THE DYNAMICS OF TERRA ROSSA SOILS

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Introduction

The recent analysis by Buru (1968) of red soils developed from limestone in El-Marj Plain, Cyrenaica, represents a timely and impressive attempt to study one of the most difficult and unsatisfactorily-understood soil formations in the sphere of pedology. As Buru (1968) emphasises, attempts by pedologists to describe the origins, properties, and agricultural capabilities of Red Limestone Soils are shrouded in controversy. In the past, differing interpretations have been placed on the significance of the various properties of Red Limestone Soils.

The present paper reviews some of the more tenable theories for the formation of a red solum from limestone parent rock, and discusses some of the important diagnostic profile features which have to be noted and analysed. The material for this discussion is derived from the author's own fieldwork and observations in Jordan and in Turkey, and also from many interesting discussions with Dr. Buru on the properties of red soils in Cyrenaica. The author would like, at the outset, to acknowledge the stimulus and interest which Dr. Buru's work has provided.

Nomenclature and Classification

Much of the confusion in the literature concerning red soils developed over limestone is derived from the large number of different terms used to describe them, terms often having differing meanings and connotations. Throughout the history of soil terminology, the individual names current at particular periods have varied, as also have the soil names favoured from one country to another. Thus it is not surprising that the position of limestone soils in schemes of soil classification varies from one classificatory system to another.

Early schemes of classification recognised that limestone soils could not be fitted into any zonal pattern; as a group, limestone soils were regarded as 'transitional' by Dokuchaiev (1886), 'endodynamomorphic' by Glinka (1932), and 'intrazonal calcimorphic' by Thorp and Smith (1949). All these systems placed stress on the special influences which a limestone has on the solum developing on it. This was certainly no new observation, for Zippe (1853) had recognised earlier in Italy the relationship between red soils and crystalline limestones. He in fact used the term 'terra rossa', an Italian local name ,for such soils, a usage which has of course influenced nomenclature ever since.

As with many other examples, however, the adoption of a colour term, 'terra rossa' or 'red earth', to describe a particular soil type has led to many abuses and inconsistencies in the literature. Soils which are red but which have few other properties of terra rossa profiles have been designated as 'terra rossa soils', particularly in the case of red soils developed from non-calcareous parent materials. Similarly, the designation 'terra rossa' has been used for many soils developed from limestone but having few diagnostic 'terra rossa' characteristics.

One of the most comprehensive and useful schemes for classifying sub-tropical limestone soils is that provided by Kubiena (1953). This classificatory procedure is outlined in Table 1. The subdivision of sub-tropical limestone soils into brown (terra fusca) and red (terra rossa) sub-types is an important innovation introduced by this classificatory scheme.

TABLE 1. The classification of sub-tropical limestone soils according to Kubiena (1953).

Division	C. Terrestrial Soils				
Class	CE. Terrae Calxis				
Type	Terra Soils				
Sub-type	Terra Fusca			Terra Rossa	
Variety	Typical Terra Fusca	Bleached Terra Fusca	Earthy Terra Fusca	Siallitic Terra Rossa	Allitic Terra Rossa

According to Kubiena (1953), the Terrae Calxis, to which class the Terra soils belong, are « very mature, extensively weathered, usually completely lime-free soils, with ochre yellow, ochre brown, to red coloured (B) horizons which contain iron in the form of ferric hydroxide, with varying water content...... » Terra fuscas are « usually humus deficient loamy soils with ochre yellow to reddish brown colour on limestone rocks, which contain ferric hydroxide in the form of limonite». Terra rossa is described as a red soil, « usually humus deficient and free of lime, rich in inorganic colloids containing ferric oxide in water deficient compounds ». A basic element in the distinction between terra fusca and terra rossa is thus the degree of hydration of the iron oxides as reflected in soil colour; the sub-humid terra fusca soils contain hydrated iron oxides (particularly limonite) which have a characteristic brown hue, whilst the drier terra rossa contains anhydrous iron oxides (expecially hematite) which have a brighter red coloration.

