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Assessing soil potassium in view of contemporary crop production

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Increasing land productivity is a must

Increasing production costs in industrialized countries, increasing land scarcity at soaring population growth in developing countries are the common scenarios under which farmers have to crop their land. Use of mineral fertilizers contributed substantially to improve soil fertility and hence to increase the productivity of the cropped land. As shown in figure 1, the global production of the major cereals increased parallel to the fertilizer use, although the production levelled off during the last years (data source: FAO, 2003). Because the area under cereals has hardly changed in the last decades, the higher production has to be attributed to increasing yields and thus, to higher productivity of the land.

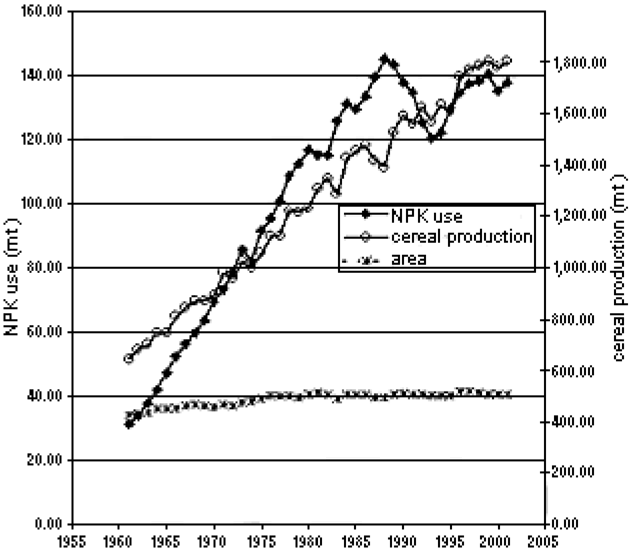

Figure 1: Global fertilizer use and cereal production (maize + rice + wheat)

The rather close correlation between use of mineral fertilizers and crop yield became very obvious in Central/Eastern Europe. Fertilizer consumption in this region plunged from about 10 million t end of the 80ies to less than 3 million t in the early 90ies; correspondingly, cereal yields decreased from almost 4 to less than 3 t/ha.

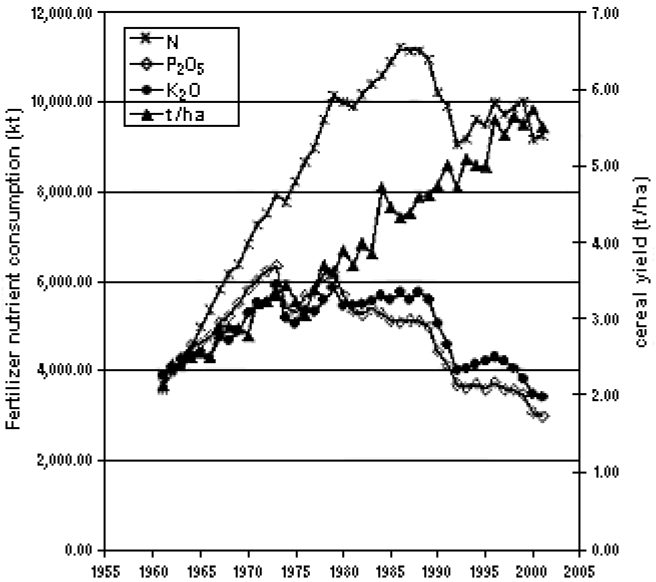

Figure 2: Cereal yield and fertilizer consumption in EU-15

An interesting relationship between fertilizer use and cereal yields is seen in the countries of the European Union (Figure 2; data source: FAO, 2003). Although fertilizer use, P and K in particular, went down in the last decade rather drastically, cereal yields remained to increase. This reflects improvements in the genetic potential, in crop husbandry and in nutrient management. The recycling of organic manure and the relatively high share of its nutrients in the total nutrient supply also compensated substantially the lower consumption of mineral fertilizers. The European Fertilizer Manufacturers Association, EFMA, estimated that about 47% of the total nutrient input to the EU agriculture derive from organic manure (EFMA, 2000).

