NEW CONCEPTS IN POTASSIUM NUTRITION

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Potassium, one of the three "major" fertilizers, is indispensible in plant nutrition. The specific functions of K in plant metabolism(Figure 1) are examples of the general function of optimizing photosynthetic efficiency.

Figure 1

POTASSIUM

FUNCTIONS IN THE PLANT

1. ENZYME ACTIVATION
2. WATER RELATIONS— STOMATAL CONTROL, TURGOR
3. ENERGY RELATIONS— ATP PRODUCTION
4. TRANSLOCATION OF CARBOHYDRATES
5. NITROGEN ASSIMILATION & PROTEIN SYNTHESIS
6. STARCH SYNTHESIS

Potassium has been called the "currency" of energy relations in plants. It enables energy produced at one location in the plant to be transferred to another. This movement of energy within the plant is reflected in efficient production of support tissue for strength, conversion of nitrogen to biomass, and movement of carbohydrates to fruit.

As important as K nutrition is, it is probably the least understood of the major nutrients. The literature is very garbled in the areas of what constitutes an "adequate" level in plants, and whether "excessive" additions are detrimental to plants.

Potassium exists in several interrelated forms in combination with soil on a microscopic scale. All soil tests for K depend on measuring the amount of one of these forms in the soil as it comes from the field. Experience is then used to classify the measured amount as adequate or not for the crop.

Several workers, both university and commercial, have found that classical soil tests often are not a good predictor of crop response to fertilizer.

For instance, E.O. Skogley found, in a long-term study in Montana, that grains and potatoes responded favorably to added K in about 50% of trials, even though the soils tested "high" to "very high" in the standard soil test for K. This is typical also of potato culture in eastern Washington and Oregon, where experience leads growers to add preplant K, in spite of very high soil test levels.

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So, there is some question whether K fertilizer materials are being used efficiently, and whether growers are missing opportunities for increased yield and quality by over-dependence on soil testing.

This report outlines efforts at Unocal to learn:

1) What are limiting factors in plant uptake of potassium;

2) How to determine when those limits are set by the soil; and

3) How to overcome those limits when they are likely to limit optimum productivity.

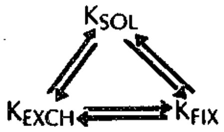
The studies have produced new concepts of how the soil may limit the plant's ability to takeup adequate K, and a new soil test method based on these concepts. The ultimate goal is not to make magic, but to increase the probability of success in using K fertilizer efficiently.

The classic description shows potassium in a three-way equilibrium in the soil(figure 2).

Figure 2

POTASSIUM

BEHAVIOR IN THE SOIL



K_{SOL}: SOLUBLE K^+, "READILY AVAILABLE"

K_{EXCH}: EXCHANGEABLE K^+, "AVAILABLE" (?)

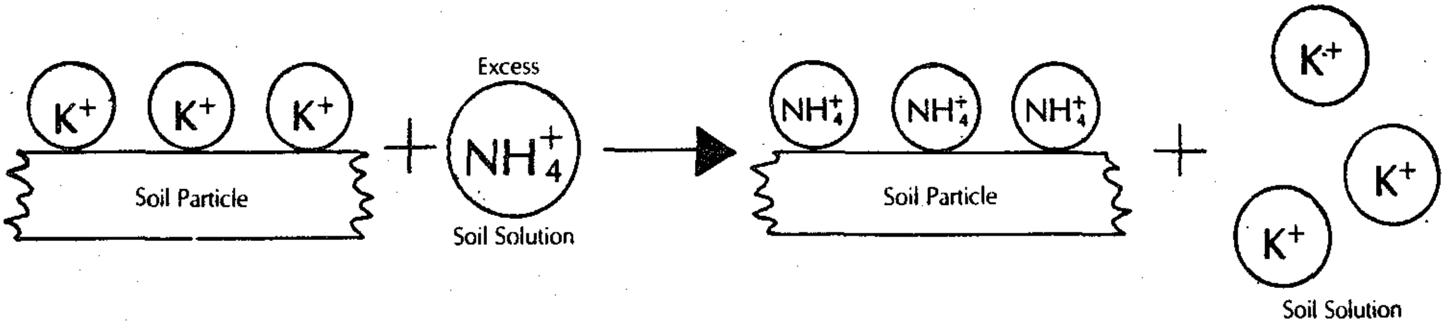
K_{FIX}: FIXED K^+, "UNAVAILABLE"

Around and within each microscopic soil particle are different interchageable forms of the positively charged potassium ions. "Fixed" K is bound up within the particle, and is released only when the particle opens up, for instance, due to weathering. "Exchangeable" K is bound to the negative surface of the particle by electrostatic force (opposite charges attract).