The subdivision of terra rossa soils into 'siallitic' and 'allitic' varieties is again a useful innovation. Siallitic terra rossa is «terra rossa with high colloid content, when wet highly plastic and viscous »; allitic terra rossa, on the other hand, is « loose, well crumbled terra rossa with low to negligible plasticity ».

Despite the value of Kubiena's (1953) work, particularly as regards the needs of soil survey and the possibilities of establishing soil series based on further subdivision below the variety level, its importance seems to have been grossly underestimated by many pedologists. Classificatory schemes which have appeared since have merely added to nomenclature confusion rather than helped to simplify it. Many countries, e.g. France, Italy, and Spain, prefer to use the terms « Brown Mediterranean Soils » and « Red Mediterranean Soils » rather than terra fusca and terra rossa; many of the soils so described have developed from a wide range of parent rocks other than limestone. The terra terminology of Kubiena (1953) does at least remove this difficulty.

Traditional soil concepts and terminology have also been greatly revised by two recent systems of classification, both of which propose new nomenclatures for terra rossa soils.

The first of these is the recent work of the United States Departement of Agriculture (1960, 1967) on a Comprehensive System of Soil Classification, the Seventh Approximation. This system not only introduces many new terms for world soil groups but also defines very precisely the analytical limits for all categories. Comprehensive details on nomenclature and definition are given in the relevant U.S.D.A. publicatiions (1960, 1967). The proposed nomenclatures for terra rossa and terra fusca are given in Table 2.

<u>TABLE 2.</u> The classification of sub-tropical limestone soils according to the Seventh Approximation (1967)

Order	Alfisols	
Sub Order	Zeralfs	
Great Soil Groups	a) Haploxeralfs	b) Rhodoxeralfs

The Terra soils of Kubiena (1953) are grouped in the Alfisol Order of the Seventh Approximation, i.e. they are soils with an *argillic* subsurface horizon. In this Order, they belong to the suborder of Xeralfs on account of their pronounced summer dry season. Further subdivision at the Great Soil Group level is made on the basis of colour— the group of Haploxeralfs have hues of 5YR or yellower on the Munsel notation and the Rhodoxeralfs have hues redder than 5 YR. These Great Soil Groups can thus be broadly correlated with Brown Mediterranean and Red Mediterranean Soils respectively.

Although the Seventh Approximation is being used in several countries for purposes of soil survey and classification, many pedologists have criticised the new terminology and the sharpness of limits between categories. Certainly many national Soil Survey organisations have rejected this scheme, largely due to objections so ably set out by Webster (1968).

The second new scheme of terminology is contained in the recent publication of F.A.O. (1968) on the definition of soil units for the Soil Map of the World project. Terra rossa soils are called 'Chromic Luvisols' if they have an argillic B horizon and 'Eutric Cambisols' if they have a weathered (B) horizon. Considering the large number of different terms in use and the discrepancies in meaning between each, there is a strong case for retaining the comprehensiveness and simplicity of the Kubiena system, at least until more information is gathered on soil characteristics.

Soil Forming Factors.

Terra rossa soils are common soil formations in many countries surrounding the Mediterranean Sea. In addition to the famous occurences in Cyrenaica, they have also been recorded in Portugal, Spain, France, Italy, the Balkan States, Malta, Cyprus, Turkey, Lebanon, Syria, Palestine, Jordan, Algeria, and Morocco. Soil maps of these countries show the extent of the terra rossa cover.

Reifenberg (1947) was the first to emphasise the importance of the Mediterranean climatic regime in the factors which account for the distribution of terra rossa. Since his work was published, many more climatic statistics have become available and all underline the marked climatic regime of a temperate moist winter alternating with a hot dry summer. This alternation in atmospheric climate has important influences on the nature of the soil climate, which in turn governs the processes of weathering and pedogenesis in the soil profile. The sharp distinction which has to be made between 'moist' and 'dry' pedogenic processes is vital to understanding the formation of these soils.

