

SOIL MINERALOGY AND POTASSIUM AVAILABILITY

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In this talk, I will try to answer four questions. The outline below gives the overall framework for the presentation.

1. What are the mineral sources of potassium?

Primary minerals crystallize from the magma. Those that contain K are:

- Feldspars (microcline and orthoclase)
- Micas (biotite and muscovite)

Primary minerals weather – decompose – by several mechanisms.

- Chemical bonds are destabilized by acid attack.
- Al ions are complexed by organic anions and kept in solution.
- Fe²⁺ ions are oxidized to Fe³⁺ ions, creating a charge imbalance.

K-bearing primary minerals occur in sand and silt fractions of north-central region soils.

- They have low surface area and fairly low chemical activity.
- This K is called *structural* K. The size of this reservoir depends on the soil parent material and the degree of weathering that has taken place.

2. Once released from primary minerals, where do K ions go – if not to plants?

Before answering that question, let's take a slight detour to recall the basic characteristics of layer silicate clay minerals.

- Variation in *isomorphic substitution* leads to variation in the negative charge of minerals.
- *Smectites* may range in charge, but the lower the charge the higher the surface area.
- *Illite* is a high charge, moderate surface area mineral, mainly derived from muscovite.
- *Vermiculite* is also a high charge, moderate surface area mineral, mainly derived from biotite.
- In acidic soils, vermiculite and smectite can be “pillared” with hydroxylated Al polymers. These forms are called *interlayered vermiculite and smectite*.
- The proportions of these minerals in the clay fractions of soils in the north central region are highly variable.
- In the real world of soils, all of these minerals commonly occur “*interstratified*” with one another.

Solution-phase potassium

- In soil water (the aqueous soil solution), K occurs mainly as a hydrated cation.
- Concentrations are highly variable.

- Most of the potassium that is bioavailable passes through the solution phase to get to a root.

Exchangeable potassium

- Exchangeable definition: Empirical, lab-based definition – K that can be flushed from the solid phase with NH_4^+ ions (or other cations). In the context of soil testing, exchangeable K normally refers to that which is extractable using ammonium acetate, ammonium nitrate + ammonium fluoride (Mehlich-3), or calcium lactate.
- Organic matter contains negatively charged functional groups that contribute to the cation exchange capacity of the soil and retain K^+ .
- Smectite is a mineral with negatively charged surfaces that also attract K^+ .
- Other cations, such as Ca, Mg, and NH_4^+ compete dynamically with K for these negatively charged sites and surfaces.
- Exchangeable K^+ is held loosely near negatively charged mineral surfaces or negatively charged organic functional groups.

Fixed potassium

- Some K^+ ions are held more tightly at specific sites on mineral surfaces where the negative charge is high.
 - Near tetrahedral charge sites
 - Near reduced Fe sites
- The bonds between K^+ and the mineral remain electrostatic, but they are more effective at holding the K ions in place when there is a flush of other cations in a soil-test procedure.
- On the other hand, these K^+ ions may be released slowly to the soil solution as the solution is depleted in K during plant uptake and if Ca^{2+} , Mg^{2+} , NH_4^+ , or H_3O^+ are available to take their place.
- Al-hydroxy polymers in vermiculite and smectite (pillared clays) may also prevent the exchange of K^+ with Ca^{2+} , NH_4^+ , or H_3O^+ .

3. Which forms of K are more “available” to plants for uptake?

Structural potassium: Weathering of K from primary minerals is slow in the context of a single growing season.

Solution-phase potassium

- *Advection* in the transpiration stream brings K close to root surfaces.
- *Diffusion* of K ions in water and exudates immediately adjacent to root surfaces.

Exchangeable potassium

In the context of soil testing, “exchangeable potassium” is a convenient surrogate for what we really want to know, i.e., the amount of potassium available for uptake over the course of a growing season. When we measure the amount of soil potassium that can be *exchanged* with ammonium (or some other cation) in a soil-test extraction, we are assessing some fraction of the potassium might be taken up by a crop. Under some conditions, that fraction can be a reasonable predictor of seasonal plant uptake, but the prediction is not always as reliable an index as crop

producers need. It is useful to remind ourselves that “soil-test exchangeable” does not equal “available.”

Fixed potassium

- Fixed forms of K are not permanently prevented from getting to the solution phase of the soil. Think of fixed K as “slow-release” potassium. It may or may not be released during the course of a growing season when the plant needs it, so it may or may not be available for plant uptake.
- Potassium ions held at reduced Fe sites will be held less tightly when the soil is drained, oxygen enters the system, and Fe^{2+} is converted to Fe^{3+} . At that point, the K^+ ions become more exchangeable.
- Potassium ions at other high-energy sites may eventually diffuse out to the soil solution as low-energy sites are depleted by plant uptake, but the rates are not readily predictable because they depend on the abundance of the different minerals in the clay fraction as well as the concentrations of other cations in the soil solution.
- A number of empirical soil tests have been proposed and implemented for quantitatively assessing the *amount* of fixed K, but the *rate of its release* during a given growing season remains difficult to predict.

4. What can be done to increase the bioavailability of K ions that are associated with minerals?

Keeping the cation exchange capacity high will provide an abundance of low-energy sites and surfaces where K^+ ions can be held until the plants start to draw on them. In most soils, the cation exchange capacity can be increased by increasing soil organic matter and by maintaining soil pH in the range of 6.5 – 7.0. Some degree of potassium fixation probably occurs in most soils that contain layer silicate minerals such as smectite, vermiculite, or hydroxy-interlayered forms of smectite and vermiculite. But soil management that promotes good drainage, increases soil organic matter, and maintains pH near neutral is likely to minimize the risks associated with fixed, slowly available potassium.

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