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Fertilizer use became unbalanced to the detriment of potassium

As indicated in figure 2, fertilizer use in Western European countries became increasingly unbalanced. This applies also to other industrialised countries and even more to the developing ones. The NK ratio in the countries of EU-15 depreciated from a balanced ratio of 1:1 in the 60ies to a NK ratio of 1:0.54 in the 80ies and ultimately to a current NK ratio of 1:0.37. In other words, farmers in EU apply 3 times more N fertilizers than potash. The global trend is similar, the NK ratio went down from 1:0.74 in the 60ies to currently 1:0.27.

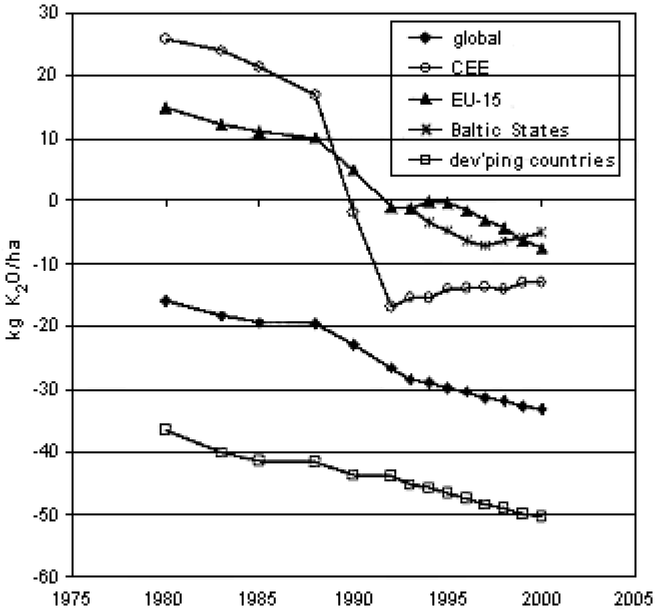

Figure 3: Apparent K balance (K removal by crops - potash use)

On the other hand, plants absorb and remove both nutrients at a fairly balanced ratio. Consequently, with continuing imbalance in the use of fertilizer nutrients, soil K mining has to be expected. Figure 3 shows correspondingly that the apparent K balance (K removal by crops minus K use with potash fertilizers) declined with time and reached negative values, which indicates soil K mining (data source: FAO, 2003). The situation in developing countries is much worse than in the European countries.

More detailed calculations confirm this trend. VOSTAL (2003) reported that the K balance of arable soils in the Czech Republic decreased from +9 kg/ha K during the pre-reform period to currently -27 kg/ha K even the K input from organic manure became a multiple of the input from potash. In Germany the K balance has declined since 1980 from 88 kg/ha with an annual rate of 5.5% to 37 kg/ha in 1995 and should have reached a negative value if the trend would persist. Arable farms in Germany had already in 1995 a negative K balance of -3 kg/ha (BACH *et al.*, 1997). In comparison, Vietnam and China have currently a negative K balance of about -60 kg/ha with a trend to go worse (SYERS *et al.*, 2002).

In contrast to K, use of N exceeds in most of the countries N removal by crops, which indicates a positive balance. Germany for instance had in 1995 an annual N surplus of 111 kg/ha (BACH *et al.*, 1997), the Republic of Korea or Vietnam has a current surplus of 30-40 kg/ha, whereas the N balance of China fluctuates around equilibrium (SYERS *et al.*, 2002).

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Why does the use of potash lag behind its requirement?

The apparent preference for N fertilizers as compared to potash has several reasons:

- Most of the countries have their own domestic N production that provides good availability and easy access to N fertilizers. Potash, which is produced only in a few countries, has to be imported. Untimely imports and inappropriate price policies very often affects potash availability at the market. A good example is India where, during the early 90ies after the removal of subsidies on potash fertilizers, the consumption decreased sharply by 30% in response to the trebled price increase. Potash use resumed to normal immediately after reintroduction of supported prices, which made potash fertilizers affordable to the small-scale farms in India.