This form can be removed by introducing a large amount of another positively charged ion, such as ammonium ion NH_4^+(figure 3).

Figure 3

Removal of Exchanged K with Ammonium Ion



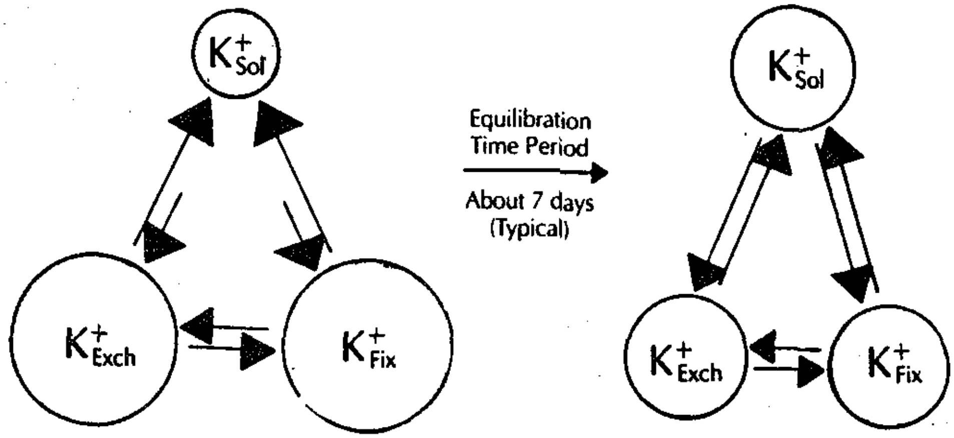
"Soluble" K moves freely in the film of water surrounding each soil particle, and can move from particle to particle. All forms are interchangeable, however, at equilibrium in a given soil, the relative amounts of each form are fixed. In other words, at any instant, a soil sample will have levels of fixed, exchangeable, and soluble potassium characterisitic of that soil.

When a plant is making a large demand for potassium, however, the equilibrium may be disturbed. It is a universal principle that when any equilibrium system, e.g., soil, is disturbed, it will react to restore equilibrium.

For instance, if a plant rapidly depletes the soluble potassium in the soil, there will be a release of K from the exchangeable and/or fixed pools as the system restores itself to equilibrium (Figure 4).

Figure 4

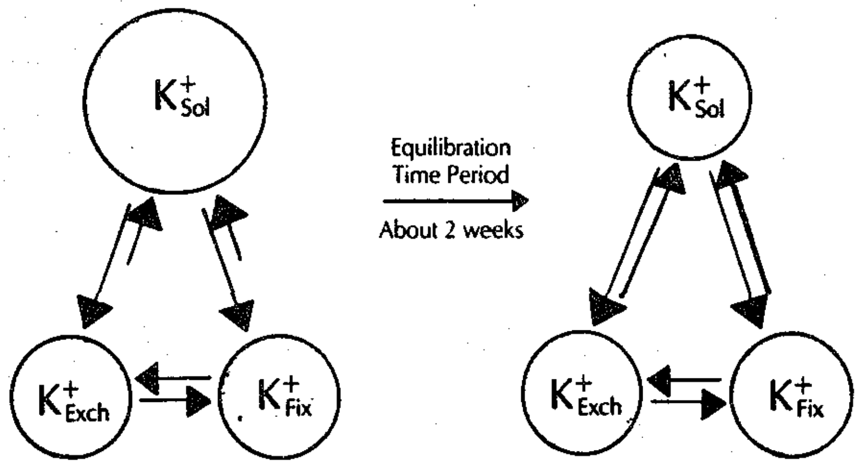
Re-establishment of Equilibrium After Depletion of Soluble K



On the other hand, if a large quantity of soluble K is added rapidly, as in preplant application, the soil will receive soluble K into exchangeable and/or fixed sites until equiblibrium is restored(Figure 5).

