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Potassium supplying capacity of northeastern Portuguese soils

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Abstract

In Portugal, the response to K application is often inconsistent with the Egner-Riehm values for available K. This is partly related to high K reserves of some soils. Twenty surface soils representative of different parent materials from NE Portugal were studied to determine their K supplying capacity. Continuous cropping with perennial ryegrass permitted the assessment of the relative ability of soils to release non-exchangeable K. Soils were classified in the range of available K from medium to very high. However, their ability to supply K in the short and long term are very different. In some soils K status measured by plant growth does not fall appreciably, whilst others are rapidly exhausted, and 30% of them are very deficient in K. The supplying capacity varied both with the nature of the parent material and the degree of weathering. The soils deficient in K are those derived from basic rocks and those with more weathered clay minerals. This is the case of the soils with the largest content of organic matter where the dominant clay minerals were kaolinite and vermiculite. Soils that have the highest capacity for supplying K are highly micaceous, like those developed from mica schists, phyllites or river alluvium. In fact the amount of K released from non-exchangeable form is well correlated with the amount of illite in the clay fraction. Soil types and K buffer power coupled with available K must be taken into account when planning any application of K.

Introduction

Most of the methods used for determining available K are based on the extraction of the exchangeable form. The method of Egner-Riehm, which is an approximate measure of exchangeable K, has been systematically used in Portugal. However it has been recognized that exchangeable K is an indifferent index of K availability for many soils (Alves, 1968; Alves et al., 1979; Cooke, 1982). One reason for this partial failure of the exchangeable K to account for uptake is the release of K from a non-exchangeable form during cropping.

The mineralogical composition of the soil has an enormous influence on K dynamics. Total soil K reserves are generally large, although the distribution of K forms differs from soil to soil as a function of the dominant minerals present. Knowing soil K reserves and distribution of K forms coupled with mineralogical data should reveal more about the status of soil K in the major soil types of the region. Although the release of non-exchangeable K depends on the soil mineralogy there have been few successful attempts to relate it to mineralogical composition of soils.

The main objective of this study is the assessment of the K supplying power of soils of NE (Trás-os-Montes region) Portugal. The relative ability of soils to release non-exchangeable K was evaluated by biological and chemical methods. In addition, soils were examined by X ray diffraction to determine whether differences could be established in their mineralogical composition.

Materials and methods

Soil analysis

Soil samples were taken from the 0–20-cm surface layer of 20 sites of NE Portugal. The physico-chemical characteristics of the soil samples are given in Table 1. The soils represented the major soil types and were associated with a wide range of parent materials (Table 2) and climatic conditions. Most of the soils fall in the range of available K regarded as 'medium', 50–100 mg kg^{-1} (Table 3). The soils received little or no K fertilizers up to the time of sampling. Only soil 9 had been limed, in the previous year.

Mineralogical analyses was done on the <2 μm and 2–20 μm soil fractions by X-ray diffraction. The methodology for preparing soil samples and estimation of mineral abundance is described by Silva (1983). Estimates of the amount of mineral specimens present should be regarded as semi-quantitative.

The 20 soil samples were each analyzed for several forms of soil K. The K concentration in soil solution was obtained by displacement procedure (Adams, 1974); exchangeable K was determined with 1*N* NH_4OAc (pH 7); 1*N* boiling HNO_3 was used to determine the reserve of non-exchangeable K and HF digestion to extract total K (Knuden et al., 1982); available K was extracted with NH_4-lactate-acetic acid (pH 3.75). Analyses were made on air dried soils, K in the extracts was measured with an EEL flame photometer.

K buffer power was given by the slope of the line relating the change in exchangeable K (Δ Kex) and the change of the K in soil solution (Δ Ks). Buffer curves of soils were obtained by adding, in the laboratory, graded doses of KCl to subsamples of 1 kg of soil. After treatment, the soils were maintained at a room temperature of 18°C ± 2°C during 21 days at 33 kPa moisture tension. At the end of this period soils were analyzed for exchangeable K and solution K. The resulting plots showed an approximately linear relationship, and buffer power was determined as Δ Kex/Δ Ks.