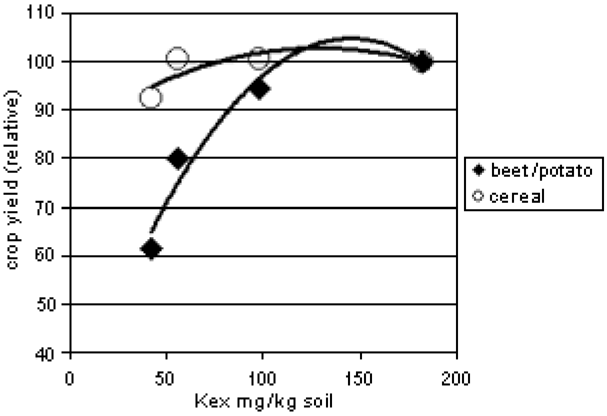

Figure 4: Crop response to K in a longterm experiment (1949-91)
(after MERBACH *et al.*, 1999)

- Crops often fail to respond immediately to omitted or inadequate K supply. This refers in particular to cereals as shown in figure 4. In a long-term experiment running for more than 40 years, the yield of cereals hardly responded to decreasing soil K contents whereas leafy crops such as sugar beet and potato showed substantial yield losses (MERBACH *et al.*, 1999).

- Symptoms of K deficiency are often hidden and less recognisable. CAKMAK (2003) showed for instance that beans with the same low K content revealed only at high light intensity the typical deficiency symptoms, namely chlorosis and necroses, but not at low light intensity (Figure 5). The damages are caused by excessive reactive O_2 species propelled by high light intensity and, at the same time, the reduced photosynthesis in response to inadequate K supply. K deficiency symptoms can also atypically appear on younger leaves for instance in cotton on twigs with a high boll load because the high K demand of developing bolls have to be met from those leaves attached adjacent to the fruits.

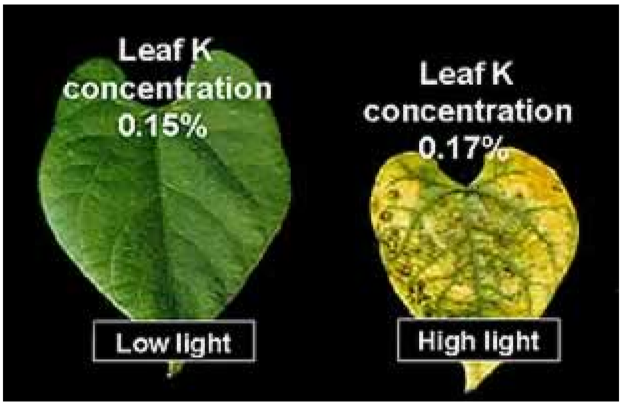

Figure 5: Enhancement of leaf chlorosis by high light intensity is not related to differential K concentration in leaves

- Low crop quality and high susceptibility to biotic and abiotic stress are not attributed to inadequate K supply. Numerous field trials, also conducted by IPI, demonstrated frequently that crop quality is improved when balanced fertilization with adequate K is applied. This refers in the same way to the nutritive value of cereals and oilseeds, the processing properties of potatoes and beets, and the taste, appearance and shelf-life of fruits and vegetables. The higher resistance of plants to pests and diseases at adequate K supply is as well documented as the better appearance at soil borne and climatic stress situations like salinity, drought or frost.

- Inappropriate soil tests and interpretation often leads to inadequate K recommendations. JOHNSTON & HOLLIES (2003) rightfully stressed that, in order to manage plant nutrients like potassium properly, three important steps have to be fulfilled: (i) correct soil sampling and analysis, (ii) correct interpretation of the analytical data, which leads to (iii) the correct recommendations for nutrient additions. This subject is of particular importance for potassium and will be discussed in the following more in details.

- Why does the use of potash lag behind its requirement? Also often a question of knowledge.

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Assessing soil potassium, a crucial moment for accurate recommendations
Soil tests are indispensable to monitor the soil fertility status. Testing soil for its content of plant available nutrients has been common practice for many decades. The basic principle to estimate the availability of K is to replace K from the exchange sites with an excess of another cation such as NH_4 as ammonium acetate or nitrate, or with calcium (Ca) as calcium lactate or chloride. The soil K determined by this method is the so-called exchangeable K (Kex), or "readily available" soil K. Less frequently used methods are soil extraction with diluted HCl, with resins or with the help of a low electrical voltage in the Electro Ultra Filtration (EUF) method. A review of the different agents for extraction of soil K is given in the IPI Research Topics No. 4 by MUTSCHER (1995).

