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Potassium Considerations for Southern Idaho Soils[1]

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Potato tuber yields of over 500 cwt/A are being achieved by many of Idaho's potato growers. At this production level, tubers can remove over 200 lbs K/A. A recent study (Westermann and Tindall, 1995) showed that many southern Idaho fields responded to a K fertilizer application when the soil test K concentration was less than 175 ppm K in top 12 inches of soil. That study also showed that the K fertilization rate necessary to achieve maximum yields at a given soil test K concentration was significantly higher than that presently recommended in the fertilizer guide for potatoes (McDole et at., 1987).

Soils in southern Idaho formed largely from loess parent materials. In many areas these materials were sorted by alluvium action, giving rise to coarser textured materials being left behind. Common minerals found in the clay fractions are smectite, illite and kaolinite, with smaller amounts of vermiculite, quartz and feldspars. Illite is the dominant clay-sized mineral, being defined as a mica-type mineral altered by pedogenic processes (Lewis et al., 1991). In the fine silt fraction and clay fractions, K feldspar minerals are abundant. Volcanic glass, micas, quartz, and feldspars are also found in the very fine sand and coarse silt fractions on many sites (Lewis, 1987). These minerals are important sources of non-exchangeable K that replenish both exchangeable and solution K-fractions removed by plant uptake (Sparks, 1987; Mengel and Rahmatullah, 1994).

Soil test K concentrations have declined from 400-plus ppm in the late 1960's to 100-200 ppm today in southern Idaho. No information is available that quantifies the magnitude of the various soil K fractions, their inter-relationships, or that provides an explanation for the apparent higher K fertilization rate requirement reported. This information is needed to enhance our ability to develop and make reliable K fertilizer recommendations. Our objectives were to determine the magnitude of selected K fractions, and their inter-relationships to each other and to standard soil test K concentrations.

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METHODS AND MATERIALS

Soil samples were obtained from a variety of sources and locations (Table 1). All samples were from the 0-12 inch depth, air-dried, pulverized with a flay-grinder, and stored until analyzed. Soil textures varied from loamy sand to silt loam. Most samples were derived from loess parent materials, with possible water transport and deposition involved at some sites.

Table 1. Source of soil samples used in study.

Source/Location	Number of Samples
K Experiments-Southern ID	20
Columbia Basin	3
Potato K Survey-Southern ID	29
Utah Expt. Station-Logan	1
Aberdeen R&E Center	1
Parma R&E Center	1
ARS & Kimberly R&E Center	13

Soil samples were analyzed for $NaHCO_3$-extractable K (STKC) (Olsen and Sommer, 1982) and hot-acid extractable K to estimate slow-release K (Anon. 1985). Potassium adsorption isotherms were developed by equilibrating a three gram soil sample in 30 ml of 0.006M $CaCl_2$ containing K concentrations between 0-20 ppm for 24 hours with continuous mild shaking. The isotherms were analyzed for initial soil solution K concentration, equilibrium solution K concentration where the isotherm line crosses $y=0$, and the slope of the isotherm line at $y=0$. Soil samples from the five field experiments were further analyzed with the Unocal® K-diffusion procedure (DIFFK) (Green, 1984), and the phytoavailability test procedure equilibrated for 48 hours (PST-K) (Skogley et al., 1990).

Potassium concentrations in solution were analyzed by flame spectrophotometer in the appropriate ion matrix. Data were analyzed by calculating coefficients of determination (r^2) and standard errors of the estimate (SE) determined by least squares regression analysis.