In addition to emphasising the nature of the soil climatic regime, Reifenberg (1947) also noted the restriction of terra rossa to hard, crystalline limestone strata. He notes that soft, porous limestones give rise to rendzinas, and highly calcareous marls occur on marly, friable limestones. This correlation between limestone lithology and soil type is an important one in Mediterranean countries, as has been recently emphasised by observations in the Northern Highlands of Jordan (Atkinson and Beaumont 1967). Here detailed soil mapping on the scale of 1:10,000 revealed that the lithology of the underlying limestone strata was the most useful index of the distribution of terra rossa.

Analyses of the insoluble residue content of crystalline limestones beneath terra rossa have been made by the author from samples collected widely in Jordan and in Turkey. The acid-insoluble non-carbonate residue left after dissolving limestone samples in dilute acids in the laboratory provides a means of assessing the soil material which will accumulate when the limestone is chemically weathered. Generally, the crystalline limestones from which terra rossas form have very low (L 2%) contents of insoluble residue. The hard, white crystalline limestone is thus extremely pure, a feature which reflects the intensity and time of weathering reqired to pruduce deep sola. Insoluble residues also often show reddish brown hues, again a feature similar to the red colours of the weathered surfaces of the limestone in the field and the bright red clay which typically accumulates in limestone cracks and fissures. Studies of the primary and clay mineralogy of crystalline limestone residues and overlying terra rossa material are likely to play an important future role in elucidating the formation of terra rossa.

Soil Forming Processes.

Soil forming processes which give rise to terra rossa soils are now more fully understood than at the time of Reifenberg's (1947) classic analysis. This is largely the result of the increased attention given to these soils in recent years.

The fundamental process which produces terra rossa is, of course, the chemical weathering and dissolution of the crystalline limestone to produce an insoluble residue from the parent rock. This process of limestone weathering has been the subject of much research by karstic geomorphologists in recent years and the chemistry of the process is reasonably well understood. Dissolution is carried out by aqueous solutions and is thus largely confined to the moist season, particularly along cracks and fissures in the rock along which water can easily penetrate. The chemical agency involved is held to be soil water charged with carbon dioxide in the form of carbonic acid. As the carbon dioxide content of soil moisture is primarily dependent on the vegetative and biological activity of the soil, the process of dissolution is thought to be most intense under a vigorous vegetation cover. Added importance to the vegetation factor is given by the recent work of Khan (1959) who shows experimentally that aqueous plant extracts are far more efficient than carbonic acid in releasing the insoluble residue of limestone.

The pedogenic process which operates simultaneously with rock weathering is the process of decalcification, or the removal of free calcium carbonate from the soil. The relative slowness of the dissolution process and the very sharp weathering front between unweathered and weathered material mean that free carbonates are readily leached away. On soft and porous limestones (e.g. chalks and marl), weathering usually proceeds so rapidly as to leave fragments and powders of limestone throughout the solum, giving rise to calcareous rendzina and marl soils. Terra rossas, on the other hand, are typically decalcified and completely leached of free carbonates. Terra rossa profiles with calcium carbonate accumulations have usually been recalcified by the in-washing of lime-rich waters.

Processes of weathering and decalcification take place in aqueous media during the humid season. A further process which is the result of downward percolating soil moisture is the process of argillation which results in the formation of the argillic B horizon; as noted above, the presence of the argillic B is one of the prime diagnostic morphological features of terra rossa soils used in the classificatory system of the Seventh Approximation. Argillation is the process of leaching of fine clay particles from the A horizon into the B. It results in the formation of a textural B or B horizon characterised by clay coatings or cutans on soil structural units, giving typically blocky or prismatic structures in the subsoil.

Although the above processes are common to terra rossa, there is little doubt that the process of rubefaction is the most important process giving terra rossa soils their characteristic colours and composition. By rubefaction is meant the process whereby the soil material acquires its striking red coloration and its iron-rich mineralogy.

