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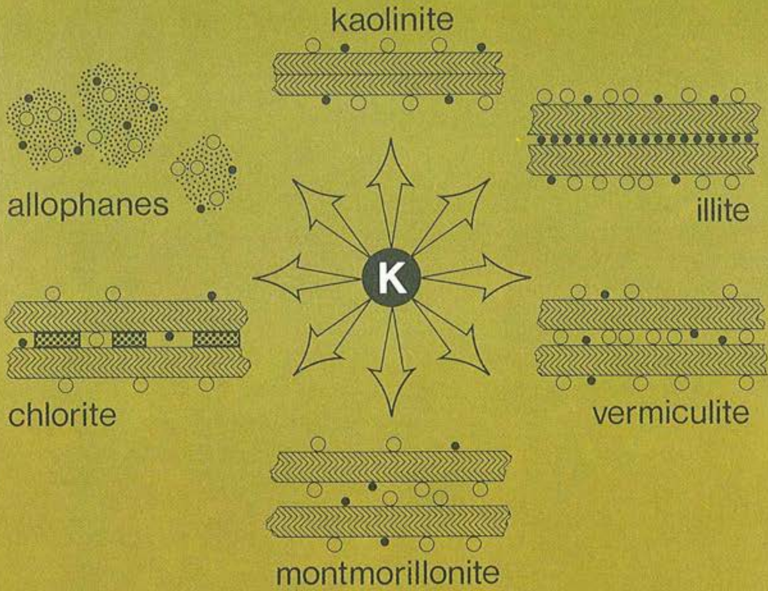


Potassium dynamics in the soil

International Potash Institute
CH-3048 Worblaufen-Bern/Switzerland

Introduction

Soil analysis is an important tool when evaluating soil nutrient status. The results of soil tests are frequently taken as a basis for fertilizer recommendations. This is justified in such cases where a correlation exists between soil test results and crop response to fertilizer application. As a rule, the effect of a fertilizer nutrient should be the lower the higher its content in the soil.

As to potassium, however, many cases are known in which no correlation has been found between soil test data and yield response to potash application. In hundreds of trials with rice in India good responses to applied potash were observed on soils testing high in "available" or exchangeable K, but sometimes low or no effects of potash on soils with poor K status.

In extreme cases, even negative correlations may exist between exchangeable K and yield, while the correlation between the K concentration of the soil solution and the yield is positive and highly significant (fig. 1).

The scientific background of these phenomena and practical consequences for soil test interpretation and fertilizer application are the subject of this leaflet on potassium dynamics in the soil.

Availability of potassium in the soil

Only a small fraction of the potassium requirements of the plant is attained by direct contact through root interception. The largest proportion of the K needed by the plants has to be transported in the soil to the roots (fig. 2). This transport of potassium ions is an important factor of K availability. It occurs mainly in the soil solution, the liquid phase of the soil, by mass flow (with the water moving to the plant root) and diffusion along a concentration gradient that is built up by the absorbing root. In the immediate vicinity of the roots, the soil solution is rapidly exhausted of nutrients due to removal by the plants (fig. 3). Continuous potassium supply to the growing plant is only ensured when the rate of potassium release to the soil solution and transport to the roots keeps pace with the rate of nutrient uptake.

Clay minerals are the most important source of soil K. They hold the bulk of mobile K and release it when the concentration of the soil solution falls due to plant uptake or to an increase in soil moisture. A good K saturation of the clay minerals results in an equilibrium with a high K concentration of the soil solution, whereas poor K saturation is in equilibrium with low K concentration in the solution (fig. 4).

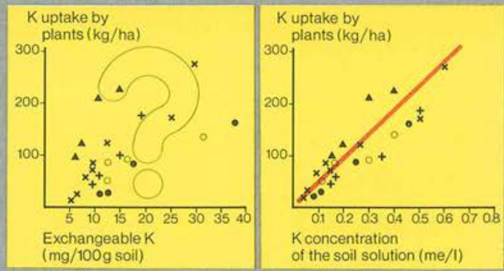
The composition of the soil solution can change rapidly due to variations in soil moisture, nutrient uptake by plants and other factors. Nevertheless, it has been found experimentally that the K concentration of the equili-

In numerous cases it is difficult to find any correlation between crop yield or potassium uptake and soil test potassium (exchangeable K), while there is a close correlation with the K concentration in the soil solution.

