Potassium dynamics in the soil and yield formation in a long-term field experiment

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ABSTRACT

The influence of an interrupted K fertilisation on different K fractions of the soil, yield formation and K uptake by different crops was investigated in a long-term field experiment on Luvisol derived from loess. Irrespective of the previous K fertilisation, the interruption of K fertilisation resulted in a sharp decline of CAL extractable K. K concentration in the saturation extract as well as HCl extractable K were reduced while K fixation capacity increased within 10 years after omitting K. Omitting K fertilisation decreased yields of sugar beet and potatoes while cereals were not affected, although K uptake of all crops reacted to the differentiated K supply to a different extent.

Keywords: potassium; fertilisation; availability; yield formation; potatoes; sugar beet; winter wheat

Except nitrogen, K is a mineral nutrient plants require in the largest amounts (Marschner 1995). The optimum concentration in vegetative parts of plants and tubers ranges between 2 and 5% K in dry matter (DM). Potassium deficiency does not immediately cause visible symptoms, but it results in a reduction of growth rate. Inadequate K supply delays vegetative development of plants as well as development of generative organs and the supply of photosynthates to storage organs. As an example, the growth of potato tubers and roots is influenced by K nutrition (Haeder 1975). In agricultural practice it is thus imperative to know the K requirements of the crops and their response to K fertiliser application. Recommendations should be based on soil tests as well as on crop analysis. At an optimum K level, K fertiliser should compensate for the amount removed by the crop. At levels of plant available K below the optimum, K application rates must be higher whereas at supra-optimal K levels, lower K fertiliser rates should be applied (Mengel and Kirkby 1980).

The optimum level of plant available K is still a matter of debate. For this reason, a long-term field experiment was set up in 1960 at an Experimental Farm of the Institute of Agricultural Chemistry at the University of Bonn. The experiment was first set up to learn about optimum K fertiliser levels for high crop yields (cereal grain, sugar beet, and potatoes). Since 1991, the main interest has been to learn about the influence of interrupted K fertilisation on the development of plant available K, and on the changes in different soil K fractions and yield formation of the crops.

MATERIAL AND METHODS

A field experiment was set up in 1960 on Luvisol derived from loess on an experimental farm of the Institute of Agricultural Chemistry (now: Institute of Plant Nutrition) of the University of Bonn, Germany. The soil has the following texture: 5.9% sand, 67.3% silt, 17.8% clay (5% smectites, 16% vermiculite, 69% illite, 10% kaolinite).

Treatments

Control (without K)
KCl, NaCl, $MgCl_2$ (11% K) (2 application rates)
K_2SO_4; $MgSO_4$ (25% K) (2 application rates)
KCl (33% K) (2 application rates)
K_2SO_4 (42% K) (2 application rates)
The mean K application rate in the rotation was 125 kg K/ha/year (low K application rate) and 250 kg K/ha/year (high K application rate).
In 1991 the experiment was modified: no further K was added in some plots with formerly low and some with high K application rates.
These new treatments are denominated as:
K0 (control, no K fertiliser application since 1960)
K1+ (continuous low K fertiliser application)
K1– (discontinued formerly low K fertiliser application)
K2+ (continuous high K fertiliser application)
K2– (discontinued formerly high K fertiliser application)

Soil analysis

CAL (Ca-acetate-, Ca-lactate-solution) extractable K according to Schüller (1969): add 100 ml CAL solution to 5 g of soil; shake for 90 min on a rotary shaker.
HCl extractable K according to Schachtschabel (1961): with 1 mol/l HCl to 5 g of soil (10:1 soil weight) at 50°C for 20 h.
Wet K fixation according to Schachtschabel (1961): add 25 ml 0.01 mol/l KCl solution to 10 g soil (= 98 mg K/100 g soil); shake for 1 h on an overhead shaker; add 25 ml 1 mol/l NH_4 acetate solution; (calculation of the K fixation: the amount of added K minus K in the filtrate plus

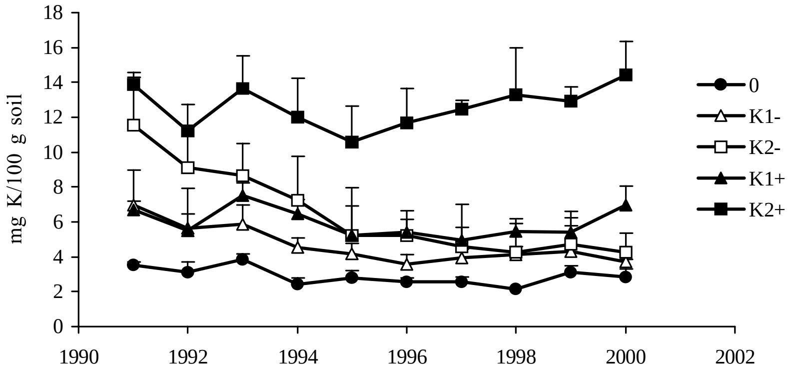

Figure 1. Influence of an interrupted K supply on CAL-extractable K (bars = standard deviation)

exchangeable K (add 50 ml 0.5 mol/l NH_4 acetate solution to 10 g soil; shake for 1 h on an overhead shaker). K was determined in the filtrate by flame photometry.