Exhaustion experiment

Soils were air-dried and passed through a 2-mm sieve. One kg of each soil was placed in plastic

Table 1. Chemical and physical properties of the soils

Soil	Particle size (%)			Organic matter	pH 1:2.5		Exchangeable cations ($cmol_c$ kg^{-1})					
	>20 μm	2–20 μm	<2 μm	(%)	H_2O	KCl	Ca	Mg	K	Na	Ac	CECe
1	79.5	13.3	7.2	1.0	5.5	4.2	1.23	0.17	0.18	0.03	1.34	2.95
6	78.2	15.3	6.5	0.5	5.5	3.8	1.39	0.11	0.11	0.03	0.97	2.61
15	79.8	11.5	8.7	3.0	5.4	4.3	1.35	0.40	0.10	0.07	0.86	2.78
9	73.9	15.5	10.6	0.9	6.1	5.0	3.05	0.27	0.17	0.03	0.16	3.65
10	74.7	14.8	10.5	0.6	5.1	3.9	4.09	1.58	0.16	0.07	1.70	7.60
2	54.4	37.7	8.6	0.6	6.5	3.8	7.66	2.20	0.10	0.08	0.70	10.74
4	57.8	32.4	9.8	0.7	7.3	5.8	8.07	0.54	0.12	0.08	0.12	8.93
8	78.5	12.7	8.8	0.5	5.7	3.9	4.34	1.81	0.21	0.07	1.90	8.33
17	63.3	26.9	9.8	0.7	5.5	4.1	2.14	0.20	0.25	0.03	0.86	3.48
11	61.7	30.3	8.0	1.0	5.5	3.9	0.71	0.18	0.19	0.03	1.39	2.50
18	59.6	30.3	10.1	1.1	5.5	3.8	3.52	1.07	0.16	0.05	1.20	6.00
19	61.5	27.5	11.0	1.4	5.4	4.0	1.92	0.33	0.43	0.05	1.05	3.78
20	63.7	24.0	12.3	0.8	5.3	3.8	1.73	0.43	0.16	0.04	1.24	3.60
12	68.4	16.1	15.5	1.8	6.5	5.1	5.64	5.60	0.21	0.04	0.16	11.65
13	54.3	18.4	27.3	1.7	6.4	4.5	11.06	6.00	0.11	0.18	0.23	17.58
14	60.8	26.3	12.9	1.1	6.1	4.3	5.44	2.72	0.08	0.09	0.30	8.63
5	59.4	31.8	8.8	6.0	5.3	3.9	1.48	0.28	0.15	0.07	3.11	5.09
16	71.7	20.5	7.8	12.5	4.7	4.1	0.40	0.30	0.18	0.05	3.11	4.04
7	70.1	19.1	10.8	0.7	5.2	4.1	1.01	0.18	0.11	0.03	0.87	2.20
3	39.5	47.7	12.8	1.4	7.1	6.1	6.40	1.13	1.13	0.14	0.14	8.94

Ac – exchangeable acidity; CECe – effective cation exchange capacity.

Table 2. Soils, taxonomy, parent materials and mineralogy of clay and silt fractions

Soil	Soil taxonomy	Parent material	Mineralogy											
			<2 μm						2–20 μm					
			K	I	M	V	I–V	Cl–V	K	Mi	M	V	Cl	O
1 Carrazeda	Humic cambisol	Alkaline granites	4	1	1	1	–	–	4	2	–	–	–	1
6 Peredo	Distric cambisol	Alkaline granites	3	2	–	2	–	–	2	3	–	–	–	2
15 S. André	Humic cambisol	Alkaline granites	3	1	–	2	–	–	1	1	–	2	–	4
9 Malhadas	Aplic alisol	Calcic granites	3	1	–	1	1	–	2	2	–	–	–	2
10 Miranda	Distric cambisol	Calcic granites	2	1	3	–	–	1	2	2	2	–	–	2
2 Carrascal	Eutric cambisol	Mica schists	3	2	1	2	–	–	3	2	–	1	–	1
4 Muxagata	Aplic luvisol	Mica schists	3	2	2	1	–	–	2	3	–	1	–	1
8 Sendim	Eutric leptosol	Mica schists	3	3	–	1	–	–	2	2	–	–	–	2
17 V. Real	Distric cambisol	Mica schists	3	1	–	1	–	1	3	2	–	1	–	1
11 Vimioso	Distric cambisol	Phyllites	3	3	–	1	–	–	1	3	–	1	–	3
18 Alfandega	Distric cambisol	Phyllites	3	3	–	1	–	–	2	3	–	1	–	1
19 Curopos	Distric cambisol	Phyllites	2	2	–	2	–	–	2	2	–	2	–	1
20 Mirandela	District cambisol	Phyllites	2	3	–	1	1	–	2	2	–	2	–	1
12 Bragança	Chromic luvisol	Peridotites	1	–	2	–	–	4	–	1	1	–	2	4
13 Izeda	Chromic vertisol	Amphibole schists	1	–	4	1	–	–	–	1	4	–	–	1
14 Frieira	Chromic leptosol	Amphibole schists	2	1	–	1	–	4	2	1	–	–	3	—
5 Reboredo	Humic cambisol	Schists and quartzites	3	1	–	3	–	–	2	2	–	1	–	2
16 Montalegre	Humic cambisol	Hornfelses	3	1	–	1	2[a]	–	2	1	–	2	–	2
7 Sanhoane	Aplic alisol	Coarse sediments	4	1	–	1	–	–	2	2	–	–	–	3
3 Vilariça	Eutric fluvisol	River alluvium	2	3	1	–	–	2	2	3	1	–	–	2