Whilst the crystalline limestone is being chemically weathered and the calcium carbonate dissolved away, the non-calcareous primary and clay minerals which occur as impurities in the limestone are released and they too are hydrolysed in their turn. The rapid and intense hydrolysis in the soil during the moist season breaks them down into their essential constituents, namely, colloidal silica, iron oxides, and alumina. The fate of these three constituents is of vital concern in understanding the evolution of terra rossa. Some of the silica combines with the alumnai to form secondary species of clary minerals, e.g. kaolinite, illite, and montmorillonite, which contribute to the clay fraction of the soil. Some of the silica is lost from the profile by leaching together with the bases and lime. The rest of the silica is retained as a colloidal groundmass in which the iron oxide materials is largely precipitated in the amorphous form. Iron oxides normally flocculate and coagulate in soils, but in terra rossa profiles the iron oxides form complexes with the free silica which, being electronegative, keeps them dispersed and mobile.

In the ensuing hot and dry season, the iron-silica complexes are destroyed, and the increase in salt concentration of the soil solution by concentration through evaporation (Reifenberg 1947) stimulates the precipitation and crystallisation of the iron oxides. Under dry conditions the amorphous iron oxides crystallise to form hematic (Fe_2O_3), one of the anhydrous iron minerals. This process is a dehydration process which is irreversible, giving a permanent and strong red iron hue to the soil. Where the soil profile still retains significant moisture during the summer, crystallisation takes place but does not result in complete dehydration. Thus under damper conditions the browner hydrated oxides of iron are formed, primarily limonite (FeO. OH, nH_2O) but also goethite (FeO. OH) and lepidocrocite (FeO. OH).

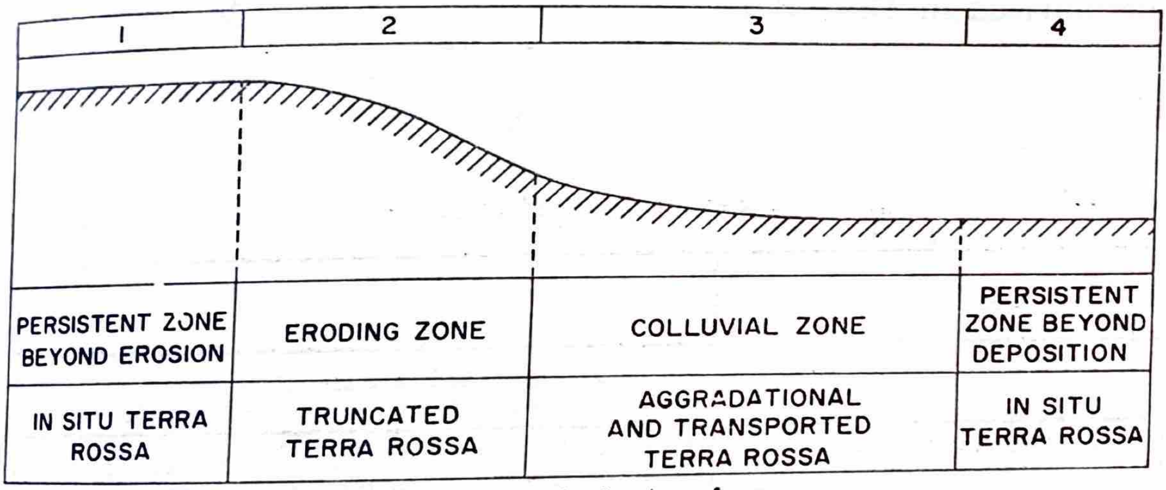

Fig. I Profile form as related to position in the land surface

A final set of processes which can influence horizon sequences in terra rossa profiles are the geomorphic processes of erosion and accretion. Using Butler's (1959) model of a four unit land surface, stable profiles occur in the persistent zones beyond erosion and accretion; eroded and truncated profiles occur on eroding slopes, whilst aggradational profiles are characteristic of areas of colluvial deposition. These general surface-soil relationships are shown in figure 1.

Horizon sequences of terra rossa profiles thus show a variety of forms depending on their position in the karstic landscape. Thin eroded profiles, stone lines at differing depths, and complete stone horizons are common field observations. Due to the upstanding and outcropping nature of limestones, there are few sites that are not affected to some degree in this way. In soil survey work it is thus often necessary to distinguish classes of 'transported terra rossa' (Fisher et al., 1966).