Plant analysis

K was determined after dry ashing in a muffle furnace at 500°C for 24 h.

RESULTS AND DISCUSSION

Soil testing has to provide a basis for the proper fertiliser recommendation for maximum yields and best quality simultaneously minimising unproductive losses. As K fixation and buffer capacity can vary considerably between sites due to different mineral composition and site history, choosing the right amount of K fertiliser is not an easy task. For this reason a long-term field experiment was established on Luvisol derived from loess, which is representative for the region close to Cologne (Germany), to examine the efficiency of kainite, potash magnesia, muriate of potash and potash sulphate as K fertilisers in a rotation of crops. According to Kick and Poletschny (1974) the higher K supply increased the K concentration in beets and potatoes and in the straw of cereals, irrespectively of the K fertiliser form. The K concentration of the grain remained unchanged. Beets and potatoes reacted to the higher KCl supply immediately by increased K concentrations. The low K application rates were not sufficient to compensate K removal, and thus the fraction of the lactate soluble K decreased. In the case of the high K application rates, the fraction of lactate soluble K increased slightly.

Under optimum levels, German legislation requires that the fertiliser application shall compensate only for losses due to crop removal. Lower levels (classes A and B) receive elevated fertiliser amounts, at higher levels (class D) only a half of the crop removal is added and no fertiliser is required when the levels reach E. Because the K fertiliser consumption sharply decreased in Germany in the last years, our field experiment was modified in 1991 to investigate the influence of discontinued K fertilisation on different K fractions in the soil, on crop yields and K uptake. K application was omitted and continued, respectively, in treatments with formerly low and formerly high K application rates. Interrupting K application resulted in progressive reductions of CAL extractable K (Figure 1). Previously differentiated K application rates became apparent within two years. Especially in the treatment with the formerly high K application rate (K2–), CAL extractable K declined in the following years and reached in 1998 almost the level of the treatment with the formerly low K application discontinued by 1991 (K1–).

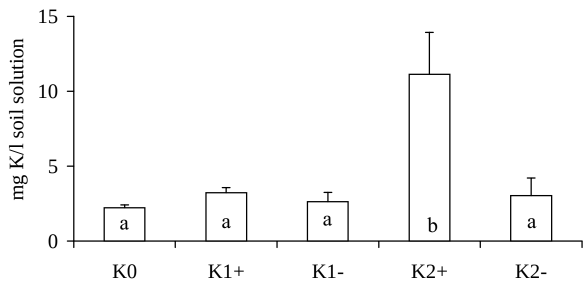

Figure 2. Influence of an interrupted K supply on the K concentration in the saturation extract, end of 1997 (means followed by the same letter do not differ at $p = 0.05$)

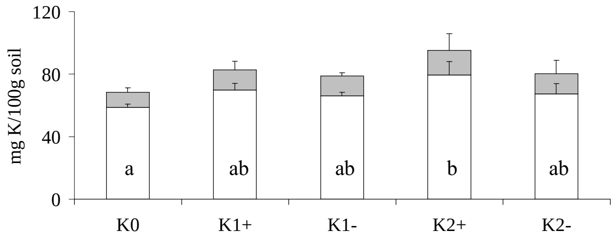

Figure 3. Influence of an interrupted K supply on HCl-extractable K, end of 1997 (lower part of the column = 1st extraction; upper part of the column = 2nd to 10th extraction; = standard deviation; means followed by the same letter do not differ at $p = 0.05$)

In 1995, the content of CAL extractable K of treatment K1– reached about 4 mg K/100 g and remained at this level. As compared to the control (K0), which was not fertilised for about 40 years, it was only 1 mg/100 g soil higher. It can be deduced from these results that an interruption of the K supply should be avoided.

Potassium in the soil solution, which represents a very small fraction of total soil K, is an important indicator of K availability (Nye 1972) because the mainly diffusive flux of K to roots takes place in the soil solution (Diest 1978) and the diffusion rate depends on the concentration gradient that develops in the soil adjacent to an actively absorbing root. We investigated the K concentration in the saturation extract. Even in the treatment K2+ (continuously high K fertiliser application) the K concentration in the saturation extract was relatively low (Figure 2). This low concentration may be due to the late sampling date (autumn after wheat harvest) when the soil solution was largely exhausted. Nevertheless, a sharp decrease of the K concentration in the saturation extract could be observed in the treatment with the formerly high but discontinued K fertilisation (K2–). In this treatment the K concentration decreased to the level of the treatments K1+ and K1–, respectively. The K concentration in the saturation extract K1– is almost at the same level as the control (K0) that did not receive any K fertiliser for about 40 years. It should be mentioned that K in the soil solution could become a limiting factor in supplying K to plants.

