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AGRONOMY NOTES

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MINERALOGY AND SOIL PRODUCTIVITY

A. D. Karathanasis

The soil that is often called "dirt" is not as dirty as many people think. If we remove the 5 to 10% of the soil material, composed of organic matter and amorphous Fe, Al and Si hydrous oxides, the remaining 90 to 95% is a mixture of crystalline or subcrystalline minerals. We are able to see and identify with the naked eye, the large crystalline particles of the sand fraction. For the smaller mineral particles of the silt and clay fractions microscopic or other more sensitive methods (x-ray diffraction, thermal) are needed for their identification and quantification. While little attention is often given to these crystalline minerals as to their relation to soil productivity, their different morphological and physicochemical properties play a very important role in controlling soil behavior. Sometimes the presence of even very small amounts of certain minerals in the soil is more critical than the presence of large amounts of others because of unique characteristics affecting their reactivity. For example, the mineral smectite (montmorillonite) with its high cation exchange capacity, surface area, and shrink-swell potential is a determining factor in ion exchange reactions, sorption processes and mechanical strength of soils. On the other hand quartz, the dominant mineral in many soils, is relatively non-reactive and is largely considered as a dilutant of other more reactive mineral components in soils. Other soil minerals such as mica and kaolinite are intermediate in reactivity between those of smectite and quartz.

Generally, the effect of the soil mineralogical composition on soil productivity is two-fold: (1) it influences chemical reactions regulating nutrient availability and uptake and (2) it affects physical properties controlling soil moisture balance and physical conditions of the soil.

Soil Mineralogy and Nutrient Availability

Two aspects which relate soil mineralogical composition to nutrient availability are noteworthy. First, soil minerals are the source from which most plant nutrients are released in available forms into soil solution. Such release comes about through mineral transformation, weathering, or dissolution - reprecipitation reactions, i.e. K-release from weathering of micas; P and Ca release from phosphate and carbonate minerals. Secondly, due to their ion exchange properties and surface reactivity, soil minerals control the ionic equilibrium of the soil solution. This is the equilibrium on which mineral uptake necessary for plant growth depends. It is regulated by ion exchange and fixation processes.

The available nutrient supply in soils is considered to be the sum of both soluble and exchangeable forms. Roots of living plants absorb nutrients from the soil's solution phase which is in equilibrium with the exchange phase, with the plant root itself being a cation exchanger. The capacity of the soil to replenish the solution nutrient concentration after it has been lowered by plant nutrient uptake depends on

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the mineralogical composition of the soil. This is because a great portion of the exchange capacity of the soil which determines the ability of the soil to supply growing plants with nutrients is related to crystalline and subcrystalline mineral components. The magnitude of the ion exchange reaction is determined by the type of ions involved, nature of the soil solution and the strength of attraction between a particular mineral and a specific cation. Generally minerals with high cation exchange capacity (CEC) such as smectite, have a greater attraction for polyvalent (Ca^{2+} , Mg^{2+}) than monovalent (K^+ , Na^+) ions. The reverse is true for minerals with low CEC such as kaolinite.

Equally important is the role of soil minerals in controlling anion exchange and fixation phenomena. Minerals with low CEC and low crystallinity often have higher affinity for anions (e.g., H_2PO_4^-), especially under acid pH conditions. The greater the negative charge per unit of surface area of the mineral (e.g., smectite) the more anions are excluded from the particle surface and lost by leaching from the rooting zone.