The result of the soil test is compared with "critical" soil test values to determine whether the use of a potassic fertilizer will give an economically justified increase in yield. Frequently a common critical soil test value is used for a wide range of crops and soil types. But it is becoming more widely recognized that different critical values are more appropriate depending on the clay content or the cation exchange capacity (CEC) of the soil and the crop being grown.

There are a number of observations which question the exclusive use of just one parameter, namely the content of Kex, to determine the need for fertilization. As shown in figure 4, MERBACH *et al.* (1999) reported that after more than 40 years of exhaustive cropping without applications of potash, the critical Kex was lower for cereals than for potatos and sugar beet. And below the critical value, the yield of cereals (wheat, barley) decreased merely by 8% whereas leafy crops like potato and sugar beet suffered a loss of almost 40%. Where no K was applied the content of Kex decreased within the first ten years from an initial value of 90 mg/kg to around 50 mg/kg and remained at that level for the following 30 years. Using only one critical soil test value for all crops would lead either to over-fertilize cereals or to under fertilize potatoes and sugar beets.

A long-term experiment with grassland at Rothamsted showed that the content of Kex after 7 years without potash fertilization hardly changed, it even increased slightly, although considerable amounts of K had been removed by the harvested grass (Figure 6) (JOHNSTON *et al.*, 2001). This shows that substantial quantities of K are absorbed by plants from a fraction of soil K, which is not determined by routine soils tests. The dynamics of exchange between the different soil K fractions were obviously quick enough to hide any change in the content of Kex.

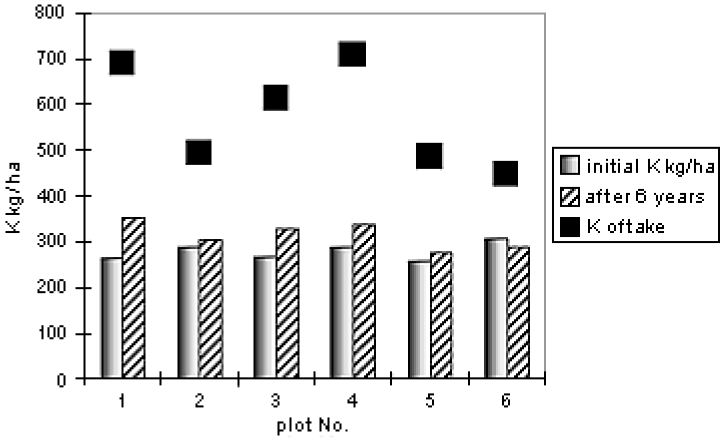

Figure 6: Relationship between the change in soil Kex and K removal by crops (after JOHNSTON *et al.*, 2001)

JOHNSTON and co-workers (2001) also reported that in the Garden Clover Experiment in Rothamsted, a total balance of 1667 kg K over a period of 10 years increased the content of exchangeable K by only 690 kg/ha, which is only 41% of the K balance (Figure 7). Almost 60% of the K balance had gone into a pool of K that did not belong to the Kex fraction always assuming that no large amount of K was lost through leaching. On the other hand, in the same experiment the subsequent long-term omission of K, and thus, a negative K balance of 1494 kg K/ha due to crop removal, resulted in a reduction in the content of Kex by only 563 kg K/ha, i.e. a reduction by 38%. The other 62% of the K removed had to be supplied by K in other soil K pools.

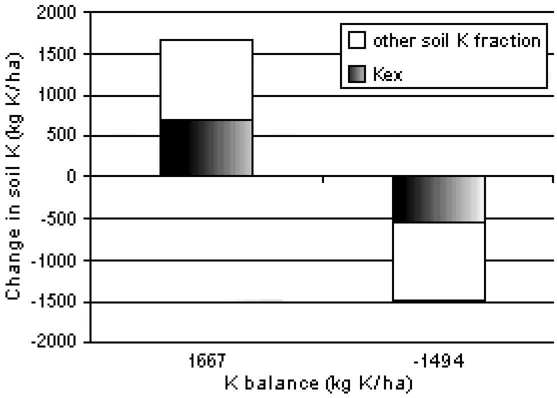

Figure 7: K balance and changes in Kex (after JOHNSTON *et al.*, 2001)

Therefore, finding a smaller increase in Kex than the K balance, and removing more K from the soil than was indicated by the decline in Kex at cropping without application of K, questions the validity of relying only on one parameter when assessing the soil K status.