Plants are fed not only from K in the soil solution and from exchangeable K but also from non-exchangeable K. For this reason Schachtschabel (1961) proposed to extract soils with 1 mol/l HCl to assess the portion of non-exchangeable K that is available to plants. However, according to Mengel and Uhlenbecker (1993) HCl soluble K does not provide reliable information about the availability of non-exchangeable K as it reflects the depletion of interlayer K only poorly. Nonetheless, the HCl extractable K could provide some information on the K buffer potential (Figure 3). As expected, it was highest in the treatment K2+ (about 95 mg K/100 g soil) and lowest in the control (about 70 mg K/100 g soil). Especially in the treatment with the formerly high K application rates (K2–) the content of HCl extractable K decreased. However, the availability of interlayer K is dependent not only on the quantity of interlayer K but also on the type of K-bearing minerals (Sparks 1987).

Several factors control potassium fixation in soils, and among them it is the K fertiliser dose over a long period of time (Sardi and Csitari 1998). We found the highest K fixation capacity in the control that did not receive K fertiliser for about 40 years and the lowest in the treatment with the high continuous K application rate (Figure 4). However, treatment K2– reached almost the level of treatment K1–. This confirms results of Rupa et al. (2001) from a long-term field experiment with 27 years of continuous cropping resulting in the greatest depletion of non-exchangeable K reserves and the highest K fixation capacity in the plots that did not receive any K fertilisation. According to Conti et al. (2001) K fixation responded to the soil type, but not to K fertiliser doses.

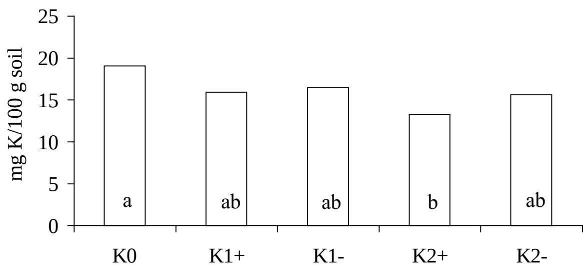

Figure 4. Influence of an interrupted K supply on the K fixation capacity (means followed by the same letter do not differ at $p = 0.05$)

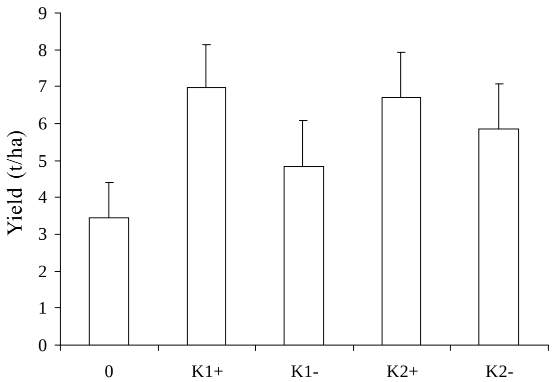

Figure 5. Influence of an interrupted K supply on dry matter yield of potatoes in 1996

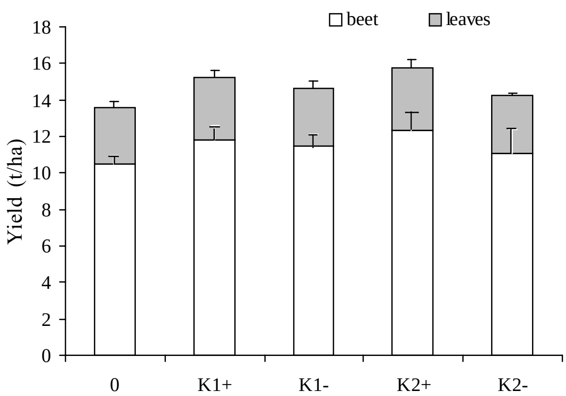

Figure 6. Influence of an interrupted K supply on dry matter yield of sugar beet in 1999

Plant species differ in their capability of exploiting soil K and can exhibit differential responses to K fertilisation. These differences can be explained in terms of root metabolism and rooting pattern. In general, root and tuber crops respond to K fertilisation more efficiently than cereals (Pretty 1978). This should be taken into account in fertiliser recommendations when calculating the fertiliser needs over the entire rotation. Under our experimental conditions, in the first year the interrupted K fertilisation

