K FIXATION AND SIGNIFICANCE FOR CROP PRODUCTION

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ABSTRACT

Some cultivated soils in California found on the east side of the San Joaquin Valley (SJV) and derived from granitic parent material have the capacity to fix added K, making it unavailable or less available to crops. The main soil mineral responsible for K fixation is vermiculite, which is a weathering product of mica, and which can occur in the clay, silt, and fine-sand size fractions. We have developed a model that predicts the location of K-fixing soils in the region and a practical soil test procedure for measuring K fixation capacity. K fixation in cotton soils in California can be mitigated by repeated application of high rates of K fertilizer. K-fixing soils have recently been mapped in the Lodi winegrape district in the northern San Joaquin Valley. The implications of K fixation for vineyard establishment and ongoing management are the subject of current research.

K FIXATION CAPACITY – AN IMPORTANT PROPERTY OF SOME ALLUVIAL SOILS IN CALIFORNIA

Soil K can be classified as occurring in four forms: (1) solution K, which is plant-available, (2) exchangeable K, also plant-available, (3) fixed K, a portion of which is available depending on soil clay mineralogy, and (4) matrix K, which is not plant-available except very slowly as part of the soil weathering process. In most soils, solution and exchangeable K constitute only a few percent of the total soil K.

Fixed K is K in a surface complex with oxygen atoms in the interlayers of certain silicate clay minerals. A portion of the K fixed by the common clay mineral montmorillonite readily diffuses back into solution as the K level is depleted due to plant uptake or (in sandy soils) by leaching. In contrast, the clay mineral vermiculite, complexes K more strongly, and K fixed by this mineral is only very slowly released back into the bulk soil solution.

Vermiculite is a weathering product of biotite mica and is found in California on the east side of the San Joaquin Valley in weakly to moderately weathered soils formed in alluvium derived from granitic rocks. An example of such a soil that fixes K is California's State Soil, the San Joaquin series. This has been formed in old alluvium on low terraces bordering the eastern margins of the Central Valley floor. The San Joaquin soil has a silica-cemented hardpan below a claypan, but the surface is usually well-drained sandy loam or loam. This soil in its native condition often strongly fixes K and is more generally infertile. It was historically used for cattle grazing but in recent decades, it has become an important winegrape soil as well as used for housing and commercial retail developments.

Over the past 10 years, two PhD students in our laboratory have mapped the location of K-fixing soils in the southern part of the San Joaquin Valley (cotton study by Maria Murashkina, dissertation published in 2006) and in the northern part of the San Joaquin Valley (winegrape study in Lodi winegrape district by Hideomi Minoshima –dissertation currently in preparation).

We have not yet extended our studies to the Sacramento Valley (the northern half of the Central Valley), but it seems reasonable to expect K-fixing soils to occur there where soils have formed in alluvium derived from granitic parent material.

In Coast Range alluvium in the state, K fixation is not found except occasionally in subsoil layers. Also K fixation capacity is not observed in soils formed in Sierra Nevada alluvium where the parent material is volcanic or metavolcanic or in material very highly weathered with kaolinitic mineralogy. Valley floor alluvial fan basin clayey soils dominated by smectitic clays or formed in very young, coarse textured alluvium also do not consistently show K fixation.

An important finding of both the winegrape and cotton studies is that while vermiculite is chemically a clay mineral, i.e., a layer silicate, it occurs in the silt and fine-sand size fractions. Some of the soils we have collected have non K-fixing smectite (montmorillonite) clay sized material together with K-fixing vermiculite in the silt and sand fractions. This is consistent with the common observation by cotton growers in the San Joaquin Valley of K deficiencies on sandy loam and loam soils that require repeated, large doses of K fertilizer to correct.

IMPORTANCE OF K FIXATION FOR CROP PRODUCTION

Late-season K deficiency in cotton in California and response to K fertilizer was first reported by researchers in the early 1960s. The deficiencies are widespread in the San Joaquin Valley, apparently occurring on many soils derived from Sierra Nevada granitic alluvium, which contain significant amounts of K-fixing minerals such as vermiculite, hydrous biotite, and biotite mica at different weathering stages. In these soils under field conditions, long term fixation of added K continues for at least three years, and K inputs in excess of 1500 lb K_2O/acre are sometimes required to achieve maximum cotton yields (work published by Cassman, extension bulletin by R. Miller et al.). Such micaceous soils that are intensively cropped in high-yield environments may not only require a higher-than-normal rate of K fertilizer application to overcome deficiency, but may also need a special soil test that reflects the K fixation potential – discussed further below..

