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IMPLICATIONS OF SOIL MINERALOGY IN THE SOIL FERTILITY CAPABILITY CLASSIFICATION (FCC) SYSTEM

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INTRODUCTION

It is the intent of the Fertility Capability Classification (FCC) System to generate soil groups within which similar responses to soil management practices can be expected (Sanchez et al., 1982). FCC creates soil groupings such that management practice recommendations can be more accurately evaluated. All soil test procedures have only short contact time between the extractant and the soil sample whereas the plant roots of all crops are in contact with the soil for at least 90 days. FCC allows consideration of the inherent properties of the soil that influence nutrient availability as an aid to a refined interpretation of soil test results. Almost all soil management practices are administered through the soil surface. Therefore, the FCC system places more emphasis on the surface and subsurface soil.

Particle-size Types

Particle size distribution indirectly controls the soil's mineral interaction because it is generally correlated with surface area and the physical properties of the soil solution. FCC has grouped the 21 USDA textures into three textural groups primarily to reflect three relative levels of AWC. Three ranges of AWC have been arbitrarily selected to separate textures into three groups or "textural types": Sandy, Loamy, and Clayey. Where textural types are contrasting within the upper 50 cm, the surface and subsurface types are stated. These groupings also allow general relative statements to be made regarding infiltration rates and nutrient movement. Various condition modifiers, discussed below, where accompanying textural type designations, allow modification and addition of the kinds of statements made about those textures. Also recognized at this level in the system but not discussed in this paper are organic soil materials, lithic and other root restricting materials, and coarse fragments.

Of the 20 non-coarse fragment related FCC condition modifiers, 10 either directly or indirectly indicate the presence of various soil mineral suites or are defined to relate to the mineralogical properties of the soil.

Carbonate Influenced Soils

The b modifer identifies the presence of at least 0.5% total carbonates in the less than 2 mm fraction or uniform effervescence with dilute acid throughout the upper 20 cm or plow layer whichever is shallower. The U.S. Salinity Laboratory Staff (1969) has stated that as little as 0.5% carbonates can be detected under field conditions with the

application of dilute acid. This value has been adopted by FCC to be consistent with effervescence criteria.

The primary reason for recognizing the presence of carbonates is to segregate soils that foster lime induced micronutrient deficiencies in many cultivated plants. Jurinak and Bauer (1956) have reported that there is an increased sorption of zinc on carbonate crystals as the proportion of magnesium is increased. The criteria in FCC makes no distinction between carbonates. Also, where the carbonate content is greater than a given amount, which varies by texture, moderate to high rates of P fertilizer applications will likely be required for newly cultivated soils or for soils that have been uncultivated for a number of years. Additionally, a statement is provided noting the increased volitalization potential of anhydrous ammonia due to carbonate presence.

Acid Sulfate Soils

Potential or actual acid sulfate soils are recognized by use of the c modifier. Recommendations in FCC for soils that have a c modifer involve reclamation, liming practices and water table management. The kinds of practices are a partial function of the rainfall patterns or rather whether a diked soil is prone to a fluctuating water table because of a distinct dry season or not and whether or not there is a tidal influence.

Low Activity Surface Horizons

The e modifer defines soils that have a low cation exchange capacity in the plow layer or upper 20 cm. The intent is to recognize soils that have a CEC under the conditions in the field for a limed or unlimed condition that equals 4 $cmol(+)kg^{-1}$ or less. Sanchez (1976) states that materials having greater than this level of charge generally retain a sufficient amount of cations for the production of one annual crop. Extrapolation of critical calcium, magnesium and potassium values and critical magnesium levels reported for alfalfa (Kamprath, personal communication) agrees with this value. Because the interest is the CEC in the field, the effective cation exchange capacity (ECEC), defined as the sum of 1N NH_4OAc extractable calcium, magnesuim, potassium, and sodium plus 1N KCl extractable aluminum, is used as the primary criteria. Alternate criteria using CEC determined by 1N NH_4OAc buffered to pH 7.0 is also provided.

The classifier is also querried as to whether the soil, if acid, is to be limed or not in order that the criteria account for resulting CEC after liming in pH dependant charge systems. The soil organic matter (SOM) contributes to the CEC to varying degrees and is pH dependent. A portion of this contribution to CEC can be relatively transient and may decrease through cultivation from the level under uncultivated conditions. To date, FCC does not consider this potential change.

