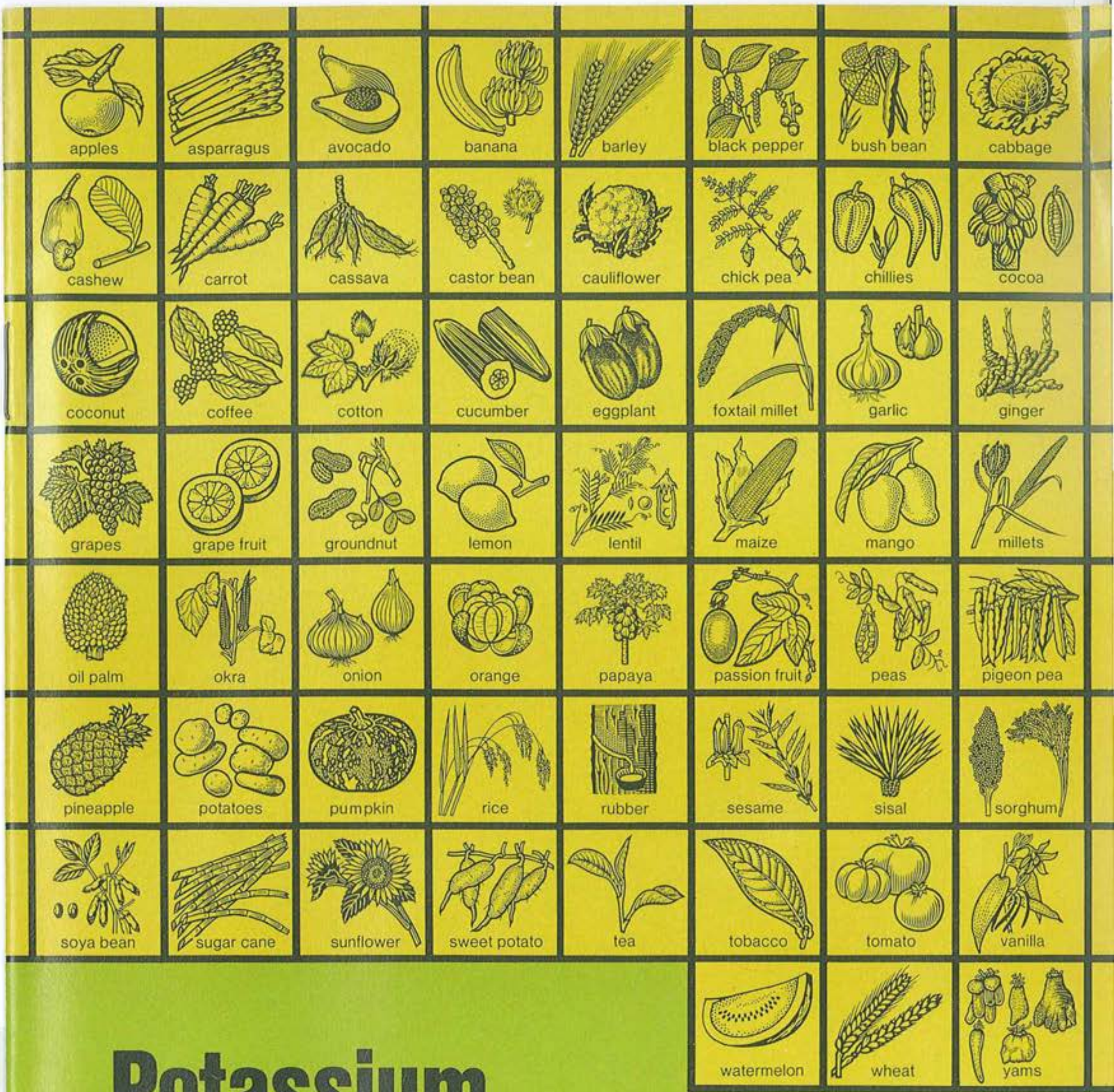

Potassium in plant production

15 colour slides with explanations

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Introduction

The plant needs large quantities of potassium (K). The uptake of K is frequently as high as or even higher than the uptake of nitrogen. Potassium is an essential element for all living organisms. Not only is plant tissue content of K higher than that of other cations but it is also the most important cation in many physiological and biochemical processes. Although the overall effects of K on photosynthesis, carbohydrate and protein synthesis and on the water economy of the plant have been confirmed in numerous experiments, the actual functions of this element in the physiology of the plant and in yield formation have for long been obscure. Only recently, with the more detailed investigation of the manifold processes of plant metabolism, have some of the questions as to how potassium functions in the plant been answered.