Only a very small fraction of the total amount of K taken up by a plant is attained by direct contact between the roots and the soil particles. The bulk of K has to be transported to the roots in the soil solution.

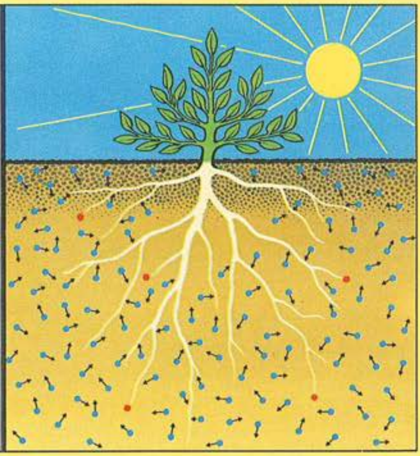
Plant roots take up nutrients from the soil solution. The more potassium ions are dissolved in the soil solution, the more are available to the plants. The K concentration of the solution depends on the release of K from soil minerals.

1 The concentration of potassium in the soil solution is a better indicator of K availability than the amount of exchangeable K



Symbols represent five different soil types

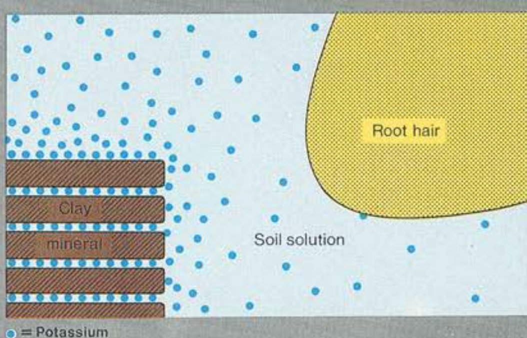
2 Plant nutrient uptake by the roots



Nutrients reached by root interception

Nutrients transported to the roots by massflow and diffusion

3 K concentration in the soil solution



brated soil solution is a reproducible value if determined at a suitable "standard moisture", e.g. field capacity or water saturation.

Under these conditions the concentration in the soil solution depends on the K saturation of the inorganic cation exchange capacity (CEC) of the soil. At a given content of exchangeable K a soil with many K adsorbing particles (clay soil) usually has a lower K concentration in the soil solution than a sandy soil with less clay (fig. 5). At equal clay content, the K concentration of the soil solution depends on the nature of the clay minerals.

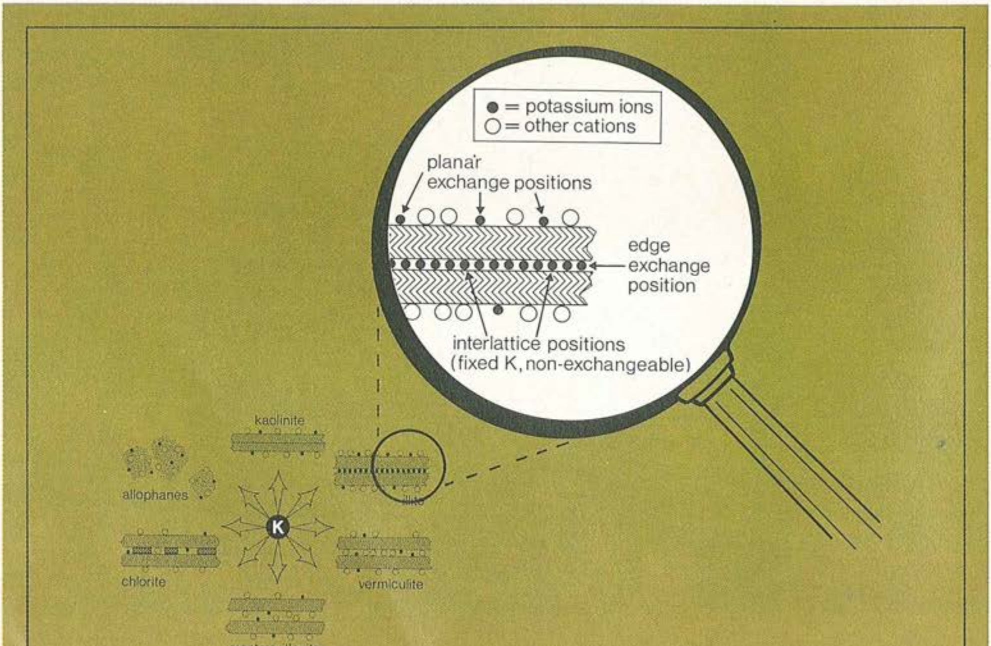
1 Kaolinitic clay minerals have no interlattice binding sites for potassium and a low cation exchange capacity. They do not hold non-exchangeable K. Therefore, they behave similarly to sand and soil organic matter, as far as K dynamics are concerned.

