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CAN WE PREDICT K FIXATION IN THE SAN JOAQUIN VALLEY FROM SOIL TEXTURE AND MINERALOGY?

M. Murashkina, R.J. Southard, G.S. Pettygrove, A.T. O'Geen
Department of Land, Air & Water Resources
University of California
Davis, CA
B.A. Roberts, D.S. Munk, B.H. Marsh, and S.D. Wright
University of California Cooperative Extension
(respectively) Hanford, Fresno, Shafter, and Tulare, CA

Abstract

We developed a map showing the location of potentially K-fixing soils in cotton-producing areas of Fresno, Tulare, Kings, and Kern Counties in the southern San Joaquin Valley, California. The map was produced from seven digitized soil surveys (NRCS SSURGO database) and a California Department of Food & Agriculture cotton database. The criteria for soil map unit selection included (1) age of soil as indicated by degree of horizonation, with younger soils presumed to have more potential for K fixation (2) formation of the soil on Sierra Nevadan parent material, which is more likely to contain vermiculite (the K-fixing mineral) formed from biotite mica, and (3) coarse to medium texture, as indicated by soil taxonomy family level texture. Laboratory measurement of K fixation by a modified Cassman incubation method and conventional x-ray diffraction supports this model, but further studies, including measurement of K fixation in a larger number of fine-textured soils with Sierra Nevada genesis and measurements across a chronosequence must be completed in order to confirm it.

Introduction

Forty to fifty years ago, University of California researchers proved that vermiculite is the soil mineral present in San Joaquin Valley soils that is responsible for making potassium unavailable or less available to the cotton plant during flowering and boll fill. In spite of much research conducted over the past 50 years to relate this problem to field symptoms and to develop diagnostic criteria, no one has described the location of K-fixing soils. Miller et al. (1997) state that 60% of the cotton-producing land in the San Joaquin Valley (SJV) is vermiculitic; however, they do not cite the source of this estimate. With the introduction of digital soil surveys by the USDA, we asked whether it might be possible to identify and produce maps showing potentially K-fixing soils based on soil texture, mineralogy or other soil properties contained in the electronic database.

Current UC guidelines (Miller et al., 1997) for management of K in cotton production include the recommendation to sample for soil K status using the 6 to 18-inch depth. Mid to late-season, cotton roots are most active at that depth. The surface layer of soil is usually very dry due to the long interval between irrigations and complete lack of rain in mid to late season in the SJV. The recommended soil exchangeable K critical value or threshold is 110 ppm (ammonium acetate extractable). If the level is less than 80 ppm, or if K fixation is >60%, the recommendation is to apply K fertilizer at a rate of 400 lb K_2O/acre. No recommendation for which K fixation soil test procedure to use is provided in the UC guidelines, but the authors list a reference (Cassman et al., 1990), which describes a seven-day incubation of the soil in a K solution and daily shaking of the sample. Soils that fix K will reduce the K concentration in the incubating solution. This procedure is suitable for research but is not practical for commercial agricultural laboratories, although some private laboratories offer it.

A map of potentially K-fixing soils would help cotton growers and production consultants/crop advisers to determine locations in the SJV where the K fertilizer requirement could be high enough to warrant a K fixation soil test.

Objective

The objective of this research was to use information from digitized USDA county soil survey databases to map the location of soils in San Joaquin Valley cotton production areas that potentially possess a high capacity to fix K in mineral interlayers.

Geology and Soil Mineralogy of the Southern San Joaquin Valley

The San Joaquin Valley is bordered by a large mountain range on the east, the Sierra Nevada, which is composed primarily of granitic rocks, and the smaller Coast Range on the west, which is composed mainly of

sedimentary rocks (Fig. 1). Both ranges include small areas of other rock types. San Joaquin Valley soils are formed mostly from alluvial parent material from those two ranges. Because the Sierra Nevada is higher and receives more precipitation than the Coast Range, a larger area of soils in the valley is formed on granitic Sierra Nevada alluvium. A smaller area is formed on Coast Range alluvium. However, because cotton production is located more on the central and western side of the valley, there is a significant fraction of SJV cotton produced on non-granitic soils.

A simple schematic diagram of formation of vermiculite is presented in Fig. 2. Based on this process, we hypothesize that soils high in vermiculite are those with weak or intermediate development of horizons and with high mica content, i.e., formed from granite. We speculate that of the soils in the San Joaquin Valley formed from granitic parent material, those that are high in clay content are older, and the clay fraction will be dominated by smectite, which is non-K fixing. Therefore, we expect K-fixing soils to be coarse textured. In some paper soil surveys, the narrative description of each soil series refers to the parent material, e.g., "formed from granitic alluvium", but terminology is inconsistent among surveys and is not accessible in the digitized surveys. Therefore, granitic parent material must be inferred from location or other information.

