Potassium Fixation and Its Significance for California Crop Production

By Stuart Pettygrove, Toby O'Geen, and Randal Southard

The fixation of potassium in the interlayers of soil minerals has been the subject of interest for fertilizer management. This review highlights the mechanism of K fixation and a case study from Central California where K-fixing soils are common.

Potassium is always present as K^+ in soils, but it is found in several fractions including: (1) solution K, which is plant-available; (2) exchangeable K held weakly on cation exchange sites—also plant-available; (3) fixed K in interlayer minerals, a portion of which is available depending on soil clay mineralogy; and (4) matrix K in rocks and minerals, which is not plant-available except very slowly. In most soils, the solution and exchangeable K constitute only a few percent of the total soil K **(Figure 1)**.

Potassium fixation occurs when K^+ ions form a surface complex with oxygen atoms in the interlayers of certain silicate clay minerals **(Figure 2)**. A portion of the K held between the layers of some clays, such as smectitic clays (montmorillonite), will readily diffuse back into solution as the K is depleted due to plant uptake or leaching. However other soil minerals, especially vermiculite, will strongly complex K in the interlayer region, releasing it only very slowly back into solution.

Vermiculite is a weathering product of biotite mica and is commonly found in soils on the east side of the California San Joaquin Valley. These soils are formed in alluvium derived from granitic parent material arising from igneous intrusive rocks **(Figure 3)**. An example of such a soil that fixes K is the San Joaquin series. This soil was formed from old (130,000 to 330,000 years) alluvium on low terraces bordering the eastern margins of the Central Valley floor **(Figure 4)**. This soil strongly fixes K and is generally less fertile than soils formed on younger alluvium. The region where this soil occurs was historically used for cattle grazing, but in recent decades it has become important for wine grape production, as well as for urban development.

In California, soils formed from volcanic or metavolcanic parent material, or weathered soils with kaolinitic mineralogy do not usually fix K. Soils dominated by smectitic clays, or formed in very young, coarse-textured alluvium also do not consistently fix K. However, because of spatial variability in deposition and erosion patterns, it is common to find both K-fixing and non-fixing soils in the same field.

One important finding of our work is that vermiculite most often occurs in the silt and fine-sand size fractions of the soil (Murashkina et al., 2007a). We also found that the highest percentage of added K was fixed by the silt-sized fraction, with significant fixation also occurring in the very fine and fine sand fraction. Some of the soils have non K-fixing smectite material mixed with K-fixing vermiculite in the silt and sand fractions. This is consistent with frequent observations by cotton growers in the San Joaquin Valley on sandy loam and loam soils where repeated, large doses of K fertilizer are required to correct deficiencies.

Common abbreviations and notes: K = potassium; KCl = potassium chloride; NH_4OAc = Ammonium acetate.

