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Exchangeable and Non-Exchangeable Potassium as Indexes to Yield Increases and Potassium Absorption by Corn in the Greenhouse

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Austauschbares und nicht austauschbares Kalium als Anzeiger für Ertragssteigerungen und Kaliumaufnahme durch Mais in Gewächshausversuchen
von G. W. Schmitz und P. F. Pratt

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Potássio permutavel e não permutavel como indicador de aumento de safras e absorção de potássio por milho em ensaios realizados em estufas.
Por G. W. Schmitz e P. F. Pratt

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Il potassio scambiabile e non scambiabile quale indicatore per l'incremento delle produzioni e l'assorbimento del potassio in esperimenti
in serra su piante di granoturco. — G. W. Schmitz e P. F. Pratt

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Mısır ile yapılan saksı denemelerinde mahsulun artışına ve kalium'un sömürülmesine dair G. W. Schmitz ve P. F. Pratt tarafından yapılan tebliğde kabili mubadil ve gayri kabili mubadil kalium

By G. W. Schmitz and P. F. Pratt

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Foreword. In the experimental plan on which this work was based, soil samples of the A-Horizons of 18 soils in Ohio were used in glasshouse culture to grow maize over a period of ten months. The effect of the potash manuring on the yield and the total uptake of potassium were determined and correlated with the results of the soil analyses.

The quantities of potassium found by extraction with HNO_3 provided a better criterion as to the possible yield increases by potash manuring than the values of the exchangeable potassium. The best approximate values for the potassium removal from soils not treated with potash were found when the values of the exchangeable potassium determined at the commencement of the growth were correlated by multiple regression with the potassium liberated from the non-exchangeable form by HNO_3 extraction. The best approximation, however, for the percentage K uptake in the control pots compared with K treated pots was obtained by a multiple regression in which the percentage of K uptake was considered as a function of the exchangeable potassium and of the potassium liberated by HNO_3.

Vorbemerkung. In der Versuchsanlage, die dieser Arbeit zu Grunde lag, wurden Bodenproben des A-Horizontes von 18 Böden in Ohio im Gewächshaus 10 Monate mit Maisanbau genutzt. Die Wirkung der Kalidüngung auf den Ertrag und die Gesamtaufnahme von Kali wurden festgestellt und mit den Ergebnissen der Bodenanalysen in Beziehung gesetzt.

Die bei Extraktion mit HNO_3 gefundenen Kalimengen geben einen besseren Anhalt für die mögliche Ertragssteigerung durch Kalidüngung als die Werte des austauschbaren Kaliums. Die besten Näherungswerte für den Kalientzug aus nicht mit Kali gedüngten Böden wurden gefunden, wenn die zu Beginn der Ernte ermittelten Werte des austauschbaren Kaliums durch multiple Regression mit dem durch HNO_3-Extraktion aus der nicht austauschbaren Form freigelegten Kali in Beziehung gebracht wurden.

Die beste Annäherung wiederum für die prozentuale K-Aufnahme in den Kontrollgefäßen gegenüber den K-gedüngten Gefäßen ergab sich durch eine multiple Regression, bei der die prozentische K-Aufnahme berechnet wurde als Funktion des austauschbaren und des durch HNO_3 freigesetzten Kaliums.

Avant-propos. Pour les essais qui servirent de base au présent travail, on cultiva en serre, durant 10 mois, du maïs sur des échantillons de sol provenant de l'horizon A de 18 terrains de l'Ohio. L'action exercée par la fumure potassique sur le rendement et l'absorption totale de potasse furent déterminées et comparées avec les résultats des analyses des divers échantillons de sol.

Les quantités de potasse déterminées par dissolution dans l'HNO_3 donnent un meilleur point de repère pour apprécier l'augmentation éventuelle de rendement ensuite d'une fumure potassique que les valeurs exprimant le potassium échangeable. Les meilleures valeurs approximatives concernant les prélèvements de potasse dans les sols n'ayant pas reçu de fumure potassique ont été obtenues lorsqu'on a comparé par régression multiple les chiffres relatifs au potassium échangeable obtenus au début de la récolte avec la potasse libérée par dissolution dans l'HNO_3.