RESULTS

STKC varied from less than 80 ppm to over 400 ppm, while slow-release K ranged from about 500 ppm to nearly 1800 ppm (Fig. 1). There was no apparent relationship between the two soil K fractions. When the STKC was less than 150-175 ppm there appears to be an upper concentration limit for the slow-release K

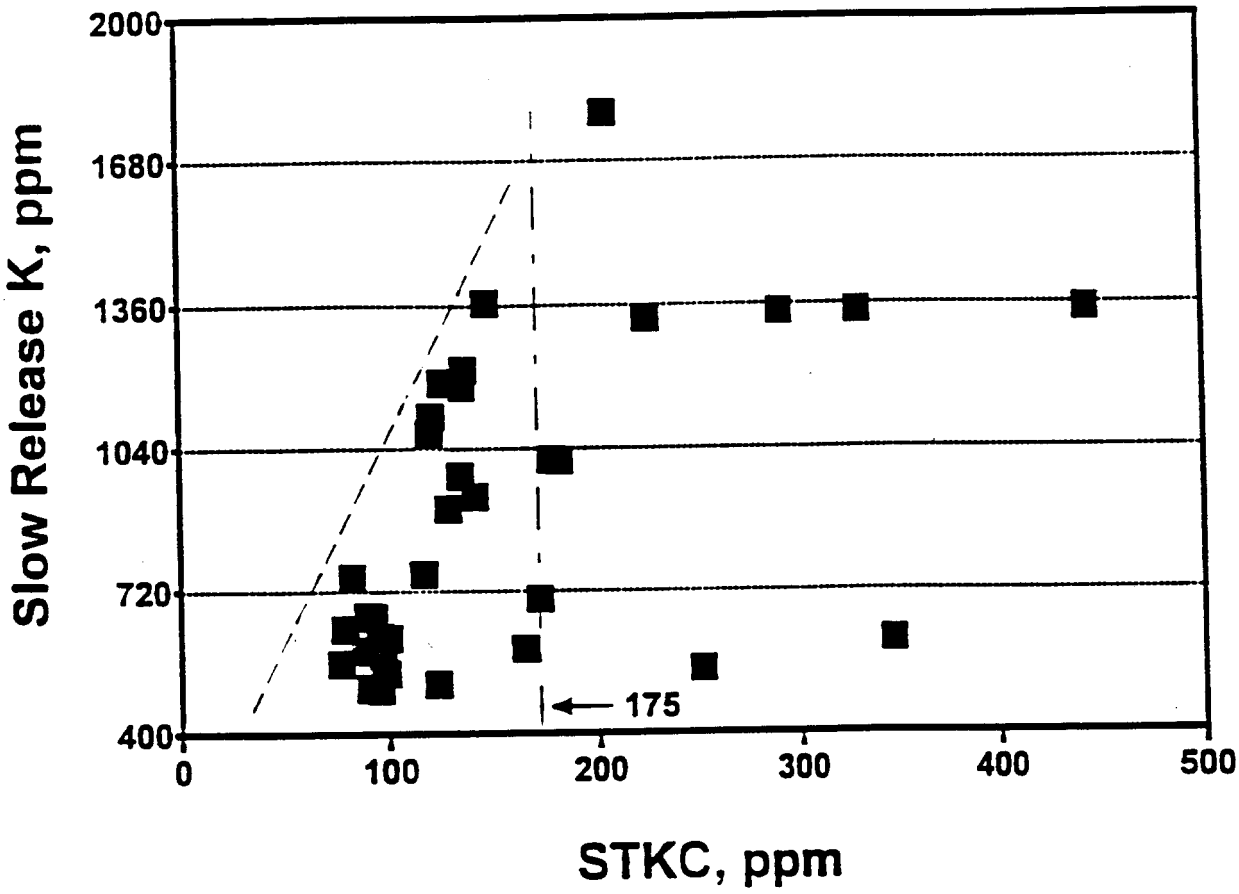

Figure 1. Relationship between STKC and slow-release K.

