

Potassium in the Soil: Is It There or Isn't It? Some New Findings that May Explain Its Behavior

By Joseph W. Stucki

Because of its great importance as a plant nutrient, K in soils has been studied extensively. But in spite of these efforts, the fundamental chemical and physical phenomena that govern its fate, movement and plant availability have yet to be characterized fully. Soil tests for K often fail to reveal the true fertilizer demand in the field, resulting in unreliable and inefficient fertilizer recommendations.

Many factors contribute to this problem, but perhaps the one factor making the problem so intractable is that soil K is distributed among soluble, exchangeable, fixed, and insoluble forms, and can be redistributed among these forms in a rapid and unpredictable manner. Only

that portion which is either soluble or exchangeable is available to the plant. This situation affects soil test recommendations for K because the form may change between the time of testing and the time the plant needs the nutrient, or

it may change during the time between sampling in the field and analysis in the laboratory.

Early studies provided empirical evidence that K behavior is correlated with a number of different soil and environmental factors, such as the types of soil minerals present, moisture regime, cropping and fertilizer history, temperature fluctuations, and weathering. But no unified explanation linking all of these variables in a consistent manner has been established.

Studies at the University of Illinois and Purdue University are shedding some light on factors that influence potassium (K) availability in soils. Soil conditions leading to chemical reduction of iron (Fe) have been shown to result in more K fixation in montmorillonitic clays.

TABLE 1. Total, fixed and exchangeable K of oxidized and reduced clays.

Sample	Treatment	Fe ⁺⁺ % of total Fe	Total K	Fixed K meq/100 g	Exchangeable K
Montm. 1	Unreduced	0.16	93.0	2.9	90.1
	Reduced	74.00	122.3	31.5	90.8
Montm. 2	Unreduced	5.80	79.5	3.0	76.5
	Reduced	66.80	102.5	25.3	77.2
Illite	Unreduced	25.40	151.4	135.7	15.7
	Reduced	60.80	122.7	89.8	32.9
Drummer (Dekalb)	Unreduced	9.50	102.4	72.8	29.6
	Reduced	20.10	105.2	66.6	38.6
Drummer (Urbana)	Unreduced	6.94	105.3	71.6	33.7
	Reduced	66.80	105.3	65.7	39.6
Cisne (Brownstone)	Unreduced	3.15	74.8	43.9	30.9
	Reduced	61.50	82.1	39.2	42.9

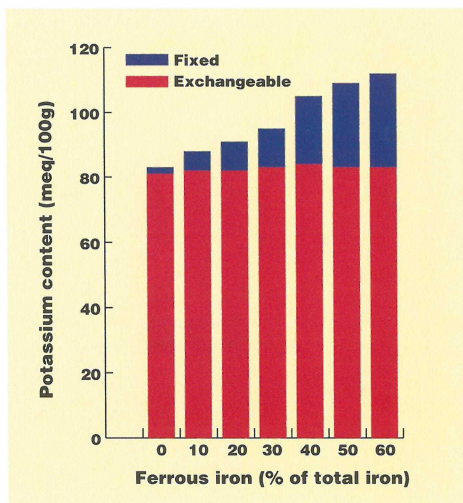


Figure 1. Fixed and exchangeable potassium.

A Potential Breakthrough

A major step toward solving this problem was reached when researchers at Purdue University and the University of Illinois, in independent studies, reported a link between the oxidation state of Fe in the crystal structure of soil clay minerals and the amount of K fixation that occurred. Common oxidation states for Fe are ferric (Fe^{+++}) and ferrous (Fe^{++}).

These recent studies showed that the change in electrical charge at the mineral's surface that occurs during Fe reduction ($\text{Fe}^{+++} \rightarrow \text{Fe}^{++}$) increases the ability of the mineral to fix interlayer cations, including sodium (Na), calcium (Ca), copper (Cu), zinc (Zn) and K. The Purdue study showed a rapid increase in the non-exchangeable form of K with increased Fe^{++} content of freeze-dried soil clays and standard reference clays, in which the total K fixation capacity reached as high as 30 percent of the total cation exchange capacity.