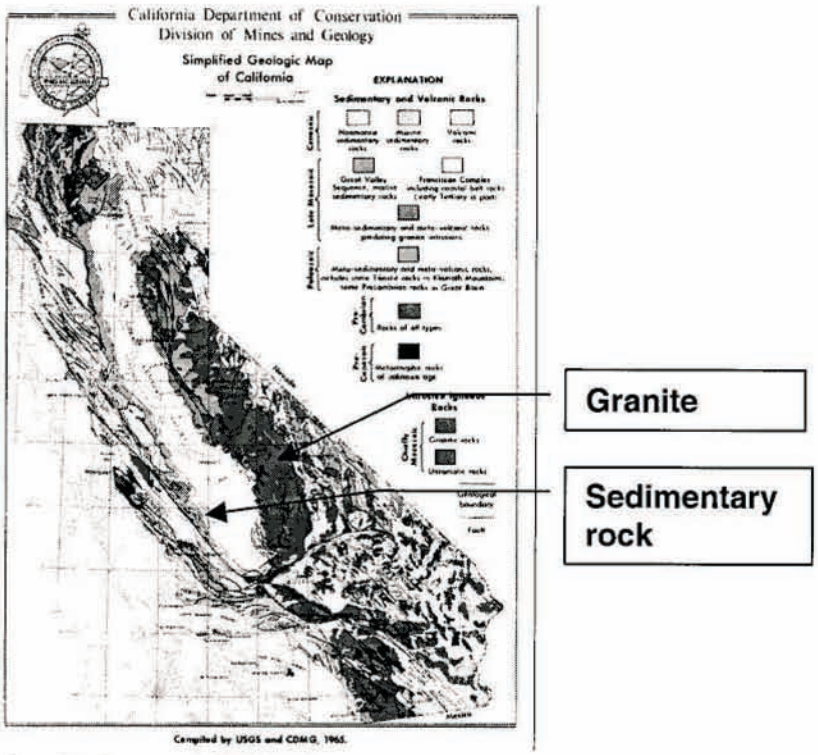


Fig. 1. Simplified geologic map of California showing predominant rock types in Coast Range and southern Sierra Nevada.

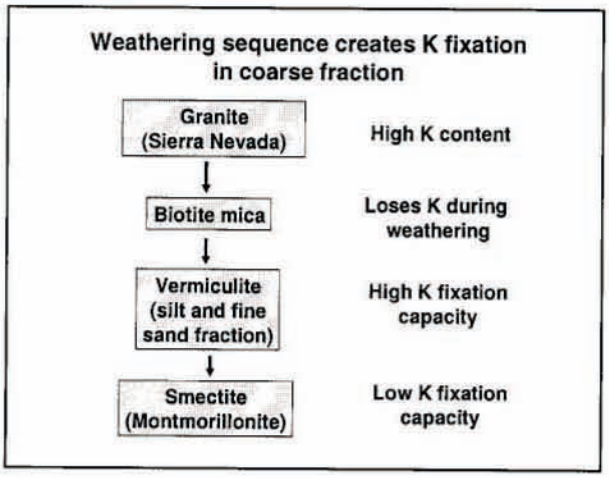


Fig. 2. Simplified schematic of the weathering of granitic rock to vermiculite and smectite and relationship to K fixation.

Methods

Mapping methods and criteria for identification of potentially K-fixing soils

Our study covered the cotton production areas of Fresno, Kings, Tulare, and Kern counties in the southern San Joaquin Valley. The soils of this area are described in seven USDA Order 2 soil surveys: Eastern Fresno Area; Fresno Co., Western Part, Tulare Co., Western Part; Tulare Co., Central Part; Kings Co., Kern Co., NW Part; and Kern Co. SE Part. These surveys are all available in digital format in the USDA SSURGO database. Using these digital soil surveys, we constructed a GIS database to develop a map of soils with the potential to fix K. Secondly, we used California Dept. of Food & Agriculture databases to determine the areal extent of land on which cotton was grown at least one year during the period 1998 through 2000. Thirds we used Tiger files available to the public that depict legal boundaries and geographic point features. The soil survey data was repackaged based upon a conceptual model encompassing the degree of soil development, family particle size class, slope, and geographic position within the San Joaquin Valley to produce a map of soils with the potential to fix K. These data were then combined with data depicting the geographic distribution of cotton from 1998-2000 (California Dep. Food & Agric.) resulting in three map layers: 1) aerial extent of cotton grown from 1998-2000 in Fresno, Kings, Tulare, and Kern counties, 2) geographic extent of soils that fix K, and 3) areas that fix K where cotton is grown, i.e., the overlap of the first two layers.