K – kaolinite; I – illite; M – montmorillonite; V – vermiculite; I–V – interlayered illite-vermiculite; Cl–V – interlayered chlorite-vermiculite; Cl – chlorite; O – others

[a] Al-vermiculite

1 = <10%; 2 = 10–20%; 3 = 20–40%; 4 = 40–60%.

Table 3. Forms of potassium and buffer power of the soils

Soil	Soil solution K (mg L^{-1})	Exchangeable K (mg kg^{-1})	Buffer power	K-reserve (mg kg^{-1})	Total K (g kg^{-1})	Available K_2O (mg kg^{-1})
1	22.0	70	2.3	336	47.2	123
6	7.0	43	2.1	1528	23.2	78
15	5.2	39	1.0	335	44.8	91
9	7.8	66	1.7	644	26.8	96
10	14.1	62	3.2	534	31.6	104
2	2.7	39	2.9	1455	29.0	65
4	4.2	47	2.3	632	27.2	80
8	8.2	82	2.0	2703	25.6	106
17	15.0	98	1.7	698	28.0	159
11	12.5	74	1.5	523	29.6	147
18	10.5	62	2.4	713	33.2	135
19	51.0	168	1.9	301	30.0	312
20	12.0	62	1.7	435	32.0	100
12	8.6	82	6.0	191	3.6	131
13	0.4	43	6.3	78	4.0	81
14	5.9	31	5.3	51	1.2	55
5	5.2	59	1.3	187	14.2	90
16	6.5	70	0.7	581	13.4	90
7	4.3	43	1.9	239	10.4	85
3	92.0	440	5.1	2067	34.6	676

pots and cropped in triplicate in the greenhouse. Those with $pH(H_2O) \leqslant 5.5$ were limed with $CaCO_3$. A basal nutrient solution (Portela, 1989) was thoroughly mixed with the soils before seeding. A 250 mg addition of K was made to half of the pots. Soils were seeded with *Lolium perenne*, cv. 'Victorian', to obtain an approximate plant density of 100 plants per pot. Distilled water was added daily to bring the soils to 33 kPa moisture tension. Dry matter production was measured at intervals by cutting the grass 3 cm above the soil. After each cutting, all pots received 100 mg N and 100 mg P, and those pots treated with K received 50 mg K. After a period of 5 months all pots were dressed with the same basal nutrient solution given at the beginning of the experiment. The number of cuttings varied according to the soil. The last harvest was taken when a response to K was first observed. Soils that never responded to K application were harvested on the 375th day of growth. Soils were separated from the roots and analyzed for exchangeable K. Plant material was dried at 65°C for 48 hours, weighed, ground and digested in nitric-percloric mixture. K was determined by flame photometry.

Results

Available K (Table 3) is well correlated with soil solution K($r = 0.978$, $p < 0.001$) and with exchangeable K($r = 0.991$, $p < 0.001$). Thus the relative merits of any of these indexes are the same. The buffer power of soils are generally low, particularly those with the highest content of organic matter.