La meilleure approximation pour le calcul du pourcentage d'absorption du potassium dans les vases de contrôle par rapport aux vases ayant reçu une fumure potassique, fut de nouveau obtenue par régression multiple, opération au cours de laquelle le pourcentage d'absorption de K fut calculé en fonction du potassium libéré par dissolution dans l'HNO_3.

Observación previa. En la instalación de la experiencia que sirve de fundamento para este trabajo se utilizaron muestras del horizonte A del suelo, pertenecientes a 18 terrenos en Ohio, en invernadero, durante 10 meses, cultivando maíz. El efecto del abonado potásico sobre la producción y la absorción

total de Potasa fué determinada y puesta en relación con los resultados de los análisis de los terrenos.

Las cantidades de Potasa determinadas por extracción con HNO_3 ofrecen un más seguro indicio sobre las posibilidades de aumentar la producción por el abonado potásico, que los datos ofrecidos por los valores correspondientes al Potasio cambiable. Los valores aproximativos mejores sobre la absorción de Potasa, en terrenos no abonados con ella, fueron alcanzados cuando al principio de la recolección, los valores conseguidos sobre el Potasio cambiable, por múltiple regresión, fueron relacionados con la Potasa liberada de la en forma no cambiable por extracción con HNO_3.

En cambio, los mejores valores aproximativos para la absorción porcentual de K en los recipientes de control, frente a aquellos abonados con K, resultaron por una múltiple regresión en la cual, la absorción porcentual de K, fué calculada en función del Potasio cambiable y liberado por el HNO_3.

Prefácio. Na instalação de ensaios, que serviu de base ao presente trabalho, empregavam-se amostras de solo do Horizonte «A», de 18 solos de Ohio, em estufas, durante dez mêses, na plantação de milho. Verificou-se o efeito da adubação com potassa sôbre a safra e a absorção da potassa, relacionando tudo com os resultados das análises dos solos.

As quantidades de potássio verificadas com extração com HNO_3 dão uma base melhor para o possivel aumento da safra, por meio de adubação com potassa, que os valores do potássio permutavel. Os melhores valores aproximados, para a extração de potássio dos solos não adubados com potassa, foram encontrados quando os valores de potássio permutavel, encontrados no início da colheita, foram, por regressão multipla, comparados com o potássio precipitado, por extração com HNO_3, da forma não permutavel.

A melhor cifra aproximada, para a absorção percentual de K, nos recipientes de controle, em comparação com os recipientes adubados com K, obteve-se por meio da regressão multipla, na qual a absorção percentual de K foi computada como função do potássio permutavel e do potássio precipitado por NHO_3.

Prefazione. Nell'esperienza che era alla base di questo lavoro, sono stati utilizzati per la voltivazione in serra di granoturco i campioni dell'orizzonte A, concernenti 18 terreni dell'Ohio.

L'effetto della concimazione potassica sulla produzione e l'assorbimento totale di potassio vennero controllati e messi in relazione con i risultati delle analisi del terreno.

I quantitativi di potassio trovati con l'estrazione con HNO_3 hanno dato una migliore indicazione nei riguardi dei possibili aumenti di produzione attraverso la concimazione potassica che non i valori relativi al potassio scambiabile.

I migliori valori approssimativi per l'asportazione di potassio in terreni non concimati con potassa vennero ottenuti quando i valori medi del potassio scambiabile, trovati al principio del raccolto, vennero messi in relazione, con regressioni multiple, con il potassio reso libero dalla forma non scambiabile attraverso l'estrazione con HNO_3.

Il miglior dato approssimativo, relativo all'assorbimento percentuale di potassio nei vasi di controllo in confronto a quello nei vasi concimati con potassa, si ottenne pure con una regressione multipla, per la quale l'assorbimento percentuale di potassio venne calcolato quale funzione del potassio scambiabile e del potassio reso libero con HNO_3.