Generally speaking there are two conditions that result in K fixation: Weakly developed soils with high mica content (when derived from granitic parent materials) and intermediately developed soils having high vermiculite clay mineralogy. Vermiculite is thermodynamically unstable, and as a result, is not present in well-developed soils. These two conditions are not stored directly in the soil survey data, but can be inferred from other soil properties that can be obtained indirectly from queries of SSURGO data. To identify these two K-fixing conditions we queried various taxonomic criteria that describe the presence of mica and/or vermiculite using ArcGIS Query Builder.

In order to represent weakly developed soils potentially high in mica we queried two soil orders Entisols and Inceptisols. We also included the following great groups Haploxerolls, Endoaquolls, Camborthids, and Salorthids. From this map we queried a subset of soils that have Coarse-loamy, Fine-loamy or Fine-silty family particle size classes. This map depicts all soils that would contain mica if derived from a micaceous parent material such as granite.

In order to depict intermediately developed soils that may contain vermiculite we queried the following taxonomic classes: Argixerolls, Haploxeralfs, Natrixerolls, Natrixeralfs and Haplargids. These soils have argillic horizons (clay enriched layers) and could have diverse clay mineralogy. Therefore, from this map, we queried all

soils that have Coarse-loamy family particle size class. The resulting map is a proxy for moderately well developed soils that are likely to contain vermiculite in the clay fraction.

The two groups of soil maps (weakly and moderately developed soils) were then combined together into a single map using the *merge* operation in the ArcGIS geopossessing wizard. The *merge* operation appends the features of two or more layers into a single layer. The next step was to separate soils derived from Coast Range alluvium, which do not fix K, from Sierra Nevada alluvium that will fix K. To do so we visually inspected drainage systems from orthophotoquad base maps (from the paper soil surveys) to identify the spatial extent of soils formed from parent material from the Coast Range. Soils that formed on these landscapes were excluded from the database. Newer soil surveys such as Fresno, Western Part contain landform descriptions that allowed us to accomplish this same task through digital queries. The resulting map represents potentially K-fixing soils derived from Sierra Nevada alluvium.

To develop a map of K-fixing soils where cotton is grown we first excluded all potentially K-fixing soils with slopes > 5 percent to exclude mountainous areas where cotton is not grown. We then imported a GIS layer that depicts the areal extent of cotton grown from 1998-2000. We used the *intersect* function of ArcGIS to develop a map of soils that fix K where cotton is frequently grown. The *intersect* operation cuts an input layer (soils that fix K) with features from an overlay layer (areal extent of cotton) to produce an output layer with features that have attribute data from both layers.

Laboratory measurement of K fixation capacity and exchangeable K

To estimate potassium fixation we modified the method of Cassman et al. (1990). The original method requires 7 days incubation with everyday shaking. We tried to decrease incubation time with KCl to 1, 2 hours and overnight shaking. One hour shaking with KCl seems to be a good alternative to 7 days incubation. Increase in concentrations of KCl from 1.8mmol/L to 2.5mmol/L, as well as increasing shaking time with NH_4Cl from 0.5 hr to 2 hr did not affect the amount of K fixed.

We used 1hr incubation method for our study. Three replicates of each soil samples were saturated with 1.8 mM KCl (1:10 ratio) and shaken for 1 hour. Ten mL of 4M NH_4Cl was then added to each sample to give 1 M NH_4Cl. After 30 min shaking and centrifuging (2000 rpm for 20min), K was measured in the solution using Perkin-Elmer AAnalyst 800 Atomic Absorption spectrophotometer. Fixed K was calculated as a difference between blank and measured solution concentrations.

Exchangeable K was extracted by 1 M NH_4OAc (pH 7) with a mechanical vacuum extractor (Soil Survey Laboratory Methods Manual, 1996). Soil samples (2.5 to 3g) were saturated with 1 M NH_4OAc and extracted overnight.