Winegrapes grown in the northern SJV region experience K deficiency; but excess K in juice and wine is also a potential problem. San Joaquin and other similar soils are almost always deep ripped in preparation for vineyard establishment, and the vineyards are drip fertigated. The implications of K fixation for vine nutrition, rootstock selection, and fertilizer management in such a setting are not known at this point; however in the past five years we have identified subregions of the Lodi Winegrape district (total winegrape acreage ~ 100,000 acres) that have a soil with a high K fixation capacity. Usually this is observed only below a depth of 8 inches, but in some vineyards, even the surface soil layer fixes K. Examples of soil test K and K fixation capacity are shown in Table 1.

An interesting question is whether K fixation is a problem for crops, such as winegrapes, that are grown under drip irrigation. We speculate that soil K chemistry is not so important when K can be applied through the drip irrigation system in a concentrated dose. On the other hand, the restricted volume of the root system under drip late in the season combined with high demand by fruit may lead to K deficiencies, especially where fruit loads are heavy and surface soil layers fix K. Cotton growers usually see K deficiencies and difficulty in correcting the problem in years with heavy boll loads. There is very little cotton acreage that is drip irrigated, and we are not aware of research to test the idea that K deficiencies are easily avoided under drip irrigation. Research by Tim Hartz (UC Davis) on fruit color disorders in processing tomato suggests that K fertigation is effective in correcting or preventing such problems, however we do not know how the K fixation capacity of farm soils in his research compares to what we have mapped in our research in cotton fields and winegrape vineyards; also generally the soil test K levels in his studies were not very low.

MEASURING SOIL K FIXATION

The NH_4OAc (1 mol/L) standard soil K test method, which extracts both soluble and exchangeable K, is the most common test used to develop K fertilizer recommendations. It has been shown, however, that this method is inadequate for soils that have micaceous or vermiculitic mineralogy, which can release some nonexchangeable (fixed) K when solution and exchangeable K pools are depleted.

A method for measuring plant-available K in midwestern US soils in which some non-exchangeable (i.e., fixed) K is plant-available was published by Cox et al. (1999). A 5-min incubation with sodium tetraphenylboron (TPB) allows the BPh_4 ion to combine with K+ in solution, causing precipitation of potassium tetraphenylboron ($KBPh_4$). This test extracted 1.5 to 6 times more K than did NH_4OAc, and the amount of K extracted was shown to be closely correlated with plant uptake of K in greenhouse studies (Cox et al., 1999). We have found that this test, while it may reveal availability of a portion of K already fixed, does not predict K fixation potential or capacity in California's K-fixing soils.

Cassman et al. in California developed a simple incubation procedure that estimates capacity of soils to fix K. This procedure involves incubating a soil sample with 18 mmol K/kg soil for 7 d with daily shaking for 45 min. This test is simple, but a 7-d incubation period and the daily shaking limit its usefulness for routine laboratory operations. Murashkina in our laboratory developed a modification of the Cassman procedure that requires a 1-hr incubation and is suited to commercial laboratory usage.

Interpretation of the K fixation capacity test is still problematic. Current recommendations for management of K in cotton production in California include the recommendation for a critical value or threshold of 110 mg/kg for soil NH_4OAc-extractable K in the 6 to 18-inch depth. (Note: This non-standard depth increment is needed because from mid-season on in SJV cotton fields, the taprooted cotton plant obtains very little of its K from the 0 to 6-inch soil depth.) At this K level and above, the likelihood of a positive lint response to added K is <10%. Soil levels <80 mg/kg, or if K fixation is >60%, indicate a high possibility of K fertilizer response. Interpretation of the shorter incubation procedure developed by Murashkina is still uncertain.

A research project begun in early 2011 funded by the California Department of Food & Agriculture in our laboratory will determine the relationship of K fixation capacity (as measured by the Murashkina procedure) to K fertilizer response. Soils with a range of K fixation capacity, CEC, and texture collected from cotton fields and winegrape vineyards will be included. A part of the study will focus on the impact of soil drying (or wet-dry cycling) on K fixation and release.

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Table 1. Examples of soil test K (by neutral ammonium acetate extraction) and K fixation potential values in winegrape K fertilizer trial sites in Lodi winegrape district, northern San Joaquin Valley, CA.

Depth, inches	Soil test K	K fixation
	------------- mg/kg soil	-----------
Site 1.Tokay, non-K fixing soil		
0-12	213	0
12-24	117	0
24-36	86	5
Site 2. San Joaquin, K-fixing soil		
0-8	133	0
8-16	62	126
16-24	59	161
Site 3. Sailboat, K fixing soil		
0-12	78	160
12-24	57	394
24-36	64	468
Site 4. Montpellier-Cometa, K fixing soil		
0-12	57	19
12-24	51	106
24-36	58	206

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