Mineralogy and Physical Soil Properties

Most physical soil properties are determined largely by the mineralogical composition of the soil. Soil texture, structure, moisture characteristics, pore size distribution, plasticity, shrink-swell potential, soil strength, and erodibility can be directly or indirectly related to soil mineral properties. Particle size distribution results from a physical degradation of soil minerals due to imperfect lattice energy distributions in the silicate layers causing strains in the mineral structure. Soil strength, aggregation and plasticity are affected by the various attractive and repulsive forces exerted by the various minerals. The overall structure of the soil is the product of the arrangement and bonding of individual soil particles into aggregates caused by ionic, organic, water and clay mineral surface interactions. The individual shape and stability of soil aggregates, however, varies with soil mineralogical composition. Smectitic minerals induce formation of spherical aggregates, whereas kaolinite promotes a platy structure. Structural stability of soil aggregates is a function of surface charge (CEC) of the minerals contained. It decreases in the order montmorillonitic > illitic > kaolinitic soils.

Soil water retention characteristics are also affected by the clay mineralogical make-up of the soils. This is due to variations in specific surface area and solute-water-solid interactions of specific clay minerals. Smectite soils retain much more water than illitic or kaolinitic soils, as is illustrated in Table 1. Because of this, water adsorption characteristics can be used for help in identifying soil mineralogical composition.

Shrink-swell characteristics of a soil is another important physical property directly related to soil mineral content. It is due to charge imbalances in the crystal lattice and surface charge density of clay minerals. Volume expansion and shrink-swell potential are much higher in smectitic than in illitic or kaolinitic soils because of their higher surface charge density (Table 1). Soil erodibility is also affected by mineralogical composition, because the mineralogy of the soil influences such properties as aggregate stability, permeability and soil shear strength. Smectite soils, despite their higher aggregate stability, are more susceptible to surface soil losses because of their slow permeability. Total erosional losses however, are generally greater from illitic or kaolinitic soils because they require less water to reach saturation. At that point their shear strength is reduced to near zero, and they erode with surface water flow (Table 1).

Mineralogy of Kentucky Soils

Very few mineralogical data have been published for soils in Kentucky. As an initial attempt to classify mineralogy of the subsoil, a general mineralogy map of the state was constructed based on currently available information (Fig. 1). The map suggests that quartz, mica, and feldspars are the dominant minerals of the sand and silt size fractions and that illite, smectite, kaolinite and hydroxyinterlayered vermiculite or smectite dominate the clay size soil fraction. Soils of the Western Coalfields, Eastern Coalfields, and Eastern Pennyrile regions generally contain more quartz in the sand and silt fraction than soils of the Purchase, Western Pennyrile, and Bluegrass regions. The sand and silt fractions of the latter regions, although still dominated by quartz, contain significant amounts of potassium feldspars and mica. The feldspar component is generally more prominent in soils of Western Kentucky, with mica being more prominent in central and eastern parts of the state. Soils with high feldspar or mica content are considered to have adequate water-soluble, exchangeable, and non-exchangeable K-supplying capacity because of the potassium released from their mineral structure during weathering. However, muscovite-type micas are more resistant to weathering than feldspars, with a rate of K-release not fast enough to replenish the solution K as it is removed by plants. Furthermore, not all mica-type minerals contain the same amount of K in their crystal structure (muscovite 11%, glauconite 5%, biotite 8%). Potassium availability to plants in these soils also depends on the rate and duration of ion exchange reactions, the nature of which is affected by soil mineralogical composition, K-specificity for certain exchange mineral sites and the nature of other ions in solution.

To date no definite regional trends have been established for the mineralogical composition of the clay size fraction of Kentucky soils. Generally, however, there is a tendency for both Eastern and Western Coalfield regions to contain less smectite and more prominent amounts of hydroxyinterlayered clay minerals than other regions. Smectite soils are most often found in some floodplain areas of the Mississippi, Ohio and Green rivers. Although when acid, these soils require more lime to raise pH because of their high cation exchange capacity, most do not have very low base saturation. Most of the soils in other regions contain variable quantities of illite, smectite/vermiculite, kaolinite and hydroxyinterlayered clay minerals. Amounts of lime needed to neutralize excessive acidity in these soils will be determined by the original acidity present and the buffering capacity of the mineral mixture.

