

ASSESSMENT OF POTASSIUM STATUS OF SOILS—RECENT DEVELOPMENTS

by M. E. SUMNER¹

The field of soil fertility deals mainly with the mineral nutrition of plants in which both the supplying power of the soil and the ability of the plant to absorb nutrients, are of importance. The soil may be considered as the rooting medium which provides water and mineral nutrients necessary for plant growth. Ionic equilibria play a fundamental role in fertility relationships because they govern the ability of the soil to supply a particular nutrient. Nutrient uptake is the resultant of the reaction of the plant to a given nutrient supply and is influenced by both biological and soil factors as illustrated in Figure 1.

As the scope of this paper is confined mainly to ionic equilibria in soils, biological factors involved in nutrient uptake will be disregarded. The following discussion will therefore be limited to the measurement of the supplying power of soils for K as influenced by ionic equilibria.

The ability of the soil to supply K is governed by the amount of nutrient present and the energy level or degree of availability at which it is supplied. For optimum growth plants will thus require sufficient K at a suitable energy level throughout the period of uptake.

Before the K status of soils can be defined, it is necessary to obtain a measure of the energy level of this nutrient in the soil. Since all soil processes can be considered as chemical reactions, a parameter with thermodynamic significance must be used to characterize the energy level viz. the thermodynamic potential. At equilibrium, the thermodynamic potential of any constituent is constant throughout the system. Thus the K status of a given soil may be fully characterized by the relationship between the amount of K present and its thermodynamic potential in the equilibrium solution. However, the thermodynamic potential of K is not directly measurable. As the nature of the complementary ions in the soil is an important influencing factor, it is necessary to obtain a measure of the thermodynamic potential of K relative to that of the predominant exchangeable ions in the soil. For most agricultural soils these ions are Ca and Mg. At equilibrium the ratio of the activities $a_K/\sqrt{a_{Ca} + Mg}$ is uniquely proportional to the difference in thermodynamic potentials of labile K and Ca + Mg in the soil. Thus the ratio may be used as a measure of the thermodynamic potential or energy level of K for soils of comparable Ca Δ Mg status.

In recent years, a very attractive technique has been developed by Beckett (1964 a & b) based on the fact that the activity ratio $a_K/\sqrt{a_{Ca} + Mg}$ in a solution in equilibrium with a soil gives a satisfactory measure

of the potential or availability of K. If one considers a soil in which the predominant exchangeable cations are Ca and Mg, one may measure the availability of K relative to the amount present as follows:

The equilibrium activity ratio $(a_K/\sqrt{a_{Ca} + Mg})_e$ is a measure of the availability, or as Beckett (1964b), prefers to call it, the "intensity" (I) of the labile K in the soil. However, this is not a measure of the capacity of the soil to release K to the plant as different soils having similar equilibrium activity ratios, do not necessarily contain the same amount of labile K. Therefore the K status of a soil may be fully described if both the current K potential in the labile pool and the way in which this potential depends on the quantity (Q) of labile K, are known. This relationship is given by the form of the quantity-intensity (Q/I) curve.

The technique used in obtaining a Q/I curve consists of equilibrating a number of samples of the same soil with a series of solutions containing variable amounts of KCl in 10^{-2} M CaCl₂. For each suspension, the difference between the K concentration in the initial and final (equilibrated) solution gives the amount by which the soil gains or loses K in reaching equilibrium with the final solution ($\pm \Delta K$). The activity ratio $a_K/\sqrt{a_{Ca} + Mg}$ for each value of ΔK is calculated from the composition of the final solution.

The relationship between $a_K/\sqrt{a_{Ca} + Mg}$ (intensity factor I) and ΔK (quantity factor Q) for the Clifford Series is illustrated in Figure 2.

The shape of the Q/I curve is characteristic. Every soil so far investigated by Beckett (1964b) has given a linear upper part for the Q/I curve while the lower part curves asymptotically to the Q axis. This curvature is due to the release of non-exchangeable K when very little K is present in the soil solution and offers an explanation why exchangeable K determinations are not always precise. It is for this reason that changes in the amount of labile K should be measured relative to the amount in the unchanged field soil and not against a zero state of the soil as, for example, when it has been stripped of all labile K.