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Soil K is subject to dynamic exchange processes between different fractions
A widely accepted concept divides soil K into four pools or compartments:

i. the soil solution K (Ksl)

ii. the exchangeable K (Kex)

ii. the fixed or non-exchangeble K (Kf)

v. and the K in the lattice of certain primary minerals (Kl).

The amount of K in each fraction varies and depends on past cropping history, past fertilizer and manure use, i.e. the K balance, soil pH and soil water content.

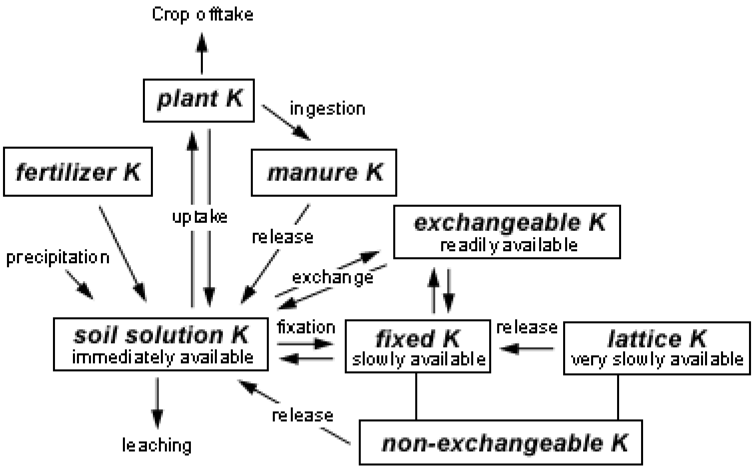

Figure 8: The potassium cycle in the soil-plant-animal system (from SYERS, 1998)

GOLAKIYA *et al.* (2001) for instance reported that the content of soluble K in the calcareous soils of Gujarat, India ranges from 0.003 to 0.21 $cmol_c$/kg soil, the exchange-able K varies from 0.03 to 2.00, non-exchangeable or fixed K from 0.32 to 21.7 and total K from 1.10 to 20.30 $cmol_c$/kg soil. WARREN & JOHNSTON (1962) found for a particular soil type that, for soils with Kex above 170 ppm, about 15% of the Kex is water-soluble.

As indicated in Figure 8, the fractions Ksl, Kex and Kf are related to each other through reversible exchange processes. K removed by uptake of plants and/or leached into the subsoil is replenished by K released from both the Kex and Kf pools. There can be simultaneous release of K from both pools to the soil solution or a linear exchange process, from the non-exchangeable to the exchangeable pool, and from the exchangeable pool to the soil solution. Whether one or other of these two possible mechanisms predominates is of little practical importance provided that the K in the soil solution is replenished quickly enough to meet the maximum demands of a rapidly growing crop. When there is surplus K in the soil solution, after the addition of fertilizer or manures, K is transferred to both fractions through exchange and fixation processes.

The concept of a 'tripartite' relationship is supported by the findings of JOHNSTON and MITCHELL (1974). They showed that the release of K from the non-exchangeable pool was linearly related to the content of initial exchangeable K (Figure 9). There was also a close linear relationship between the decrease in exchangeable K and the release of K from the non-exchangeable pool. The higher the initial content of exchangeable K the more K was released from the non-exchangeable pool, and with the decline in the uptake of K from the Kex pool, the release of K from the Kf pool also declined. In the soil used by JOHNSTON and MITCHELL, the uptake of K from the non-exchangeable pool was twice the amount taken from the exchangeable fraction, suggesting there was an equilibrium between the K in the Kex and Kf pools. It can be assumed, however, that the ratio of K released from these two fractions will differ with the type of clay minerals, degree of weathering, etc. Nevertheless, it is probable that the K in the Kf pool is of importance especially for crops with a restricted root system such as potato. As shown by JOHNSTON and co-workers (1998), the poorer the root density the higher should be the concentration of K in the soil solution to sustain a particular K uptake rate.