The results of the exhaustion experiment are summarized in Table 4. The data listed refer to the pots which have not been fertilized with K. If K concentration in plants at the first harvest is taken as a measure of K supply, this is poorly correlated with available K ($r = 0.629$, $p < 0.01$), and this index only explains 40% of variation. The K concentration of the first cutting is, for some soils, lower than the level considered sufficient for optimum growth of ryegrass (16 g kg^{-1} by Cook, 1982). Surprisingly, out of the 10

Table 4. Dry matter yield of *Lolium perenne*, K concentration of the first and the last cuttings, K uptake per kg of soil, fall in exchangeable K and release of non-exchangeable K

Soil	No of cuttings	Dry matter (g)	K concentration ($g\ kg^{-1}$)		K uptake ($mg\ kg^{-1}$)	Fall in exchangeable K ($mg\ kg^{-1}$)	Release of non-exchangeable K[a]	
			1^{st} cut	last cut			($mg\ kg^{-1}$)	(%)
1	7	27	18.6	4.6	282	55	227	80
6	7	27	11.6	9.1	424	16	408	96
15	3	16	8.4	4.7	97	16	81	84
9	6	23	13.0	5.7	228	35	193	85
10	15	49	21.4	4.9	728	39	689	95
2	15	52	16.2	17.1	941	16	925	98
4	15	50	16.8	8.6	982	16	966	98
8	15	52	37.7	12.5	1275	43	1232	97
17	8	31	24.5	7.2	499	70	429	86
11	8	32	24.4	10.2	618	39	579	94
18	15	55	32.8	10.2	1246	31	1215	98
19	8	34	31.2	12.4	752	105	647	86
20	15	54	17.0	6.7	884	35	849	96
12	6	26	18.2	4.9	278	39	239	86
13	2	10	5.1	3.6	43	4	39	91
14	2	10	7.4	3.7	51	4	47	92
5	2	11	5.6	3.4	50	8	42	84
16	2	12	4.3	2.5	41	16	25	61
7	2	11	6.3	5.0	61	8	53	87
3	15	54	40.2	16.3	1577	402	1175	75

[a] Non-exchangeable K was calculated from total K uptake by grass minus fall in exchangeable K.

soils classified as 'medium', 8 are K deficient, particularly soils 5, 7, 13, 14, 15 and 16, which showed a prompt response to K application. The remainder were maintained under cropping until 4 to 12 months of growth. In these soils the percentage of K released from non-exchangeable form is ≥75%.

Figure 1 gives some typical curves of the cumulative uptake of K by ryegrass selected from soils that have the same initial exchangeable K. The rate of K uptake can be obtained from the slope of the curve when the cumulative K uptake is plotted against days of growth. The amount of K absorbed by the crop is approximately linearly related with the growth period in all soils. So it is possible to fit regression equations to the observed values (Table 5). If we consider the percentage of non-exchangeable K released from most of the soils (Table 4), it can be seen that the rate of K uptake is approximately the same as the rate of K released. It is possible to distinguish two rates of K release in soils that have been maintained until the 15th cut (Fig. 1). One initial rate applies to 5 months of

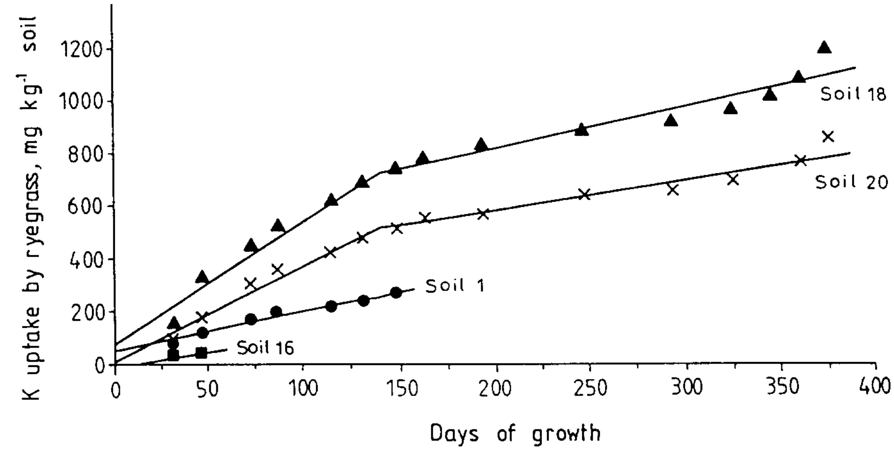

Fig. 1. Cumulative K uptake by ryegrass in four soils, with similar initial exchangeable K.