The study at the University of Illinois followed the distribution of K between exchangeable and non-exchangeable fractions with increasing Fe^{++} content of undried montmorillonite. It found that K

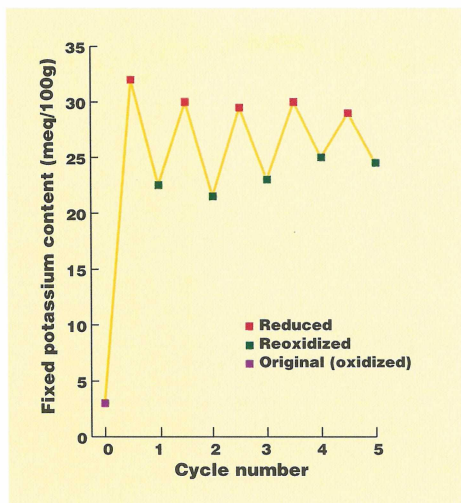


Figure 2. Redox cycle effects on fixation.

fixation increased steadily with increasing Fe^{++} . However, the exchangeable fraction remained almost constant (**Figure 1**).

The data in **Figure 1** can be used to estimate how much K in the soil would become fixed. For example, when 20 percent of the Fe is reduced ($\text{Fe}^{++} = 20$) the amount of fixation is about 10 meq/100 g of clay. In a soil having a clay content of 15 percent by weight, of which perhaps two-thirds would be montmorillonite, this translates into a fixed amount of K of about 900 lb $\text{K}_2\text{O}/\text{A}$. In other words, the oxidation state of Fe in the mineral is an extremely important factor for determining ion fixation in soil clay minerals. Outside of the studies cited above, this phenomenon has apparently been overlooked by soil fertility research, but appears to be a vital factor which must be taken into account.

Effects of Clay Mineral Type on K Fixation

The type of clay mineral present in the soil has a great impact on the fate of K. The calculations shown above are for a montmorillonite mineral. For other types of clay we found different behavior. Six

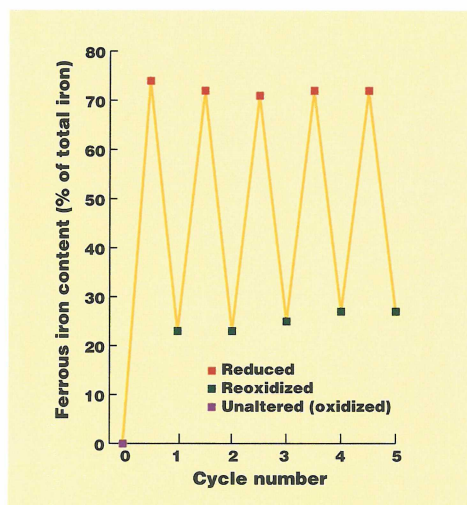


Figure 3. Redox cycle effects on ferrous iron.

different clays were studied, including two montmorillonites (expandable clay mineral), one illite (non-expandable clay mineral), and clay fractions from the A horizon of three Illinois soils (Drummer from Dekalb, Drummer from Urbana, and Cisne from Brownstown). Results indicated that illite behaved differently from montmorillonite and soil clays were more complicated, presumably due to the presence of mixtures of clay mineral types (**Table 1**).

The total and fixed K in montmorillonite increased when the clays (and Fe) were reduced, while the exchangeable K remained about constant. So structural Fe reduction increased K fixation in montmorillonite and would then be expected to decrease K availability in montmorillonite soils.