A salient feature of K is the high rate at which it is taken up by the plant. Though, in contrast to many other indispensable elements, K is not a constituent of organic compounds, it is omnipresent in the plant and very mobile. This mobility and the participation of K in the activation of important enzyme reactions are two fundamental characteristics of this element.

K in plant metabolism and yield formation

Life on earth depends on the photosynthetic activity of plants: on the conversion of solar energy into chemical energy (fig. 1). Everything which helps plants to absorb more solar energy makes this process more efficient. POTASSIUM PROMOTES PHOTOSYNTHESIS (fig. 2). It activates those enzymes which are involved in the energy transfer, in the build-up of ATP (adenosine-tri-phosphate) which stores the energy needed for CO_2 assimilation and the synthesis of sugar, starch, proteins etc. ATP is the major carrier of energy in plant metabolism. Obviously, high concentrations of potassium are necessary for optimum efficiency of energy transfer.

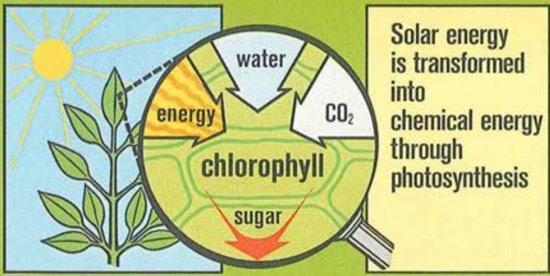
A high rate of CO_2 assimilation can be maintained only if the assimilates are removed from the leaves to other plant organs, particularly to roots and storage tissues. This transport is as important as the photosynthetic process itself. POTASSIUM SPEEDS UP THE FLOW OF ASSIMILATES (fig. 3). How is K involved in these processes? Translocation of assimilates and other solutes takes place in the sieve tubes of the phloem tissue. The phloem sap is especially rich in sucrose and potassium and K seems to be directly involved in the process of "phloem loading". A high rate of phloem loading in the leaves i. e. at the "source" and of phloem unloading in the storage tissues ("sink") brings about a speedy flow of assimilates in the sieve tubes. Consequently, more sugar is transported from the source to the sink if plants are well supplied with potassium. The first observations concerning the positive influence of K on sugar transport were made with sugar cane (fig. 4). They have been confirmed later in experiments with many other plants.

Better delivery of assimilates improves the filling of storage organs as shown by results on root and tuber crops (fig. 5), cereals (fig. 6) or vegetables (fig. 7). Generalizing, one can say that POTASSIUM INTENSIFIES THE STORAGE OF ASSIMILATES. Taking cereals (fig. 6) as an example, we find no great effect of K

Only plants can perform the basic process of solar energy utilization on which all life on earth depends. Part of this energy is absorbed in their green organs and, in the presence of chlorophyll, converted into chemical energy by building up sugars from carbon dioxide (CO_2) and water (H_2O).

1

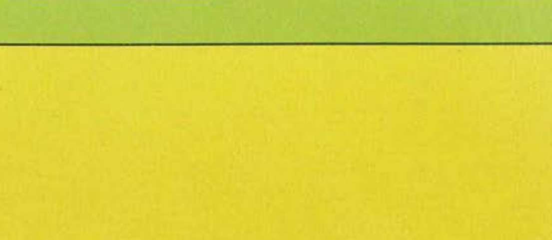
Plants trap solar energy



The process of photosynthesis or CO_2 assimilation can be summarized as follows: $6\ CO_2 + 12\ H_2O$ + solar energy $\rightarrow C_6H_{12}O_6$ (sugar) $+ 6\ O_2$ (oxygen) $+ 6\ H_2O$. As potassium is vital for the activity of many enzyme systems involved in this process, an adequate K supply to the plant is essential for the functioning of photosynthesis. Research has shown that green leaves with a high potassium content are able to assimilate twice as much CO_2 as leaves with lower K contents.

2

Potassium promotes photosynthesis



on the first yield component, which is tillering i.e. the number of ears per plant or per unit area. But K has a marked influence on the other two yield components, number of grain per ear and weight per grain. Generally the number of florets within the ear exceeds the number of grains set because some of the florets degenerate. To keep a fair percentage of them alive, a sufficient supply of assimilates is needed and this is supported by the stimulating effect of K on photosynthesis and assimilate transport. The influence of potassium in single grain weight can be explained in a similar way. It has been observed repeatedly that the leaves of wheat plants well supplied with K remain green for a longer time during grain filling, thus providing the ears with assimilates over an extended period. As a result more starch can be synthesized and the grains grow larger. In addition, K also enhances the synthesis of lipids in oleaginous crops, thus improving oil production.