Giriş. 18 toprağın A-horizonundan alınan toprak numunelerinin Ohio 'daki vegetation tesisatında denemeye alınarak 10 ay mısır ekimine tahsis edilmiş olması, bu çalışmaya esas teşkil etmiştir. Bu denemede Kalium ile gübrelemenin mahsul ve mecmu Kaliumun alınması üzerine olan tesiri tesbit olunmuş ve bu neticeler ile toprak analizi neticeleri arasında münasebet kurulmuştur.

HNO_3 — ekstraksionu ile bulunmuş olan Kalium mikdarları, kabili mübadele Kalium

değeri olarak, Kaliumlu gübrelerin mahsulu mümkün olduğu kadar arttırdığı hakkında çok iyi bir tutamak veriyorlar. Serbest Kaliumun gayri kabili mubadele formundan HNO_3—ekstraksionu vasıtası ile ve mükerrer regression hesabları yapılarak bulunan kabili mubadele Kalium kıymetleri hasadın başına doğru bir münasebet sağlamışlardır.

K — ile gübrelenmiş saksılar ile kontrol saksılarındaki K — un yüzde olarak alınışı karşılastırılarak mükerrer bir regressionla en yakın değer elde edilmiştir. Mükerrer regressionla Kalium'un yüzde olarak alınma nisbeti, kabili mubadele ve HNO_3 ile açığa çıkarılan Kalium'un bir fonksionu olduğu hesap olunmuştur.

Exchangeable and Non-Exchangeable Potassium as Indexes to Yield Increases and Potassium Absorption by Corn in the Greenhouse

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Greenhouse cropping and laboratory extractions of soils with various reagents have been used to predict the availability of soil K to plants. Laboratory methods of measuring release of K from nonexchangeable forms have been shown to extract amounts of K that are highly correlated with K release to plants in greenhouse cropping (1—3, 6, 7, 9). The relative value of exchangeable K and of K release in predicting K-supplying power of soils has been reported (6, 9).

The objective of the work reported in this paper was to determine the extent to which exchangeable K and release of K from nonexchangeable forms served as indexes to yield increases to K fertilization and to K absorption by corn in the greenhouse.

Materials and Methods

Samples of the A_p layer of 18 Ohio soils were collected for greenhouse cropping and for laboratory extraction. The equivalent of 6000 g. oven-dry soil was put into 2-gallon pots and treated with lime, nitrates, and phosphates in addition to K. The K treatments included a check and KCl added at the rate of 120 pp2m. K for each crop of corn. The experiment was a randomized block with three replications of each K treatment. Ten plants of Iowa 4059 hybrid corn were allowed to grow for 6 to 8 weeks. The tops of the plants were harvested, weighed, and analyzed for K. The roots were mixed with the soil. Five crops were harvested, and the roots of the last crop were also harvested and analyzed.

Potassium determinations were made on a model 52-C Perkin-Elmer flame photometer. The K in the plant material was extracted with NH_4Ac. Exchangeable K was extracted from the soils by leaching 100 ml. of *N* NH_4Ac through a 10-g. sample of soil in 4 hours.

An extraction of the soil samples with *N* HNO_3 was made by a procedure described by Pratt (6). Other investigators have used a similar procedure for laboratory measurement of K release from nonexchangeable forms (7, 9, 11).

An extraction of the soil samples with a cation-exchange resin was made by a modification of the procedure described by Pratt (6). Five grams of soil was mixed with 2.5 g. of air-dried H-Amberlite IR-120 resin. Water was added to the mixture, and after an incubation period the mixture was leached with *N* NH_4Ac to extract the exchangeable K. The K release from nonexchangeable forms was calculated by subtracting the K extracted by NH_4Ac before mixture with the resin from that extracted after incubation with the resin.

[1]) Contribution from the department of agronomy, Ohio Agricultural Experiment Station, Project B.J.58, Journal paper number 66—52. The senior author is now agronomist, Zonolite Research Laboratory, Evanston, Illinois.