The linear portion of the Q/I curve is a special case of the Gapon equation as can be seen from the following derivation: The linear portion of the Q/I curve can be expressed mathematically in the form:

$$\Delta K = \sqrt{\frac{k a_K}{a_{Ca} + Mg}} \quad (1)$$

where k = constant.

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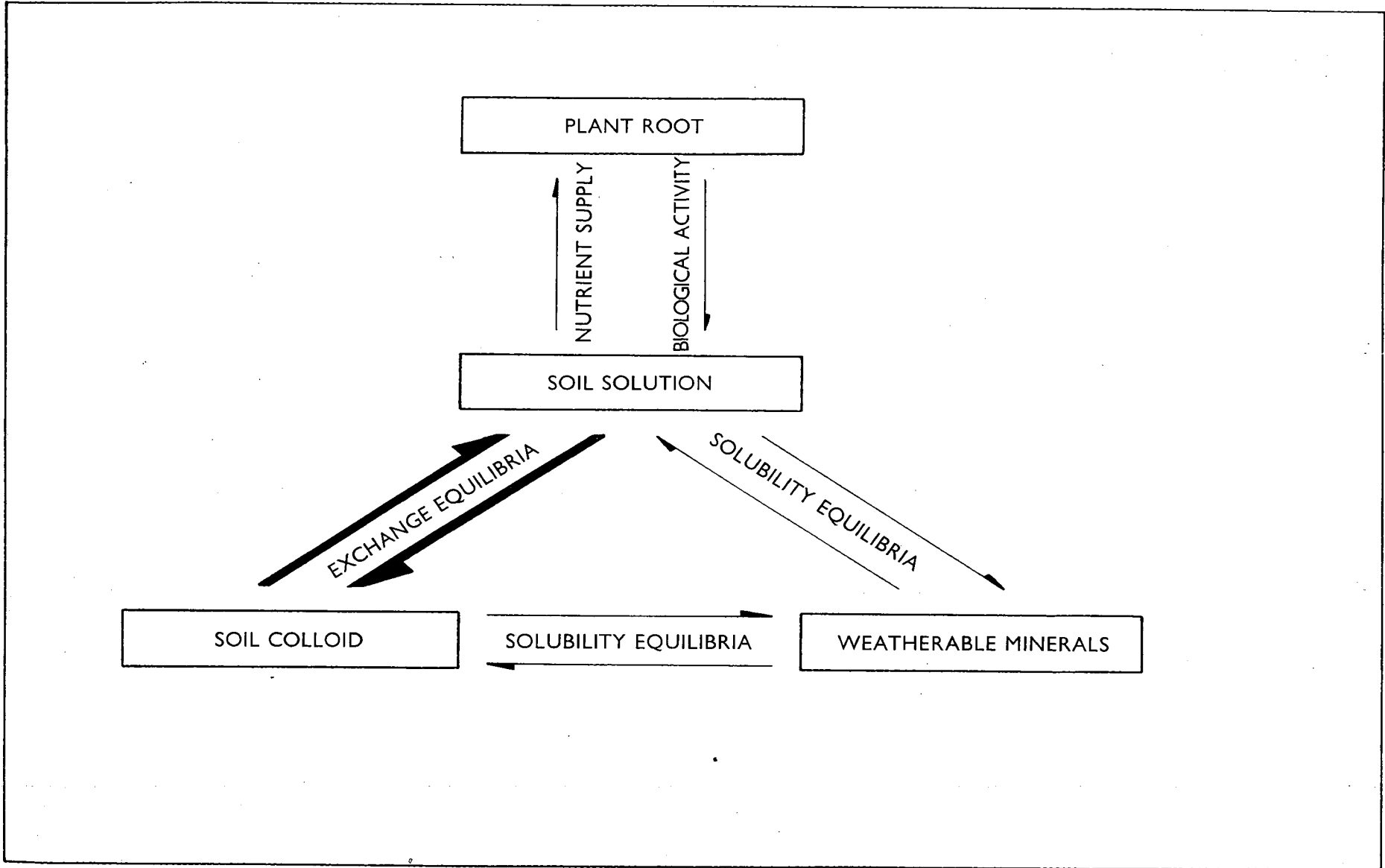