Potassium (K) and nitrogen (N)

The inorganic nitrogen taken up by the plant as nitrate (NO_3^-) or ammonium (NH_4^+) must be converted into organic N compounds which contain the nitrogen primarily as NH_2-groups. The first products in this conversion process are amino acids of quite simple structure. They are the substrates for the synthesis of the more complicated organic N compounds, such as nucleic acids or proteins. The conversion of inorganic nitrogen and the synthesis of organic N compounds are both energy-consuming processes. POTASSIUM FAVOURS THE PRODUCTION OF PROTEINS by stimulating a) the generation of energy-rich ATP, b) the reduction of NO_3 to NH_2 and c) the supply of assimilates for amino acid synthesis. It is of little use for the plant to take up much inorganic N unless this can be converted into amino acids and proteins. A high concentration of ammonia or nitrates in the plant would actually be poisonous. Good K nutrition favours the rapid turnover of inorganic nitrogen into proteins (fig. 8) and consequently, POTASSIUM IMPROVES THE EFFECT OF NITROGEN fertilizer. In fact, high rates of N can be utilized by the plant and transformed into high yields only in the presence of high K levels (fig. 9,10).

This strong positive N/K interaction is also effective in leguminous plants. These plants are able to bind atmospheric nitrogen through the agency of the Rhizobium bacteria living in their root nodules. They convert gaseous nitrogen (N_2) via ammonia into the NH_2 group of the amino acids. As the N_2 gas is very inert, complex enzymatic processes are involved in nitrogen fixation, and a considerable amount of energy is needed.

Considering the important role of potassium in energy transfer, it is not surprising that K ENHANCES THE FIXATION OF ATMOSPHERIC NITROGEN (fig. 11).

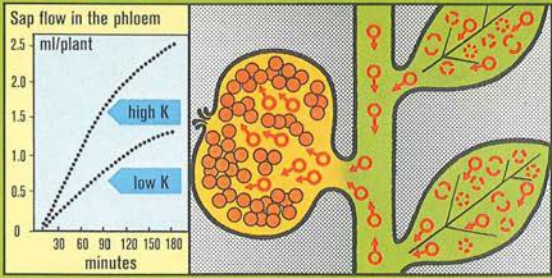
Recent investigations have shown that by improving the K nutrition of the host plant bacterial N_2 fixation can be considerably increased. Experiments, in which nitrogen was labeled with ^{15}N and CO_2 with ^{14}C, showed that K not only favoured the translocation of ^{14}C labeled sugars from the leaves to the roots and root nodules but also the assimilation and turnover of molecular nitrogen within the nodules.

The result was an increase of amino acid production in the nodules, leading to improved protein synthesis and growth. Such data from greenhouse experiments help to explain why leguminous forage crops, such as clover and alfalfa, show better growth and nitrogen uptake when properly supplied with potash fertilizers (fig. 12).

Sugars, the first products of photosynthesis, and other assimilates are transported from the leaves to the storage organs (e. g. the fruits). The flow of assimilates in the phloem vessels where this transport takes place is faster when plants are well supplied with K. This result was obtained in studies with castor oil plants which yield much phloem sap after incision.

3

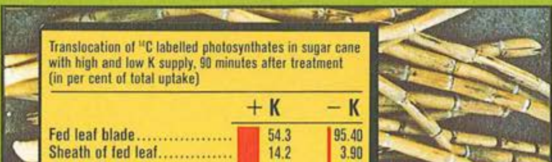
Potassium speeds up the flow of assimilates



The movement of assimilates within the plant can be traced in experiments with radioactive carbon dioxide ($^{14}CO_2$). 1 ½ hours after $^{14}CO_2$ treatment, cane plants grown in solution culture with K had already accumulated in the stalk 20 % of the $^{14}CO_2$ assimilated while under the low K treatment 95 % still remained in the leaf.