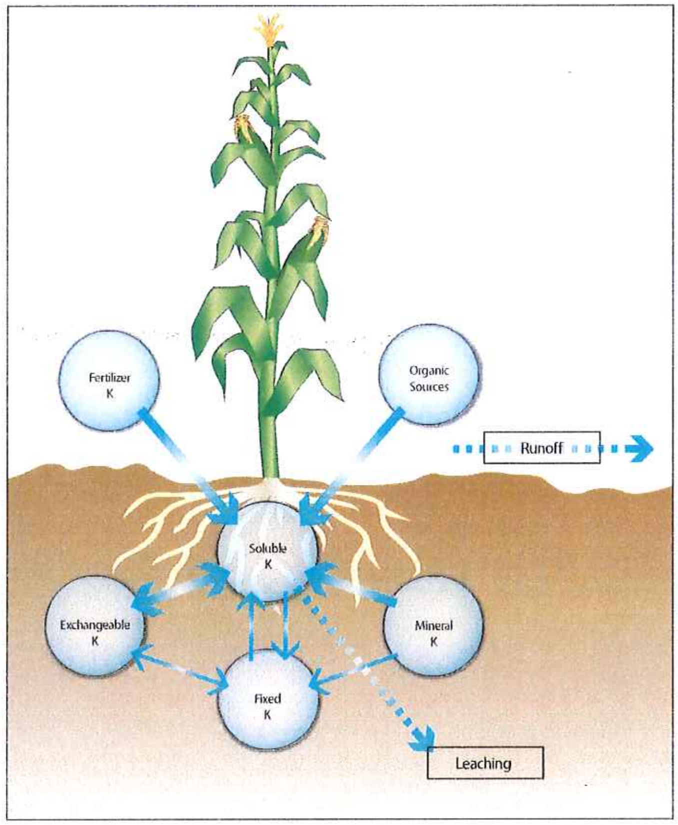


Figure 1. Although potassium can be present in several pools in soil, it is always in the form of monovalent K^+. Only a small fraction of the total K is soluble and available for plant uptake at a given time. In addition to plant uptake, leaching and runoff can also remove K from the root zone.

Importance of K Fixation for Crop Production

Late-season K deficiency in cotton in California and response to heavy applications of K fertilizer was first reported by researchers in the early 1960s. These deficiencies are widespread on the east side of the San Joaquin Valley, reflecting the prevalence of parent material derived from Sierra Nevada granitic alluvium, which contain significant amounts of vermiculite, hydrous biotite, and biotite mica at different weathering stages. Where cotton is produced on these soils, fertilizer inputs in excess of 1,500 lb K_2O/A may be required to achieve maximum yields (Cassman et al., 1990; Miller et al. 1997).

The significance of K fixation has not been studied as much for other crops in California. In UC Cooperative Extension

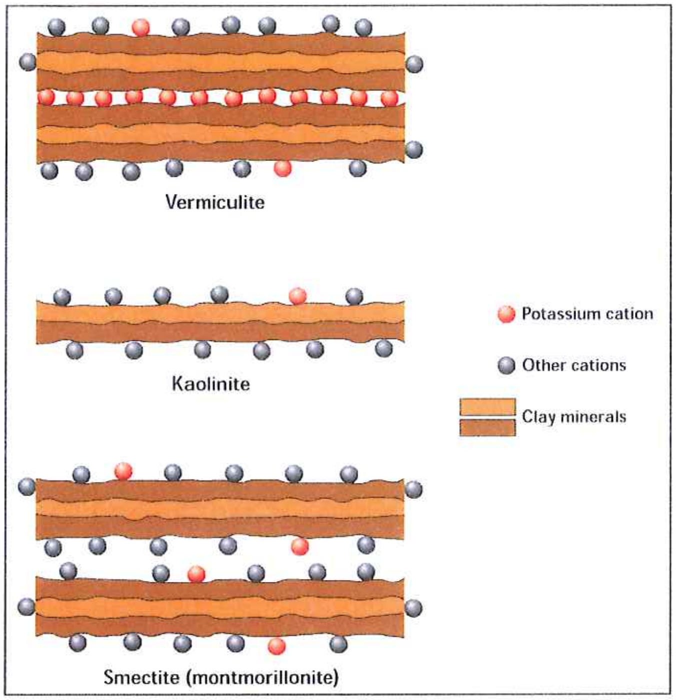


Figure 2. Fixation occurs when K is held in highly charged sites in the interlayer region of vermiculite and mica minerals. This differs from exchangeable K which is held at lower charged sites, on the surface and edges of clay minerals such as kaolinite and montmorillonite.

experiments in commercial walnut orchards in the Central Valley (Olson et al., 1990), heavy applications of 1,000 lb KCl/A did not completely correct K deficiency and did not provide a benefit for more than a few years, which suggests that K was being fixed by soil minerals.

With the widespread adoption of drip irrigation and fertigation, less K fertilizer may be needed to meet the nutritional demand of crops because the nutrients are directed to a concentrated zone beneath the plant where most of the root activity occurs. However during periods of peak nutrient demand, especially when fruit loads are heavy, this restricted root zone could lead to K deficiencies.