Moisture will also percolate downslope, of course, and receiving sites in low topographic situations are areas of moisture accumulation and are hence likely to have a more humid soil climate than shedding and freely draining sites on slope crests and slope flanks. This reflects itself in the formation in damper sites of hydrated iron oxides and hence brown soils of terra fusca type.

The pedogenic processes occuring in terra rossa profiles are summarised in Table 3 .

Table 3. Pedogenic Processes operating in Terra Rossa profiles.

Process	Result
1. Limestone weathering.	Removal of calcium carbonate; accumulation of the insoluble residue.
2. Rubefaction.	Hydrolysis of minerals in limestone; liberation of iron oxides, alumina, and silica. The formation of iron-silica complexes during the humid season, and their precipitation, dehydration and crystallization during the dry season. The production of an iron rich soil material.
3. Leaching.	The leaching of soluble salts, free lime and bases from the profile during the humid season.
4. Argillation.	The washing of fine clay particles from the A into the argillic B horizon.
5. Erosion and Colluviation.	Slope processes giving truncated profiles, mixed soils, and stone horizons.

The Question of Paleopedology.

The physical, mineralogical and chemical features of terra rossa profiles indicate that the processes outlined in the previous section have operated to produce the profiles. Unfortunately the evidence that a process has occurred gives very little indication of the actual time when the process took place. Research on what is happening at the present time in terra rossa soils is extremely limited; pedologists have been forced, therefore, to use circumstantial evidence and in so doing have come to regard terra rossa as a paleosol. This view, one which has particulary been advocated by Kubiena (1953) and Butzer (1965) among others, holds that terra rossas are relict forms, i.e. are forms which indicate development under climatic and environmental conditions of a previous period.

The evidence to support this view is largely based on what is known of environmental change during the Tertiary and Quarternary eras in areas which have a present day terra rossa cover. The **in situ** formation of 50 cm. of terra rossa material from limestone with only a 2% insoluble residue requires the dissolution of no less than 2450 cm. of limestone to produce the required residue. The weathering of such a great thickness of limestone could obviously not be accomplished during the recent time of the Holocene period, particularly as limestone dissolution is known to proceed at a relatively slow rate. Thus terra rossa soils are often described as the formations of Pleistocene Interglacial periods or even of the Pliocene or late Teriary period.

The difficulty presented by this thesis of paleopedology is that it is always dangerous to generalise about a particular soil type. The author has studied several sites, particularly in Northern Turkey, where there is direct and irrefutable evidence that a particular terra rossa is a paleosol; equally there are many literature references suggesting that in some areas, e.g. the Karst regions of Yugoslavia, terra rossa formation is going on at the present time. Equally, of course, the identification of terra rossa profiles in present day temperate climatic regions (e.g. the observations of Gardiner and Ryan (1962) in Ireland) show that terra rossa often has to be regarded as a relict soil.

Profile Characteristics.

In order to discuss the properties of terra rossa soils, use is made here of terra rossa profiles described by the author in different parts of the Middle East. Profile 1 is taken from the Wadi Ziqlab catchment of the Northern Highlands of Jordan, and Profile 2 from the Konya Ova, South-Central Anatolia. Both of these profiles have developed from hard, crystalline limestone of Cretaceous age and both have present-day vegetative covers of degraded **Quercus coccifera** woodland. Analytical data are presented in Table 4 and Table 5, as also for comparison is the data of Buru (1968) for a terra rossa profile at Farzugha, Cyrenaica. The field descriptions of the Jordan and Turkey soils are given below.

PROFILE 1.

Terra rossa profile situated in the Wadi Ziqlab catchment, the Northern Highlands of Jordan.

Open **Quercus coccifera** woodland

Aspect North-east

Slope 2°

0 — 2 cm.	Loose surface litter of oak leaves, twigs, and grass remains.
2 — 15 cm.	5YR 3/3 Dark reddish brown clay. Massive and compact, breaking down into hard large blocky units. Vertical cracking prominent. Many fine and large roots penetrate. Merging lower boundary to :
15 — 48 cm.	2.5YR 3/6 Dark red clay. Damp and extremely indurated. Breaks down with difficulty into large blocky and small prismatic units. Clay skins; fine and large roots penetrate. Rests sharply on :
48 cm.+	Solid white crystalline limestone.