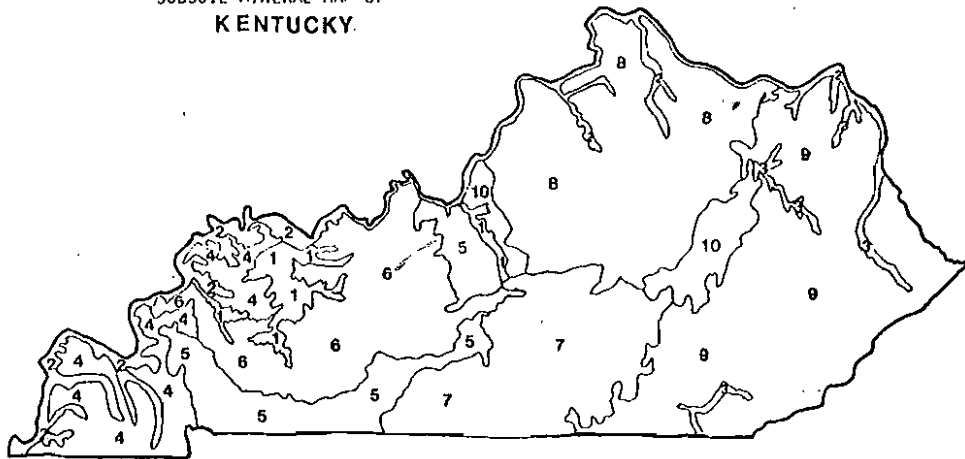
Some soils of the Outer Bluegrass region formed from shaly parent materials are relatively high in vermiculite and interstratified minerals that exhibit a significant K-fixation capacity. Higher rates of K-fertilization may be required for such soils. Soils of the Hills of the Bluegrass, however, contain significant amounts of readily available potassium and require smaller rates of K-fertilization. Bluegrass soils developed from phosphatic limestone are likely to maintain relatively high P levels in the soil solution even without fertilization, depending on the solubility of the phosphate minerals present. Liming acid soil surfaces improves P availability because it decreases phosphate fixation by Al and Fe hydroxyoxides. Unless limed adequately, however, higher rates of P fertility are required for optimum crop growth.

There is still much to be learned about physico-chemical reactions controlling soil behavior. Some of these reactions are triggered by various types of physical or chemical soil management imposed by man. To successfully quantify them and predict how soils will respond, a quantitative knowledge of the mineralogical composition of the soil system will be necessary.

Table 1: Effect of clay mineralogical composition on some physical soil properties.

Dominant Mineralogy	Water Content (%)			At Zero Shear Strength	Volume Expansion %
	at different tensions				
	0.1 bars	0.33 bars	15 bars		
smectitic (montmorillonitic)	>50	>35	>18	>20	>150
illitic or mixed	35-50	22-35	9-18	5-20	70-150
kaolinitic	<22	<15	<9	<5	<50

SUBSOIL MINERAL MAP OF
KENTUCKY.



DOMINANT MINERALOGY

Area	DOMINANT MINERALOGY	
	Sand and Silt Fraction	Clay Fraction [†]
1.	<60% quartz; mica	smectite > illite > kaolinite
2.	40-80% quartz; mica	illite > kaolinite > smectite > HEX
3.	40-80% quartz; feldspars	illite > HEX > kaolinite
4.	40-80% quartz; feldspars	HEX > illite > kaolinite
5.	40-80% quartz; mica	kaolinite > illite > smectite > HEX
6.	40-80% quartz; mica; feldspars	HEX > kaolinite > illite
7.	40-80% quartz; mica; feldspars	illite > smectite > kaolinite > HEX
8.	40-80% quartz; mica; feldspars	illite > HEX > kaolinite > smectite
9.	40-80% quartz; mica	illite > kaolinite > HEX
10.	<60% quartz; mica	kaolinite > smectite > HEX > illite

[†] HEX - hydroxyinterlayered minerals