2 Illitic clay minerals, vermiculite and chlorite, on the other hand, adsorb K selectively.

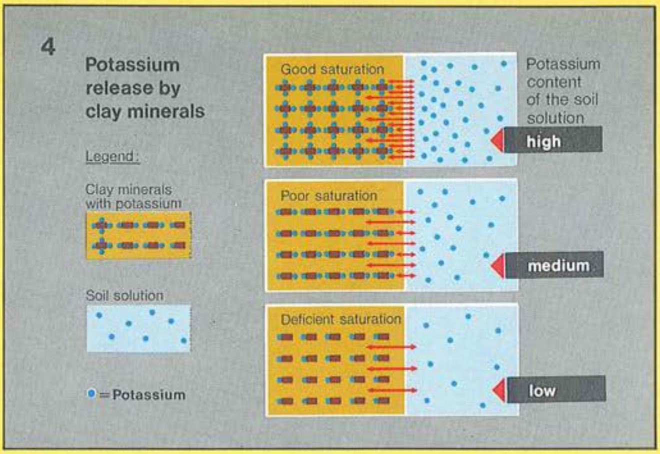
3 The selectivity of montmorillonitic clay minerals (smectite) for potassium is lower than that of illitic but greater than that of kaolinitic clay minerals.

4 Allophanes contain very small amounts of K, but experiments indicate, that K is preferentially adsorbed.

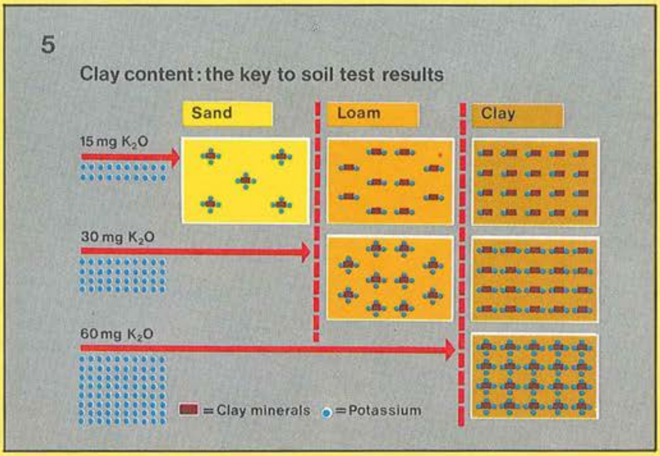
Depending on the degree of K saturation or depletion of these minerals, they will either release K into the soil solution or adsorb it from the solution. Apart from the type of mineral the selectivity of the clay minerals for potassium depends on the site of K adsorption (see below).



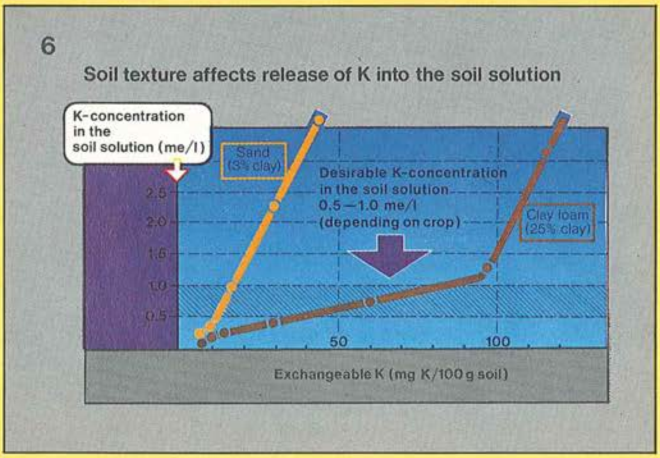
The capacity of a soil to release sufficient K into the soil solution depends on the nutrient saturation of the clay particles. Only clay minerals well supplied with potassium ensure an adequate K concentration in the soil solution.



For equal saturation of the clay minerals, heavier soils need much more potassium than light soils because of their higher clay content. 15 mg exchangeable K_2O per 100 g soil can mean high saturation in a sandy soil but poor saturation in a clay soil.



The relationship between exchangeable K and K concentration in the soil solution of two soils clearly shows that a heavier soil requires far more exchangeable K than a sandy soil to reach the same K concentration in the soil solution.