PROFILE 2.

Terra rossa profile situated in the Tauros foothills, 8 km. to the west of Konya, South-Central Anatolia, Turkey. Degraded **Quercus coccifera** woodland with signs of previous cultivation between the trees.

Aspect West

Slope 3°

0 — 1 cm.	Litter layer of oak leaves, twigs, grass remains, and animal coproliths. Many large stones lie on the surface.
1 — 10 cm.	5YR 3/3 Dark reddish brown clay. Massive structure, but breaking down readily to medium and small blocky. Roots penetrate and many signs of faunal activity. Stone free. Merging lower boundary to :
10 — 46 cm.	2.5YR 5/8 Red clay. Massive but breaking down to medium blocky. Clay skins present. Fine medium and large roots penetrate. Rests sharply on
46 cm.+	Hard crystalline limestone.

Location	Depth cm.	Mechanical Analysis %			p^H	E_c at 25° C. mmhos.
		Sand	Silt	Clay		
Wadi Ziqlab, Jordan	2-15	12.5	33.5	54.0	7.4	0.71
	15-48	2.5	34.5	63.0	7.4	0.55
Konya ova, Turkey.	1-10	19.3	29.4	51.3	7.6	0.12
	10-46	16.2	30.6	53.2	7.5	0.16
Farzugha, Libya.	A	53.4	12.2	34.4	7.1	0.84
	B	50.0	15.6	34.4	7.1	0.69

Table 4

Analytical data for selected terra rossa profiles.

From the field descriptions it can be seen that these two profiles show many morphological similarities. In each case a thin litter layer overlies a dark reddish brown A horizon which in turn grades into a B+ horizon of red clay, the whole profile resting sharply on crystalline limestone. Structures are generally massive throughout, breaking down to blocky peds in the A horizon and prismatic units in the B. The presence of clay coatings in the B horizon is a typical feature of the argillic horizon. Although structures are massive and compact, roots can penetrate freely to the base of the solum.

Comparison of the analytical data for these soils, together with the Farzugha profile, shows that despite the field similarity

Location	% Carbon	% Nitrogen	% $CaCo_3$	% Free Fe_2O_3	Exchangeable Cations me/100 g Ca	Mg	K	Na	Total Exch. Cations me/100g	Avail. nutrients mg/100 g. P_2O_5	K_2O
Wadi Ziqlab, Jordan	0. 6	0.04	1.3	7.3	39.3	5.0	2.7	1.2	48.2	0.21	5.4
	0.24	0.03	0.6	9.1	42.1	8.1	2.3	1.6	54.1	0.26	13.1
Konya ova, Turkey.	1.9	0.20	4.3	5.1	57.3	1.4	0.3	0.2	59.2	0.32	8.9
	0.9	0.15	2.9	3.2	51.2	3.2	0.7	0.3	55.4	0.19	4.6
Farzugha, Libya.	-	0.13	0.2	9.5	20.6		1.5	1.3	23.4	7.5 ppm.	751 ppm.
	-	0.13	0.2	10.5	21.9		1.9	3.0	26.8	3.4 ppm.	440 ppm.

Table 5

Analytical data for selected terra rossa profiles.

there are significant differences in physical and chemical properties. The Jordan and Turkey soils are of heavier textures than the Libya profile, and conversely have much lower sand contents. This is probably due to colluvial inwashing of sand in the el-Marj profile.

Values for pH and free calcium carbonate content again show differences from profile to profile. In general the Turkey terra rossa has a significantly higher content of lime and hence a slightly higher pH. In this specific profile this was ascribed in the field to the more active faunal activity of this soil. Soil animals bring lime fragments into the upper part of the soil profile and in this way counteract the pedogenic process of leaching and lime removal.