4

K promotes translocation of assimilates



Translocation of ^{14}C labelled photosynthates in sugar cane with high and low K supply, 90 minutes after treatment (in per cent of total uptake)

	+ K	− K
Fed leaf blade	54.3	95.40
Sheath of fed leaf	14.2	3.90
Joint of fed leaf	9.7	0.60
Stalk below joint	20.1	0.04

K and the water regime of the plant

POTASSIUM IMPROVES WATER-USE EFFICIENCY (fig. 13). As mentioned earlier, much K is taken up by the plant. Accumulation of potassium in the cells leads to an increase of their osmotic pressure so that water moves into the cell and this, in turn, increases the turgor pressure of the cell. As turgor is essential for cell expansion, supplying the necessary pressure from inside the cell for cell wall extension, it can be concluded that K is involved in the basic process of cell enlargement.

Through its contribution to the osmotic pressure and turgidity of cells K has a dominant role in the opening and closing of the stomata, which regulate the transpiration of water and the penetration of atmospheric carbon dioxide into the leaf. In water stress, plants well supplied with K very quickly close their stomata, thus preventing excessive water loss by the plant. If, on the other hand, the plant obtains sufficient water the stomata open wide and CO_2 assimiation is high. Thus K improves water use efficiency.

According to recent investigations, the involvement in "osmoregulation" i.e. in the adjustment of plant cells to environmental conditions, seems to be one of the most important biophysical role of potassium. Thus it is plausible that K, in addition to its many biochemical functions, improves the tolerance of the plant to various stress situations, such as drought, low temperature or salinity.

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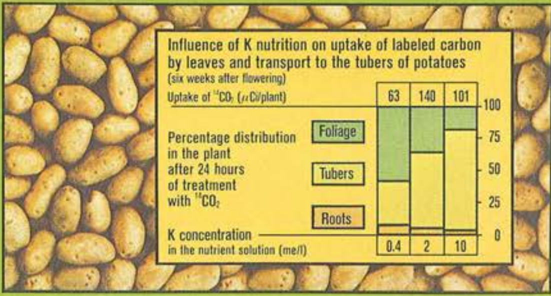
Rapid transport of assimilates to the storage organs is important not simply because more assimilates are stored thereby increasing yield but also because evacuation of assimilates from the leaves enables photosynthesis to continue. In solution culture experiments in which potato plants were supplied with labeled $^{14}CO_2$ for a short time, nearly 80 % of the ^{14}C was translocated into the tubers of high K plants within 24 hours. In plants grown at lower K concentrations more than 50 % remained in the leaves and probably exerted a feedback inhibition on photosynthesis.

5

K intensifies storage of assimilates



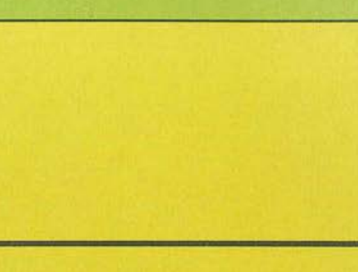
The yield of a grain crop depends on (a) the number of ears per unit area, (b) the number of ripe grains per ear, (c) the weight of the grain (the so-called 1000 grain weight). Due to its influence on photosynthesis and assimilate transport potassium is particularly effective for the improvement of (b) grain number and (c) grain weight. This has been confirmed not only in pot experiments with wheat, as shown in the picture, but also in numerous field trials with this and other cereal crops.

6

Potassium improves grain filling

Wheat: average figures of 5 varieties and 4 replicates

Yield components /24 plants	K_1 11 mg exch. K/100 g soil	K_2 30 mg exch. K/100 g soil
Number of ears	76	77
Number of grains per ear	28.1	31.8
Thousand grain weight (g)	32.1	34.7
Total grain yield (g)	68.4	83.6



Vegetative growth, fruit setting, fruit development and ripening are biological processes which are catalysed by enzymes. Potassium influences a number of very important enzymes and keeps them active for a longer time, thus extending the ripening period of fruits and improving fruit quality. Plants well supplied with K are able to produce assimilates for a longer time and to do so more intensively. This leads to higher yields and better quality, as shown in an experiment with tomatoes: plants well supplied with K produced considerably more and larger fruits. Picking time was extended allowing the farmer to market a better product over a longer period.