Planar positions do not represent specific K binding sites.

Edge positions bind K more selectively.

Interlattice positions have the highest K selectivity. Potassium held at interlattice positions is generally "non-exchangeable".

Adequate K concentration in the soil solution (above 0.5 me/l) is attained only when the K selective sites have been saturated with K so that no fixation of K takes place, and a sufficient number of planar positions are occupied by K.

The exchangeable (or "available") potassium, as determined by soil analysis, does not give satisfactory information on the level of the actually available soil potassium unless related to the clay content and to the nature of clay minerals. 15 mg K_2O per 100 g soil (150 ppm) means high availability in a sandy soil but poor saturation in a clay soil containing illitic or montmorillonitic clay minerals (fig. 5). In laboratory tests it is possible to assess the amount of exchangeable potassium which is needed in a heavy soil to raise the soil solution concentration to an adequate level. In a clay loam with predominantly illitic clay minerals this may amount to 60 mg K_2O/100 g soil (600 ppm) or even more (figs. 5 and 6). In other words: heavy soils require considerably more fertilizer potassium to attain a high level of K availability than light soils (fig. 7).

On the other hand, clay soils possess a better K buffering capacity than sandy soils. They can maintain the K concentration of the soil solution at a similar level for a long time (fig. 8). In sandy soils, the soil solution concentration decreases rather fast so that split applications of potash may be expedient.

As the soil solution is depleted of nutrients in the immediate vicinity of plant roots, the disturbance of the equilibrium will result in a release not only of exchangeable K but also of potassium which initially had been non-exchangeable. This release of K from non-exchangeable sources can be considerable.

In most cases, however, the rate at which non-exchangeable K is set free is too low to ensure an adequate K supply for high yields. Experiments have shown that yields were lowest on soils where the plants were left to the release of K from non-exchangeable reserves (fig. 9).

These graphs are to demonstrate that with the same quantity of exchangeable potassium present in the soil the concentration in the soil solution may be different, depending on the capacity (e.g. clay content) to adsorb K. At equal levels of exchangeable K, a light soil will release K at a higher rate into the soil solution than a heavy soil. The same is true for added fertilizer potassium.

For crop production it is of importance whether the concentration of the soil solution decreases rapidly during the growing season or is maintained at a fair level = well buffered. Sandy soils show poor K buffering and may need repeated K dressings or a higher initial K concentration in order to ensure an adequate concentration during later growing stages.

When the exchangeable K is depleted in the root zone, plants can take up potassium which was initially non-exchangeable. But the speed of release from this source into the soil solution is too low as to sustain a high-yielding crop, as shown by the results obtained on 19 different soils kept moist at field capacity.

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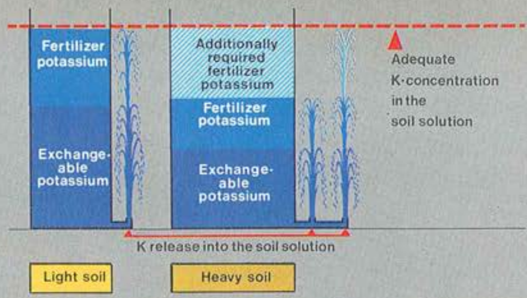
K dynamics (simplified) Release of K from two soils with equal level of exchangeable K and equal fertilizer supply



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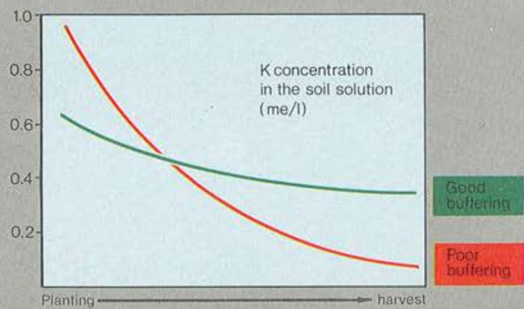
K buffering is essential



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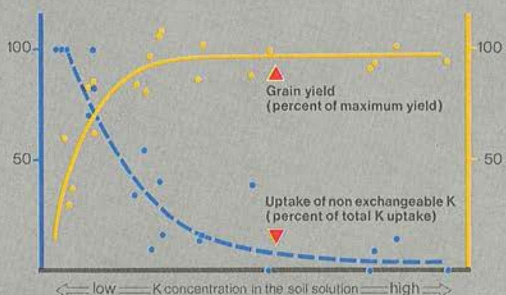
Yield and uptake of initially non-exchangeable K