Illite behaved very differently from montmorillonite. The amount of fixed K decreased, rather than increased, upon Fe reduction and the amount of exchangeable K actually increased. The total K content of the illite also decreased when Fe was reduced, probably because illite initially contains a substantial amount of K, which is

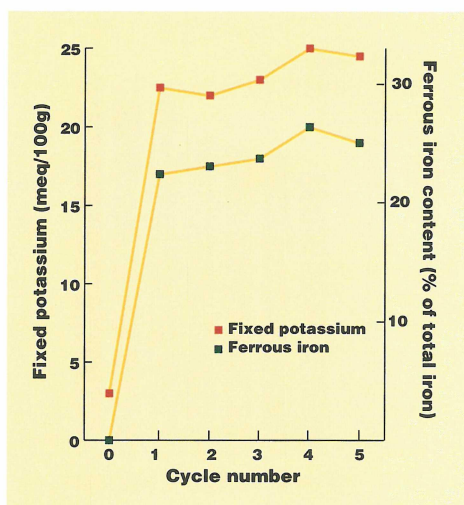


Figure 4. Reoxidized Montmorillonite.

released during Fe reduction. Soils containing a mixture of illite and montmorillonite could then either fix or release K during reducing conditions (waterlogging, lowered oxygen content) depending on which clay dominates. If these minerals were present in the same amounts, no change in K availability would occur because the amount that one releases would be fixed by the other.

Studies of the soil clays revealed that the total K content of both Drummer soils remained about constant during Fe reduction, but varied slightly in the Cisne. The distribution of exchangeable and fixed K forms, however, fluctuated measurably, but less than in the montmorillonite and illite. The behavior of these soil clays appeared to be closer to that of illite than of montmorillonite. X-ray powder diffraction revealed that illite did comprise a significant portion of the clay fraction.

Effects of Redox Cycles on K Availability


Redox (reduction-oxidation) processes are common in nature, so the link between oxidation state and K fixation

leads us to expect the distribution of K between available and non-available forms to change over space and time in the field. These processes repeat themselves because of wetting and drying cycles during the growing season, which cause the soil to alternate between oxidized and reduced states. Bacterial activity, which is affected by temperature and organic matter, also has a large effect on the oxidation state of the soil minerals and will rise and fall throughout the year. As these and other redox processes proceed throughout the season, and over the years, the distribution of K will be affected.

We attempted to mimic these processes by subjecting Fe-rich montmorillonite to six redox cycles in the laboratory. The amounts of Fe^{++} and fixed K were measured in the initial, reduced, and reoxidized state (which comprises one complete redox cycle) for each cycle. The results for K fixation during five redox cycles are shown in **Figure 2**. During each reduction step the amount of fixed K increased sharply, then decreased after reoxidation but failed to return to the pre-reduction level. With the completion of each cycle, the fixed K progressively increased, at first sharply then only gradually (**Figure 4**). The amount of Fe^{++}

also increased sharply during the reduction step of each cycle, but reoxidation failed to restore all the Fe to the Fe^{+++} state (**Figure 3**). The amount of Fe^{++} remaining in the sample after reoxidation steadily increased with the completion of each cycle (**Figure 4**). This indicates that Fe^{++} in the clay is protected to some extent by the presence of K, presumably because of the collapse of superimposed clay layers. This same action could contribute to a stabilization of fixed K.

Summary

These results are encouraging, but much has yet to be learned because direct correlation between the control of oxidation state during soil tests and plant response to the resulting fertilizer recommendations have not been established. Some new ideas are emerging, however, and offer hope for the future. Perhaps we will soon be able to tell exactly how much K will be available to the plant during the growing season. 

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Great Plains Soil Fertility Leadership Award to John T. Harapiak

Mr. John T. Harapiak is the 1996 recipient of the Great Plains Soil Fertility Leadership Award. The Award was presented during the Great Plains Soil Fertility Conference in Denver, CO. It recognizes individuals who have contributed substantially to the development of information and to education in the area of soil fertility, plant nutrition and fertilizer use.

Mr. Harapiak is Manager of Agronomic Services for Western Cooperative Fertilizers Limited (Westco). He is noted for development and promotion of the deep banding concept widely used in Prairie agriculture. Adoption of this technology has resulted in improved nitrogen use efficiency and economics for small grain producers. 