fraction. A linear line drawn along the upper points downward to where STKC is zero, crosses the y-axis at about zero for slow-release K. Samples with greater than 250 ppm STKC and relative low slow-release K concentrations (<700 ppm) may be caused by non-equilibrium conditions from very recent K fertilizer applications. It is not known to what extent solution K from fertilizers can re-enter the interlayer mineral lattices and become slow-release K in these soils. Cation exchange selectivity coefficients at equivalent ion activities indicate that K would replace Ca, Mg and Na on the exchange complex in these soils (Robbins and Carter, 1983). This would normally be a transient condition but it could exist around a dissolving K fertilizer granule in the soil-solution system. Soils with relatively high slow-release K concentrations (>1300 ppm) were from the Columbia basin (three samples), a native soil site in central Idaho (Portneuf) or from fields with a known history of heavy manure applications (two samples).

The K adsorption isotherms (Fig. 2) were generally linear within the range of initial K solution concentrations used. There was a tendency for some relationships to be curvilinear but the improvement in SE and r^2 did not justify using a curvilinear model. Slopes were generally steeper for the silt loam soils

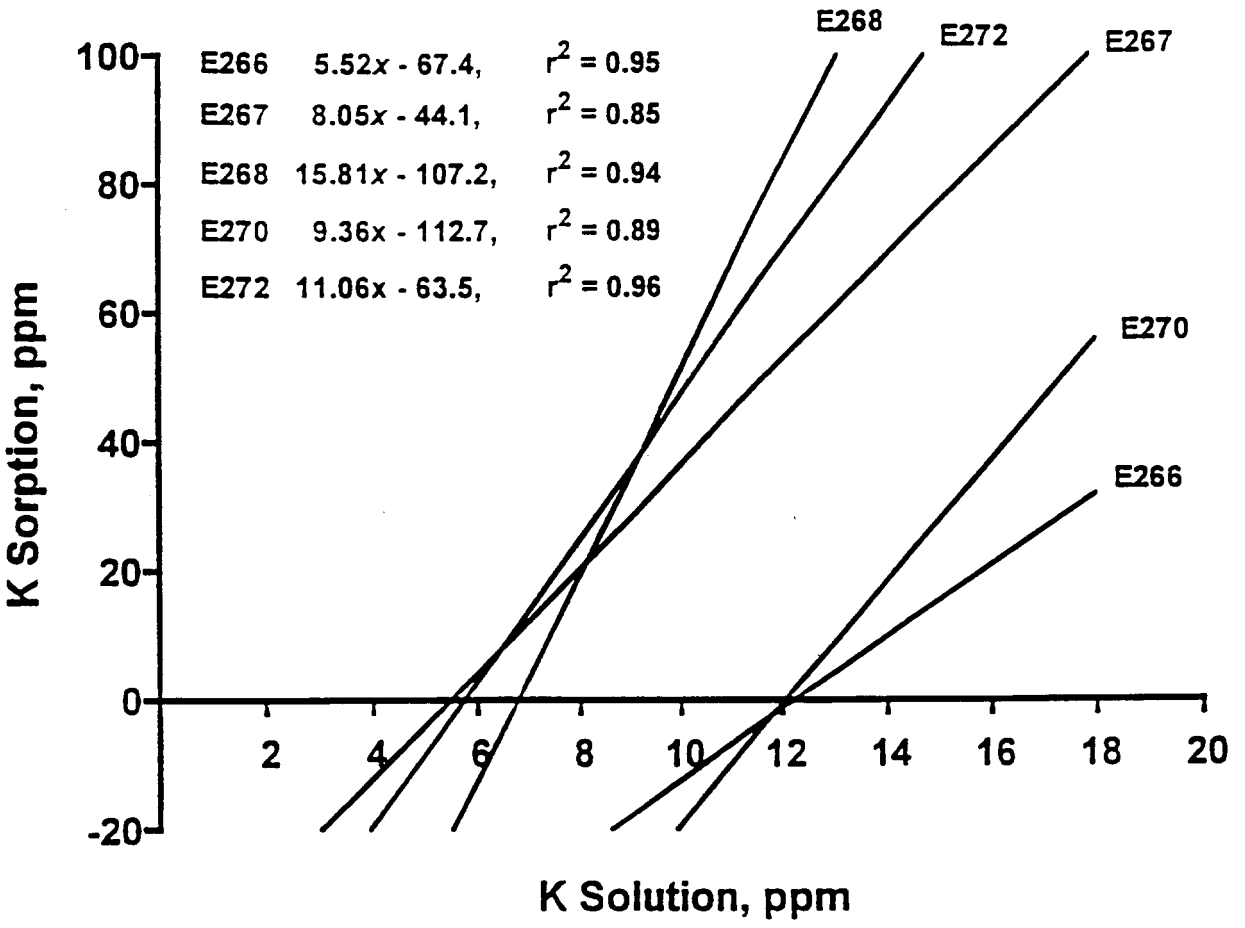

Figure 2. Potassium sorption isotherms for the five field experiments conducted in southern Idaho between 1992 and 1995.

compared with the lighter textured soils (E268 vs. E266 or E270 in Fig. 2). Isotherm slopes @y=0 were from 2.1 to 19.1, averaging 10.9 for all samples. Steeper slopes, indicate greater K sorption and potential buffering of soil solution K concentrations (Sparks and Liebhardt, 1981), and lower critical solution K concentrations (Mengel and Busch, 1982). There was a general tendency for the isotherm slope @y=0 to decrease as STKC increased (slope=14.95-0.0265*STKC, r^2=0.21). Conversion of the K isotherm data to equilibrium activity ratios (Beckett, 1964) did not change the interpretation of the data since the 0.006M $CaCl_2$ extractions contained nearly equivalent concentrations of Ca^{++} and Mg^{++}.

The K concentration in the 0.006M $CaCl_2$ solution with no initial K was related to the STKC (Fig. 3). In addition the calculated solution K concentration where the isotherm line crosses y=0 was also related to the STKC, except for three outliers. One was from the Columbia basin and two sandy loam samples were from western Idaho and central Idaho, respectively. These samples were able to maintain a much higher concentration of K in solution than the others at a similar STKC. Slow-release