Such conditions prevail in many heavy soils which have not received adequate potash applications for decades. These soils do not only strongly bind the fertilizer potassium, but even fix it. Potassium then migrates into the expanded clay minerals which contract, thereby trapping the K ions (fig. 10). Thus K is transferred into a sparingly available form instead of being readily available to the plant. It goes without saying that under such circumstances the K concentration in the soil solution is too low for optimum plant growth. The lack of yield response to usual potash dressings sometimes observed on soils testing low or medium in "available" K can often be ascribed to the strong fixation of fertilizer potash in the soil. This applies particularly to clay soils. There heavy rates of potash, e.g. several thousands of kilograms per hectare, may be necessary to overcome fixation. When applied at lower rates, band placement is advisable.

As mentioned before, diffusion is one of the major factors of potassium movement in the soil. It increases with improved K saturation of the clay minerals. When comparing two soils with equal levels of exchangeable K, but different contents of clay, higher diffusion rates are found in the soil with lower clay content because of its higher degree of K saturation and, consequently, higher K concentration in the soil solution (fig. 11).

The diffusion rate also depends on the moisture status of the soil. In laboratory tests it has been shown that K movement is faster in a moist soil than in a dry soil (fig. 12). The influence of soil moisture on K availability has been confirmed in greenhouse trials and in field experiments. The results show that at optimum soil moisture conditions, less K is needed to produce a certain yield level (figs. 13 and 14).

In a relatively dry soil more K has to be given in order to overcome the decrease in K mobility. This is of special importance in rainless periods of short duration. Due to impaired movement of nutrients, potash deficiency and corresponding losses in yield and quality will occur in case of insufficient K saturation. In a wet soil additional potash supplies help to counterbalance the diminished nutrient uptake capacity of the roots caused by poor aeration and to avoid unfavourable reduction processes in the soil.

When K fertilization is insufficient and plants have to rely on non-exchangeable potassium, K is removed from the interlattice positions of the clay minerals (2). Subsequent potash supplies first of all replenish the clay minerals (3) and are only in part available to plant roots. To overcome K fixation heavy rates of potash may be necessary.

K movement by diffusion depends on soil moisture and soil solution concentration. At equal moisture status and exchangeable K content, a light soil shows a better K saturation and hence a higher K concentration in the soil solution than a heavy soil. Consequently, diffusion proceeds faster in a light soil than in a heavier soil.

Diffusion rates are high when the soil is moist and low when the soil is dry. Consequently, dry soils need more potassium to maintain a high diffusion rate. With poor diffusion only a small part of the total nutrient potential of the soil is actually available to plants.

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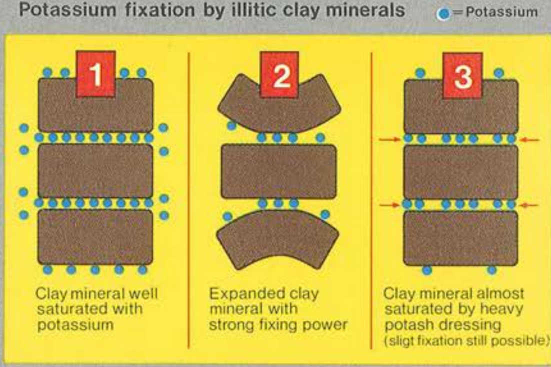
Potassium fixation by illitic clay minerals



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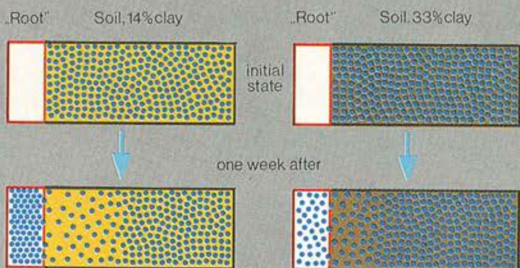
High clay content · Slow diffusion · Restricted availability



Diffusion of K into an ion exchanger = artificial „root"
(equal moisture status, equal original content of exchangeable K)

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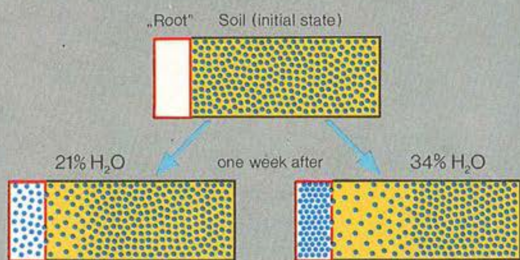
Good soil moisture · High diffusion rate · Increased availability