The mineralogical interpretation is dependant on the FCC type and other condition modifers present or not present

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for a given soil. Where the e modifer is associated with an S type, the clay mineralogy can be quite varied because of the low maximum amount of clay allowed in this textural type (15 percent). A loamy sand texture with less than 15% clay content and 4 cmol(+) kg^{-1} soil or less, can have a charge ranging from 0 to about 33 cmols(+) kg^{-1} clay plus SOM. Where an S type is present and an e modifer is not, the clay plus SOM CEC can range from about 27 to over 100 cmol(+) kg^{-1} clay. Obviously, only gross statements, if any, can be made regarding S e or S FCC classifications. Where the b modifier and a distinct dry season is present (d or d^+ modifier) is also present (Sbd or d^+e), the setting is mainly one where 2:1 clay minerals are present. Conversely, where S ae is the classification (a modifier equaling 60% or more aluminum saturation, lack of d or d^+ modifiers indicating udic or perudic soil moisture regime (SMR), and no g or g^+ modifiers present which indicates aquic or peraquic SMR) it is probable that 1:1 silicate clays are present which may include iron and aluminum oxyhydroxides. Similar senarios can be made for L or C types with and without the above-mentioned modifiers. A "C e" or other C type soil with an e modifier will allow narrower groups of mineralogical suites to be predicted than for sandy soils. For example, a soil classified as "C ei" (i = high crystalline iron content - discussed later) infers a mineralogy dominated by goethite or hematite, and with or without kaolinite and gibbsite. If the soil is classified C e, kaolinite dominates and there is less than 5.7% Fe_2O_3 extracted by the dithionite-citrate procedure.

The importance of recognizing low CEC in FCC involves low cation buffering capacity and the recognition of one factor contributing to cation leaching. Recommendations focus on reducing amounts and increasing frequency of fertilizer and amendment application.

Iron Minerology

The <u>i modifier</u> recognizes soils high in iron oxyhydroxides. The intent of this recognition is to segregate soils that sorb medium to high quantities of P to provide critical P in solution via crystalline iron clays. Primary criteria requires the presence of 5.7% Fe_2O_3 or more extracted by the dithionite-citrate method in the upper 20 cm. This value has been shown to accurately predict phosphorous requirements of 100 ppm P or more added to the soil to achieve 0.2 ppm in solution for about 86% of the samples analyzed (Pope, 1976). Wada (1977) summarizes that the dithionite-citrate is effective in extracting iron in crystalline and noncrystalline hydrous oxides (as well as from organic complexes). The FCC system querries the classifier whether or not andic properties (discussed below) are present prior to the i modifier querry in order to better group soils dominated by crystalline iron hydrous oxides (primarily goethite and hematite).

A key feature of recognizing P retention by iron oxides is that this P requirement can be satisfied by one initial

application. Subsequent applications are then of a more "normal" magnitude.

Soils classified as having an i modifier are normally associated with good physical properties although where an eroded soil has exposed a high iron containing Bt horizon, higher bulk densities, blocky structure and slower infiltration rates can be expected.

Potassium Limiting Soils

The k modifier identifies soils that have a low ability to furnish labile and solution K because of a low amount of potassium bearing minerals that are capable of being weathered at a sufficient rate. The criteria requires that a soil be classified as having a siliceous mineralogy family as defined in Soil Taxonomy (Soil Survey Staff, 1987) in conjunction with having an Arenic or Grossarenic taxonomic subgroup and sandy or loamy particle size family, soils with an E horizon at least 10 cm thick within the upper 50 cm, or have both an e and an i modifier. Additionally, a k modifier is assigned where the 1N NH_4OAc extractable K is equal to or less than a stated K level which depends on the presence of other related FCC soil properties. The variation in the critical value is based on the effects these properties have on the potassium's quantity/intensity relationships. It can only be said that soils qualifying as having a k modifier are low in weatherable K bearing minerals which may be due to coarse textures, highly weathered conditions or low mineral content such as in organic soils.

Recommendations associated with the k modifier involve the need for careful monitoring of K status and, in most instances, a requirement for split K applications for most crops.