FIGURE 1
Ionic equilibria in soils in relation to nutrient uptake

$$\text{But } \gamma K = \gamma K_e + \Delta K \quad (2)$$

where γK = amount of exchangeable K
and γK_e = value of γK at $(aK/\sqrt{aCa + Mg})_e$
Substituting (2) in (1) we obtain:

$$\gamma K = k \frac{aK}{\sqrt{aCa + Mg}} + \gamma K_e \quad (3)$$

Dividing the LHS of equation (3) by $\gamma Ca + Mg$ we obtain:

$$\frac{\gamma K}{\gamma Ca + Mg} = k' \frac{aK}{\sqrt{aCa + Mg}} + \gamma K_e \quad (4)$$

which takes the same form as the Gapon equation.

The slope, $\Delta Q/\Delta I = k$, gives the amount of labile K that can be removed before $aK/\sqrt{aCa + Mg}$ decreases by more than a given amount. Beckett (1964b) has called this slope the Potential Buffering Capacity (PBC^K) of the soil for K. From equation (4), PBC^K is proportional to k' ($\gamma Ca + Mg$) and is therefore dependent on variations in the amount of exchangeable Ca and Mg. Bolt (1955) has shown that k' is a function of the surface charge density of the clay. Consequently PBC^K should be dependent on surface area and should vary with γK_{Ca+Mg} as a measure of the exchange surface. Thus for a given value of value of γK_{Ca+Mg} , PBC^K should decrease with increasing K saturation.

If the linear portion of the Q/I curve is extrapolated to the point where $aK/\sqrt{aCa + Mg} = 0$, we obtain a value $-\Delta K^\circ$ which is a measure of the labile pool of K in the soil.

The intercept of the Q/I curve on the I axis gives the equilibrium activity ratio $(aK/\sqrt{aCa + Mg})_e$ which is a measure of the energy level or availability of K relative to Ca + Mg in the soil.

Thus the K status of the soil in its field condition may be fully defined by any two of the following parameters: $(aK/\sqrt{aCa + Mg})_e$; PBC^K and $-\Delta K^\circ$.

At present, few results are available to indicate whether crop response can be predicted adequately from Q/I curves although the technique appears to be theoretically sound and should give a reliable basis for prediction. Some preliminary data from a 3⁴ factorial fertilizer experiment with maize on the Clifford Series at Tabamhlope will be presented to illustrate how this technique may be used. The factors consist of dressings of N, P, K and L (L = agricultural lime) each applied at three levels viz. 0, 1 and 2. Nine plots comprising those with the highest level of N and P with all combinations of the three levels of K and L were chosen for the investigation. The original Q/I curves were determined by Beckett (1964b). Data derived from his Q/I curves together

with the grain yield and the K content of the fifth basal functional leaf are presented in Figure 3. The treatment combination code for each set of points in this figure indicates the levels of N, P, K, and L respectively in that order.

Both the equilibrium activity ratio $(aK/\sqrt{aCa+Mg})_e$ and the pool of labile K in the soil, $-\Delta K^\circ$, are seen to be closely related to the K content of the leaves. In theory, these curves should be sigmoidal in shape and the limited number of points available tend to support this view.

When these curves are compared with that for yield against K content of the leaf, it is clear that values for the pool of labile K in the soil at which good yields are obtained correspond to the plateaux of the two curves. It would appear, therefore, that there are limits between which the K potential and pool of labile K in the soil must lie in order to obtain high yields. Values outside these limits correspond to either deficiency or excess of K which leads to nutritional imbalance and thus poor yields.

If the pool of labile K ($-\Delta K^\circ$) is plotted against yield (Figure 4), it is clear that for this soil, the pool of labile K should lie between approximately 0.115 and 0.180 me% in order to obtain a satisfactory yield. The decrease in yield at high values of $-\Delta K^\circ$ is probably due to a deficiency of Ca (2220 plot). Should this plot be limed, the pool of labile K would be decreased and adequate growth would result. This can be seen by comparing the points for treatments 2220, 2221 and 2222. Thus a balance must be struck between the pools of labile K and Ca in the soil. In all cases, liming decreases the pool of labile K in the soil. In some cases, this results in an increase in yield due to improved nutritional balance whereas in others the reverse is true.