Changes in fertilization and irrigation practices reinforces the need to better characterize the phenomenon of K fixation. For example, the widespread conversion of processing tomatoes to drip irrigation and fertigation has prompted a re-examination of fertilization practices in K-fixing soils. Large orchards of fruit and nut trees now receive nutrients through micro-sprinklers. Cotton grown with furrow irrigation and pre-plant K fertilization may be more subject to K deficiency in fixing soils than fertigated crops.

In grapes, a careful approach is needed for K management because while wine grapes grown in this region can experience K deficiency, a high concentration of K in juice can be a problem during winemaking. The San Joaquin soil series and other similar soils are almost always deep ripped in preparation for vineyard establishment, and the vineyards are most commonly drip fertigated. The implications of K fixation for vine nutrition, rootstock selection, and fertilizer management in such a setting are not completely known. Fixation is usually greatest below a depth of 8 in., but in some vineyards the surface soil layer also fixes K. **(Figure 5)**.

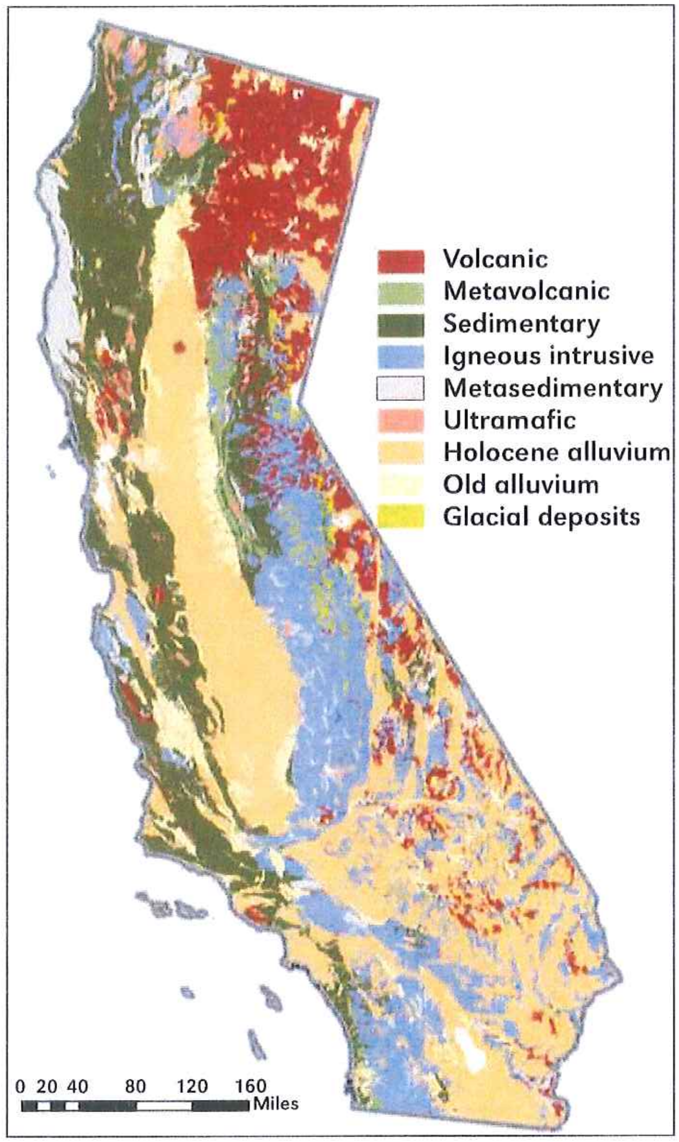


Figure 3. The soils of the Central Valley of California are primarily derived from granitic material from the East and sedimentary material from the West. Potassium-fixing soils are typically associated with granitic (igneous intrusive) parent material.