Results and Discussion

The resulting map shows (Fig. 3) in red the combination of land used for cotton production and potentially K fixing soils. The total area of potentially K-fixing soils is approximately 1.4 million acres. We have not yet determined the area of cotton land and the overlap of the two layers. By visual inspection, it appears that much less than 60% of the total cotton acreage is potentially K fixing, as claimed by Miller et al. (1997).

What evidence is there that our revised model is correctly identifying K-fixing soils?

- Measurements of K fixation in the laboratory do indicate that soils formed in Coast Range alluvium do not fix K, except to a small extent in deeper horizons. Soils formed in Sierra Nevadan alluvium do tend to fix K, especially in the subsurface horizons.
- The relationship of soil texture to K fixation in our model is contradictory to what Miller et al. (1997) and other soil scientists from other regions have claimed. They state that fine-textured soils are where K-fixation occurs, because fine-textured soils are high in vermiculite clay content. We find vermiculite in the silt and fine sand fractions (x-ray diffractograms -- not shown) and in fine-silty, fine-loamy and coarse-loamy textural classes (Fig. 4). However, we need measurements on a larger number of samples of fine-textured soils developed on Sierra Nevadan parent material to confirm that non K-fixing, smectite clays dominate such soils.
- Additional research is needed to determine if degree of horizon development can be used as an indicator of lack of K-fixation. We have identified a chronosequence of soils in eastern Fresno Co.

developed on geomorphic surfaces ranging in age from a few thousand years to perhaps 700,000 years. This will be sampled in the spring of 2004.

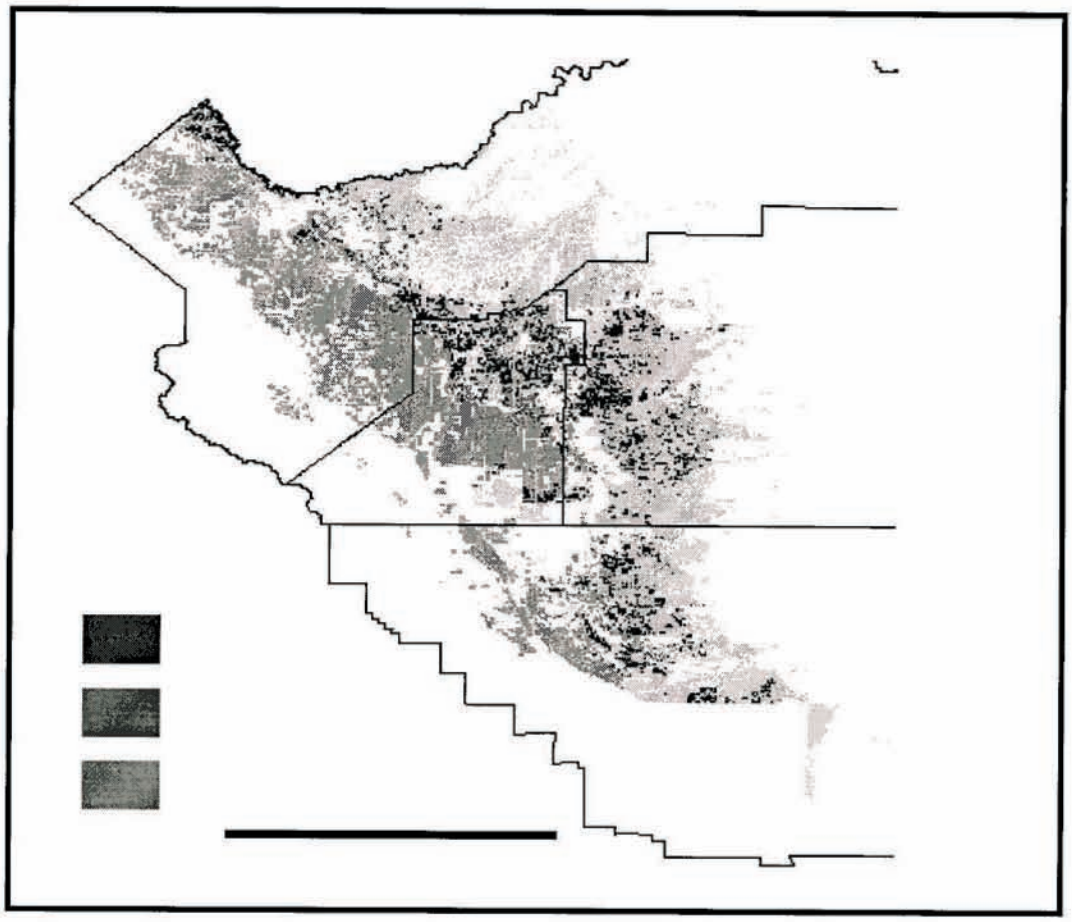
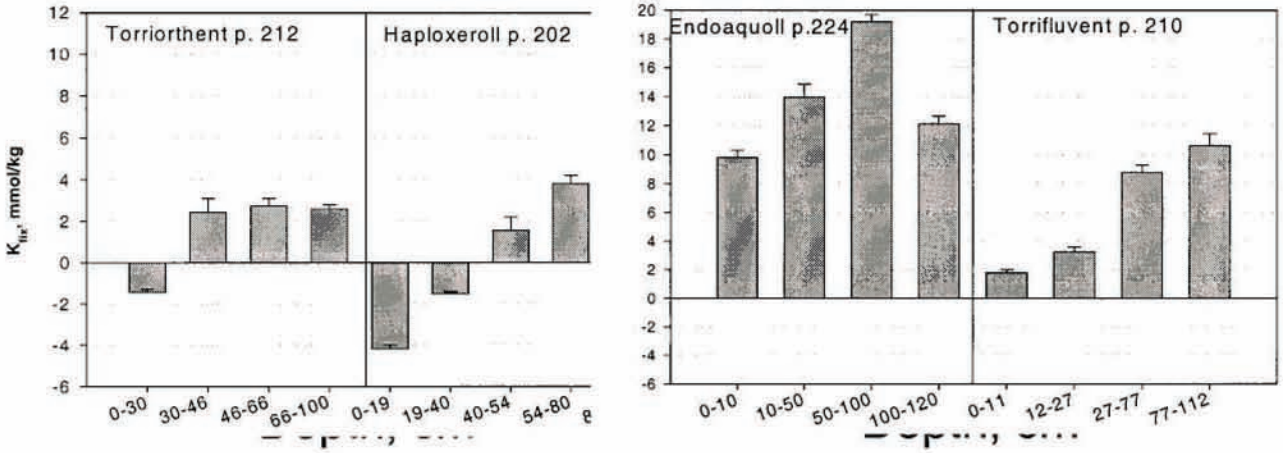