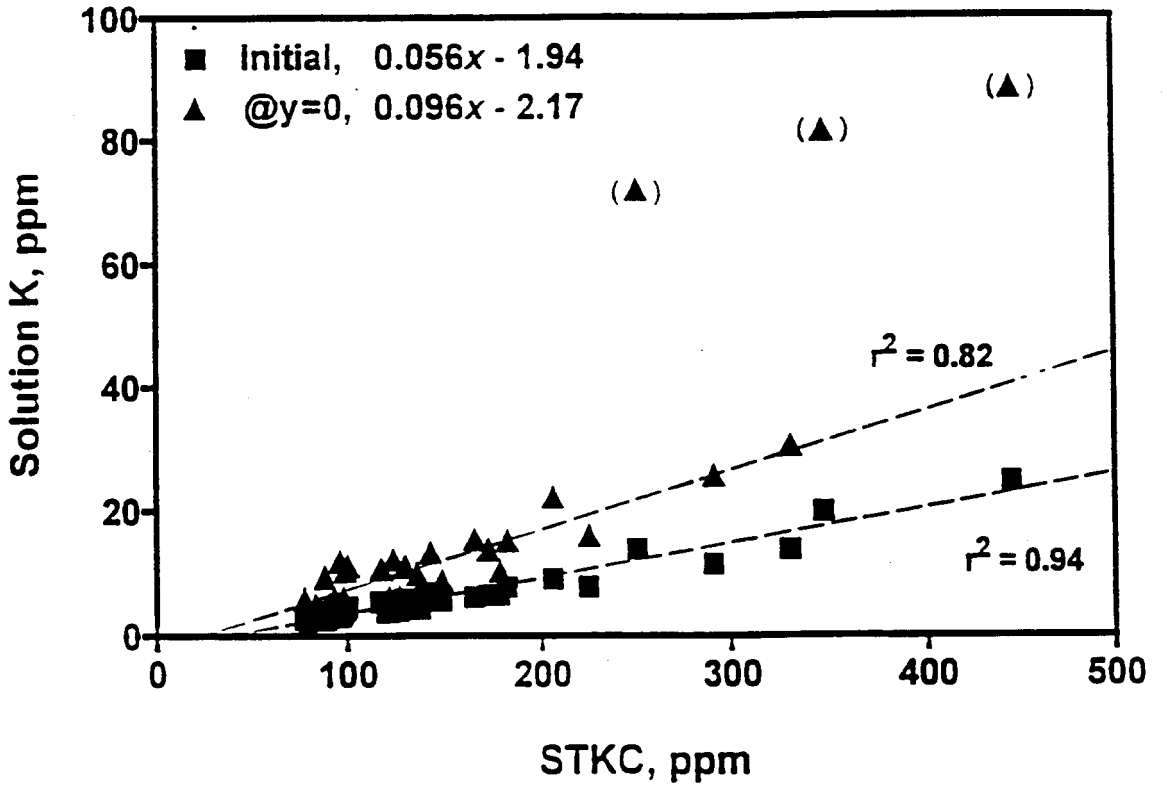

Figure 3. Relationship between STKC and solution K initially and @y=0 for the isotherm line. Points in parenthesis were not used in the regression analysis.

K was 1355 ppm for the Columbia basin sample and 550-610 ppm for the two sandy loams. Their isotherm slopes @y=0 (2.1-3.2) were lower than any of the other samples. Addition of K fertilizer to the three soils would increase soil solution K concentrations much more than in the other samples, with proportionally less K fixed or moving onto cation exchange sites. In general, K additions are distributed between water-soluble, exchangeable and nonexchangeable forms in portion to the clay content and dominant mineralogy of the soil (Sharpley, 1990).

The STKC was linearly related to the DIFFK estimated with the Unocal® procedure for the soil samples from the five field experiments (Fig. 4). For a STKC of 150 ppm, the calculated diffusion rate would be 1.77 ppm K/day or about 6.4 lbs K/day for an acre-foot. A previous availability classification would rank this rate as low and predict a response to K fertilization (Green, 1984). Even if plant roots were able to extract 50% of the K supplied to the soil solution by this mechanism, it would barely be adequate for potato production since tubers growing at 700 cwt/A-day require about 3 lbs K/A-day. There was also a relationship between the y-intercept K diffusion rate calculated from the Unocal® procedure and the initial K solution concentration found in the isotherm analysis (Data not shown, $\hat{Y}=0.943X-0.034$, $r^2=0.55$).