Soluble Salt Limiting Soils

The s and s^- modifiers indicate the presence of excess soluble salts as reflected by the saturated paste extract's electrical conductivity somewhere within the upper 1 meter of the soil. The s modifier requires an EC of 4 mmhos cm^{-1} or more. The s^- modifier requires between 2 and 4 mmhos cm^{-1}. The well known salts present in saline soils involve mainly the calcium, magnesium, and sodium cations and the chloride and sulfate anions. Salts of minor constituency involve potassium, bicarbonate, carbonate and nitrate (U.S. Salinity Laboratory Staff, 1969). In the absence of the b modifier, it can be assumed that the total carbonate mineral content is less than about 0.5%. General recommendations regarding reclamation are provided.

Soils with Vertic Properties

The v modifier identifies large amounts of 2:1 expanding clay minerals in the upper 20 cm having: a high reversible shrink-swell potential using a coefficient of linear extensibility (COLE) value of 0.06 or more; a taxonomic classification including a vertic subgroup; or the soil

classified as a Vertisol. A minimum clay content to achieve a COLE value of 0.06 for clays having a charge of 50 cmol(+) kg^{-1} (dominating in relatively non-interlayered 2:1 clay minerals) is about 35%. For mixed mineralogy clay systems, a v modifier can still be achieved where the clay content is about 50% or more (Brasher, unpublished data). It is unlikely that kaolinitic/oxidic clay systems would qualify as having a v modifier. The FCC classification, on rare occasions, includes an L type with v modifier. In this instance, there is reasonable assurance that the clays are dominantly smectite and vermiculite. Where the C type designation is present, the mineralogy can also include 2:1 hydroxy interlayered minerals with increasing amounts of kaolinite as the charge decreases and clay content increases.

The properties of interest to FCC in recognizing the v modifier include consistance and shear strength as a function of moisture status as it affects timing or tillage operations, and relatively high buffer capacity.

Soils with Andic Properties

The <u>x modifier</u> recognizes x-ray amorphous materials, primarily allophane and imogolite, where they dominate the soil system. Wada (1977) states that aluminum and iron in noncrystalline hydrous oxides are effectively extracted by the use of an acid ammonium oxalate (AAOE) procedure (Wada and Wada, 1975). These elements determined by this procedure are used in Soil Taxonomy as partial criteria for placing soils within the Andisol soil order. The main intent of recognizing these materials in FCC is to separate soils that retain high to very high amounts of phosphorous to obtain critical solution P levels for crop growth and which also have a high probability of subsequently requiring high levels of P fertilization for continued crop production. P rentention is determined for the purposes of Soil Taxonomy for Andisols by the method of Blakemore et al. (1981). This method does not directly identify P application levels necessary to provide adequate levels of P for plant growth. However, this level of P retention has been shown to correspond to 200 kg P ha^{-1} or more required to obtain adequate soil test levels (the 200 kg value has been subjectively determined to be a significant level of P retention to recognize in FCC). A plot of AAOE Al vs. P retention from a subset of the USDA National Soil Survey Laboratory database shows that 90% P retention corresponds to 2.3% aluminum content with an 89% accuracy of separation of the data using the technique of Cate and Nelson (1971). It has been shown (USDA, 1988) that several Spodosols and Inceptisols in the northeastern U.S. also exhibit these properties and in those instances, the authors found that considering the AAOE Fe content allowed an improved prediction of P retention over using Al values alone. This was not found to be true for the overall NSSL data set used. Other properties correlated to P retention include dithionite-citrate extractable aluminum, and NaF pH values.

The $\bar{x}$ modifier is new to the system and presented for further testing. It identifies other soils that have lesser levels of AAOE aluminum and iron and sorb medium to high quantities of P to provide a critical solution level. P rentention values of between 30% and 90%, and AAOE aluminum values of between 0.2 and 2.3% are used as primary criteria. Data shows that some soils from the northeast U.S. also contain quantities of mica, vermiculite-mica, and kaolinite clay minerals.

Summary

FCC attempts to account for the presence of soil minerals by using chemical and physical criteria measured in the surface soil. In this way, the recommendations made from soil testing procedures can better consider the interactions of fertilizer material and soil minerals over a growing season or longer period of time.

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