7

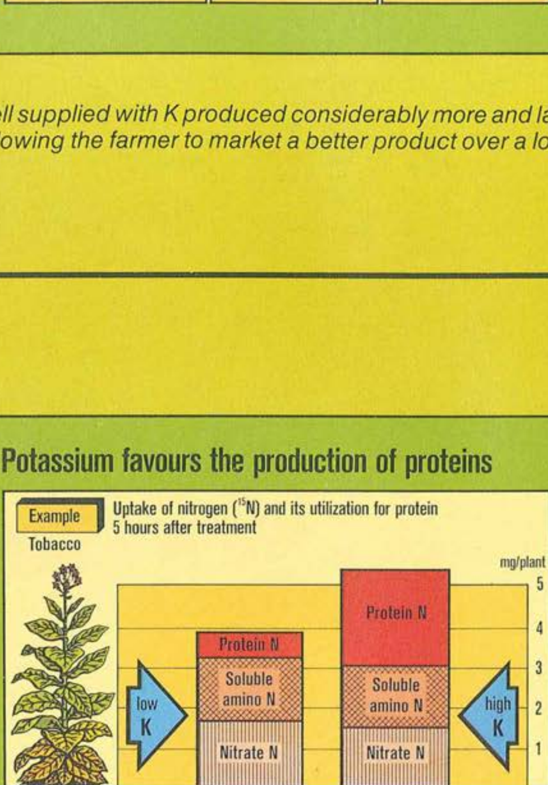
K fertilization → longer assimilation → higher yield

Tomatoes (average values)		K_0	K_3
Late crop	Yield g/plant	20	416
	Fruits/plant	1	13.4
Early crop	Yield g/plant	673	1157
	Fruits/plant	17.4	23.1
Total	Yield g/plant	639	1573
	Fruits/plant	18.4	36.5

The uptake and utilization of nitrogen – the most important plant nutrient – is considerably enhanced by potassium. In experiments with the nitrogen isotope ^{15}N it was shown that plants well supplied with K were able to take up more nitrogen (N) and moreover to convert the nitrogen more rapidly into protein. In plants with lower K supply protein formation was inhibited leading to an accumulation in the plant of nitrate-N and soluble amino-N. In these experiments tobacco (shown in the picture) and sugar beet were used as test plants.

8

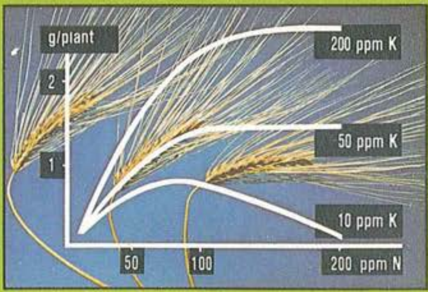
Potassium favours the production of proteins



As N uptake and utilization are promoted by K, the effect of nitrogen on crop production will only be optimal if the plants are adequately supplied with potassium. The interaction of N and K was studied in Canada with barley in hydroponic culture. At low K levels an increase in N supply depressed yield. At medium K concentration higher N rates neither decreased nor increased the yield level. At the highest K rate, however, the maximum yield was obtained with the highest N supply.

9

Potassium improves the effect of nitrogen



The effect of increasing N supply at three different K levels on the grain yield of barley

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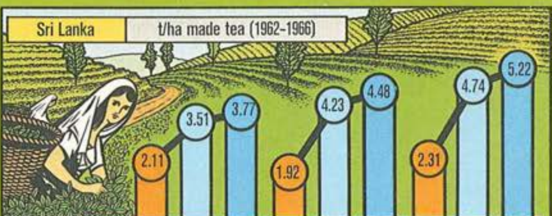
N/K interactions have been observed in numerous field experiments. One example is the classical long-term fertilizer experiment at the Tea Research Institute of Sri Lanka (Ceylon) commenced in 1931. Although there was no K response in the early pruning cycles, the effect of K on tea yield became very marked later on. In the 11th cycle (1962–66) the differences in yield between low, medium and high rates of N was only relatively small when no K was applied whereas in plots which had received 112 kg/ha K_2O the tea yield increased from 3.77 t at N_{134} to 5.22 t at N_{202}. Potash improved the effect of nitrogen at all N levels.

10

Potassium improves the effect of nitrogen



Treatment kg/ha										
	N	134	134	134	168	168	168	202	202	202
	P_2O_5	34	34	34	34	34	34	34	34	34
	K_2O	0	56	112	0	56	112	0	56	112

Leguminous plants are able to utilize nitrogen from the air. This is fixed by Rhizobium bacteria living in symbiosis with the plant in the root nodules. Nitrogen assimilation is greatly enhanced if the leguminous plants are well supplied with K. Greenhouse experiments with broad beans have shown that the root nodules of the plants were larger at higher K levels. Experiments with the isotope ^{15}N revealed increased activity in the nodules. They fixed about twice as much atmospheric nitrogen as the nodules of low-K plants.