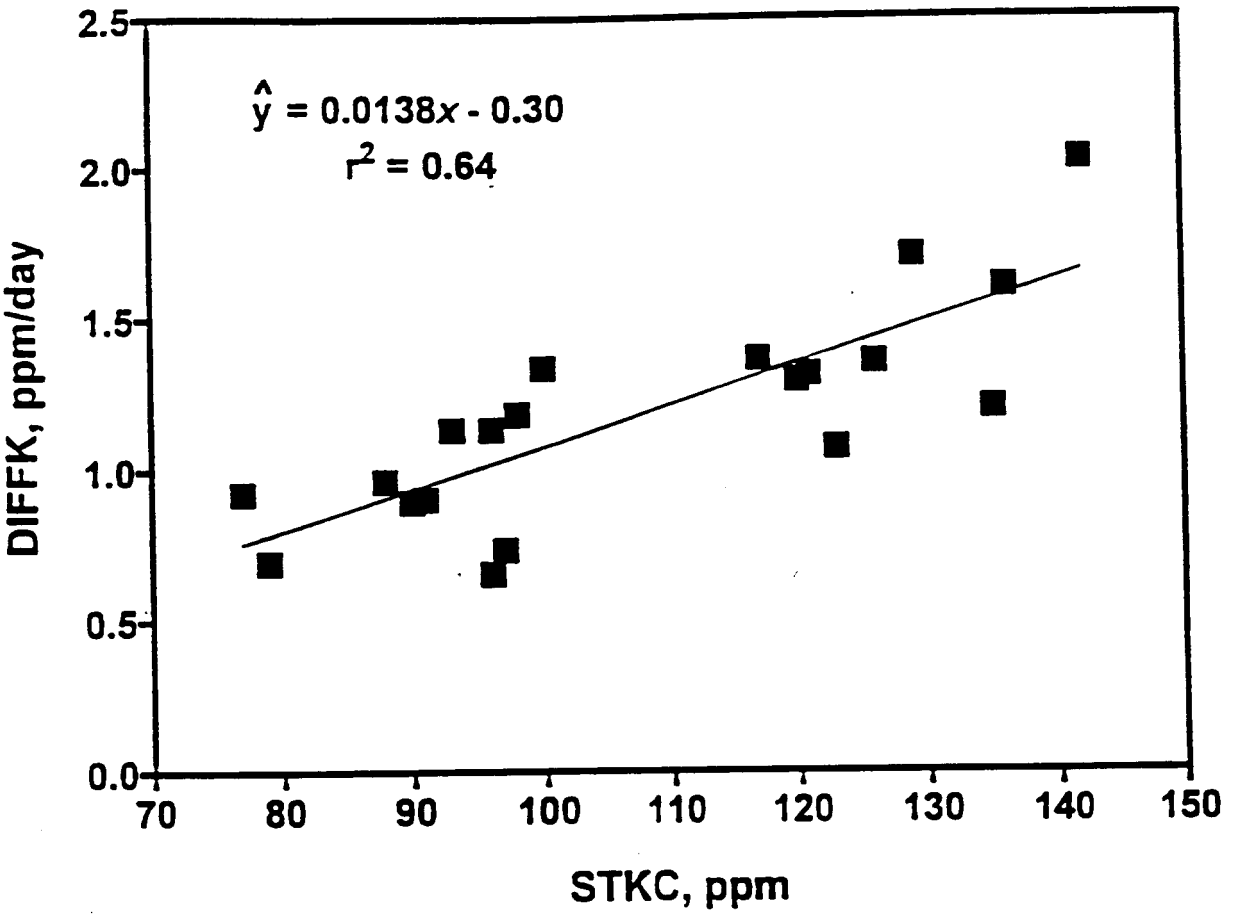

Figure 4. Relationship between STKC and the K diffusion rate (DIFFK) estimated by the Unocal® procedure.

There was a tendency for the PST-K rate to increase as STKC or DIFFK increased (Data not shown). The PST-K was related to the K solution concentration @y=0 (Fig. 5) and also to the initial K solution concentration (Data not shown, r^2=0.40). The phytoavailability soil test, PST, was developed to mimic how nutrients come in contact with plant roots and should be related to soil solution concentrations. It was not related to the isotherm slope @y=0 nor to the slow-release K fraction (Data not shown).

DISCUSSION AND CONCLUSIONS

Sodium bicarbonate should extract all the soluble and most of the exchangeable K fractions. The K extracted by 0.5M $NaHCO_3$ was related to the K in 0.006M $CaCl_2$ initially and where y=0 for the sorption isotherm. In addition, it was related to the DIFFK estimated by the Unocal® procedure but not to the phytoavailability soil test results (PST-K). Both solution K concentrations were less than 10% of that extracted by $NaHCO_3$. Sodium bicarbonate did not appear to extract a significant portion of nonexchangeable K as there was no apparent