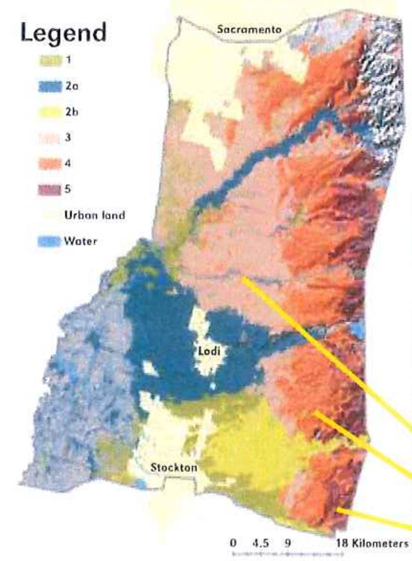
Measuring Potential Fixation

There is a wide range of K-fixation potential among soils that contain significant amounts of K-depleted mica and vermiculite (O'Geen et al., 2008). In some K-fixing soils, the subsequent release of K is significant during a growing season. In other soils, the K present in interlayer fixation sites may be very slowly released and not be a significant source of plant nutrition.

The ammonium acetate extract (1 M NH_4OAc, pH 7) is a widely used soil extractant to estimate both soluble and exchangeable K. However this procedure is inadequate for soils that have micaceous or vermiculitic mineralogy, which can release some non-exchangeable (fixed) K when the solution and exchangeable K pools are depleted.

An alternative method for measuring non-exchangeable plant-available K in soils (i.e. the plant-available portion of fixed K) is using the sodium tetraphenylboron extraction. A practical version of this procedure involves a 5-minute incubation (Cox et al., 1999). They report that in Midwest US soils, this procedure extracted 1.5 to 6 times more K than did NH_4OAc and closely correlated with plant uptake of K. However, this method did not adequately measure K fixation capacity in California's K-fixing soils (Murashkina et al., 2007b). Our procedure for measuring K fixation capacity requires a 1-hr incubation and is suited to commercial laboratory usage. We are currently working to measure the relationship between soil K fixation capacity and K fertilizer response for a variety of crops.

The extent of K fixation is largely determined by the soil mineralogy. When vermiculitic clay and mica-based parent material are present, K fixation can be a significant barrier to meeting the nutritional requirements of crops. In most other soils, K-fixation should not be a significant factor to consider. New laboratory techniques for estimating both the K-fixation potential and the release rate will help with K management decisions. BC



	Description	Soil, example	K fixing soil?
1	Clayey, basin alluvium	Stockton clay	Usually not
2a	Coarse, fans	Columbia sandy loam	Commonly, but variable with depth
2b	Clayey, Calaveras R.	Archerdale clay loam	Uncertain
3	Low, moderately old terraces	San Joaquin loam	Yes
4	Gravelly weathered old terraces	Redding gravelly loam	Usually not
5	Volcanic, eastern part of district	Pentz sandy loam	No

Figure 4. An example of mixed soil mineralology and its impact on K-fixation potential in the Lodi Winegrape District in Central California.

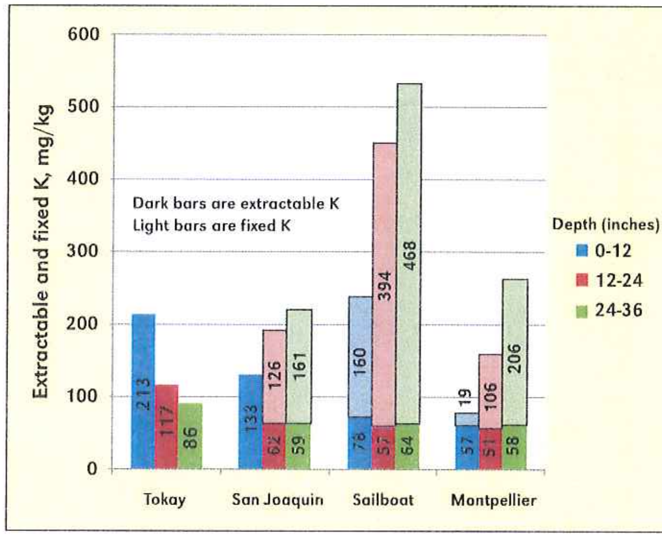


Figure 5. Examples of extractable K (NH_4OAc) and fixed K (Murashkina et al. 2007b) of four soils in Lodi winegrape district in Central California

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