Diffusion of soil K into an ion exchanger = artificial „root"
(same soil, different soil moisture)

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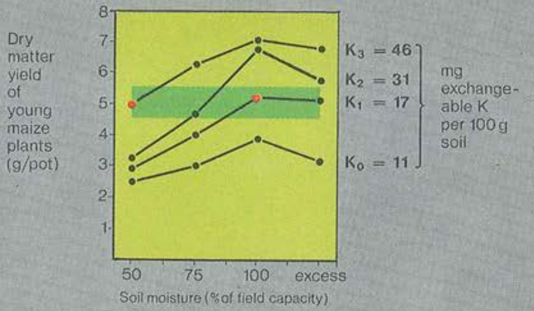
Good yields due to improved soil K status even with poor moisture conditions



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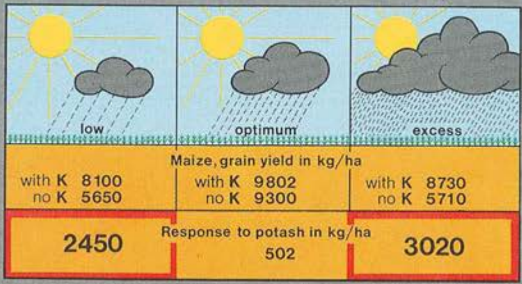
K fertilizers may counterbalance unfavourable soil moisture conditions



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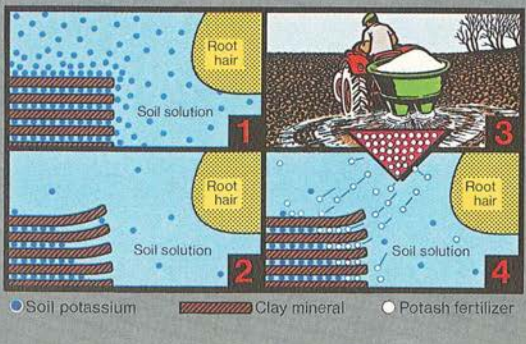
Why do some soils „swallow" potash?



Restricted nutrient availability due to unfavourable soil moisture conditions can be counterbalanced to a certain extent by improving the K status of the soil, e.g. by fertilizer application. A similar yield can be obtained with K_3 at low moisture as with K_1 at optimum soil moisture.

Improving K availability by potash application is essential, particularly in case of unfavourable soil moisture: at insufficient rainfall to overcome low mobility of K in the soil, at excess moisture to compensate for the restricted absorption power of roots caused by oxygen deficiency.

This graph summarises part of the processes concerning potassium dynamics in the soil. It shows the state of equilibrium existing between the K concentration in the soil solution and the K ions adsorbed by the clay minerals.
The K slightly bound on the surface of the clay is the first to be taken up by the plant root (1). Further extrac-

tion by intensive cropping causes exhaustion (2). When fertilizer K is applied (3) this will be trapped by K-depleted interlattice sites of the clay minerals (4). Only after the K selective interlattice positions have been filled up, external (planar) surfaces of the clay minerals become gradually occupied by K. As long as K is mainly bound by interlattice sites the K concentration in the soil solution remains low, because these sites have high selectivity (bonding strength) for K. Only if also a certain proportion of planar positions (external sites of low selectivity) is occupied by K ions, a K concentration is attained in the soil solution which is adequate for optimum plant growth.

Under Central European conditions with soils containing predominantly illitic clay minerals, soil test values, as stated on the adjacent table, indicate good K saturation (depending on the clay content).

Once the given values have been attained, e.g. after corrective potash dressings, normal application rates based on the potassium removal at the expected yield level are sufficient.

Soil texture	% clay	Exchangeable potassium mg K_2O/100 g soil	Exchangeable potassium ppm
Sand	0—5	up to 15	150
Loamy sand	6—10	15—25	151—250
Sandy loam	11—15	26—30	251—300
Loam	16—30	31—45	301—450
Clay loam/clay	> 31	> 45	> 450

References

Graphs were adapted from

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No. 2 *Barber, S. A.:* J. Agric. and Food Chemistry, 11, 204–207 (1963)

No. 5 *Németh, K. & Grimme, H.:* Soil Science, 114, No. 5, 349–354 (1972)

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