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Decoding Soil Chromatic Patterns: The Science of Redoximorphic Features, Hidden Water Clues and Why They Matters?

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Colour perception is a fascinating aspect of human vision; we experience it when light is intercepted by the human eye and the brain analyses it. The properties and existing condition of the soil can also be determined by observing soil colour. The colour shown by soil is the result of the interaction between mineral and organic matter content, moisture levels, and other environmental factors [13]. Soil colour is also involved in the identification and classification of soils [16,12,14,10]. It also reflects the processes that are carried out in lower layers of soil profile. Thus, soil colour plays a vital role in soil quality assessment, evaluation, classification and management [6] and also handy in the reconstruction of ancient landscapes and also helps in detecting the modifications carried out during historical agricultural practices [3].

Factors influencing soil colour

Soil colour is the end product of the interplay (Fig. 1) of interaction between various factors such as mineral composition, parent material, environmental factors and others.

The composition of parent material, such as the type of mineral actually present, acts as a deciding factor of soil colour in that area (13). For instance, specific minerals like montmorillonite also contribute to soil colour by influencing stability and transformation of soil minerals [8].

Soil reflectivity is significantly affected by organic matter, which in turn results in colour change in soil [4]. The darkening of soil due to organic matter is mainly caused by the decomposition of plant and animal residues [5].

Soil colour significantly varies based on the moisture levels in soil. Well-drained soils typically exhibit brighter colours due to oxidation of minerals. In contrast, poorly drained soils are frequently characterized by gleying due to prolonged water stagnation [8].

The proportion of soil particles, i.e., sand, silt and clay, determines the appearance of soil in totality. For example, the soil with higher sand content tends to show lighter soil colour. Whereas, soil clay particles associated with iron oxides indicate towards darker hue [9].

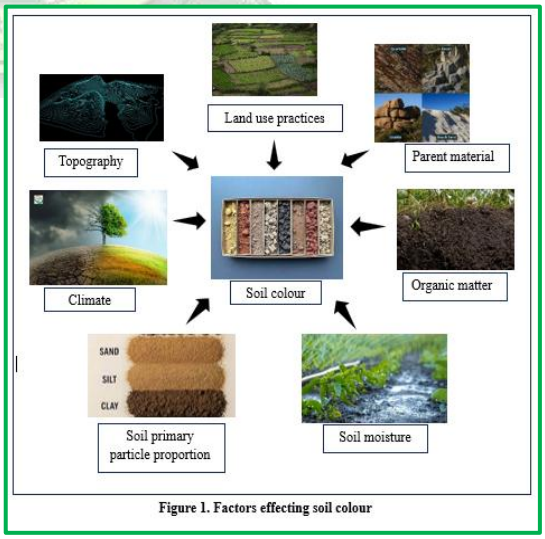

Figure 1. Factors effecting soil colour

Climate and topography also plays an important role in implying colour to soil. Climtes role in organic matter decomposition and weathering of rocks and minerals which influences soil colour over time. Higher precipitation leads to soil with red colour due to oxidation of iron oxides. Topography influences soil colour by affecting soil moisture, organic matter accumulation and drainage conditions.

Land use practices like agriculture affect soil processes which in turn alters soil colour. Operations like plowing and erosion accelerates decomposition of organic matter which shows noticeable impact on soil colour [1].

Redoximorphic features: Redoximorphic features form in water-saturated and reduced soils (when all the oxygen has been used up by the microbes). Identification of redoximorphic features is possible due to the distinctive colour patterns that developed under prolonged stagnation conditions and are visible to our naked eye. In terms of soil science, redoximorphic features as those formed as a result of oxidation, reduction and translocation of iron and manganese compounds in soil during alternate wet and dry conditions [15].

Formation of redoximorphic features: Redoximorphic features, formation relies on Fe and Mn chemistry in the soil. Presence of iron oxides imparts red, brown, yellow or orange colour to the soil. Whereas, the presence of manganese oxides imparts black colours to the soil. As the organic matter decomposition progresses in soil, the electron released are taken up by the Fe (III) and Mn (III or IV) and gets reduced to Fe (II) and Mn (II). Then dissolution of these reduced ions in the soil takes place. The reduction of elements under saturation conditions takes place in an orderly manner (Fig. 2). The first to be reduced is oxygen, as the oxygen is removed completely, anaerobic conditions prevail in the soil under saturation conditions. Following oxygen, Nitrate (NO^{3-}) gets reduced to nitrogen gas (N_2). The reduction of nitrate and oxygen in saturated conditions does not have any significant impact on soil colour. Then the reduction of Mn (III or IV) to Mn (II) followed by Fe (III) to Fe (II) takes place. If the saturated conditions prolong, sulphate (SO_4^{2-}) ions are reduced to H_2S and lastly CO_2 is reduced to CH_4.