Potassium fixation in the laboratory was measured by adding KCl at the rate of 469 pp2m. K to a 25-g. sample of soil, subjecting the sample to several wetting and drying cycles, and determining the amount of K retained.

Results

Yields of dry matter and K removal from the soils by the corn are shown in table 1. There was considerable variation in yields of dry matter for the K-treated pots. These variations seemed to have no relationship to K levels in the soils, except that the low yield for the Clyde soil may have been a result of a net fixation of K. The net fixation of K during cropping, on the K-treated pots, was less than 24 pp2m. except for the Clyde soil, in which the value was 137 pp2m. Since adequate amounts of N, P, and lime were added, these variations in yield were probably caused by differences in physical nature of the soils. The variations in yield on the check pots are definitely related to K levels in the soils.

Table 2 gives the data for exchangeable K and for K released from nonexchangeable forms by cropping and by extraction with HNO_3 and Amberlite resin. Soils with less than 128 pp2m. exchangeable K before cropping showed a slight increase in exchangeable K after cropping; other soils showed a decrease in exchangeable K after cropping. During the experiment there were no values of exchangeable K below 100 pp2m., but this does not mean that the exchangeable K did not fall below this figure. All extractions were made on air-dried samples, and several investigators (4, 8) have shown that air-drying may increase exchangeable K to relatively high values compared to the values found in the same soils when moist.

The HNO_3 extraction released more K from nonexchangeable forms than did cropping or treatment with Amberlite resin.

Table 1

Yield of dry matter and removal of K by corn in the greenhouse from 18 Ohio soils*

Soil series	Yield		Potassium removed	
	Check	K, 600 pp2m., added	Check	K, 600 pp2m., added
	g.	*g.*	*pp2m.*	*pp2m.*
Clyde	61.7	97.6	138	404
Clermont	67.8	132.6	151	561
Russell	71.8	132.0	174	543
Mahoning	72.3	115.2	207	602
Rossmoyne	73.4	115.9	250	645
Miami	73.4	103.9	246	619
Miami	73.5	113.1	216	600
Wooster	75.2	117.8	248	648
Wellston	76.8	133.4	236	664
Miami	79.8	115.0	220	589
Brookston	81.3	117.6	209	558
Miami	82.1	116.8	296	665
Trumbull	83.7	124.2	384	768
Ravenna	86.5	131.0	365	757
Brookston	90.9	102.5	354	586
Marengo	96.3	114.1	260	621
Alexandria	98.7	122.4	374	798
Brookston	108.9	103.6	604	792

* All data represent average of three replications.

Table 3 gives the linear correlation coefficients for relationships between cropping data and the laboratory data. The K release to HNO_3 gave the highest correlation with K release during cropping. The difference between the K release to HNO_3 and the K release to Amberlite resin as indexes to K release to plants was not statistically significant. But both the K release to HNO_3 and that to Amberlite resin were significantly better than the exchangeable K before cropping as indexes to K release by cropping. As indexes to total K removal by the corn plants from the check pots, the exchangeable K before cropping and the total K in the HNO_3 extract were nearly identical. Theoretically the exchangeable K and the rate of K release from nonexchangeable forms are the controlling factors for the amounts of K available to the plants if no K is added to the soil. In this group of soils the exchangeable K and the rate of release were somewhat independent of each other, as shown by the low correlation between them. Forty per cent of the variation in one was associated with the variation in the other. A multiple regression might be expected to give a significantly higher correlation than a simple regression. The regression, $\hat{Y} = 2 + 0.946\ X_1 + 0.195\ X_2$, where $\hat{Y}$ = the total K removed by cropping, X_1 = exchangeable K before cropping, and X_2 = the release of K to HNO_3, was found to fit the data. The multiple correlation coefficient for this regression was 0.959, which is significantly higher than the value 0.902, the highest value for the simple correlations. The relationship between Y, X_1, and X_2 is shown graphically in figure 1.