Table 5. Regression equations and regression coefficients for the relation between cumulative K uptake and days of growth of the soils maintained under 3 to 12 months cropping

Soil	No of cuttings	Regression equation of initial observations[a]	r^2	Regression equations of last observations[b]	r^2
1	7	$y_1 = 1.54\,x_1 + 45.8$	0.963	-	—
6	6	$y_1 = 2.85\,x_1 - 17.1$	0.979	-	—
9	6	$y_1 = 1.46\,x_1 + 25.4$	0.973	-	—
10	15	$y_1 = 5.06\,x_1 - 62.2$	0.978	$y_2 = 0.75\,x_2 + 379$	0.96
2	15	$y_1 = 4.43\,x_1 + 30.3$	0.982	$y_2 = 1.49\,x_2 + 256$	0.937
4	15	$y_1 = 3.91\,x_1 + 17.6$	0.988	$y_2 = 1.34\,x_2 + 364$	0.879
8	15	$y_1 = 4.73\,x_1 + 26.6$	0.982	$y_2 = 1.87\,x_2 + 408$	0.862
17	8	$y_1 = 2.57\,x_1 + 56.0$	0.977	-	—
11	8	$y_1 = 3.48\,x_1 + 12.7$	0.983	-	—
18	15	$y_1 = 6.43\,x_1 - 10.2$	0.963	$y_2 = 1.67\,x_2 + 475$	0.929
19	8	$y_1 = 3.85\,x_1 + 80.1$	0.978	-	—
20	15	$y_1 = 5.17\,x_1 + 68.2$	0.988	$y_2 = 1.25\,x_2 + 419$	0.940
12	6	$y_1 = 1.73\,x_1 + 42.0$	0.943	-	—
3	15	$y_1 = 6.99\,x_1 + 12.8$	0.956	$y_2 = 2.34\,x_2 + 491$	0.924

[a] This refers to the first 6 to 8 cuttings.

[b] This refers to the last 8 cuttings.

growth, and a second rate applies to the remaining period. In Table 5 these rates (mg kg^{-1} day^{-1}) are represented by the angular coefficient of the two regression equations, y_1 and y_2 respectively. The first rate corresponds to a higher amount of K diffused from interlayer position, probably from K fixed close to the edges of clay mineral, and a second rate of release of K, which has to diffuse from the core of the micaceous minerals (Sinclair, 1979).

It is evident that some soils are more rapidly exhausted (soils 1, 6, 9, 12 and 17), but others (soils 2, 3, 4, 8, 18 and 20) continue to release K at an appreciable rate for a very long time. It seems that soils with an initial rate of release $\geqslant 3.5$ mg kg^{-1} day^{-1} could be considered as good K suppliers.

As shown in Table 2 the mineralogy of the clay and silt fractions depends on the nature of parent material from which the soil is derived. Similarly, the total K content of the soils is connected with the parent material and the mineralogy. Correlations were sought between the estimates of clay mineral constituents of the soils and the values for non-exchangeable K released by intensive cropping (Table 4). Since the mineralogical analyses of the soils are not quantitative estimates of mineral abundance, some simplification is necessary in order to relate the uptake of non-exchangeable K and mineralogy. So, a mean value of the ranges given in the footnote of Table 2 was taken. The simplification allows some assessment of the variation between soils. The best correlation ($r = 0.822$, $p < 0.001$) was achieved between non-exchangeable K uptake and the percentage of illite in soil (Fig. 2). Adding a term for the percentage of mica from the silt fraction did not improve significantly the correlation. Although some studies demonstrated significant K release from the silt fraction during cropping (Doll et al., 1965; Feigenbaum and Levy, 1977), the influence of this fraction is not evident from this study. Inspection of the deviations from the regression showed that a large portion of the variation was due to a few soils, namely soils 2, 4 and 10. When the results from these three soils were omitted the correlation was improved ($r = 0.903$, $p < 0.001$) and only 19% of the variation remained unaccounted for. As shown in Table 5, these three soils have an appreciable rate of K release, if only the percentage of illite is considered. Table 2 shows that besides the presence of illites, soils 2, 4 and 10 also have certain amounts of montmorillonite. Rich (1968), suggested that the combined presence of illites and montmorillonite may promote the release of K to plants. Niederbudde and Fischer (1980) studied this phenomenon with pure specimens and reached the conclusion that the presence of smectites