Figure 5

Re-establishment of Equilibrium After Addition of Soluble K, as in Preplant Addition



Note: Length of arrow indicates relative rate of each process.

The greater the imbalance from equilibrium, the faster the rate of change toward equilibrium.

The current soil test typically measures the equilibrium amount of exchangeable plus soluble K in a soil sample. A solution containing a high concentration of a positively charged ion, e.g., ammonium(NH_4^+), is added to the soil sample, in order to drive exchanged K from the soil surface(Figure 3).

Having left the soil particles, the K enters the surrounding solution. From the amount of K present in the extracting solution, the amount originally present in the soil as exchanged K is calculated and reported in ppm(parts per million) by weight in the soil sample.

Correlations are available which are intended to show whether the measured value is sufficient to carry a crop to completion. These correlations were determined by growing a crop in soils after measuring the exchangeable K levels.

At some low level of exchangeable K, the yields decline. The number of geographical areas where such data has been developed is limited.

There is an unstated assumption in this soil test method that all measured exchangeable K is available on the time scale of plant growth. In other words, the soil can make the K available to the plant at least as fast as the plant is demanding it.

As we will see, this assumption may not be good in high intensity irrigated western agriculture. Instead, the rate at which the processes in Figure 4 are occurring can be limiting to the uptake of K by the crop. This leads to a new concept in soil testing, based on rates of supply of K to the plant root system.

Earlier, we saw that potassium(K) takes several forms in combination with soil, and that the forms are in equilibrium, as shown in Figure 2.

A universal characteristic of any equilibrium system is that when it is forced out of balance, it will respond to restore that balance. How fast this response occurs will depend on the rates of the steps shown by arrows in Figure 1.

The current K soil tests measure the amount of exchangeable plus soluble K in the soil at equilibrium. The test methods have been in use many years. Yet reliable fertilizer K recommendations are difficult, and many unexplained exceptions have been seen in widespread areas.

We will now describe evidence that crops may not be growing in an equilibrium situation with the soil. The rates of equilibration in Figure 1 may be more important than the absolute amounts of various K forms. In other words, the rate of uptake by a plant may be limited by the rate that K is made available by the soil.

Growers in eastern Oregon and Washington often find unacceptably low levels of petiole K, e.g., 5 percent, in otherwise healthy potatoes in June and July. The soils typically test "high" to "very high" in exchangeable K by the standard soil test. These growers also typically add large amounts of preplant K, in spite of the soil tests. This is a clear example of a case where correlations of exchangeable K with yields have broken down.

Unocal Science and Technology Division studies on soils from this area led to some successful new approaches to K fertilization and soil testing. These are now being developed in other areas, including Idaho, California, and Arizona.

Assuming that a disease or other plant limitation was not causing the low petiole K levels, the object was to discover what soil characteristic limited K uptake.

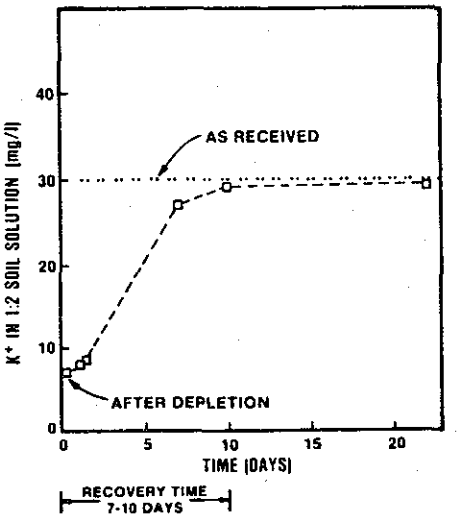
Exchangeable K levels in the soils studied ranged from 175-590 ppm, of which 15-30 percent was soluble K. These equilibrium values would generally be interpreted as adequate for a potato crop.

However, the literature shows that the root/soil system is not at equilibrium. If the rate of demand for potassium by the plant is greater than the maximum rate of production of available potassium by the soil, then the plant will fall behind, no matter how much potassium is measured at equilibrium.

Since soluble K is the only form truly "available" to the plant root, its behavior is most important. In experiments where soluble K was rapidly depleted by washing, the level of soluble K typically returned to an equilibrium level, but the time period was about 7-10 days (Figure 6).