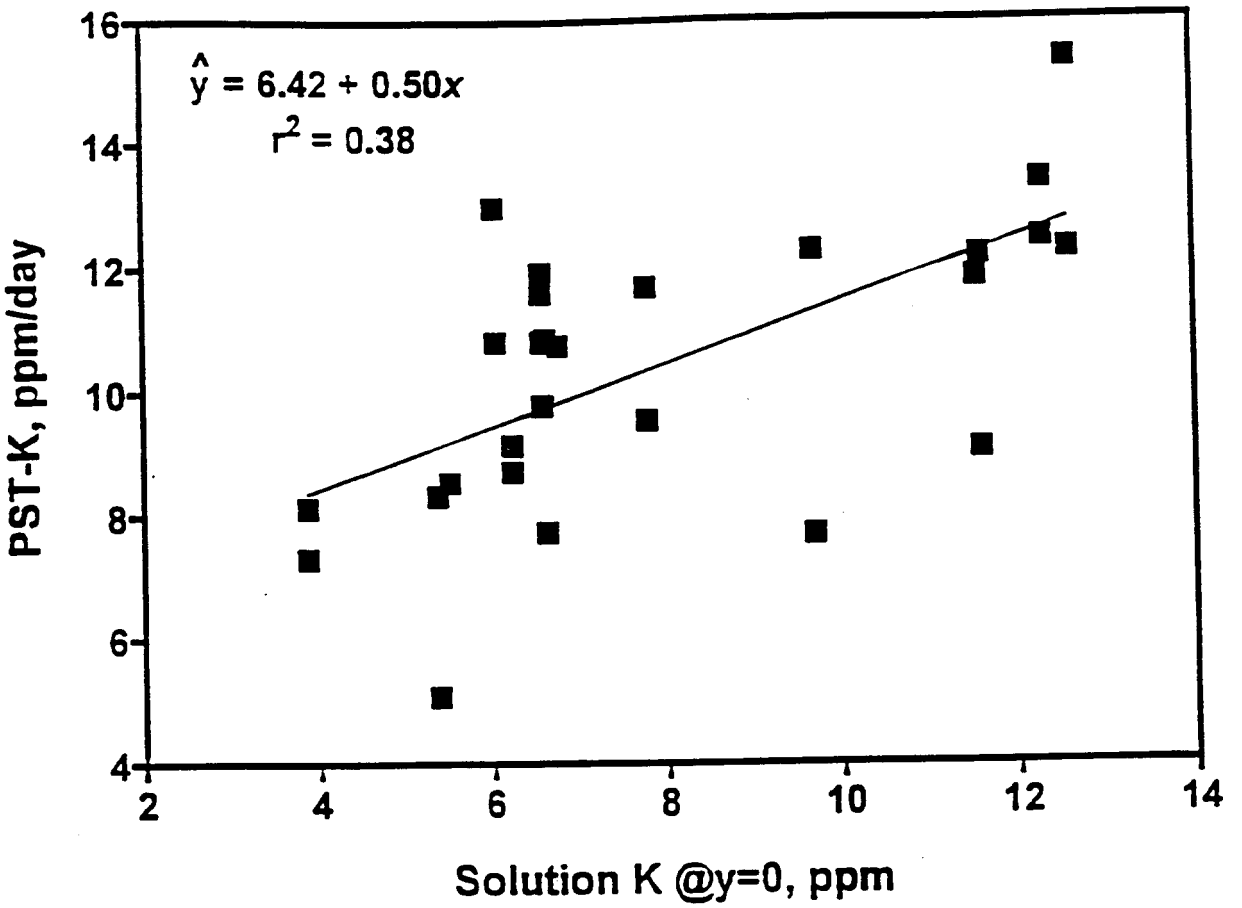

Figure 5. Relationship between the solution K @y=0 and the phytoavailability soil test, PST-K.

relationship to slow-release K.