Fig. 3. Potentially K-fixing soils based on model and land in cotton production at least one year during 1998-2000. Potentially K-fixing soils cover approximately 1.4 million acres. Area of cotton production and cotton + K-fixing soils has not yet been determined.



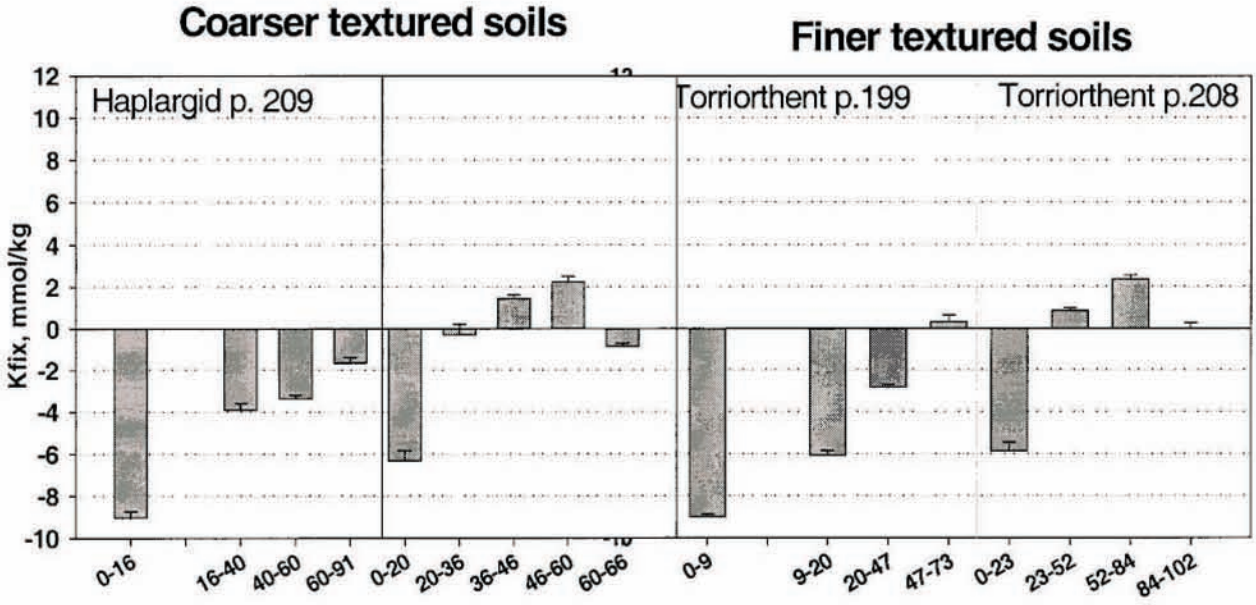


Fig. 4. K fixation as measured by a 1 hr incubation. Soils formed on granitic Sierra Nevadan parent material fix significant amounts of K with K fixation increasing with depth of horizon. Soils formed in Coast Range sediements are lower in vermiculite and do not fix K, except in small amounts at the deepest horizons.