Figure 6

DEPLETION AND RECOVERY OF SOLUBLE K^+ POOL IN A TYPICAL SOIL



The amount released into the soluble pool was typically 2-4 ppm per day. When distrubed, the system responds to restore an equilibrium condition, but the response takes time.

In another experiment, the soil equilibrium system was disturbed by the addition of 250 ppm of soluble K. Another soil sample received no added K.

The soils were later depleted of all soluble K as described above. Again, the soluble K returned to equilibrium over several days. But the required time, and the final level of soluble K, were identical in both soil samples. In other words, the soil with added K behaved as if no K had been added. The soil had tied up much or all of the added K in slowly-soluble forms.

The rates of release of available, i.e., soluble, K described above are similar to the rates of demand for K by several crops(Table 1).

Table 1

RATE OF K-UPTAKE BY SEVERAL CROPS

CROP	GROWTH PERIOD (days)	YIELD (tpa)	K-UPTAKE (lb)	DAILY RATE (lb/a/day)
ALFALFA (2nd cut)	0-35	3.0	170	4.8
SUGAR BEET	0-120	33	500	4.2
POTATOES	30-90	22.5	240 (80%)	4.0
CORN	30-60	4.2	99 (55%)	3.3
	30-90		144 (80%)	2.4
TOMATOES	0-120	33	450	3.8
COTTON	75-100	1.5	55 (50%)	2.2
SNAP BEANS	0-40	6.7	98 (75%)	2.4
CELERY	122-164 (POST-PLANTING)	84	700	11.4
LETTUCE	80-108 (POST-PLANTING)	24	185	5.9

For instance, at a 24-ton target yield of potatoes, there is a 60-day period in which the crop is demanding 5 lb/A/day of potassium. If the soil is capable of releasing only, say 2 lb/A/day, then the crop will eventually fall behind, no matter how much total K can be found in the soil.

Based on these and other results, a new soil test has been developed. The test measures the rate of supply of soluble K by a soil sample, and does not depend on the measurement of any equilibrium quantity. Soils from throughout the western U.S. have been tested, and some results are shown in Table 2.

Table 2

TYPICAL K-SUPPLY RATE AND SOLUBLE K LEVELS IN SEVERAL SOILS

SOIL ID.	CROP	SOLUBLE K (ppm)	K-SUPPLY RATE (ppm/DAY)***
PASCO, "X"*	SPUDS	7.7	3.9
PASCO, "Y"**	SPUDS	9.2	0.7
RITZVILLE (SILTY)	WHEAT	40.7	13.4
COLUMBIA FINE SAND	—	27.9	0.8
HANFORD SANDY LOAM	—	2.9	0.5
YUBA CITY	PEACHES	3.0	0.5
TURLOCK	GRAPES	1.6	0.4
KERMAN	GRAPES	7.9	0.7
WOODBURN (1)	—	11.0	4.0
WOODBURN (2)	—	4.0	1.8

* EXCHANGEABLE K: 170 ppm

** EXCHANGEABLE K 155 ppm

*** TO CONVERT TO LBS/A/DAY MULTIPLY ppm × 2

K-supply rates in ppm/day can be converted to lb/A/day in mineral soils by multiplying by 2.

As a first approximation, the K-supply rate of the soil can be compared with the K-demand of the crop at the target yield to determine whether the soil can produce soluble K at a rate sufficient to keep up with the plant demand.

For instance, Pasco, Washington soil X, with a supply rate of 3.9 ppm/day (7.8 lb/A/day), is expected to support a 25-ton potato crop easily, while its neighbor, soil Y, is expected to fall behind, with a supply rate of only 1.4 lb/A/day.

Note also that the two Pasco soils have essentially identical exchangeable K levels as measured by the traditional soil test, yet differ by a factor of almost 5 in supply rates.

Thus, the rates of the processes in Figure 2 may be very different in soils, even when the amounts of K present are the same. This can have a large effect on the potassium status of the crop.

The problem the plant faces is that it must compete with the soil for soluble K, and in many cases, the soil is a formidable opponent. The new soil test may say that the soil will not keep up with the crop, because it is "unwilling" to release soluble K. But reasonable quantities of fertilizer K are ineffective in increasing the K-supply rate within a short time after addition. This suggests that there is no solution to a K-deficiency.