The higher level of lime in the Turkey profile is also reflected in the data for the exchangeable cations. Figures for exchangeable calcium are high in all soils and any variations can be seen to correlate with free calcium carbonate content. Variations in the content of total exchangeable cations for these three soils are largely explained by their contents of colloidal material. The low values for the Farzugha profile reflect the low clay contents of the horizons, whilst the higher values for the Turkey profile are due to its higher content of both clay and organic colloids.

Figures for the content of free iron oxides are typical of many profiles analysed by the author. Values range between 3.2 and 10.5 per cent $Fe_2 O_3$ with a tendency to increase in the redder subsoils. The total amount of free iron oxide in a particular horizon is not always a reliable reflection of its Munsell colour notation. It will be noted that the B horizon of the Turkey profile has the lowest free iron content and yet the reddest hues. Much depends on the proportion of hematite to other iron oxides and also on its fineness and distribution throughout the groundmass. Research into the mineralogy of iron oxides in terra rossa is clearly an important field for future research. In the past the difficulty of analysing mineralogically the different species of iron has undoubtedly discouraged further investigations. Now, however, with the growing use of x-ray and Differential Thermal methods of analysis, more fruitful work can be expected.

Some interesting features can be noted from the point of view of the chemical fertility of the profiles. Conductivity levels are uniformly low (1 mmho), and exchangeable sodium forms a minor proportion of the cations on the exchange complex. Hence limitations due to salinity and alkalinity do not arise. All horizons have a high content of exchangeable calcium and magnesium, pH values that are near the optimum range for plant growth, and an exchange complex that is base-saturated. There are thus several favourable characteristics from the point of view of plant nutrient requirements.

On the other hand, there are also notable deficiencies from the point of view of major nutrients which the plant requires in large amounts. In particular, there is a general lack of organic matter in the profiles, as shown by the figures for per cent carbon, and related to this a low content of nitrogen. When it is considered that nitrogen is overwhelmingly the most important plant nutrient, it becomes obvious that proper agricultural management of these soils depends heavily on practices to alleviate the nitrogen deficit, either by chemical fertilisation or by introducing a legume into the crop rotation.

Available phosphates, too, are insufficient to meet crop needs. In the absence of free calcium carbonate in the profiles, it is likely that most of the soil phosphate is being made unavailable to plants by reversion to insoluble iron phosphate. Under normal management practices this deficiency can only be remedied by additions of readily available phosphate fertilisers e.g. fertilisers of the superphosphate group.

More variability can be seen in the figures for available potash. The Jordan and Libya profiles are of 'medium' status, as shown by available and exchangeable potassium, whereas the Turkey soil is 'low'. Potash deficiency is not general feature of terra rossa soils, although it can occur at particular sites. The content of potash is undoubtedly related to the sand and clay mineralogy of the detrital minerals in the limestone and reflects whether they are potash-rich or not.

Conclusion

Although much more is now known of terra rossa formation and properties than at the time of Reifenberg's (1947) work, there are still obvious gaps in our knowledge of these soils. In particular there are two main lines of approach which would amply repay future research.

The first is the study of the clay and sand mineralogy of terra rossa profiles to throw more light on pedogenic processes. What clay mineral species are present and how far are they derived or secondary minerals ? What is the mineralogical composition of the iron oxide fraction ? In addition to providing data on how terra rossa soils form, answers to questions such as these will also go a long way toward explaining the fertility and management responses of the soils.

The second line of work for the future should be more directly concerned with assessing fertility and crop response to management. Field trials for particular crops and tree species will indicate fertility and management problems in a much more reliable way than will the laboratory analysis of soil samples. An assessment of crop potential needs, at some stage, a rigorous system of experimentation on fertiliser response. Only in this way will some of the more favourable physical characteristics of terra rossa soils be realised.

Throughout future work, there is obviously a need for the interchange of research findings and conclusions from the many countries which have a cover of terra rossa. Differences in present environment and soil history are great in the Mediterranean region, and terra rossa soils differ in detail from site to site, as we have seen. Similarities in form and formation are even more striking, however, and hence would amply justify more detailed comparative studies.

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