It is possible on the basis of Q/I curves to predict the quantity of K required to increase the yield by a given amount. If, for example, we compare treatment 2202 with 2222, 400 lb. KCl/morgen was applied to increase the yield to 40 bags/morgen. The difference in the amount of labile K in these two plots is 0.07 me% which corresponds to 220 lb. KCl/morgen. At the time of sampling the soils for analysis, the plants had been growing for about 4 months and would have removed approximately 120 lb. KCl/morgen from the 2222 plot and very little from the 2202 plot. Thus the pool of labile K in the soil appears to adequately predict the amount of K available to the plant during the growing season and may be used as a basis for fertilizer recommendations.

It should be pointed out that the above reasoning is strictly true only for soils containing similar amounts of labile Ca+Mg. Therefore some adjustment may be necessary when comparing plots or soils of widely different Ca or Mg status.

In conclusion, it should be stressed that the results presented in this paper are only of a preliminary nature and that much more work is required before

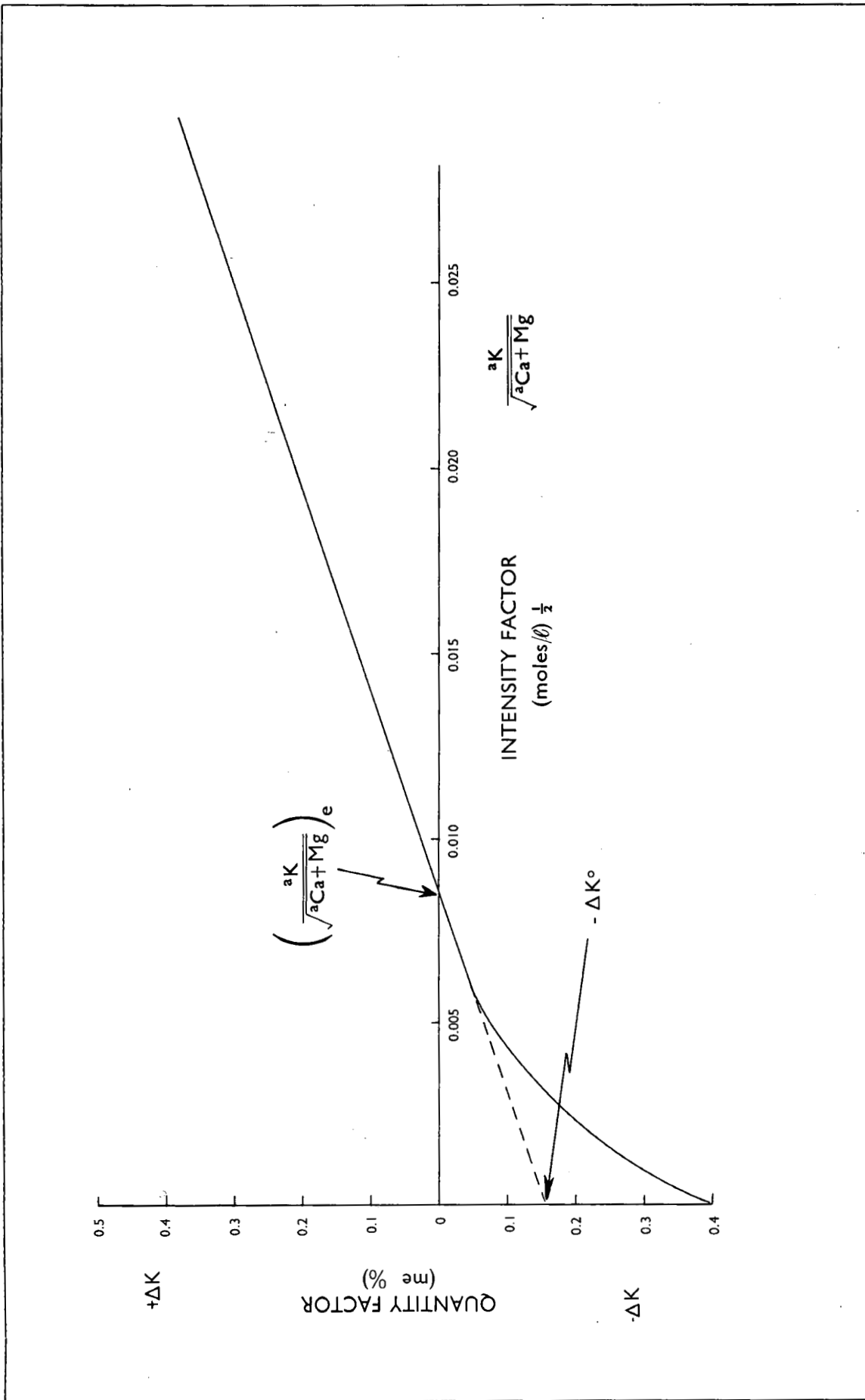


FIGURE 2
Quantity-intensity (Q/I) curve for Clifford Series

what appears to be a promising technique in assessing the K status of soils can be accepted with confidence.

Summary

A new technique for assessing the K status of soils based on the measurement of the quantity-intensity (Q/I) relationship of labile K in the soil is reviewed. Data from a 3⁴ factorial fertilizer experiment with maize on the Clifford Series at Tabamhlope are presented to illustrate the potentialities of the method. Preliminary results indicate that Q/I relationships may serve as a useful basis for fertilizer recommendations from soil analyses.

References

- Beckett, P. H. T. (1964a). Studies on soil potassium I: Confirmation of the Ratio Law and measurement of potassium potential. *J. Soil Sci.* 15: 1-8.
- Beckett, P. H. T. (1964b). Studies on soil potassium II: The "immediate" Q/I relations of labile K in the soil. *J. Soil Sci.* 15: 9-23.
- Bolt, G. H. (1955). Ion adsorption by clays. *Soil Sci.* 79: 267-76.

Mr. Bishop: Dr. Sumner has given an excellent illustration of the Q/I curve. He also used this curve for explaining field results, and has shown courage in attempting to do so. In some spheres it is held that empirical methods are of no value and the theoretically correct aspects provide the only answer.