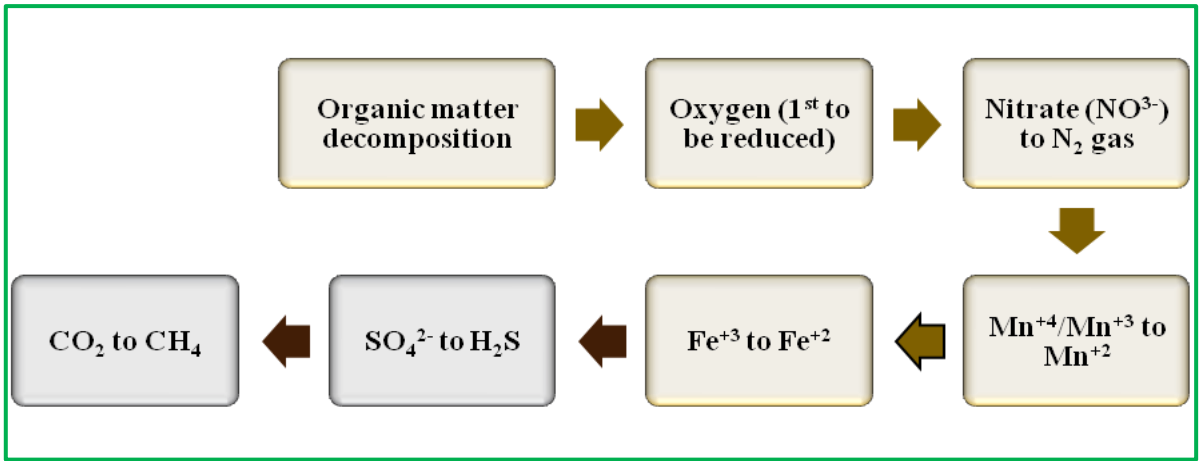

Figure 2. Flow chart showing the order of reduction in soil saturation conditions

These oxides of Fe and Mn acumulate as coatings on the soil primary particles i.e., sand, silt and clay. As the oxides of Fe and Mn dissolves in the soil in reduced pH conditions, soil attains gray colour and the dissolved oxides translocate within the soil due to diffusion and leached into deeper layers of soil [7]. The Fe (III) and Mn (III or IV) are initially decomposed by the bacteria under anaerobic conditions. The Fe oxides does not reduce until O_2, NO^{3-} and Mn are reduced.

Types of redoximorphic features

The redoximorphic features were classified for their use in field descriptions, respectively.

1. **Redox Concentrations**: These are the accumulations of oxides of Fe and Mn. These are further classified as:

-**Nodules and concretions**: Irregular shaped bodies, firm to extremely firm. If broken, concretions show concentric layers and nodules show homogenous internal fabric.
-**Masses**: They occur within the matrix, variable shapes, soft bodied. reddish mottles is also one of the former feature of masses used by scientists.
-**Pore linings**: Accumulation of oxides of Fe and Mn as pore linings on the surface of soil pores or in soil matrix beside the pore.
2. Redox depletions: Removal of only Fe and Mn oxides alone or along with clay. They have low chroma (≤2) and high value (≥4).
-**Iron depletion**: Also called gley mottles or gray mottels or neoalbans or albans. They exhibit low chroma and the clay content is similar to that of the next matrix. Occur mostly along the macropore linings or within the soil matrix. These are considered as iron depletions only when the chroma is ≤2.
-**Clay depletions**: These can be described as silt coatings or skeletans. Formed along the surfaces of ped or channel linings. They show low chroma than the adjacent matrix. The washed out clay coats the surfaces of underlying peds.
3. Reduced matrices: Initially shows low chroma but as they are exposed to air the colour change takes place. Colour change is expected in 30 minutes or less after exposure to air.