Table 2

Exchangeable K before and after cropping, K release by cropping, and K release by extraction with HNO_3 and with Amberlite 1R-120 resin

Soil series	Exchangeable K		K release from nonexchangeable forms		
	Before Cropping	After Cropping	By Cropping	HNO_3	Resin
	pp2m.	*pp2m.*	*pp2m.*	*pp2m.*	*pp2m.*
Clyde	118	147	167	334	186
Clermont	104	120	167	168	94
Russell	114	133	193	314	176
Mahoning	128	130	209	380	154
Rossmoyne	178	137	209	286	104
Miami	146	127	226	398	222
Miami	122	137	231	454	214
Wooster	174	130	204	446	166
Wellston	172	120	184	368	128
Miami	150	137	207	410	186
Brookston	182	177	204	478	258
Miami	152	137	281	480	238
Trumbull	332	150	202	320	58
Ravenna	284	146	247	448	138
Brookston	260	237	331	588	240
Marengo	208	180	232	676	250
Alexandria	272	176	278	676	302
Brookston	336	270	538	1284	564

For comparisons of yield increases from K fertilization with soil analysis, yields of the check pots were expressed as percentages of yields on the K-treated pots. The resultant percentage figures are called "yield percentages". The correlation and regression for yield percentage and exchangeable K before cropping are shown in figure 2. The exchangeable K was not an accurate index to the yield percentage. Forty-seven per cent of the variations in yield percentage were associated with variations in exchangeable K.

The correlation and regression for the yield percentage and the total K in the HNO_3 extract are presented in figure 3. The K in the HNO_3 extract was a significantly better index to yield percentage than was the exchangeable K. Of the variations in yield percentage, 88 per cent were associated with variations in the K in the HNO_3 extracts. A multiple regression analysis of the data showed no significant increase in accuracy of prediction over the simple correlation between the yield percentage and the HNO_3-extracted K.

The total K in the HNO_3 extract was highly correlated with the uptake of K from the checks expressed as a percentage of the K uptake from the treated pots. There was no significant difference in the total K in the HNO_3 extract, the exchangeable K before cropping, and the K release to HNO_3 as indexes to the uptake percentage. The multiple regression $Y = 15 + 0.0823X_1 + 0.024X_2$, in which Y = uptake percentage, X_1 = exchangeable K before cropping, and X_2 = K release to HNO_3, was calculated. The multiple correlation coefficient for this regression was 0.941, which is significantly better than the coefficient 0.909 for the correlation between the uptake percentage and the total K in the HNO_3 extract.

Table 3

Linear correlation coefficients for relationships between amounts of K extracted from soils by laboratory procedures and yield and K absorption by plants in greenhouse cropping

	Release of K to plants	Total K uptake by plants	Yield percentage*	Uptake percentage†
Exchangeable K before cropping	0.631 (0.232—0.848)×	0.899 (0.746—0.960)	0.683 (0.318—0.868)	0.851 (0.640—0.938)
Exchangeable K after cropping	0.858 (0.658—0.922)	0.747 (0.426—0.895)		
Total K in HNO_3 extract		0.902 (0.750—0.962)	0.940 (0.840—0.976)	0.909 (0.766—0.964)
Release of K to HNO_3	0.927 (0.818—0.970)	0.817 (0.560—0.924)	0.919 (0.790—0.966)	0.841 (0.620—0.934)
Release of K to Amberlite resin	0.875 (0.690—0.948)			

* Yield on check pots as a percentage of yield on treated pots.

† Uptake of K on check pots as a percentage of K uptake from treated pots.

× Numbers in parentheses refer to fiducial limits at 5 per cent level of significance for the respective correlation coefficients.