Dr. Sumner has been responsible for bringing this new trend in soil science to South Africa. In theory his results are sound but in practice, at this stage, they are open to criticism.

The two views can be compared. In figure 3 the critical point in the whole paper is the 2220 plot at the end. The whole argument revolves round that point. Had the other school of thought attempted to correlate exchangeable potash against potash percent in the leaf, they would have left that point out, as Dr. Sumner has done in figure 4 with point 2212. If the point at 2220 is eliminated the result is a straight line.

The question of balances always gives rise to argument. The important thing is the balance in the plant, not the balance in the soil. If the nutritional requirements of the plant are satisfied the balance in the soil is immaterial.

Giving the other interpretation of Dr. Sumner's paper, we would say the soil was suffering from an extreme potash and calcium deficiency.

The potash and no calcium yields are very low. The next lowest yields, 2210 and 2220, confirm what Dr. Sumner has been saying, that without calcium at the first level of potash, you obtain a very much better yield than you do when you have a second level of potash. However, as there are only nine points on the graph definite conclusions cannot be reached.

Considering again the other points, the best yielding plot in the experiment is 2222, then 2221 then 2212, so that the three best plots have every possible combination of calcium and potash together. Why, therefore, is the balance of ions important in the no calcium or potash plots, but unimportant in plots where calcium and potash are together?

Dr. Sumner: According to Mr. Bishop, by omitting point 2220 it would be possible to draw a straight line through the other points, giving a relationship of increasing K content in the leaf with increasing labile K. One cannot, however, believe that a plant will go on and on absorbing potash linearly with increasing labile K.

Mr. Bishop: Up to a point it will.

Dr. Sumner: That is what I am saying. I have taken the nine best yielding of eighty-one plots and the values for the pool of labile K all lie between 30 and 53 milli equivalents per cent of potassium.