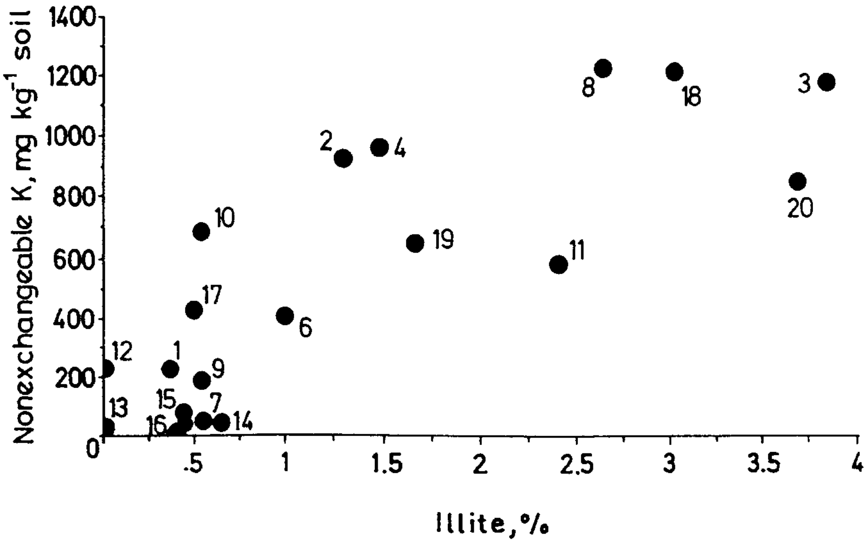

Fig. 2. Relationship between the percentage of illite in soil and release of non-exchangeable K.

helped to maintain K in solution at a lower level. Thus the amount of K diffused from interlayer position was higher. The results from this study suggest that a good K supplier, illite, combined with a mineral that keeps low K in soil solution, montmorillonite, would enhance the K release from non-exchangeable form.

The K reserves (extraction with HNO_3) were plotted against the non-exchangeable K absorbed by the crop. The correlation ($r = 0.678$, $p < 0.001$) between them revealed that the method of boiling HNO_3 only explains 46% of variance among soils. In fact, there were some discrepancies. For example, in soils 6, 9, 15 and 16 the HNO_3 extracted a large amount of K when compared with K released by exhaustive cropping and underestimated non-exchangeable K in soils 4, 18 and 20.

Discussion

Soils from mountainous areas of NE Portugal, 1000 to 1450 mm of rainfall and classified as Humic cambisols (soils 1, 5, 15 and 16) show the highest degree of weathering. Gibsite, which is reported to be common, in upper and subsurface horizons of such soils (Silva, 1983), was not detected in the surface horizons of the soils studied. However, there is a high percentage of kaolinite and the presence of vermiculite and/or Al-vermiculite in the clay fraction, which indicates a high degree of weathering. These soils release small amounts of K, in spite of the high content of total K in the soils, particularly in soils 1 and 15 (Table 4). Obviously, in soils developed from alkaline granites the K in bearing minerals is very tightly held in feldspars and micas of coarser fractions. In addition, those with the highest percentage of organic matter (soils 5, 15 and 16) are very K deficient and gave a prompt response to K application. The low K buffer power of these soils might also be responsible for their limited K supply, due to their high susceptibility to K leaching. Fertilizer K recommendations in these soils should compensate for their low K buffer power and for the high precipitation occurring in these areas.

A second group of soils, developed on basic rocks (soils 12, 13 and 14), have low K reserves due to low content of K bearing minerals. However, as they have higher K buffer power than any other group of soils, the K is less susceptible to leaching.

The largest and most representative group of soils in Trás-os-Montes are Distric and Eutric cambisols. They are derived either from mica schists or phyllites, are less weathered, and have an appreciable percentage of micaceous minerals in both clay and silt fractions (soils 2, 4, 8, 11, 17, 18, 19 and 20). This group releases an extremely high percentage of K from non-exchangeable form, with an initial rate of K release of 2.6 to 6.4 mg kg^{-1} day^{-1}. The only Fluvisol studied (soil 3) behaved similarly to soil 18, however its rate of release was higher in the second stage. In soils derived from alluvial material, the K is less tightly held, and, therefore, more readily available to plants (Binnie and Barber, 1964; Talibudeen and Dey, 1968).

It is difficult to use data obtained in pot trials for assessing the field situation since the volume of soil from which K is removed by plants is much smaller in pots. Besides, as shown by Seffens (1986), the test plant, ryegrass, has a great potential for exploiting soil K from the non-exchangeable pool. The high density of the root system is able to reduce K in the soil solution, promoting release of K from the interlayers. Weber and Grimme (1986) suggested that one year of intensive cropping with ryegrass was approximately equivalent to 10–15 years of normal cropping in the field. However the results of the pot experiment can be used as a guide in assessing the field situation.

Since available K does not fully describe K supplying power of the soils, soil types and K buffer power must also be taken into account when planning any application of K to the soil in the interest of fertilizer efficiency and economy.

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