We will argue that there is a solution, and that is to supply incremental additions of K. Rather than being at the mercy of the slow release characteristics of a deficient soil, we will take advantage of the slow tie-up of added K when the amount added is very small. Several examples will show that it is possible to produce pronounced increases in K uptake in this way, along with yield and quality increases, even in highly deficient soils.

As a quick review, we have considered the case where a crop rapidly removes a large amount of soluble K from the root zone. The rate of production of new soluble K by the soil after removal by a crop may, in some cases, by less than the rate of demand by the crop.

In such a case, the tissue potassium level may drop, no matter how much K is apparently present in the soil by the standard soil test.

In other words, the amount of K is not as important as the rate that it is made available in soluble form. We discussed a new soil test intended to measure the soluble K-supply rate of the soil.

We also saw that adding reasonable amounts of K does not affect the K-supply rate after a short time, e.g., 14 days. This is due to "fixation" of K, as the soil re-establishes equilibrium.

It appears, then, that there may be no good way to get K into the plant. However, we propose an answer to the dilemma. Since the soil is a competitor against the crop for K, the answer is to bypass the soil.

The undesirable effects of soil equilibrium of K can be avoided by adding only a small amount (increment) of soluble K at a time. A small disturbance to equilibrium (Figure 1) produces a slower response by the soil than does a large disturbance.

Meanwhile, the plant has a better chance to absorb the added K. In effect, the added K is used more efficiently by tipping the competition in favor of the crop.

However, since only a relatively small percentage of the crop's total need is added at one time, the process must be repeated at intervals. This is most easily accomplished by using irrigation water as the carrier of the added K.

So, in a soil which has a soluble K-supply rate lower than the demand rate of the crop, the potassium should be added at a rate equal to the demand of the crop. It should be added when the crop is demanding it (Table 1). In other words, the recommendation is to partially bypass the soil as a source of K for the crop.

An ideal example is, if soil supply rate tests low, and crop demands 5 lb/A/day in the period from 30 to 90 days after planting, then soluble K should be added at the rate of 5 lb/A/day. If irrigation is each 7 days, then each irrigation between 30 and 90 days should contain 35 lb of K (7 days x 5 lb/day).

Obviously local practices will determine how feasible the method of incremental additions will be. However, the principle is simple, and has fit into irrigated agriculture in those areas where it has been applied.

Although irrigation water is the most practical vehicle in many cases, other methods of addition may be used. The recommendations are summarized in Figure 7.

FIGURE 7

GENERALIZED K-RECOMMENDATIONS

BYPASS THE SOIL!

ADD K AS NEEDED IN INCREMENTS
- IRRIGATION WATER
- MULTIPLE SIDE DRESS, BROADCAST, ETC.
- FOLIAR

ADD AT THE RATE THE PLANT IS USING
- e.g. 4-5 LB/ACRE/DAY

ADD WHEN THE PLANT NEEDS IT THE MOST
- EXPONENTIAL GROWTH PHASE
- CARBOHYDRATE TRANSLOCATION PHASE

MAINTAIN A BALANCE OF N-P-K-S
- THEY ALL INTERACT IN MAXIMIZING PHOTOSYNTHETIC EFFICIENCY.

NEW CONCEPTS IN POTASSIUM NUTRITION

Dealers and growers in eastern Oregon and Washington, and Idaho, have been using these principles successfully in center-pivot and solid-set sprinkler systems since 1978 on potatoes, corn, and wheat. Preplant K, while not usually eliminated, is generally reduced. Approximately half the total K is applied through the sprinklers. The net result has been a decrease in total K added, with no loss in tissue levels, and increased quality and yield.

The concepts described here are intended to increase the odds of finding and curing potassium nutrition problems. They are obviously not a "cure-all."

Since the ultimate goal of K nutrition is optimizing photosynthesis, it must be used in a complete management system which does not ignore the other nutrient inputs, such as nitrogen, phosphorus, and sulfur.

There are certainly cases when incremental applications of K are not feasible. Dryland and rainfall only systems do not lend themselves well to multiple fertilizer applications.

The principle of prolonging the availability of applied K particularly during peak crop demand periods is, however, valid and deserves further evaluation. Supplemental applications at extremely low rates(1 lb/A/day) have proven highly successful where K nutrition is a problem.

It is our opinion that this strategy is applicable to many other plant nutrients as well.