11

Potassium enhances nitrogen fixation

Assimilation of atmospheric nitrogen by broad beans			
Labeled N_2 absorbed by plants through root nodules (µg ^{15}N/plant/12 hrs)	580	853	1130
Number of nodules per plant	233	250	251
Fresh weight per nodule (mg)	6.5	7.2	8.4
K concentration in the solution (me/l)	0.5	1.5	4.5

The favourable effect of potassium on nitrogen fixation in leguminous plants has also been studied in field experiments. In a long-term fertilizer trial in Japan with grass-legume mixtures K application more than tripled the fixation of atmospheric nitrogen. In the K-treated plots the growth of leguminous plants was improved, they assimilated 128 kg N/ha per year more than those in the zero K plots. With annual dressings of 300 kg K_2O/ha this means an additional assimilation of 0.4 kg atmospheric nitrogen for each kg K_2O applied.

12

Potassium enhances nitrogen fixation

Grass legume forage on a sandy loam soil
Long-term fertilizer experiment

N-fixation, kg N/ha

K_0 = 58.3 — Effect of K = + 127.8

Amounts of N contained in the forage (Annual average of 5 years, kg/ha)

K_2O - treatment kg/ha/yr	0	300
Alfalfa + orchard grass	54.8	192.5
Ladino clover + orchard grass	61.8	179.7
Average	58.3	186.1

It is well known that plants abundantly supplied with potassium can utilize the soil moisture more efficiently than K-deficient plants. As a consequence, crops with an optimum K status need less water for the production of a given yield than crops undersupplied with K. This is demonstrated by a nutrient culture experiment with sugar beet. The yield increased with increasing K concentration, while the water consumption per beet remained constant. Thus less water was consumed per gram of sugar beet at the higher K level.

13

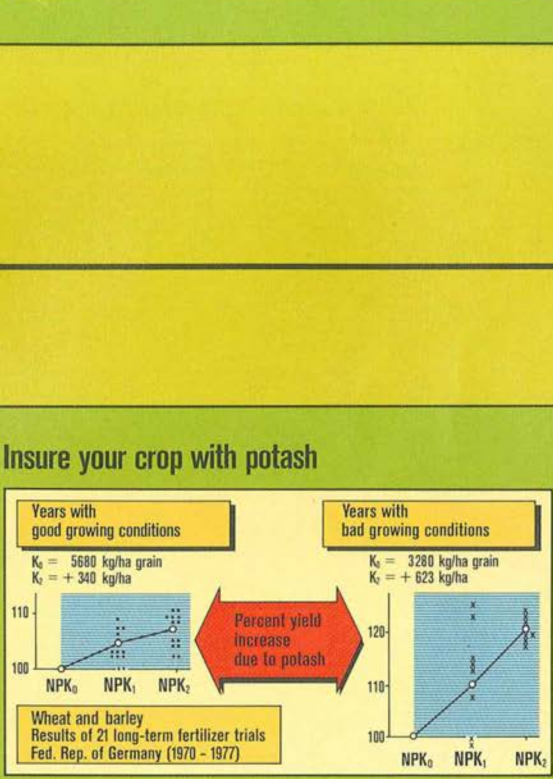
Potassium improves water-use efficiency

K concentration in the nutrient solution (me K/litre)	0.2	1.0	5.0
Beet weight (grams/plant)	392	602	647
Total water consumed per beet (litres)	27.8	27.7	27.2
Grams of water consumed per one gram beet	71	46	42

Optimum conditions of soil, climate and farm management produce maximum yields provided the crop receives a balanced and adequate nutrient supply. But yields decrease sharply when the growing conditions are less favourable, e. g. due to frost, drought, excessive rainfall etc. Here an abundant supply of K together with optimum rates of N, P, Mg and other nutrients can limit the extent of the damage. Long-term fertilizer trials with cereals proved that the low yields of years with bad growing conditions can be corrected to a certain degree by high K fertilizer dressings. In those years the yield increase due to K was much higher than in years with good growing conditions.
These results confirm the positive effect of K on plants under environmental stress.

14

Insure your crop with potash



Potassium in plant production

- K promotes photosynthesis
- K speeds up flow of assimilates
- K intensifies storage of assimilates
- K favours production of protein
- K improves efficiency of fertilizer N
- K enhances fixation of atmospheric nitrogen
- K improves water-use efficiency

Insure your crop with potash!

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