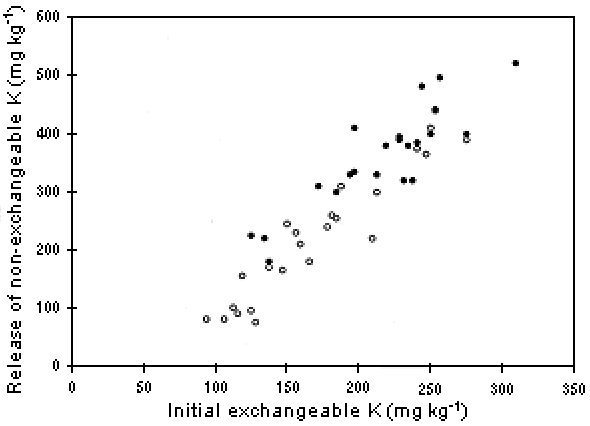

Figure 9: Release of fixed (non-exchangeable) K related to initial exchangeable K
(adapted from JOHNSTON & MITCHELL, 1974)

As an example of the likely difference in rates of K release from the Kex and Kf pools CHENG MINGFANG *et al.* (1999) measured, in soils from North China, release rates of 5 to 9 mg K/kg soil per minute from the Kex fraction and only 0.1 to 0.5 mg K/kg soil per minute from the non-exchangeable fraction. In consequence, the more the plant depends on K released from the non-exchangeable fraction the lower the yield when only small amounts of K are in the Kf pool (GRIMME, 1974).

It also has to be taken into consideration that the K concentration in the soil solution depends very much on the K saturation of the exchange complex and on the nature of the clay minerals (MUTSCHER, 1995).

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Is there need to revise the standards of soil K assessment?

Much current evidence suggests that exchangeable K is a good indicator for the likely response of crops to an application of K. Of course, as mentioned earlier, crops with a poor root system that does little to explore the soil for nutrients, will have a smaller critical Kex value and respond more to potash fertilization than crops with a dense root system. Leafy crops, like potato and vegetables belong to the first group while cereals and grasses belong to the later group. Thus, there is need for crop specific fertilizer recommendations.

It is also evident that, as shown in Figure 10, K uptake rate of a growing crop depends on the concentration of K in the soil solution and its replenishment from K reserves. Barley cultivated on soils with 300 mg/kg Kex had a maximum daily K uptake of almost 6 kg K/ha, whereas the same crop but grown on a soil poor in K (50 mg/kg Kex) at the maximum took up only 0.5 kg K/ha a day, i.e. only a tenth of the maximum K uptake rate of the crop grown on the soil well supplied with K. The total K uptake (Figure 10) and ultimately the final yield differed correspondingly. Barley on the soil poor in K produced 3.08 t/ha grain and 1.12 t/ha straw, the crop on the soil with adequate K produced 4.91 t/ha of grain and 2.58 t/ha straw (JOHNSTON *et al.*, 2001).

A sufficiently high soil K status sustains not only K release under "normal" growing conditions but also in stress situations such as declining soil moisture. JOHNSTON *et al.* (1998) calculated that in a wet soil it required a K concentration of around 120 µM/l in the soil solution to sustain a daily K uptake rate of 5 kg/ha. In contrast, in a dry soil it needed more than 4 times the K concentration, namely 490 µM/l to sustain the required K uptake rate of 5 kg/ha a day. A sufficient high soil K reserve can therefore be considered as an insurance against adverse climatic conditions.