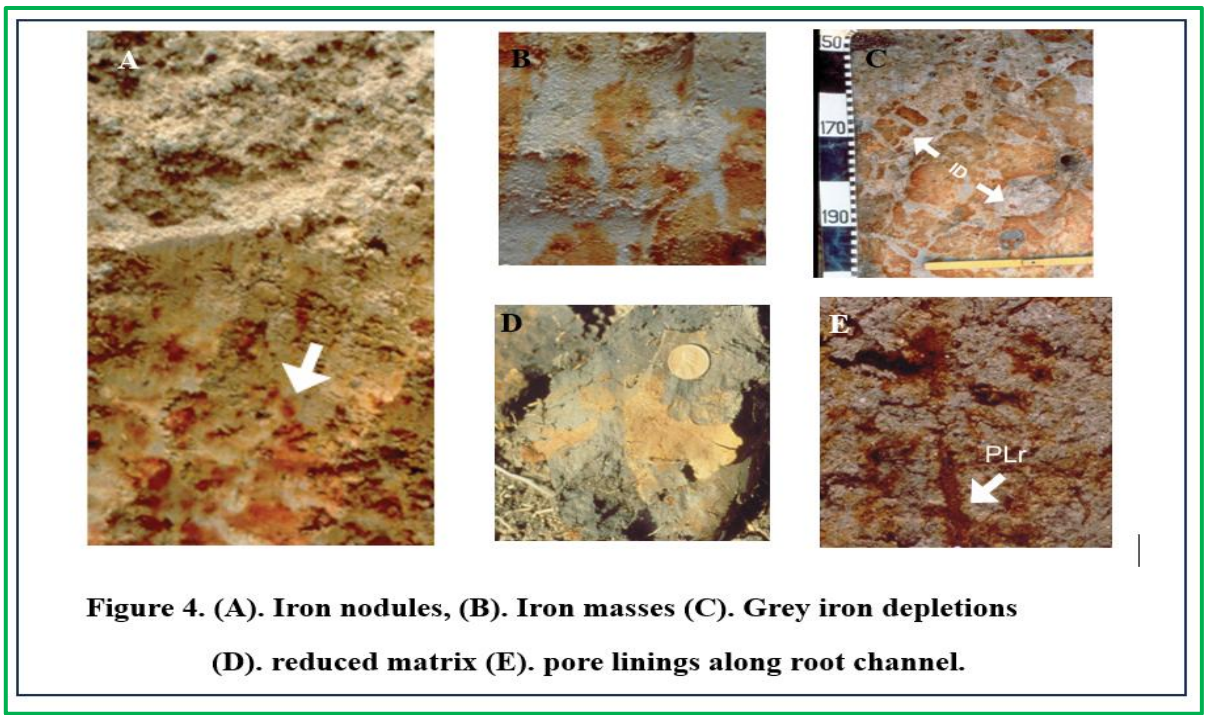

Figure 4. (A). Iron nodules, (B). Iron masses (C). Grey iron depletions (D). reduced matrix (E). pore linings along root channel.

Identification of redoximorphic features
To ease the identification of these redoximorphic features in soil micropedological studies, they were further divided into 3 types:

1. **Intrusive redox features:** As the oxidation state of the element changes, the oxides of Fe and Mn occurs as infillings in voids or accumulate as coatings in voids or on grains and aggregates. These are also referred as ferrans or magnans [2] repectively. The identification of intrusive redox pedofeatures is carried out by means of XRD and SEM-EDS analyses, because the presence of very minute quantity of Mn can darken the soil colour to a greater extent.
2. **Impregnative redox pedofeatures:** These occur as nodules in the matrix or quasicoatings or hypocoatings along the voids or coarse mineral grains. Also referred as neoferrans and quasiferrans or rusty or reddish mottles and neomagnans [2].
3. **Depletion redox features:** They occur due to reduction of Fe or Mn oxides and subsequent dissolution of the Fe and Mn oxides and are lost from the zones of formation. Most common of depletion pedofeatures are Fe/Mn oxide depletions [12].

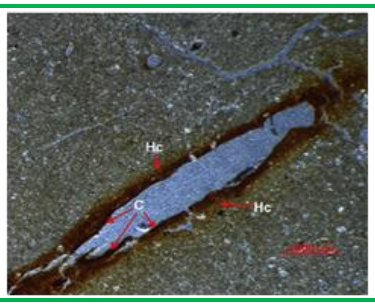

Figure 4. : A) Intrusive redox pedofeatures-Fe oxide hypocoatings (HC) and iron oxide coatings (c) occurred along a void in an Fe oxide-depleted groundmass indicated by grey colour.

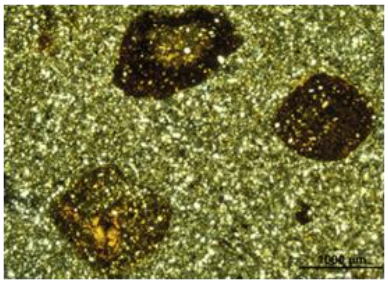

Figure 4. : B) Impregnative redox pedofeatures- nodule formation of oxides of Fe/Mn with regular outline.

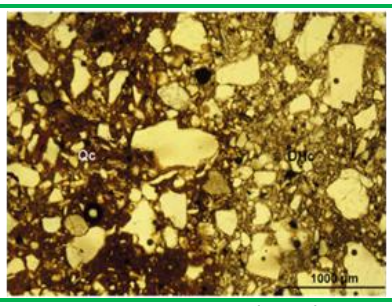

Figure 4. : C) Depletion redox pedofeatures-fe oxide depletion hypocoatings (DHc) on the lighter side of the image and Fe oxide quasi coatings on the left side of the image.

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