Slow-release K concentrations are at least 1200 ppm or greater for the native silt loam soils in southern Idaho. Except for manured sites, the slow-release K fraction was smaller with a cropping history, particularly for the coarser textured soil samples. Isotherm slopes were also smaller for the latter samples. This indicates that a K fertilization response will probably occur on the coarser textured soils at a higher STKC than for the silt loam soils. It also suggests that K applications may be susceptible to downward movement and leaching losses in the coarser textured soils with excess water applications. A portion of applied K might be expected to become fixed in the slow-release K fraction, since the equilibria between solution, exchangeable, and nonexchangeable K forms is reversible. Only small amounts of applied K may be recovered by plants if a high portion of the applied K is fixed the season of application. This may necessitate even larger K fertilizer applications for adequate plant growth on these soils.

Potato tuber yield responses to K fertilization were related to STKC (Westermann and Tindall, 1995). Data in this paper indicate that yield responses would probably be related to a

solution K concentration and to the K diffusion rate estimated by the Unocal® procedure. Both procedures are more difficult to perform than the 0.5M $NaHCO_3$ procedure, normally used to estimate soil P availability. Additional information is needed to further evaluate these indices of soil K availability with crop K uptake.

The current fertilizer guide for potatoes in Idaho has a critical STKC of 150 ppm K and no K recommendations higher than 250 lbs K/A (McDole et al., 1987). The 1992-1995 field study by Westermann and Tindall (1995) showed that the critical STKC should be raised to 175 ppm K and higher K fertilization rates were needed for 95% relative tuber yields (Table 2). Most of their experimental sites were on the coarser textured soils,

Table 2. Fertilizer K recommendations (lbs K/A) for potatoes by different approaches assuming fertilization of 12 inches of soil.

	Approach for K Recommendation			
Initial STKC (ppm)	1987 F.G. Potato	92-95 K-Study (95% RY)	Soil Mass	Soil Sorption (@y=0)
175	0	0	0	0
150	0	85	95	100
125	42	170	190	210
100	84	255	280	335
75	126	340	380	470
50	167	425	475	620
25	208	510	570	780

with only one silt loam site. Assuming that $NaHCO_3$ will extract all the soluble and most of the exchangeable K fractions, and that added K fertilizer contributes to only those two fractions, about 380 lbs K/A would be required to change the STKC 100 ppm in an acre 12 inches with a bulk density of 1.4 g/cm^3 (Table 2, *Soil Mass* column). Conversion of any added K to nonexchangeable K (fixed or interlayer K) would further increase the fertilization rate. We adjusted the fertilization rate for K fixation by using the relationship between isotherm slope and STKC for the field experimental sites, and the relationship between STKC and solution K concentration @y=0 (Fig. 3). The adjusted rates are higher than those derived from the field study or using the mass balance approach (Table 2, *Soil Sorption* column). Part of this difference occurs because all the soil particles and surfaces are exposed during isotherm equilibrium while in the field studies only the soil around the dissolving fertilizer particles would be

exposed to higher K concentrations. Predicted K fixation would be 5% at 150 ppm STKC, increasing to about 27% at 25 ppm STKC. This compares with 26% predicted for smectitic soils with 20% clay or 20 meq CEC/100g (Sharpley, 1990)

The K extracted by 0.5M $NaHCO_3$ was related to other soil K fractions, except for the slow-release K fraction. The 0.5M $NaHCO_3$ extractable K appears to a good indicator of K availability in these soils. The magnitude of the STKC and slow-release K fractions in southern Idaho soils has decreased significantly with cropping history, necessitating K fertilizer applications for optimum plant growth and to replenish the nonexchangeable K fraction. There was reasonably close agreement between K fertilization rates from recent field experimental data for potatoes and those calculated using a mass balance approach. Potassium fixation could be as high as 27% of the applied K at relatively low STKC. Potato growers may want to consider a maintenance K fertilization program to avoid the higher corrective rates required to alleviate potential K deficiencies. This practice would especially be appropriate on the coarser textured soils.

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