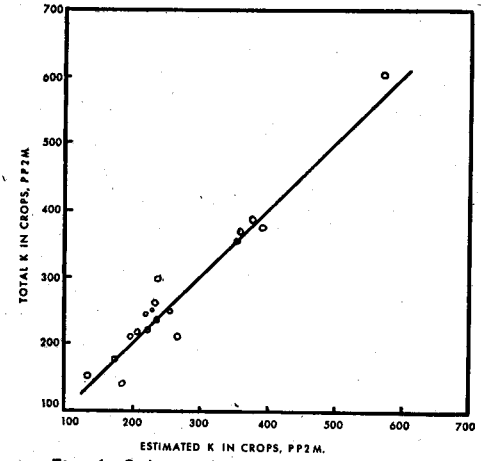

Fig. 1. Relationship Between K Absorbed by Crops in the Greenhouse and Estimated K Absorbed

The estimated values were calculated from $\hat{y} = 2.0 + 0.946X_1 + 0.195X_2$ where $\hat{y}$ = estimated K absorbed, X_1 = exchangeable K before cropping, and X_2 = K release from nonexchangeable forms to HNO_3. The coefficient of multiple correlation was 0.959.

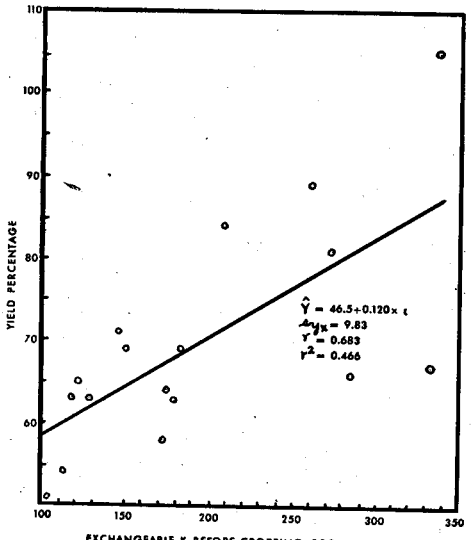

Fig. 2. Relationship Between Exchangeable K Before Cropping and Yield of Dry Matter on Check Pots Expressed as a Percentage of Yield on K-Treated Pots

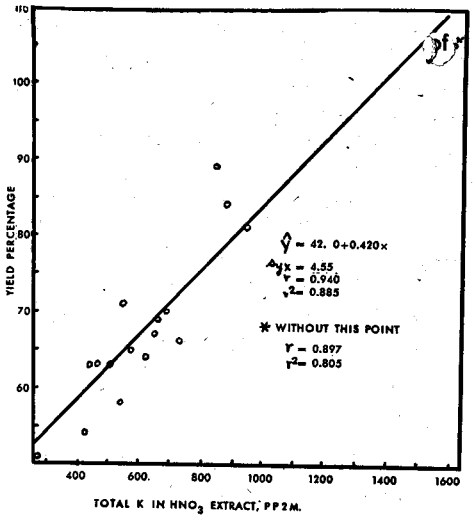

Fig. 3. Relationship Between HNO_3-Soluble K and Yield of Dry Matter in Check Pots Expressed as a Percentage of Yield on K-Treated Pots

Discussion

A chemical extraction of soils, for the purpose of estimating or predicting the fertility status of a given nutrient must extract amounts that are (*a*) highly correlated with the amounts of the nutrient available at the time of extraction and (*b*) highly correlated with amounts of the nutrient that are released to available forms during the course of one or several growing seasons. For a chemical estimation of K levels in soils, the extractant should measure the exchangeable K and also be highly correlated with rates of release of K to the exchangeable form. It is assumed here that the exchangeable K is highly correlated with the available K at the time of extraction. One test of the use of exchangeable K as a method of predicting K availability would be to determine whether the exchangeable K is highly correlated with rates of K release during cropping.

There is reason to believe that in moderate to highly weathered soils that have been cropped heavily for a considerable time, the exchangeable K is not highly correlated with rates of release of K from nonexchangeable forms. Because these soils have relatively slow rates of K release in comparison to capacity of plants to remove K, and because of luxury consumption of K by plants growing in soils of high exchangeable K and restriction of growth of plants on soils of low exchangeable K, the exchange K values in all these soils may tend to be the same. Eight soil samples collected in Ross County, Ohio, in 1951 had exchangeable K values within $\pm$ 12 pp2m. and yet their values of K release from nonexchangeable forms to HNO_3 varied from 483 to 1030 pp2m. Thus, in these soils, there may be small variations in exchangeable K that are not highly correlated with much larger variations in K release from nonexchangeable forms. This suggests that exchangeable K is not so reliable a test for these soils as it is for younger soils where the exchangeable K is more highly correlated with rates of release.