There appears to be a certain anomaly in the yield results, but this is hardly surprising as we are considering single results in factorial experiment. Each plot is subject to large errors.

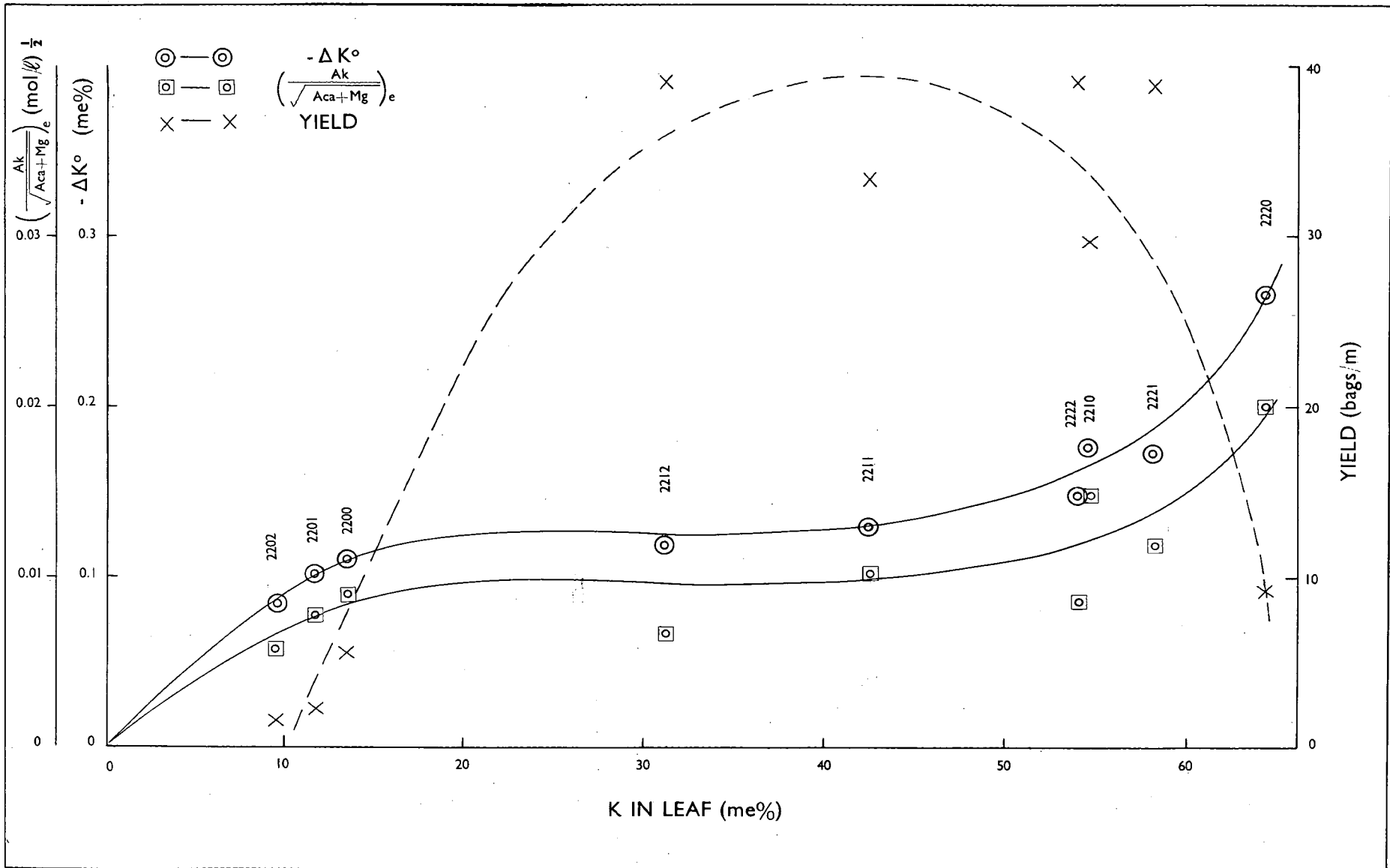


FIGURE 3
 Relationship between K content of maize leaves and the pool of labile K in the soil ($-\Delta K^{\circ}$), the equilibrium activity ratio ($a_K/\sqrt{a_{Ca+Mg}}$) and the yield of maize for the Clifford Series