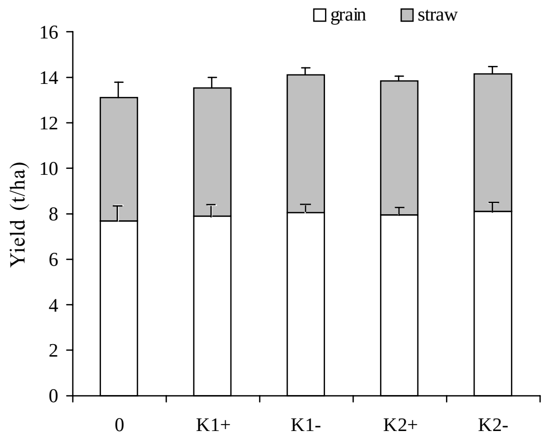

Figure 7. Influence of an interrupted K supply on dry matter yield of winter wheat in 1995

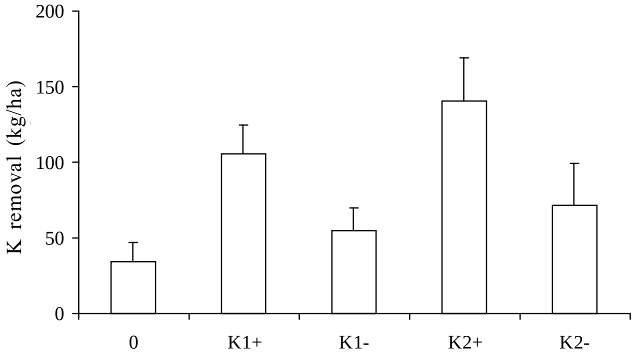

Figure 8. Influence of an interrupted K supply on K uptake of potatoes in 1996

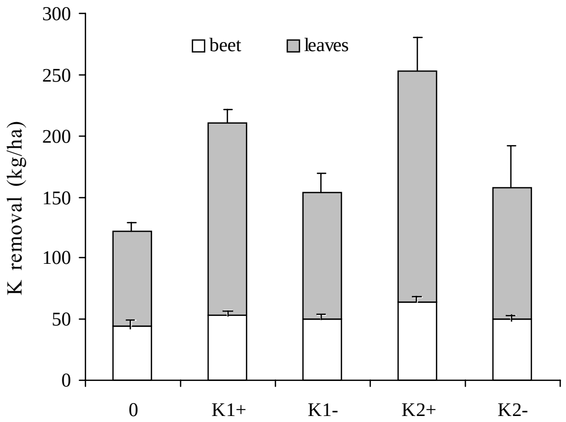

Figure 9. Influence of an interrupted K supply on K uptake of sugar beet in 1999

resulted in a slight yield decrease of sugar beet (data not shown). Later the yield depression of potatoes (Figure 5) and sugar beet (Figure 6) was more pronounced. However, in general we did not observe any influence of K fertilisation on the yield formation of winter wheat (Figure 7) and summer barley.

K uptake responded to a differentiated K supply faster than yield formation as K could be taken up in luxury doses. In 1996 the discontinued K supply resulted in a decrease of the K uptake of potatoes by about 45% (K1+/K1–) and 50% (K2+/K2–), respectively (Figure 8). K uptake also strongly decreased in sugar beet in the treatments with the interrupted K supply (Figure 9). However, K uptake of the leaves was more affected than K uptake of the beets. Although yield formation of cereals was less affected by the interrupted K fertilisation, K uptake partly reflected the treatments. In 1995 K uptake of winter wheat was lower in the corresponding treatments with the discontinued K supply.

Our results demonstrate the importance of continuous K fertilisation, taking into account the special requirements of the different crops. The systems of crop production that remove the entire aboveground portion lead to a more rapid depletion of soil K, thereby requiring higher additions of K fertilisers.

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ABSTRAKT

Dynamika draslíku v půdě a výnos plodin v dlouhodobém polním pokusu

V dlouhodobém polním pokusu (Luvisol na spraši) byl sledován vliv ukončení hnojení draslíkem na změnu zastoupení K v půdních frakcích, tvorbu výnosu a příjem K různými plodinami. Bez ohledu na předchozí hnojení došlo po přerušení K hnojení k významnému poklesu obsahu půdního K extrahovatelného CAL. Koncentrace K v půdním roztoku, stejně jako obsah K extrahovatelného HCl, byly také redukovány, zatímco půdní fixační kapacita K postupně rostla během deseti let po přerušení hnojení. Ukončení hnojení K vedlo k poklesu výnosů cukrovky a brambor. Výnosy obilnin nebyly ovlivněny, ačkoliv odběr K rostlinami se lišil v závislosti na diferencované zásobě K v půdě.

Klíčová slova: draslík; hnojení; přístupnost; tvorba výnosu; brambory; cukrovka; ozimá pšenice

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