Significance for Cotton Growers in the San Joaquin Valley

Is it necessary for production managers or crop advisers to determine K-fixation capacity with a soil test? We compared exchangeable K (using the standard ammonium acetate procedure) with the 1-hr K fixation test. Samples with exchangeable K levels 50 ppm (mg K/kg soil) or less always fixed K (Fig. 5). No samples with >200 ppm exchangeable K fixed K. Soils with soil test K values between 50 and 200 ppm exhibited K fixation ranging from negative (i.e., increasing the K concentration of the incubating solution) to strong K fixation. We suggest that for

cotton production, soils with exchangeable K values between 50 and 200 ppm and located within the area identified as potentially K fixing in the map shown in Fig. 3, a K fixation measurement should be strongly considered. Further research is needed to translate the K fixation test result into a K fertilizer application rate.

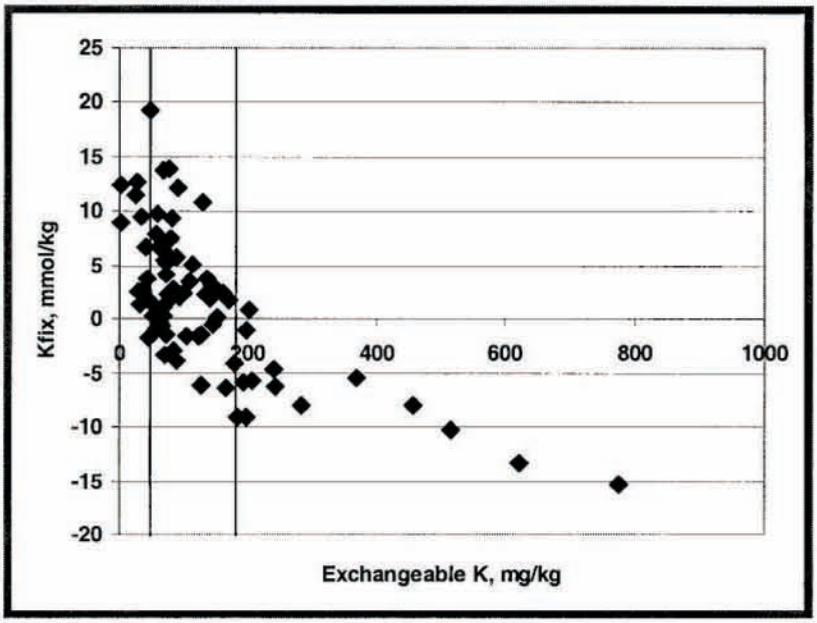


Fig. 8. Exchangeable K vs. K fixation in soil samples collected for this project. Samples include all horizons from approximately 20 profiles from both Sierra Nevadan and Coast Range alluvium.

Conclusions

In the San Joaquin Valley, CA, we were not able to identify K-fixing soils directly by Soil Series, because patent material is not an element in the USDA soil taxonomy and because mineralogy, while referred to in soil series narrative descriptions, is not described with consistent terminology across soil surveys and cannot be accessed in the USDA electronic soils databases. We were able to infer the potential for K-fixation based on degree of soil development and other properties, which can be extracted from soils database using taxonomic criteria.

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References

Cassman K.G., Bryant D.C. and Roberts B.A. 1990. Comparison of soil test methods for cotton response to soil and fertilizer potassium on potassium fixing soils. Commun. in Soil Science. Plant Anal., 21(13-16): 1727-1743.

Miller, R.O., B.L. Weir, R.N. Vargas, S.D. Wright, R.L. Travis, B.A. Roberts, D.W. Rains, D.S. Munk, D.J. Munier, and M. Keeley. 1997. Cotton potassium fertility guidelines for the San Joaquin Valley of California. Pub. 21562. Division of Agriculture and Natural Resources, University of California. Oakland, CA