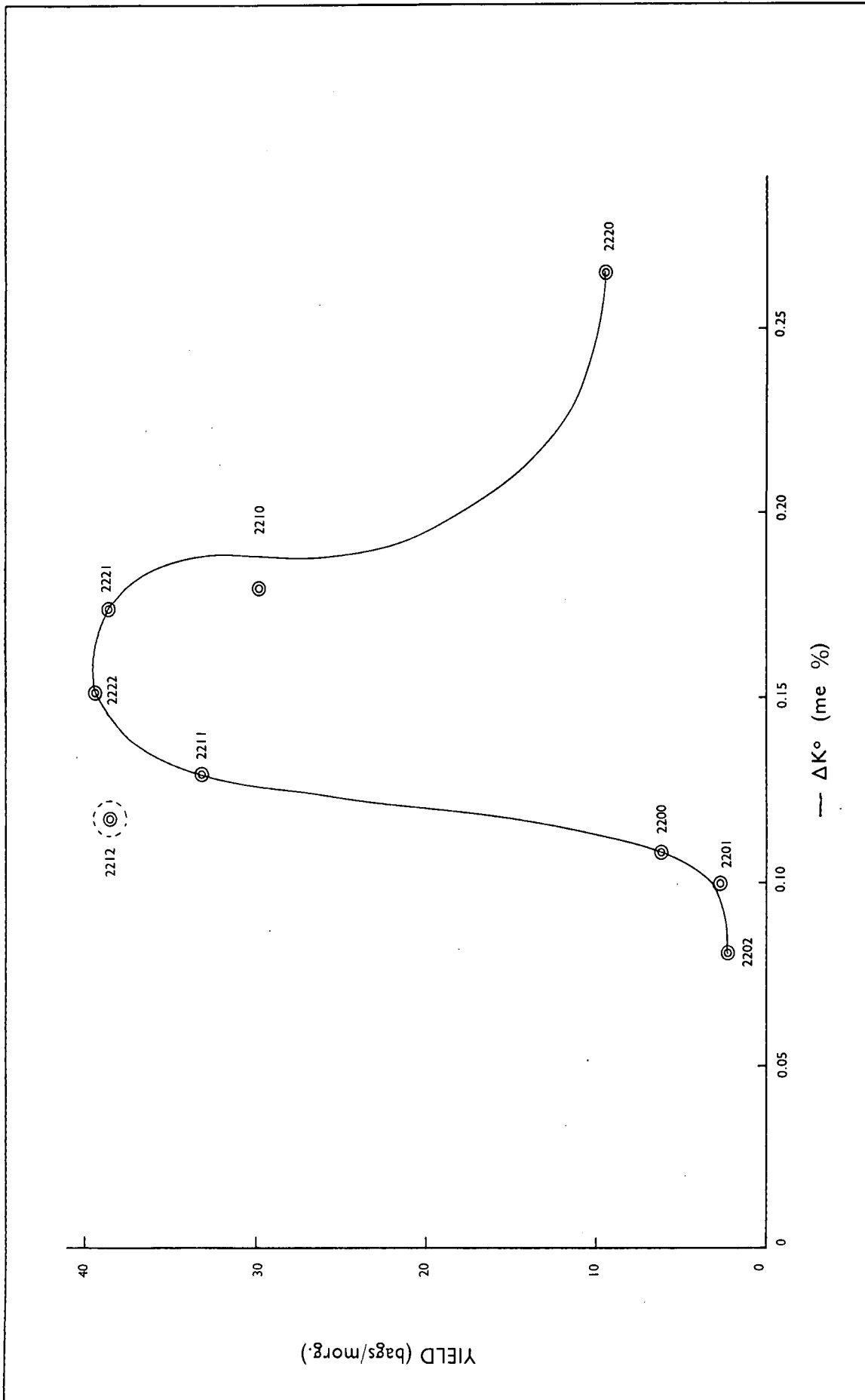


FIGURE 4
Relationship between the yield of maize and the pool of labile K (ΔK°) in the Clifford Series