral to slightly acid. Deep subsoils, with some exceptions, are near neutral to slightly basic in reaction.

6. The per cent of base saturation is consistently higher than 50 in surface horizons and it increases in subsoils to values that often are higher than 80 or 90.

7. Calcium and magnesium are by far the dominant exchange cations with the exchange-calcium content ranging from 2 me. per 100 g. or less in surface horizons to about 15 in lower subsoils. Ca/Mg ratios are greater than one, but variable in surface horizons and narrow, or with magnesium in excess of calcium in the subsoils of older profiles.

8. All stages of profile development, including the maximum with an iron-silica cemented hardpan, are attained within the noncalcic brown group of soils in California.

REFERENCES

(1) Arkley, R. J., *et al.* 1962 Soil survey of the Merced Area, California. *U. S. Dep. Agr. Series 1950, No. 7.*

(2) Retzer, J. L., *et al.* 1951 Soil survey of the Stockton Area, California. *U. S. Dept. Agr. Series 1959*, No. 10.

(3) Shaw, C. F. 1928 Profile development and the relationship of soils in California. *Proc. Intern. Congr. Soil Sci. 1st Congr.* 4: 291–397.

(4) Soil Survey Staff 1951 Soil survey manual. *U. S. Dep. Agr. Handbook No. 18.*

(5) Storie, R. E., and Harradine, F. F. 1958 Soils of California. *Soil Sci.* 85: 207–227.

(6) Storie, R. E., and Weir, W. W. 1953 *Soil Series of California*. Assoc. Students Store, University of California, Berkeley, California.

(7) Stromberg, L. K., *et al.* 1962 Soil survey of the Madera Area, California. *U. S. Dep. Agr. Series 1951, No. 11.*