Rouse and Bertramson (9) found that for a group of Indiana soils the exchangeable K was a poor index to K release from nonexchangeable forms. The coefficient of correlation was 0.18. In the work reported here the coefficient of correlation was 0.631, and in work reported from Iowa (6), it was 0.778. Stewart and Volk (10) reported that in a group of Alabama soils the K removal by plants was not related to exchangeable K, and yet Pearson (5) reported a high correlation between these two factors for another group of soils from Alabama. The relationship seems to vary from one group of soil samples to another within the same geographical area. More information is needed on this relationship in some areas where exchangeable K is being used as a soil test on which to base fertilizer recommendations. In Pearson's work (5) there was no relationship between K release from nonexchangeable forms and the exchangeable K before cropping. The K release values were extremely small in comparison with values recorded in this report and in other reports (6, 7, 9). For a group of highly weathered soils where release from nonexchangeable forms is extremely low, exchangeable K can be expected to be the most important factor in supplying K to plants.

From the work of Rouse and Bertramson (9), Pratt (6), Pearson (5), and the work reported here, as well as from theoretical considerations, one might speculate that the reliability of exchangeable K as an index to K removal by cropping in the greenhouse varies with rates of K release from nonexchangeable forms. This relationship is expressed in figure 4. In area I, the rates of release are assumed to be too low to be of importance in supplying K to plants. In area III, they are assumed to be high enough to maintain high levels of exchangeable K that are highly correlated with rates of release. In area II, the rates of release are not sufficiently large to maintain high levels of exchangeable K and yet they are important in supplying K to plants. In this area it is assumed that there is low correlation between levels of exchangeable K and rates of K release from nonexchangeable forms.

In the work reported here the combination of exchangeable K and K release from nonexchangeable forms to HNO_3 gave a more accurate index to K removal by crops and to uptake percentage than did any single factor. Pratt (6) reported that for several soils of Iowa the accuracy of prediction of K removal by alfalfa was increased by including the K release

from nonexchangeable forms to a Dowex-50 resin with the exchangeable K in a multiple regression analysis.

The total K in the HNO_3 extract showed high correlation to all yield and K uptake data. The possibility that the HNO_3 extract might be used in some soil areas as a rapid test for estimating available K, thus replacing exchangeable K in a soil-testing program, should not be overlooked. Of course, the final evaluation of a test for estimating K availability must be made by a comparison with reliable field fertility tests.

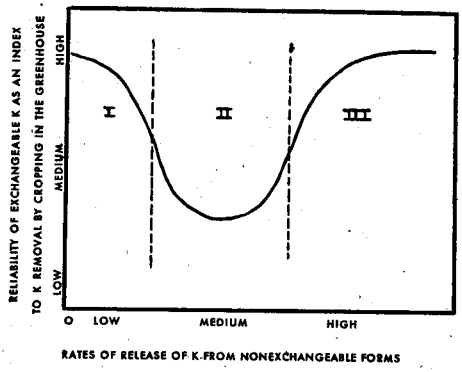

Fig. 4. Hypothetical Relationship Between Reliability of Exchangeable K as an Index to K Removal by Cropping and Rates of Release of Nonexchangeable K.

Summary

Samples of the A_p layer of 18 Ohio soils were subjected to greenhouse cropping with corn for 10 months. Yield response to K fertilization and total uptake of K were measured and correlated with soil analyses.

Amounts of K extracted by HNO_3 provided a better index than did exchangeable K in predicting yield response to K fertilization. The best index to K removal from the soils that received no K was a multiple regression in which K removal was calculated as a function of exchangeable K at the beginning of cropping and of K release from nonexchangeable forms to HNO_3 extraction. The best index to the K uptake on the check pots as a percentage of that on the K-treated pots was a multiple regression in which the uptake percentage was calculated as a function of exchangeable K and K release to HNO_3.

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