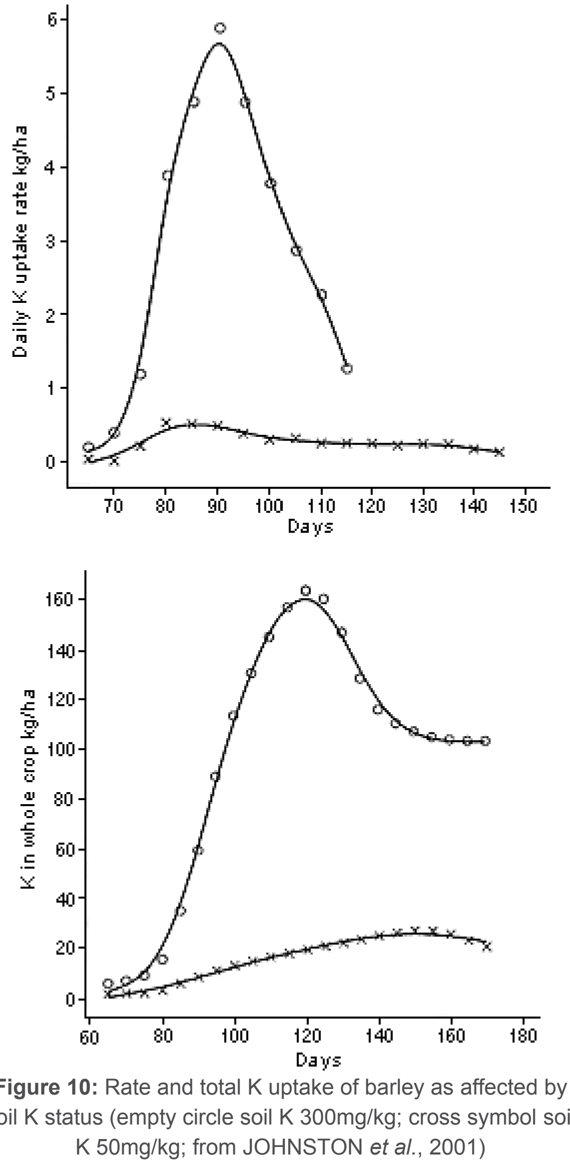

Figure 10: Rate and total K uptake of barley as affected by soil K status (empty circle soil K 300mg/kg; cross symbol soil K 50mg/kg; from JOHNSTON *et al.*, 2001)

Currently, the major unknown factor is how much K is supplied from the Kf pool to the K supply of a growing crop. MUKHOPADHYAY & DATTA (2001) quoting Singh and Brar, noted that, in the soils of the Punjab, India's continuous cropping without K applications decreased the content of available K from 166 to 85 kg/ha. Despite this, there was no response to applied K because 90% of the K demand of the crop was met by K release from the Kf pool. Similar findings were reported by SUBBA RAO *et al.* (2001) who showed that about 86% of the total K uptake by a wheat crop came from the fixed K pool. But this contribution was negligible when K fertilizers were applied. At higher levels of K application, there was a build-up of K in the Kf pool.

As indicated in Figure 8, fixed or non-exchangeable K, is K that has accumulated as a reserve from different sources. One source is weathering of soil minerals. Another is the accumulation of residues from past K applications, mainly as fertilizers or organic manures. This will happen where crop husbandry practices have resulted in positive K balances (JOHNSTON & KRAUSS, 1998).

Many methods have been used to attempt to determine Kf, 16 were reviewed by MARTIN and SPARKS (1985). Extraction with strong acids (usually boiling 1M HNO_3) is somewhat prohibitive for use in routine soil tests. More research is needed to investigate whether the close relationship between the content of Kex and the release of Kf as shown in Figure 9 also holds true for soils with different physical and chemical composition. Although K reserves in soils are necessary and desirable to buffer K supply at adverse soil and climate conditions, it is open to question to what extent these reserves can be exploited without loosing their buffering potential. In this context, BRAR (2001) quoted results from K trials with cotton, which show that cotton grown on soils with a relatively high content of non-exchangeable K (1075 mg/kg) did not respond to potash applications, whereas on soils with only 500 mg/kg Kf) the yield increased from 30.5 q/ha without K to 37.2 q/ha when 120 kg K_2O/ha were applied. Interestingly, both trial sites had similar contents of Kex, 57.9 and 55.8 mg/kg, respectively. Finally, there is need to investigate the impact of negative nutrient balances as presently occuring in many countries, to the long-term status of the different soil K fractions.

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